

INTERNATIONAL MONETARY FUND

A Semi-Structural Model for Credit Cycle and Policy Analysis

An Application for Luxembourg

Carlos de Resende, Alexandra Solovyeva, and Moez Souissi

WP/24/140

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**2024
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WORKING PAPER

IMF Working Paper
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A Semi-Structural Model for Credit Cycle and Policy Analysis – An Application for Luxembourg
Prepared by Carlos de Resende, Alexandra Solovyeva, and Moez Souissi*

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July 2024

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ABSTRACT: The paper explores the nexus between the financial and business cycles in a semi-structural New Keynesian model with a financial accelerator, an active banking sector, and an endogenous macroprudential policy reaction function. We parametrize the model for Luxembourg through a mix of calibration and Bayesian estimation techniques. The model features dynamic properties that align with theoretical priors and empirical evidence and displays sensible data-matching and forecasting capabilities, especially for credit indicators. We find that the credit gap, which remained positive during COVID-19 amid continued favorable financial conditions and policy support, had been closing by mid-2022. Model-based forecasts using data up to 2022Q2 and conditional on the October 2022 WEO projections for the Euro area suggest that Luxembourg's business and credit cycles would deteriorate until late 2024. Based on these insights about the current and projected positions in the credit cycle, the model can guide policymakers on how to adjust the macroprudential policy stance. Policy simulations suggest that the weights given to measures of credit-to-GDP and asset price gaps in the macroprudential policy rule should be well-calibrated to avoid unwarranted volatility in the policy response.

RECOMMENDED CITATION: de Resende, C. Solovyeva, A., and Souissi, M. (2024). A Semi-Structural Model for Credit Cycle and Policy Analysis – An Application for Luxembourg. IMF Working Paper 24/140.

JEL Classification Numbers:	E42, G21, G28, E37, O52
Keywords:	Macroprudential policy; credit cycle; banks; forecasting and simulation; Luxembourg
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WORKING PAPERS

A Semi-Structural Model for Credit Cycle and Policy Analysis

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Prepared by Carlos de Resende, Alexandra Solovyeva, and Moez Souissi¹

¹“The authors greatly appreciate the useful comments and suggestions received from Vincenzo Guzzo, Tarak Jardak, Emil Stavrev, and Bernardin Akitoby during the IMF Working Paper review process. Also, the paper benefits from discussions with participants in Seminars from ICD (February 2024) and Luxembourg’s authorities (March 2021).”

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I. Introduction

The 2007 Global Financial Crisis highlighted the need to comprehend the complex relationship between business and credit cycle dynamics. A large body of the literature emerged from prior research on macro-financial interlinkages, such as Bernanke, Gertler, and Gilchrist (1999; henceforth BGG) and Kiyotaki and Moore (1997; henceforth K&M). This body of research, including studies by Calstrom and Fuerst (1997), Marcucci and Quagliariello (2009), Curdia and Woodford (2010), and Mendoza (2010), aimed to uncover how financial frictions could amplify the propagation of standard macroeconomic shocks. It also explored how shocks originating in the financial sector could trigger broader macroeconomic effects and how macroprudential policies could mitigate risks and smooth fluctuations caused by these factors. The "credit cycle" concept, which emerged as an important theme in this literature, was intended to summarize information about risks to the macroeconomy and financial stability. It would be correlated with but distinct from the traditional business cycle. Another focus of this literature was the countercyclical "macroprudential rules," describing how financial regulators respond to credit developments to smooth the credit cycle and mitigate related macroeconomic risks.¹

In parallel, New-Keynesian (NK) models have become widely used to inform the policy response to inflation pressures. Major central banks and international policy institutions, including the IMF, have made significant efforts to develop micro-founded models to inform the policy response to inflation pressures. This led to the prominent use of NK models as a policy analysis and forecasting tool.² These models, among other things, allow for the identification of unobserved indicators of the business cycle (i.e., the output gap) and the role of the underlying factors. They also offer insights into the monetary policy stance, helping assess inflation developments and inform monetary policy decisions. Finally, these models are used to assess the impact of various shocks while factoring in policy responses that are guided by clear objectives (such as minimizing deviations from potential output and an inflation target).

In this paper, we combine these two strands of the literature by incorporating macro-financial linkages into a semi-structural NK model to identify an unobserved credit cycle. Our model helps (i) identify and analyze the interconnected, yet distinct patterns of the business and credit cycles based on a micro-founded economic framework, (ii) investigate the propagation of both financial and macroeconomic shocks in an economy where banks serve as sources of both financial frictions and shocks, and (iii) study the effects of a countercyclical macroprudential rule that responds to credit developments. For this purpose, we extend the multivariate filter model in Baba *et al.* (2020) to explicitly account for the demand and supply of credit, drawing from the microfoundations discussed in Dib (2010) and introducing a macroprudential policy rule. We apply this model to Luxembourg—a small open economy with a large banking sector and a countercyclical macroprudential rule—which provides a natural laboratory for the study of the interlinked dynamics between credit and business cycles.

Except for the financial sector and regulator, the model is very close to the canonical NK framework. It incorporates an aggregate demand block, an NK Phillips Curve, and a monetary policy block representing the

¹ See BIS (2008), Van den Heuvel (2008), Covas and Fujita (2009), Kannan *et al.* (2009), Galati *et al.* (2010), de Resende *et al.* (2016), and Jiménez *et al.* (2017).

² Notable examples of such models include Laxton *et al.* (2006), Carabenciov *et al.* (2008), Andrieu *et al.* (2014), and Baksa *et al.* (2020).

exogenous European Central Bank (ECB) policy (set externally to Luxembourg).³ The model deviates from canonical versions of the NK model by incorporating credit markets, an active banking sector, and a regulator that sets a countercyclical capital buffer (CCyB). The latter is a regulatory tool adjusting banks' minimum capital requirements in response to developments in the credit cycle.⁴ The demand and supply for loans are based on microfoundations outlined in Dib (2010) and de Resende et al. (2016). The demand for loans comes from optimal households' consumption-savings decisions, wherein bank deposits serve as savings vehicles, and credit is employed for consumption smoothing and risk-sharing. The supply of bank loans is represented by a version of the optimal conditions of monopolistically competitive banks. These banks collect deposits and raise capital to "produce" loans, subject to a minimum bank capital requirement defined by the regulator. They set the lending rate as a mark-up over their marginal cost of loan supply. An increase in the minimum bank capital requirement affects their marginal cost and induces them to raise more capital (at an increasing cost), cut loans to borrowers, or a combination of both. Exogenous shocks to loan demand (i.e., households' preferences) and loan supply (i.e., cost-push and riskiness shocks) can alter the equilibrium in credit markets.⁵

The model features macro-financial shocks and several channels that amplify their impact. First, shocks increasing banks' marginal costs of loan supply result in reduced loan volumes and higher lending rates, subsequently dampening aggregate demand and output. Conversely, shocks to household preferences which boost aggregate demand raise the loan demand, leading to increased loan volumes and higher market interest rates. Second, the model incorporates financial accelerator mechanisms that can amplify the propagation of these macro-financial shocks. The first is inspired by BGG, linking output, borrowers' net worth, overall loan supply risk by banks, and lending rates. The second consists of borrowing constraints à la KM, which loosen or tighten based on collateral values (e.g., house prices) that are influenced by the business cycle. Lastly, changes in the CCyB alter loan supply marginal costs, equilibrium credit volumes and interest rates, and both the business (through aggregate demand) and credit cycles.

The model is mapped to Luxembourg's quarterly data from 2010-2020, using a mix of calibration and Bayesian estimation. Once the model is parametrized, validation exercises confirm its ability to match Luxembourg's data. First, simulated data from the model replicate well the first and second moments of key macro and financial variables.⁶ Second, a mix of pseudo and truly out-of-sample one- to six-quarter ahead conditional forecasts produce unbiased forecast errors for most variables, and capture well the relevant turning points and general dynamics of most indicators.⁷ Diebold-Mariano tests confirm that the forecasts generated by the model are more accurate than simple benchmarks, such as Vector Autoregression (VAR) and Autoregressive Moving Average (ARMA) models.

Dynamic responses of key variables to changes in the macroprudential policy stance and several structural shocks qualitatively align with economic theory and literature. The tightening of

³ See Galí and Gertler (1999) and Clarida et al. (1999).

⁴ While the macroprudential policy toolkit in Luxembourg includes several instruments, the term 'macroprudential policy' in this paper refers to the authorities' decision to adjust the CCyB. In addition, we refer to the minimum capital requirements as the combination of the micro-prudential capital (invariable over the credit cycle) and additional counter-cyclical buffer requirements.

⁵ Karam et al. (2021) follow a similar approach for the Philippines, with a more detailed equation for the accumulation of bank capital.

⁶ Simulated data is generated from many bootstrapped samples with the same size as that used in the calibration/estimation.

⁷ The only exception is the short-lived downward-biased forecast of the nominal lending rate (in the near term).

macroprudential stance leads to a rapid contraction of credit volumes and increase in lending rates. Banks partially increase their capital-to-loan ratios, deleverage by cutting loans, and raise lending rates. Given the model's parameterization, the quantitative impact of these macroprudential policy changes on the real economy remains relatively modest. This suggests a favorable trade-off for the use of such policies in Luxembourg. Positive credit demand shocks, which boost credit growth above its neutral trend and raise market lending rates, prompt a swift tightening of macroprudential policy. Conversely, adverse credit supply shocks, characterized by higher lending rates and reduced credit supply, lead to a relaxation of the macroprudential policy stance. As part of robustness checks, simulations were conducted with three variations of macroprudential rules, ranging from less to more aggressive responses to credit dynamics. While faster convergence to equilibrium occurs with more aggressive responses, the overall impact on the macroeconomy remains mild across all scenarios.

The model captures well recent economic developments in Luxembourg. Our results indicate that Luxembourg entered a cyclical downturn in mid-2022, primarily reflecting unfavorable demand shocks. The model also identifies expectations, cost-push shocks (possibly related to the spikes in international food and energy prices), and robust domestic demand as the main factors driving the observed post-COVID rise in inflation. As for the credit cycle and financial conditions, the model suggests that the credit gap narrowed significantly after remaining positive amid low-for-long interest rates and was almost closed in early 2022. The model also suggests that the tightening of ECB's monetary policy rate and bank capital buffers are driving the lending rate up towards its estimated neutral level.

Under the baseline scenario, Luxembourg's business and credit cycles would deteriorate, requiring some loosening of the macroprudential policy stance. We produce forecasts for the main macro-financial variables using data up to 2022Q2. With increasing policy and lending rates, the model predicts short-term economic slack, mainly caused by weak external demand, with a negative output gap and above-trend unemployment prevailing until late 2024. By the same time, demand for credit will fall and further narrow the positive credit gap, triggering a prescribed reduction in the minimum capital requirements to help reduce lending rate gaps and support credit demand. Finally, the model's parametrization for Luxembourg also suggests that the macroprudential rule can avoid undue volatility of the macroprudential policy responses. This can be achieved by focusing on the credit indicator and assigning different weights to credit and asset prices (i.e., house prices).

The remaining of the paper is structured as follows: Section II describes Luxembourg's institutional setup regarding macroprudential policy. Section III describes the model, emphasizing the role of credit market and the banking sector, and the macroprudential policy rule. Sections IV to VII describe the data, model validation exercises, model properties from impulse responses, and out-of-sample forecasts, respectively. Section VIII concludes.

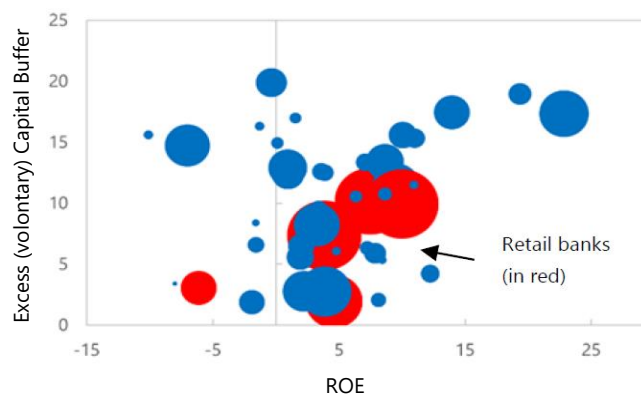
II. Macroprudential Policy and Institutional Setup in Luxembourg

Luxembourg has a large banking sector, contributing to about 10 percent of GDP.

Banks are involved in variety of activities, including private banking and wealth management, depositary and custodian activities, treasury operations for large and systemic banking groups, and traditional retail and commercial banking serving the domestic economy. With comfortable capital and liquidity buffers, the banking sector is deemed resilient overall (IMF, 2023). This paper focuses on domestically oriented banks (DOBs), which provide a significant share of credit to the resident non-financial private customers (88 percent as of end-2022).

Bank Resilience

(Percent, 2022Q3)



Sources: BCL

Note: The chart comes from the 2023 Article IV report for Luxembourg (pp. 22). Retail banks (shown in red) are mostly DOBs. The size of the circles capture bank size.

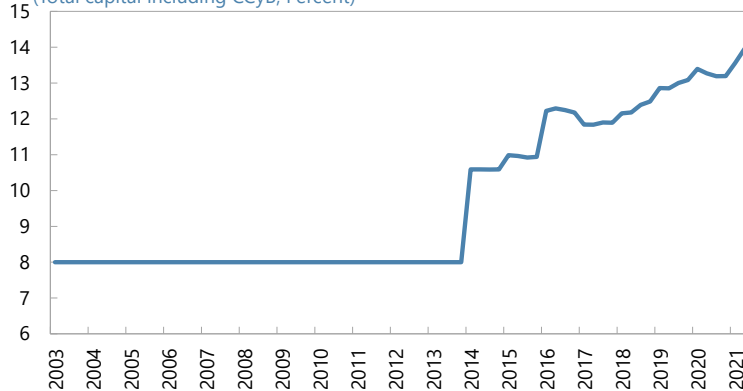
Over the years, Luxembourg has strengthened its macroprudential framework to enhance the banking system's resilience while addressing the build-up of systemic risks. To limit the build-up of imbalances during the upswing of the credit cycle, including from residential real estate exposures, Luxembourg established a macroprudential policy framework in 2015. The Systemic Risk Board (SRB), which brings together the government, the central bank (Banque Centrale du Luxembourg, BCL), and the supervisory bodies of financial sector (Commission de Surveillance du Secteur Financier, CSSF) and insurance companies (Commissariat aux Assurances, CAA), provides macroprudential oversight of Luxembourg's financial system. It coordinates the implementation of Luxembourg's macroprudential policy, including monitoring systemic risk sources and setting the targets for the available macroprudential tools to signal the authorities' macroprudential stance.

Capital-based tools, both broad-based and sectoral, have so far been the main macroprudential policy instruments in Luxembourg.

The country's macroprudential toolkit includes all the instruments contained in the EU regulation framework, in

Minimum Capital Requirements

(Total capital including CCyB, Percent)



Source: CSSF; and IMF staff calculations.

particular a CCyB.⁸ The decision on the applicable level of the CCyB relies on the analysis of several indicators of the credit cycle, including the credit-to-GDP gap, credit growth measures (such as related to the mortgage market), deviation of asset prices (including housing prices) from long-term trends, market volatility, and spreads, or measures of leverage. The CCyB level, initially introduced at zero, was increased twice (to 0.25 percent in late 2018, effective January 2020, and to 0.5 percent in March 2020, effective January 2021), reflecting increased pressures in the credit market, and has remained unchanged since then. In this paper, we focus on the implications of changes in the level of CCyB on the economy of Luxembourg.

The authorities are also implementing other demand-side tools into the policy toolkit. The macroprudential authority introduced a legal framework for borrower-based measures to address risks related to household indebtedness in the residential real estate (RRE) sector. Following a comprehensive risk assessment of residential real estate developments conducted by the BCL in cooperation with the CSSF, the SRB recommended to activate legally binding loan-to-value (LTV) limits for new RRE mortgage loans starting in early 2021.⁹

III. Stylized Facts: Recent Macroeconomic Developments in Luxembourg

Luxembourg's economy has achieved rapid growth pre-COVID, fared relatively well during the pandemic, and then decelerated. The economy expanded rapidly prior to the pandemic, with solid employment gains and a significant decline in unemployment. During the pandemic, the economy quickly adapted to health-related restrictions, helped by the unprecedented policy support (both domestically and globally) and its key structural features (i.e., the predominance of financial services, which can easily operate with low levels of human contact). In 2021, the economy achieved an exceptional performance, also taking advantage of the strong global recovery. More recently, the economy started showing signs of moderation. While growth slowed down in 2022 due to external headwinds, it remained relatively resilient, underpinned by robust consumption.

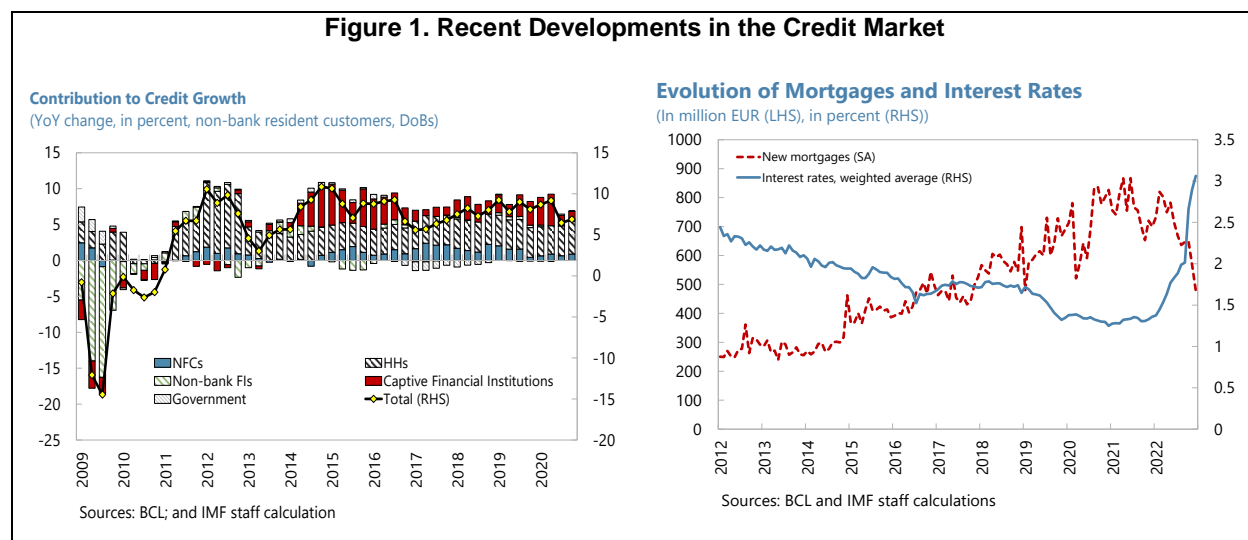
Credit to the resident non-financial private sector continued to grow, albeit at slower pace, in 2022, reflecting tighter financial conditions and credit standards. Luxembourg's credit market has remained vigorous over the past decade. Pre-COVID, fast-growing mortgage lending and credit to non-financial corporations benefited from the low-for-long interest rate environment.¹⁰ The tightening of the ECB's monetary

⁸ Other instruments include Basel Pillar II measures, the systemic risk buffer, additional capital buffers for global and other systematically important institutions, various sectoral measures (such as a risk weight floor on residential real estate for internal ratings-based banks), and the countercyclical capital buffer.

⁹ The LTV limits are set differently for various categories of borrowers. The general rule is an 80 percent limit on LTVs. However, higher LTV limits apply for first-time home buyers (100 percent) and primary residences (90 percent, with lenders allowed to issue 15 percent of the new mortgages with an LTV ratio up to 100 percent). The SRB is monitoring the implementation of the borrower-based measures. For this purpose, the BCL conducts quarterly assessments of residential real estate developments. This assessment is based on the evolution of relevant indicators (such as housing prices, mortgage credit, and lending standards) and model-based approaches. See a short analysis of the effectiveness of the differentiated LTV limits in the 2022 Financial Stability Review.

¹⁰ Captive financial institutions, which mainly consist of special-purpose entities, account for roughly 20 percent of total credit extended by the DOBs to the non-bank resident customers. We do not include this category in our measure of credit as they primarily transact with non-residents, mostly performing holding and/or intra-group financing activities (see de Mooij et al, 2020).

policy stance in early 2022 and increased uncertainty led to a significant and rapid increase in lending rates and tightening of credit standards. As a result, growth in credit to the resident non-financial sector has slowed down (4.4 percent in end-2022). Households' contribution to credit growth has been declining, although still positive, as demand for mortgages fell. Credit to the non-financial corporations has recently been more dynamic than household credit, reflecting a temporary increase in working capital needs.



IV. The Model

A semi-structural, New Keynesian model is used to analyze financial (i.e., credit) and business cycles and to model macro-financial linkages in Luxembourg. The model—a variant of Carabenciov et al. (2008)—allows the joint estimation of both the credit and business cycles. It extends the “gap model” in Baba et al. (2020), incorporating channels that are inspired by the financial accelerator mechanisms in BGG and K&M. It also features an active banking sector that is subject to regulatory minimum capital requirements, provides credit, and sets the lending rates, as in Dib (2010) and De Resende et al. (2016); an endogenous macroprudential regulation reaction function; and an exogenous monetary policy, which is set by a regional central bank (see Annex I).¹¹

In the New Keynesian tradition, the model features nominal interest rate rigidity. It captures how sluggishly banks adjust lending rates, credit supply, in response to shocks and changes in either the stance of monetary or macroprudential policies.

The core model for Luxembourg economy consists of five main building blocks:

1. Output (dynamic IS curve),
2. Inflation (New Keynesian Philips curve),
3. Macroprudential policy rule,

¹¹ Expectations are rational, i.e., the model assumes that economic agents, including banks, know the dynamics of the economy and the behavior of key macroeconomic variables (model-consistent expectations).

4. Macroprudential policy rule, and
5. Exogenous monetary policy (set by the ECB).

Throughout the paper, we rely on the following notation for gap models. For any given variable X , we denote its trend component by a lower-case letter with the symbol $*$, and the cyclical component (that is, the deviation of the variable from its trend) by a lower-case letter x . Accordingly, we write $x = X - x^*$. The model is specified for quarterly frequencies, and all growth rates are defined as quarter-over-quarter, annualized and seasonally adjusted changes. Finally, we use the letters (e) and (ss) to denote the foreign economy and steady-state variables, respectively. Except for variables that are expressed in percentage points (i.e., inflation, interest rates), all variables are in natural log terms such that their change corresponds to growth rates and their deviation from trends are measured in percentage points.

A. Output and Inflation

The aggregate demand dynamics, reflecting the relationship between the credit cycle and demand-driven output, is represented by an open economy IS curve, as follows:

$$y_t = \beta_{lead} y_{t+1} + \beta_{lag} y_{t-1} + \beta_{ye} y_t^e + \beta_z z_t - \beta_r r_t^L + \beta_c c_t - \beta_\pi \epsilon_t^\pi + \epsilon_t^y \quad (1)$$

Equation (1) incorporates feedback from the credit cycle to aggregate demand by including the impact of both the real lending rate (r_t^L) and the volume of credit (c_t).¹² The inclusion of c_t in an otherwise standard IS curve aims at capturing the tightening of credit conditions not reflected in r_t^L (i.e., the credit channel). It also means that credit market developments (including changes in lending behavior) affect aggregate demand's cyclical component through Equation (1). For instance, a reduction in r_t^L or an expansion in c_t both increase output gap (y_t).¹³ Equation (1) also captures the effect of foreign demand (i.e., net exports), which increases with the depreciation (i.e., increase) of the real effective exchange rate gap (z_t) and the euro area output gap (y_t^e).¹⁴ Terms y_{t-1} and y_{t+1} reflect factors that may cause persistence in demand and economic activity (e.g., habit-formation, time-to-build, etc.) and affect current demand via expectations about future economic developments (e.g., investment accelerator mechanism).¹⁵

¹² The standard interpretation is that the real lending rate affects aggregate demand through both income and substitution effects.

¹³ The output gap is defined as the deviation of output from its long-term trend: $y_t = Y_t - y_t^*$, where $Y_t \equiv 100 * \ln(GDP)$. GDP is the quarterly actual real Gross Domestic Product and y_t^* is a measure of potential output. The latter is defined as follows: $y_t^* = y_{t-1}^* + \frac{1}{4}g_t + \epsilon_t^{y^*}$, with potential growth (g_t) revolving around a steady state value (g_{ss}) such that $g_t = \rho_s g_{t-1} + (1 - \rho_s)g_{ss} + \epsilon_t^g$. Shocks $\epsilon_t^{y^*}$ and ϵ_t^g are temporary and permanent shocks to potential GDP. See Annex II for more details on the data sources and Section V for the estimation and calibration of the main parameters.

¹⁴ Since Luxembourg is part of the euro area, the nominal exchange rate is irrevocably fixed, and the real exchange rate is defined as $Z_t = 100 * (\log CPI_t^e - \log CPI_t)$. The real exchange rate gap (z_t) is the difference between the real exchange rate and its long-term trend: $z_t = Z_t - z_t^*$, with the gap and trend exogenously evolving according to the following equations ($z_t = \rho_z z_{t-1} + \epsilon_t^z$) and ($z_t^* = z_{t-1}^* + \epsilon_t^{z^*}$), respectively.

¹⁵ See Abel (1990) and Kydland and Prescott (1982).

The short-term supply-side dynamics is represented by an open economy New Keynesian Phillips curve.¹⁶ Headline inflation (π_t) depends on expected and lagged inflation (π_{t+1} and π_{t-1}), the output gap (y_t), and the annualized change in the real exchange rate (z_t^A) which is equal to the difference in the annualized inflation between the euro area and the domestic economy, i.e., $\Delta z_t^A = \pi_t^{eA} - \pi_t^A$.¹⁷ The latter captures the change in the real marginal costs of supplying foreign goods domestically. Specifically, the Phillips curve is of the form:

$$\pi_t = (1 - \alpha_{lag})\pi_{t+1} + \alpha_{lag}\pi_{t-1} + \alpha_y y_t + \alpha_z (\pi_t^{eA} - \pi_t^A) + \varepsilon_t^\pi \quad (2)$$

B. Credit Market and Banking Sector

Credit cycles in the model are explicitly driven by demand and supply factors. Both the aggregate credit demand (measured in real terms, i.e., deflated by domestic prices)—inspired by a demand for credit arising from the households' maximization problem—and the banks' lending rate—which reflects the marginal costs of “producing” loans by profit-maximizing monopolistically competitive banks à la Dib (2010)—are expressed in deviations from their long-term levels. We express their dynamics as follows:

$$c_t = \theta_1 y_{t-1} + \theta_2 c_{t-1} - \theta_3 r_t^L + \varepsilon_t^{CD} \quad (2)$$

$$r_t^L = \delta_0 r_{t-1}^L - \delta_1 (k_{t-1}^{act} - k_{t-1}^{reg} - k_{ss}^{buff}) + \delta_2 r_t + \delta_3 lev_{t-1} - \delta_4 p_{t-1}^h + \varepsilon_t^{r^L} \quad (3)$$

Equation (2) reflects the demand for credit (bank loans) and allows for macro-financial linkages between total real credit, the cost of credit (r_t^L), and real output.¹⁸ The business cycle affects credit demand, with a stronger (weaker) economy leading to higher (lower) demand for credit. Because economic agents cannot immediately adjust credit levels, partly reflecting persistence in access to credit, we also assume that credit levels are slow to adjust to output fluctuations (as captured by the term $\theta_2 c_{t-1}$).¹⁹ ε_t^{CD} is an autonomous credit demand shock (for example, reflecting exogenous changes in borrowers' productivity and demand for investment goods).²⁰

¹⁶ We use the same specification of the open economy New Keynesian Phillips Curve as in Baba et al. (2020). See also Galí and Monacelli (2005).

¹⁷ The annual inflation is calculated for both the foreign and domestic economy as follows: $\pi_t^A = (\sum_{i=0}^3 \pi_{t-i})/4$.

¹⁸ Credit gap in Equation (2) is defined as the difference between the real credit $C_t \equiv 100 * \ln(\frac{CRED}{DEF})$ and its trend (c_t^*), where (CRED) is total credit extended by the domestically oriented banks to the domestic private non-financial sector, and (DEF) is the GDP deflator. The trend credit aims at capturing the long-term equilibrium (or “natural”) level of credit consistent with the economy operating at potential. It is assumed to evolve according to the following equation: $c_t^* = c_{t-1}^* + \frac{1}{4} g_t^c + \varepsilon_t^{c^*}$, with trend credit growth revolving around a steady-state potential credit growth ($g_t^{c^*} = \rho_{g^{c^*}} g_{t-1}^{c^*} + (1 - \rho_{g^{c^*}}) g_{ss}^{c^*} + \varepsilon_t^{g^{c^*}}$). Shocks $\varepsilon_t^{c^*}$ and $\varepsilon_t^{g^{c^*}}$ are temporary and permanent disturbances to real credit.

¹⁹ Previous studies have provided ample empirical evidence on the persistence of firms' access to credit by assessing the determinants of loan demand and financing constraints. For example, under imperfect information and screening technologies, past credit restrictions can negatively signal firms' riskiness and lead to long-lasting credit restrictions (Gertler and Gilchrist, 1994).

²⁰ Micro-uncertainty, which represents idiosyncratic uncertainty about the evolution of individual firms' productivity, plays a crucial role in the genesis of the financial frictions (Dorofeenko et al. (2008), Christiano et al. (2014), and Cesa-Bianchi and Fernández-Corugedo (2018)).

Equation (3) provides the setting of banks' lending rates based on Dib (2010) and de Resende et al. (2016).²¹ The lending rate gap is determined by the marginal cost of interbank borrowing (r_t) and that of raising bank capital, which is assumed to be decreasing in banks' capital buffer ($k_{t-1}^{act} - k_{t-1}^{reg} - k_{ss}^{buff}$).²² Higher (lagged) capital ratios (k_{t-1}^{act}) due to increased retained earnings, *ceteris paribus*, increase bank capital buffers—i.e., the actual level of bank capital minus the regulatory level (k_{t-1}^{reg})—above the desired buffer at the steady state (k_{ss}^{buff}) and reduce the lending rate.²³ In contrast, a tightening in the macroprudential policy stance, which increases minimum capital requirements, leads to lower capital buffers, increases the banks' marginal cost to raise capital and supply loans, translating into higher lending rates.²⁴ Finally, to capture financial accelerator mechanisms à la BGG and K&M, the lending rate is positively related to aggregate leverage (lev_{t-1} , a proxy for banks' perception of borrowers' net worth) and negatively related to house prices (p_{t-1}^h , a proxy for borrowers'

²¹ In Dib (2010) and de Resende et al. (2016), the rigidity in nominal lending rates is modelled à la Calvo, entering the maximization of profit by monopolistically competitive banks. The real lending rate gap equals the actual rate minus its trend (r_t^L). The actual data on (real) lending rate used in the paper is represented by the difference between the weighted average nominal interest rate on mortgage and non-financial corporations' loans and the expected inflation. The latter reflects model-consistent forward-looking expectations. The trend real lending rate is assumed to revolve around its steady state value, as follows: $r_t^{L*} = \rho_{r^L} r_{t-1}^{L*} + (1 - \rho_{r^L}) (r_t^* + \eta_{ss}^{r^L}) + \varepsilon_t^{r^L}$, where $\eta_{ss}^{r^L}$ is the non-financial private sector's risk premium, which is assumed to be constant.

²² The real interbank rate gap (r_t) is the gap between the real interbank rate (R_t) and its trend (r_t^*). R_t is derived as the difference between the nominal rate (proxied by the 3-month Luxembourg interbank rate, i_t) and the next period expected inflation (that is $R_t = i_t - \pi_{t+1}^e$). We model r_t^* as the difference between the trend of the euro area real interbank rate ($r_{e,t}^*$) and Luxembourg's risk premium (\emptyset_t) as follows: $r_t^* = r_{e,t}^* - \emptyset_t$. Both $r_{e,t}^*$ and \emptyset_t follow similar specifications, and evolve around their steady-state values: $r_{e,t}^* = (1 - \rho_{r_e^*}) r_{e,t-1}^* + \rho_{r_e^*} r_{e,ss}^* + \varepsilon_t^{r_e^*}$, and $\emptyset_t = (1 - \rho_\emptyset) \emptyset_{t-1} + \rho_\emptyset \emptyset_{ss} + \varepsilon_t^\emptyset$.

²³ Bank capital buffer revolves around a steady state level (k_{ss}^{buff}) which is assumed to be positive to match Luxembourg data and is subject to an exogenous shock ($\varepsilon_t^{k^{act}}$). Our calibration of k_{ss}^{buff} is consistent with a positive neutral CCyB buffer and a constant minimum capital requirement ratio (Basel III) such that deviations from k_{ss}^{buff} reflect changes in the CCyB only. See Valderrama (2023) and ECB (2023) for a discussion of how implementing such a positive neutral CCyB could increase macroprudential policy space in the European banking union. Other countries are also adopting positive neutral CCyB levels, including Australia, New Zealand, South Africa, Sweden, and the United Kingdom. This may lead to less emphasis on the estimates of cyclical risk indicators, including credit-to-GDP gaps, which can be subject to significant uncertainty and thus lead to false signaling, time lags, and communication challenges.

²⁴ Equation (3) is inspired by de Resende et al. (2016), where a tightening in the macroprudential policy stance induces banks to deleverage optimally, by raising additional bank capital in the market or cutting loans at the prevailing lending rate. The authors assume a perfect complementarity between funding sources (borrowing in the interbank market versus issuing new bank capital). Raising more capital is assumed to be costly and would, therefore, result in a higher marginal cost of producing loans, which is partially passed on to borrowers by monopolistically competitive banks.

collateral), respectively. The latter channel works through the negative relationship between house prices and unemployment.²⁵

Banks are assumed to adjust their capital in response to changes in the regulatory and economic environment. We model banks' response to shocks and policy changes using structural elements in Dib *et al* (2010) and de Resende *et al* (2016). In that setup, banks are constrained to satisfy the regulatory minimum capital requirements but face dynamic adjustment costs to raise capital which adds some persistence in the dynamics of bank capital.²⁶ Accordingly, the banks' capital buffer over the neutral regulatory rate, i.e., bank capital (k_t^{act}) in deviation from the long-term level (k_t^*), is determined as follows:

$$k_t^{act} - k_t^* = \psi_5(k_t^{reg} - k_t^*) + (1 - \rho_{k^{act}})k_{ss}^{buff} + \rho_{k^{act}}(k_{t-1}^{act} - k_{t-1}^*) + \psi_6(g_{t-1}^c - g_{t-1}^{c*}) + \psi_7 D_{2008} + \psi_8 D_{2014} + \varepsilon_t^{k^{act}} \quad (4)$$

The parameter $\rho_{k^{act}}$ captures the persistence of bank capital, with changes in minimum capital requirements ($k_t^{reg} - k_t^*$) being implemented in the current period only partially (i.e., $\psi_5 < 1$). Furthermore, bank capital is assumed to be positively related to past credit growth gap ($g_{t-1}^c - g_{t-1}^{c*}$) as banks likely accumulate more capital (internally via retained earnings) when credit grows faster, and profitability improves. Equation (4) also includes two dummy variables (D_{2008} and D_{2014}) which capture the phasing-in of Basel II and III capital requirements in Luxembourg starting in 2008 and 2014, respectively.²⁷

As such, banks play an active role in the transmission of the macroprudential policy to the economy.

Banks respond to changes in macroprudential policy stance by changing their capital buffers (Equation 4), which in turn affects the cost of credit supply (Equation 3), credit demand (Equation 2), and ultimately output (Equation 1). For example, a tightening of the macroprudential stance (say, in response to a credit boom), leads to lower capital buffers, higher marginal costs of lending and higher lending rates, which in turn leads to lower demand for credit, attenuating both credit and real cycles.

²⁵ The data on aggregate leverage used in the paper is derived as the weighted average of households' mortgage-to-income ratios and non-financial corporations' equity-to-debt ratios. Weights are the share of each credit type to total credit. The leverage gap is modelled as follows: $lev_t = c_t - A_t$, where A_t is the log of (unobservable) value of assets available to households and firms (in deviation to its long-term level). The latter is assumed to be sensitive to fluctuations in economic activity as well as in housing prices, as follows: $A_t = \rho^A A_{t-1} + \sigma_1 y_{t-1} + \sigma_2 p_{t-1}^h + \varepsilon_t^A$. House price gaps are derived using the model described in IMF (2018). The house price gap is determined by the following equation: $p_t^h = \rho^h p_{t-1}^h - \sigma_3 u_{t-1} + \varepsilon_t^{p^h}$, where u_t is the unemployment gap. The latter follows a dynamic Okun's law, where the unemployment gap is function of its own lagged value (u_{t-1}) and the output gap as follows: $u_t = \tau_2 u_{t-1} - (1 - \tau_2)\tau_1 y_t + \varepsilon_t^u$. The variable u_t is defined as actual quarterly unemployment U_t minus the equilibrium unemployment rate u_t^* (i.e., its natural level or NAIRU), where the latter is determined by its steady state value u_{ss} and its growth rate $g_t^{u^*}$ according to the following equations: $u_t^* = (1 - \tau_4)u_{t-1}^* + \tau_4(u_{ss} + g_t^{u^*}) + \varepsilon_t^{u^*}$ and $g_t^{u^*} = (1 - \tau_3)g_{t-1}^{u^*} + \varepsilon_t^{g^{u^*}}$.

²⁶ De Resende *et al.* (2016) assume that banks derive quadratic gains when holding capital buffers, ensuring they optimally choose a capital ratio that is strictly above the minimum requirements. The authors also assume that the saving decisions of households, who must pay a cost to adjust their holdings of bank capital, determine bank capital, which results in bank-level persistence. The empirical literature finds that positive capital buffers are persistent both across countries and over time, possibly reflecting adjustment costs of bank capital to targets (see among others Barth *et al.* (2004) and Valencia and Bolanos (2018)).

²⁷ The trend bank capital (k_t^*) follows an autoregressive process: $k_t^* = \rho_k k_{t-1}^* + (1 - \rho_k)k_{ss}^* + \varepsilon_t^{k^*}$. It is subject to exogenous shocks ($\varepsilon_t^{k^*}$) and revolves around its steady state level (k_{ss}^*).

C. Macroprudential Policy Rule

Macroprudential policy reacts to developments in the financial cycle and house prices. Macroprudential policy in Luxembourg aims to reinforce the financial system's resilience by addressing the build-up of systemic risk during periods of excess credit growth and booming asset prices, i.e., acting countercyclically. Developments in credit and housing markets are the main factors underpinning the setting of the macroprudential policy stance in Luxembourg (IMF, 2021).²⁸ More specifically, it is assumed that the macroprudential authority changes the regulatory minimum capital requirement in response to the financial cycle as follows:

$$k_t^{reg} - k_t^* = \psi_1(k_{t-1}^{reg} - k_{t-1}^*) + \psi_2 c_{t-1} + \psi_3(g_{t-1}^c - g_{t-1}^{c*}) + \psi_4 p_{t-1}^h + \varepsilon_t^{k^{reg}} \quad (5)$$

Equation (5) describes the evolution of minimum capital requirements consistent with the financial stability objectives mentioned above (as captured by the parameters ψ_2 , ψ_3 , and ψ_4 for credit, credit growth, and house price, respectively).²⁹ For example, positive credit or house price gaps and excess credit growth trigger increases in minimum capital requirements above its neutral (regulatory) level (k_t^*).³⁰ The coefficient ψ_1 reflects the persistence in decision making to avoid undue volatility in lending rates and credit. The higher is ψ_1 , the less effective the macroprudential policy would be in addressing developments in credit and asset prices. $\varepsilon_t^{k^{reg}}$ is the macroprudential policy shock. Equation (5) means that the regulatory capital ratio will be at its neutral level when both the credit and house price gaps are zero and credit is growing at its trend pace, g_t^{c*} . While the rule focuses on the financial cycle, it also interacts with the business cycle in two ways: (i) through the effects of output gap and unemployment on credit demand and house prices, respectively; and (ii) via its impact on lending rate and in turn on output gap.

²⁸ Other European countries may have downplayed the role of these developments in setting their macroprudential policy stance. ESRB data indicates that, despite negative estimates of credit gaps, several countries have either increased or maintained their positive CCyB buffers. This is partly due to a potential negative bias in credit gap estimates and authorities' efforts to proactively preserve policy space for addressing the credit cycle.

²⁹ Equation (5) provides a simplified view of the setup of macroprudential policy in Luxembourg. As discussed in the previous section, the target for countercyclical capital requirements is announced slightly in advance to allow banks to adjust smoothly. In addition, the policy rule does not incorporate the newly introduced LTV limits to address households' high indebtedness. This rule does not consider the timing asymmetry observed in practice as upward CCyB adjustments are typically enforced with a lag following the announcement while CCyB buffers may be released immediately. Any resulting bias should be limited as (even partially) rational agents immediately react to policy announcements.

³⁰ Luxembourg's macroprudential policy authorities monitor various financial indicators while setting the countercyclical capital buffer, including the Basel III credit-to-GDP gap (the gap between the credit-to-GDP ratio and its long-term trend). Section VI discusses the implications of incorporating credit-to-GDP gap into the macroprudential policy rule.

V. Data, Calibration, Bayesian Estimation, and Model Validation

A. Data

We mapped the model to the data using quarterly macroeconomic and financial series for Luxembourg and the euro area over the period 2003-2019. For Luxembourg, we considered real GDP, GDP deflator, the Harmonized Index of Consumer Prices (HICP), the rate of unemployment, an aggregate indicator for the volume of credit, nominal interest rates (i.e., bank lending rate), selected balance sheet indicators for loans to households and non-financial corporations, capital ratios for the domestically oriented banks, and minimum capital requirements. We also collected data covering key macroeconomic indicators for the euro area. The data come from various sources, including the BCL, the CSSF, Eurostat, St. Louis FRED database, and the IMF World Economic Outlook (WEO) database. We provide detailed information on the data and their sources in Annex II.

B. Calibration and Bayesian Estimation

We parametrize the model for Luxembourg's economy through a combination of calibration and Bayesian estimation techniques. The mixture of calibration and estimation aimed at ensuring that the model properties are robust (including economically meaningful trends from filtration and plausible impulse responses) while considering available evidence from relevant studies. See Annex III for the specific calibrated and estimated values for the most relevant parameters of the model, including steady state variables.

Consistent macroeconomic intuition, understanding of Luxembourg-specific features, and empirical findings underpinned the model calibration. First, we calibrated the shocks' dynamic coefficients and standard deviations for all long-term trends. We also calibrated the parameters describing the steady state of the model. Calibration was guided by matching the observed data and by interpreting long-term trends.³¹ Standard deviations of the shocks are set by accounting for the observed variance in the available data sample (hence, delivering coherent structural stories) and aiming at smooth unobserved trends that are less volatile than their corresponding gaps. We estimated as many parameters as possible and calibrated those that were not well identified. For instance, we calibrated the main parameters governing the size and timing of credit response to changes in the macroprudential stance based on the empirical findings in Jiménez *et al.* (2017).³² More specifically, we calibrated the parameters determining the responses of the bank lending rate to changes in capital buffers (δ_1), the response of credit demand to changes in the lending rate (θ_3), and the persistence of

³¹ For example, we calibrated the steady-state levels of bank capital buffers as well as minimum capital requirements around the historical observations for the domestically oriented banks. On aggregate, these banks have established large capital buffers, partly reflecting their high profitability and liquidity as well as the relatively limited size of the domestic credit market. The parameters capturing the persistence of trend credit growth and lending rates are calibrated to match the data and reflect recent developments in both domestic and euro area credit markets.

³² As for many advanced economies, countercyclical capital measures were introduced only in 2014, which limits the number of observations available for estimating these parameters.

minimum capital requirements (ψ_1) such that a 1 percentage point increase in the countercyclical capital buffer reduces the deviation of credit from its long-term equilibrium (credit gap) by about 0.5 percentage points over 5 quarters. The calibration of the main parameters determining the macroprudential policy response to shocks will be discussed in Section VI.³³

We relied on Bayesian estimation for the main parameters of structural equations and cyclical stocks.

We use quarterly data beginning in 2003Q1 and ending in 2019Q4. We dropped the COVID pandemic from the estimation sample to avoid the effect of the noise caused by the unusually high volatility in key variables on the estimated parameters. The COVID shock combines various effects that can adversely affect the quality of the estimation, including the unprecedented policy response both domestically and globally. Since the CCyB did not change during the estimation sample, the impact of Lucas critique considerations on the estimated parameters should be minor. At the same time, given that there have been changes in the minimum capital requirements prior to 2019Q4, the estimated parameters do internalize the real/credit cycle interactions. To help identify the model parameters and shocks from the estimation sample, we set up prior distributions for the parameters governing the dynamics of key variables consistent with our priors on their behavior.³⁴ Overall, the estimation results are satisfactory, with most parameters being well identified and the data information complementing the prior information.³⁵

The estimation results suggest a weak sensitivity of the aggregate demand to changes in the lending rate and a strong persistence of credit (Figure 2).

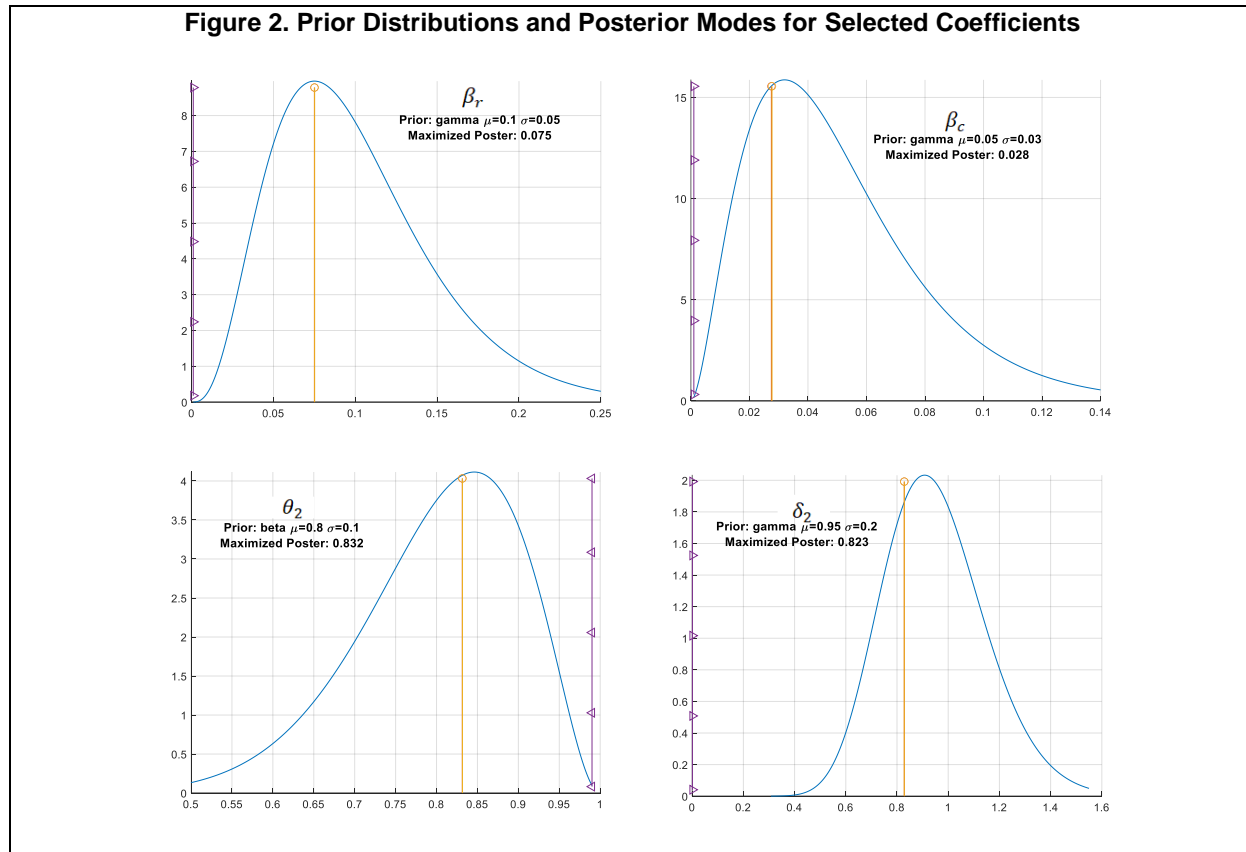
The estimated values for β_r (0.075) and β_c (0.028) indicate the output's low sensitivity to interest rates and credit, partly reflecting the structure of Luxembourg's economy (dominated by financial services). As such, changes in the macroprudential policy stance may have only marginal effects on real growth. In line with empirical literature (BIS, 2015), the estimated value for the parameter θ_2 (0.83) suggests credit's strong underlying inertia, possibly leading to lags between macroprudential policy action and the resulting economic outcomes (which then can be long-lasting). Finally, the parameter δ_2 is estimated at 0.83, indicating that interbank rates—primarily determined by the ECB's monetary policy stance—represent an important driver of bank lending rates in Luxembourg. The coefficients associated with aggregate demand and supply functions are close to those found in the relevant literature for Luxembourg and similar large financial centers.

³³ For a discussion of state-dependent responses of credit see Lang and Menno (2023).

³⁴ We implicitly imposed penalties on the estimation process à la Andrieu and Plasil (2016).

³⁵ For all parameters, we obtained a reasonable curvature of the likelihood/posterior in the estimates' neighborhood. Posterior mode estimates generally differed from the prior means, indicating that the data information helped "update" the priors. We constructed the posterior distribution based on 500,000 simulated paths and obtained an acceptance ratio of about 20 percent (which is a measure of the "quality" of the posterior density function estimate).

Figure 2. Prior Distributions and Posterior Modes for Selected Coefficients



C. Model Validation

This section analyzes the model's fit to available data and in-sample forecasting accuracy. We compare actual and simulated moments of relevant variables, perform pseudo-out-of-sample simulations, and assess the model's forecast accuracy against simple reduced-form empirical models.

Moment Comparison: Data vs. Model

We assess the ability of the model to match the moments of actual data. We compare actual and simulated data moments across various macroeconomic and financial indicators during 2010Q1-2020Q4. Specifically, we bootstrap 10,000 paths for selected variables and test whether the resulting moments match those observed in the data. Results suggest that the model accurately reproduces the moments of the main indicators, including for the credit market (Figure 3).

For instance, simulated moments for key macroeconomic indicators replicate well those from the data. Table 1 displays the tests of equality for the first two moments (i.e., mean and variance) of selected indicators. The mean values of simulated variables are close and not statistically different from those observed in the data. Broadly, the same is true for the variances, except for real credit growth, which exhibits a higher volatility in the model. The low rejection rates of the null hypothesis of moment equality (i.e., the share of cases where the null hypothesis is rejected) in bootstrapped sequences confirm these results, with real credit growth featuring a

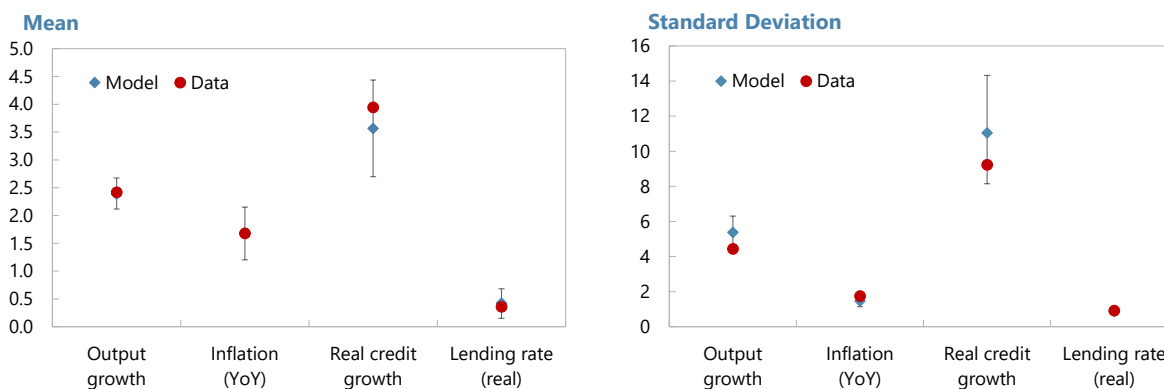
higher rejection rate (16%) than the other variables. Figure 3, which displays confidence intervals around actual and simulated moments, illustrates the model's ability to match the data (although with relatively larger uncertainty for real credit growth).

Table 1. Data vs. Model-Generated Moments

Selected variables	Mean		Standard deviation		Equality tests			
	Data	Stochastic simulations	Data	Stochastic simulations	$H_0 : \mu_D = \mu_M$		$H_0 : \sigma_D = \sigma_M$	
	(μ_D)	(μ_M)	(σ_D)	(σ_M)	F-test	Rejection rate	F-test	Rejection rate
Output growth	2.4	2.4	4.4	5.4	0.00 (0.97)	0.00	0.88 (1.00)	0.1
Inflation (YoY)	1.7	1.7	1.8	1.5	0.00 (0.98)	0.00	0.98 (0.94)	0.1
Real credit growth	3.9	3.6	9.2	11.0	0.06 (0.80)	0.00	1.16* (0.11)	0.2
Bank lending rate (real)	0.5	0.4	0.9	0.9	0.17 (0.68)	0.00	0.06 (0.95)	0.0

Notes: The table covers the 2010-2019 period. For each variable, the moments reported in the table represent the average of means and standard deviations of the 10,000 simulated paths using a bootstrap simulation technique. The tests of equality of means and variances are based on the F-test applied to actual and the average of simulated data. The values in brackets denote the respective probabilities (p-values) associated with the F-test values, indicating the areas of rejection of H_0 (probability of rejecting H_0 with a risk of error equal to p-value). The number of stars (***), (**), (*) means that we reject H_0 hypothesis with risks of error of 1 percent, 5 percent, and 10 percent, respectively. For each variable, we calculate the rejection rate as the share of cases where H_0 is rejected (based on t-test) with risk of error less than 5 percent among the 10,000 simulated paths.

Figure 3. Confidence Intervals for Simulated and Actual Moments



Notes: The error bars represent 95% confidence intervals. The red dots represent the observed moments, while the blue ones are the average moments from the 10,000 simulated paths.

Pseudo Out-of-Sample Forecasts

We next evaluate the model's predictive power using pseudo-out-of-sample forecast. We assess whether the model forecasts do not deviate systematically from the data and are consistent with priors from standard macroeconomic restrictions. We run recursive one- to six-quarter ahead forecasts of the key variables over the period 2016Q1-2020Q4 (that is, including the first year of the COVID shock).³⁶ We generate the forecasts conditional on: (1) the exogenous changes in Luxembourg's supervisory framework; and (2) the trajectory of WEO estimate of Luxembourg's potential output. We also impose WEO estimates of key euro area variables (including output trend and gap and the ECB's policy rate and inflation target) over the forecast horizon.³⁷ Figure 4 shows the evolution of the realized (thick black lines) and projected (red dotted lines) values of real GDP, real aggregate credit, inflation, and nominal lending rate.

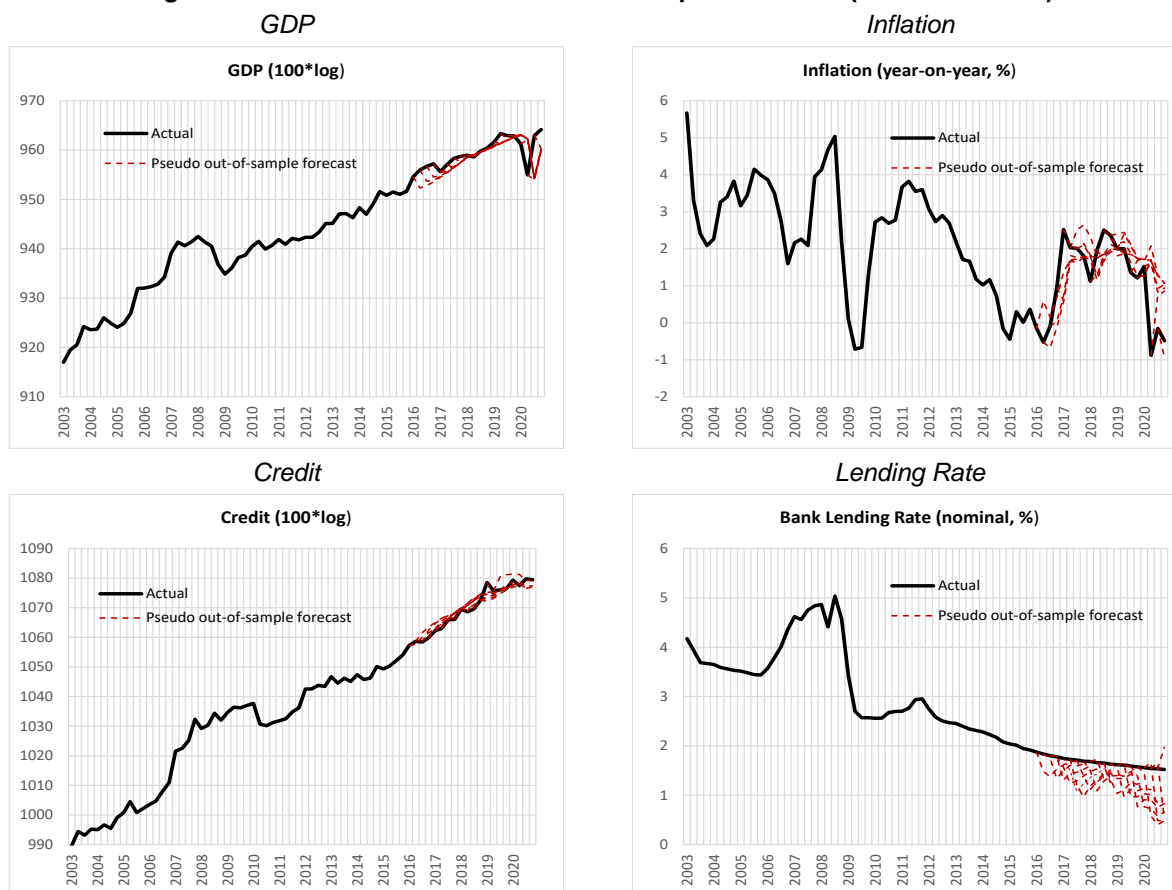
For most variables, the model forecasts match actual data well. Figure 4 indicates that forecast errors, to a large extent, are two-sided and the model captures well the relevant turning points and general dynamics of most indicators, including during the first year of the COVID shock, which generated unprecedented macroeconomic volatility. For example, the model captures the robust real GDP growth during the pre-COVID period and the sizeable COVID-driven dip in 2020. At the same time, the model approximates the domestic inflation dynamics relatively closely, and captures well the general behavior of real aggregate credit volumes as well as the downward trend in lending rates. The latter is consistent with the prevailing low-for-long interest rate environment.

The forecast of the nominal lending rate appears downward biased, mainly reflecting forecasting errors for the domestic interbank rates. The model underestimates nominal lending rates, especially in the short run (less than one year). The bias disappears for longer forecast horizons. Since the forecast for inflation looks broadly unbiased, the real lending rate is the main factor driving this downward bias. This short-lived bias is related to the interplay between the consistently decreasing estimated unobserved trend in the euro area real policy rate (i.e., the neutral rate) and that in the domestic real lending rate.³⁸

³⁶ Note that we used data up to 2019Q4 to parametrize the model. The forecasts for 2020 are, therefore, 'truly' out-of-sample.

³⁷ We use the October 2022 WEO vintage.

³⁸ The interbank rate is an important driver of both the cyclical and trend components of the real lending rate.

Figure 4. Actual Data vs. Pseudo Out-of-Sample Forecasts (2016Q1-2020Q4)

Source: Authors' calculations.

Note: the black line represents actual values of selected variables, while the red dotted lines represent their projected values.

Model vs. Simple Time Series Forecasting Methods

Finally, we assess the model's forecasting performance against that of reduced-form models by comparing root mean square forecast errors (RMSEs). Table 2 shows the results of Diebold-Mariano tests of the model's forecasting ability compared to simple time series methods, such as Vector Autoregression (VAR) and Autoregressive Moving Average (ARMA) models. More specifically, we estimate an unconstrained VAR for output growth, credit growth, and the nominal interest rate, and an ARMA model for inflation.³⁹ Table 2 reports the ratio of model-based RMSEs to those of reduced-form forecasting models across the selected indicators and forecast horizons (up to 6 quarters ahead). Any value below one indicates that the semi-structural model would be preferred as it produces lower out-of-sample forecast error.

³⁹ We control for the time series properties of these variables using unit root tests and determine the appropriate lag length using optimal lag selection criteria (including Akaike's information criterion (AIC) and Schwarz's information criterion (SIC)).

Overall, the model's RMSEs are lower than that of the simple benchmarks. For most variables and forecast horizons, the model outperforms the VAR forecasts. On average, the ratio of RMSFEs is below 0.7 for output growth, lending rate, and credit growth. Moreover, we reject the null hypothesis that models' forecasts are equally accurate within a high confidence level, especially for longer forecasting horizons (notably, for credit growth). Although the RMSEs for inflation exhibit a ratio above one over the entire forecasting horizon, the accuracy of the model's forecast is not statistically different from that of the benchmark model.⁴⁰ These results suggest that the model is a robust tool for medium-term predictions and policy analysis, *especially* for credit growth and relevant recommendations for the macroprudential policy stance, which is the basis of the paper's main contribution.

Table 2. RMSEs of the Model Relative to Simple Benchmarks

Variables		RMSE						Average
		Q1	Q2	Q3	Q4	Q5	Q6	
Output growth	Model	5.2	3.8	4.1	4.3	4.5	3.8	4.3
	VAR	17.4	18.1	18.1	18.1	18.2	18.3	18.0
	Ratio	0.3	0.2	0.2	0.2**	0.3**	0.21***	0.2
Bank lending rate (nominal)	Model	1.1	0.7	0.6	0.5	0.5	0.4	0.6
	VAR	1.7	1.7	1.7	1.7	1.7	1.8	1.7
	Ratio	0.7***	0.4***	0.4***	0.3***	0.3***	0.2***	0.4
Credit growth	Model	11.4	8.5	8.7	9.1	9.0	9.4	9.3
	VAR	10.2	14.5	13.9	13.8	13.8	13.7	13.3
	Ratio	1.1	0.6	0.6	0.7	0.7*	0.7**	0.7
Inflation	Model	0.5	0.6	0.7	0.8	0.8	0.8	0.7
	ARMA	0.5	0.6	0.6	0.6	0.6	0.6	0.6
	Ratio	1.1	0.9	1.1	1.3	1.3	1.3	1.2

Source: Authors' calculations.

The table compares the accuracy of the model's forecast to that of an unrestricted VAR for output growth, bank lending rates, and credit growth, and an ARMA(1,3) process for inflation. We calculate the ratio of RMSEs, with a ratio lower than one on average indicating a better accuracy of the model (i.e., it has a smaller root-square mean error). We also formally evaluate the H0 hypothesis that the ratio of RMSEs is equal to one—meaning that the semi-structural model is not more accurate than the reduced-form model—with Student's t-test. The number of stars indicates the risk of error of rejecting H0 hypothesis. (***) , (**), (*) imply risks of error of 1 percent, 5 percent, and 10 percent, respectively.

⁴⁰ Atkeson and Ohanian (2001) and Stock and Watson (2007) show that it has become more difficult to effectively incorporate information other than inflation itself in producing forecasts that improve over simple benchmark models. Moreover, as explained in the previous section, the model includes a simple reduced-form Philips Curve for headline inflation. Disaggregating headline inflation into subcomponents (such as food and energy inflation, which may exhibit different dynamics in response to the corresponding shocks) can improve the model feature.

VI. Model Properties

This section discusses the model’s dynamic responses to structural shocks and its ability to sensibly convey historical developments. First, we illustrate the dynamic responses to an exogenous tightening in the macroprudential policy stance, highlighting the corresponding transmission mechanisms. Second, we analyze the impulse responses of the main variables to several structural shocks. Third, we provide a narrative for the historical evolution of the credit and lending rate gaps in terms of model-specific structural factors.

Minimum Capital Requirement Shock

First, we simulate the impact of an exogenous tightening of the macroprudential policy stance. We assume an unexpected one-off one-percentage point increase in minimum capital requirements (compared to the equilibrium). For illustration purposes, we allow the model to freely converge back to equilibrium, assuming no subsequent policy response to the economic outcomes of the initial shock (i.e., to observe the “pure” effect of changes in the macroprudential stance, we deactivate the endogenous response of the regulator). The impulse response functions (IRF) showcase the transmission of the shock to the policy stance on the main endogenous variables, with particular emphasis on the dynamics of financial variables (Figure 5).

As expected, credit conditions tighten rapidly with the tightening of the macroprudential stance, gradually easing as the shock dissipates. Following the shock, banks increase capital-ratio holdings only partially (by about 0.2 percentage points at the peak), reducing their capital buffers (relative to its long-term value).⁴¹ Weaker capital buffers put upward pressure on marginal lending costs, leading to both higher lending rates (0.16 pp peak-increase) and lower volume of credit. The credit gap turns negative, reaching -0.5 percent after five quarters in line with the calibration of parameters δ_1 , θ_3 , and ψ_1 .⁴² Given the models’ parametrization, the impact of weaker capital buffers on bank lending rates far outweighs the offsetting impact of lower leverage levels, which acts with second-order effects on the credit supply function. At the same time, the decline in asset prices supports the increase in lending rates.⁴³ Given the relatively large (calibrated) persistence of the minimum capital requirements ($\psi_1 = 0.8$) and, to a lesser extent, bank capital ($\rho_{k^{act}} = 0.3$), these effects only gradually disappear as the shock fades out.

The impact of the shock on the real economy is relatively mild. Tighter credit conditions lead to weaker aggregate demand due to credit price (higher lending rates) and volume (lower credit) effects. As expected, the

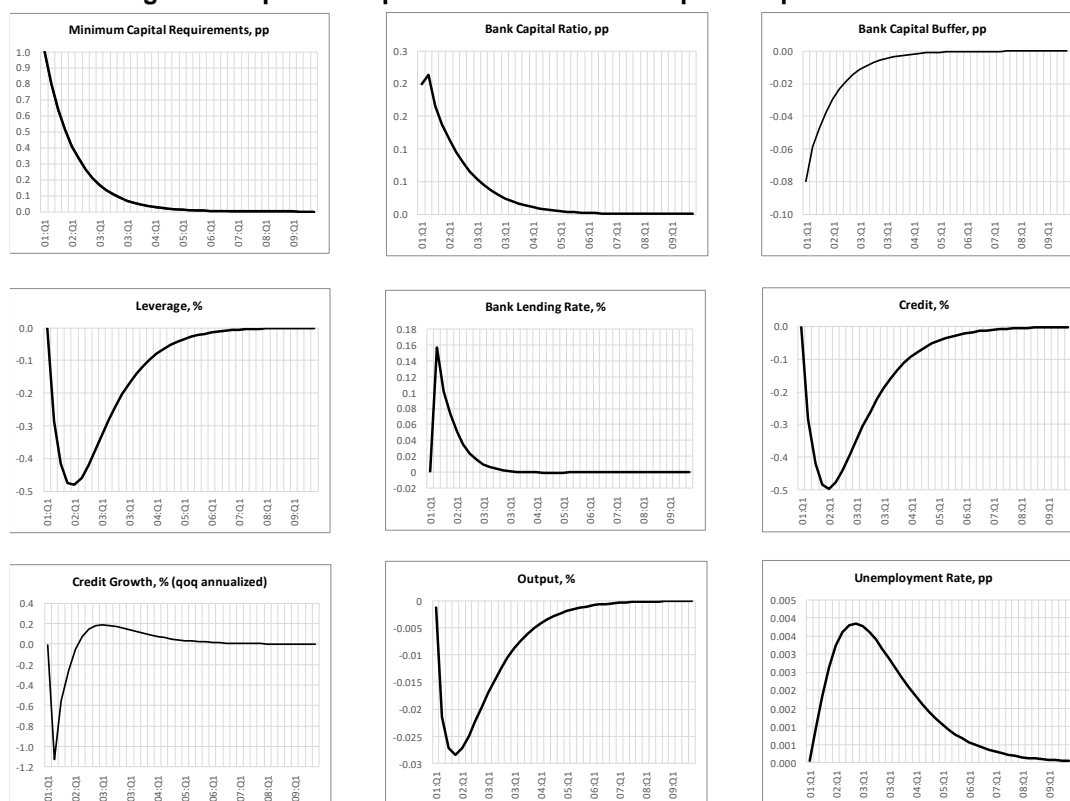
⁴¹ Note that $\psi_5 = 0.2$ in Equation (4). See Annex III.

⁴² See Section V for the discussion of the calibration of these parameters. Our model-based estimate of the impact of tighter minimum capital requirements on lending rates is broadly in line with DSGE-based evidence (0.06-0.12 pp), and relatively larger than in recent empirical research (Karmelavičius et al., 2023).

⁴³ As discussed in the model section, banks set their lending rates considering the change in their capital buffers, risk perception (borrowers’ leverage), and collateral value (housing prices). As expected, aggregate leverage and, to a lesser extent, housing prices (not shown in the chart) decline relative to their long-term levels following the tightening in the macroprudential policy stance. First, we derive leverage as the log difference between credit and aggregate asset value. The drop in the former (caused by softer credit demand due to higher lending rates) more than offsets the marginal decline in the latter (driven by the mild impact of the shock on economic activity). Second, housing prices (not shown in Figure 5) slightly decline following the weakening in economic activity and higher unemployment.

impact on output is mild, with the output gap slightly turning negative (around -0.25 percent at the peak), reflecting the weak relationship between credit and the real economy (as captured by the estimated small values of the parameters β_r and β_c). Accordingly, unemployment would only be marginally impacted, with the unemployment rate merely deviating by 0.04 percentage points from its long-term level at the peak. Finally, inflation (not shown in Figure 5) remains almost unchanged, reflecting its low sensitivity to domestic activity ($\alpha_Y = 0.005$).⁴⁴ These results seem to indicate a relatively easy trade-off facing the macroprudential regulator when acting to smooth the credit cycle.⁴⁵

Figure 5. Impulse Responses to a Minimum Capital Requirement Shock



Source: Authors' calculations.

⁴⁴ We calibrated α_Y based on the empirical findings in Rubene and Guarda (2004) which provides New Keynesian Phillips curve estimates for Luxembourg. The authors find that the slope of the Phillips curve is relatively small (between 0.003 and 0.006), and that real marginal costs (proxied by the output gap in our model) do not significantly determine Luxembourg's inflation.

⁴⁵ As discussed in the previous section, the model's low sensitivity of output to interest rate and credit partly reflects the structure of Luxembourg's economy. These results may be different in other countries where aggregate demand could be more sensitive to changes in credit. While the model can be easily applied to a wider set of European countries, this is left to future research.

A. Impact of the Main Structural Shocks in the Model

Next, we simulate the impact of the main structural shocks while accounting for the *endogenous* response of the macroprudential policy. We discuss IRFs of the main variables to shocks in the real economy (aggregate demand and supply shocks) and the credit markets (credit demand and supply shocks). All shocks are 1 percent in magnitude and unexpected. We calibrate the parameters of the macroprudential policy rule assuming that the macroprudential regulator attaches equal weights to developments in credit (both in terms of credit growth and gap) and housing (in terms of the house price gap) (i.e., $\psi_2 = \psi_3 = \psi_4 = \psi$). We derive IRFs under two possible policy stances: a Dovish stance (that is, a low responsiveness to the financial cycle; $\psi = \psi_{low}$, depicted by blue solid lines) and a Hawkish stance (that is, a high sensitivity to the financial cycle, $\psi = \psi_{high}$, depicted by red dotted lines). To highlight the role of macroprudential policy in mitigating the credit cycle and its implications for the real economy, we also show the results of a counterfactual exercise in which the macroprudential policy is kept inactive (i.e., $\psi = 0$).

Demand and Supply Shocks

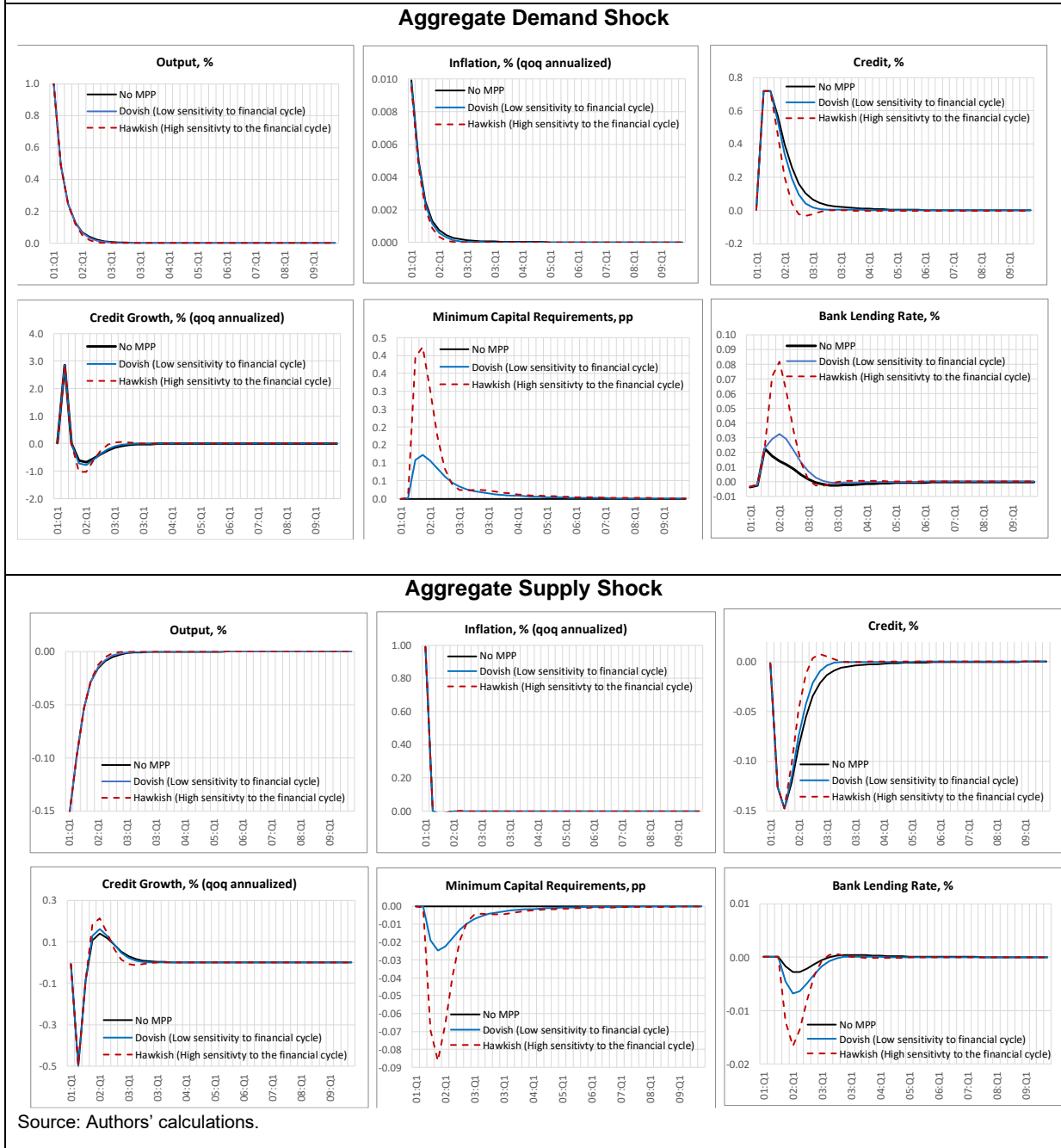
Impulse responses to standard business cycle shocks confirm that the model aligns well with economic intuition and standard literature (Figure 6). More specifically,

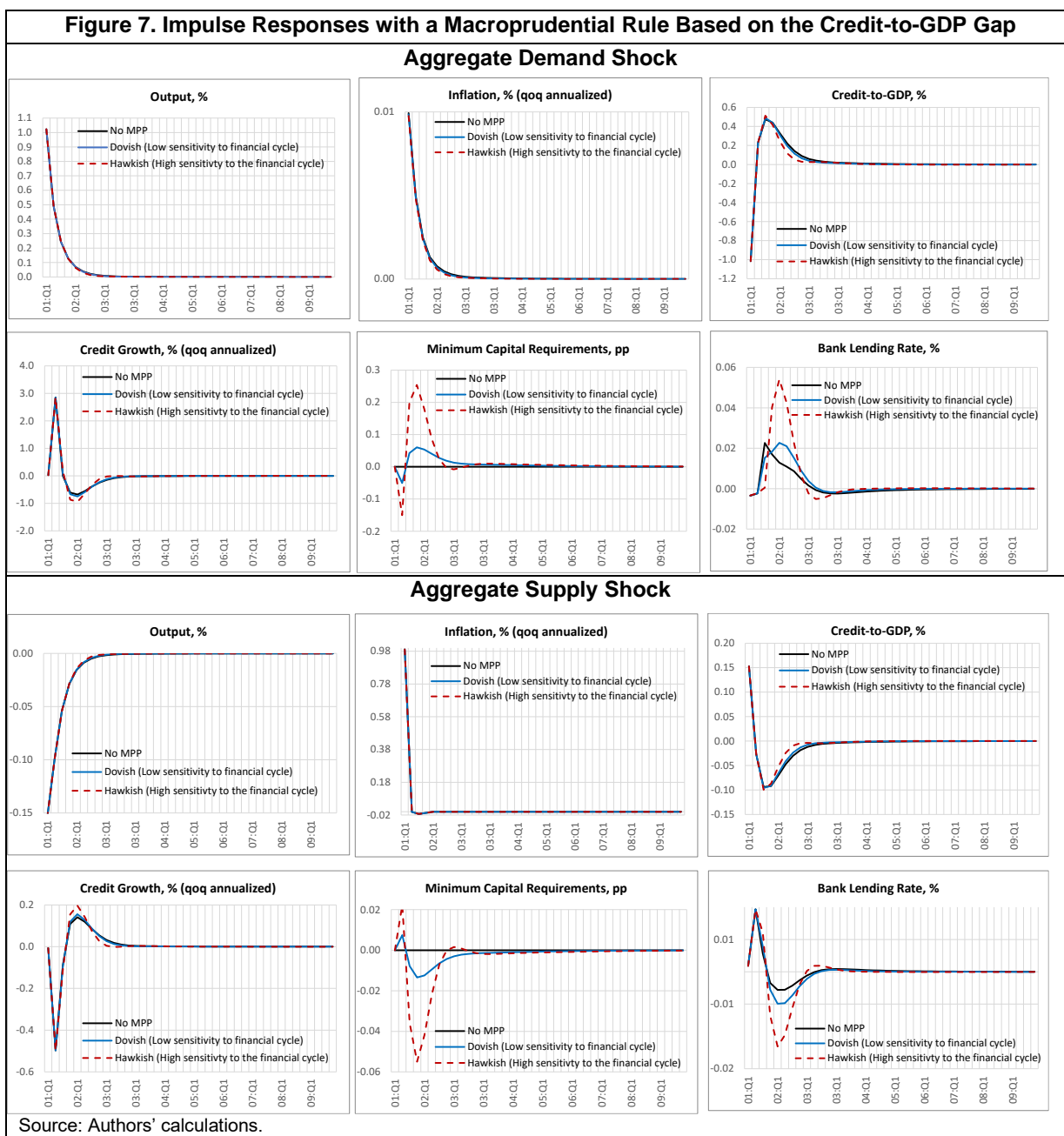
- *A positive aggregate demand shock leads to upward credit pressures, requiring a tightening in the macroprudential policy stance.* The 1-percent shock translates into only a marginal pressure on the general price level (0.01 percent). In contrast, credit increases at a rate above its long-term trend, leading to a positive credit gap (about 0.7 percent in the second quarter to the shock). As a result, both aggregate leverage and housing prices increase above their long-term levels. In response to these developments, the macroprudential policy authorities tighten the macroprudential policy stance (by raising minimum capital requirements to 0.45 percentage points under the Hawkish stance) to ease pressures in the credit market and restore equilibrium. In turn, banks reduce their capital buffers and, with increased credit risk perceptions due to higher leverage, their marginal lending costs increase, leading to higher lending rates. As a result, credit demand softens, credit growth declines (even turns negative), and both credit and output gaps close. A more aggressive macroprudential stance would result in a larger peak of the lending rate and somewhat quicker convergence of credit to its trend.
- *The supply shock—a positive cost-push shock in the Phillips curve—leads to a contraction in both output and credit, requiring a loosening of the macroprudential policy stance to restore the equilibrium.* The supply shock shows a negative correlation between inflation and the output gap. Following the shock, the latter turns negative (-0.15 percent), leading to weaker demand for credit (consistent with Equation (2)). As a result, credit falls below its long-term trend, and the credit gap becomes slightly negative, lowering aggregate leverage levels. The macroprudential policy authorities reduce minimum capital requirements to restore equilibrium. The transmission mechanism discussed in the previous paragraph works in the opposite direction, with banks slightly building buffers, which help reduce their marginal lending costs and, in turn, lower lending rates. The policy response to the supply shock (and the resulting convergence dynamics) appears milder than to the aggregate demand shock, mainly reflecting the weak, second-order initial impact of the shock on output and, therefore, credit demand.

Introducing the credit-to-GDP gap as an indicator of the financial cycle may cause undesirable volatility in the policy response to business cycle shocks. Figure 7 displays the IRFs when we assume that the macroprudential policy authorities rely on the credit-to-GDP gap as an indicator of the financial cycle instead of the credit gap, while maintaining the credit growth and housing price gaps in their reaction function. The first-order effects of the macroeconomic shocks are on output, while the effects on credit are of second order. As a result, the credit-to-GDP gap evolves in the opposite direction of the output and credit gaps. For example, a positive demand shock results in positive output and credit gaps, but because the output response to the shock initially prevails over that of credit, the credit-to-GDP gap turns negative, which would require a loosening of the policy stance. Accordingly, the initial policy response to the shock would be procyclical. As credit expands above its long-term trend, the credit-to-GDP gap turns positive, prompting a tightening of the macroprudential policy stance to mitigate the credit cycle. The opposite happens following a supply shock, with the macroprudential policy authorities initially tightening the policy stance and then loosening it as the credit-to-GDP gap turns negative. These results suggest that indicators of the credit cycle that are orthogonal to the business cycle should be preferred for a countercyclical macroprudential rule so that they do not introduce additional volatility to the macro-financial environment.⁴⁶

⁴⁶ See de Resende et al (2016) for a discussion of an optimal CCyB rule based on credit-to-GDP gap.

Figure 6. Impulse Responses with Macroprudential Rule Based on the Credit Gap



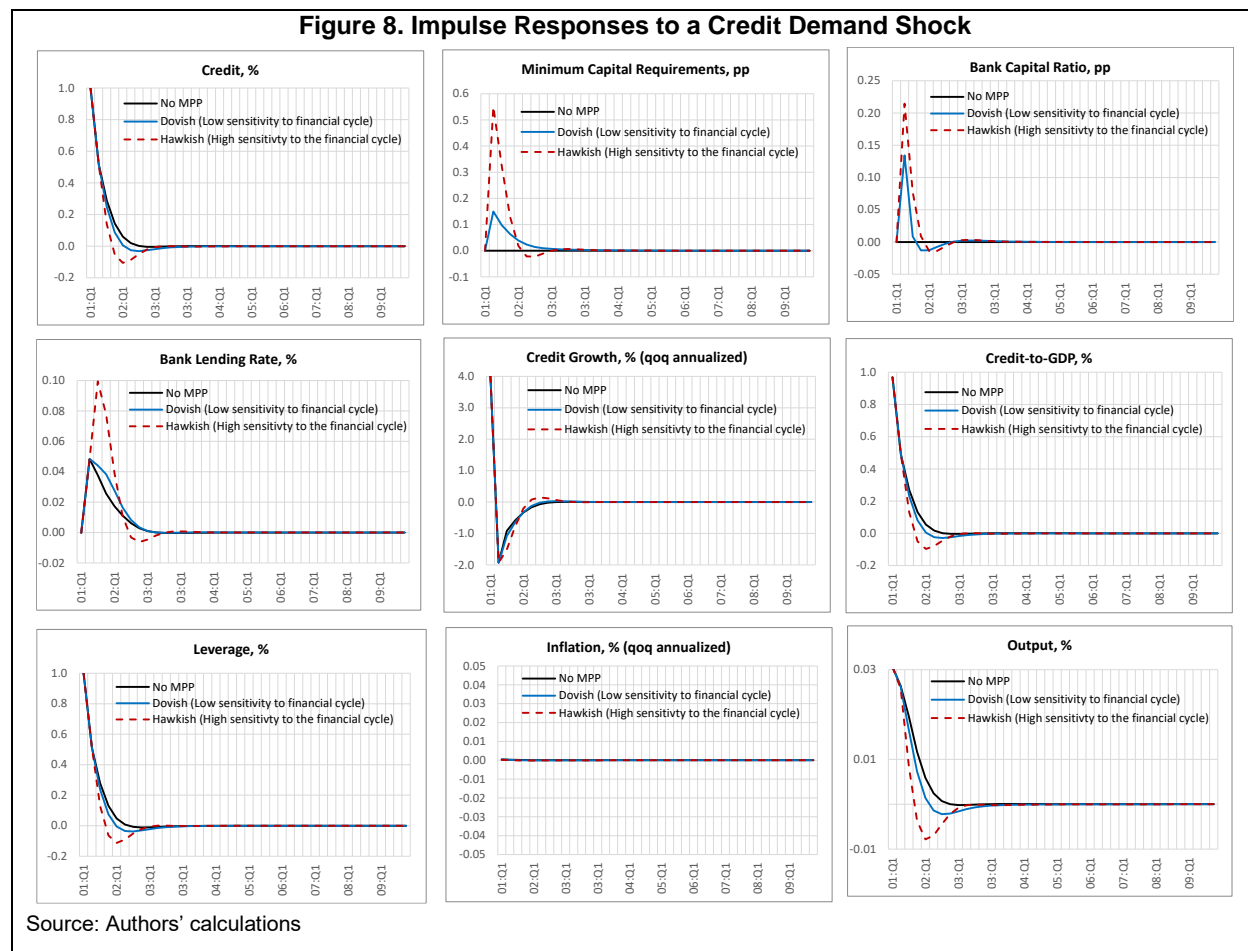


Credit Demand and Supply Shocks

A positive credit demand shock triggers a tightening of the macroprudential policy stance, which smooths the credit cycle relatively quickly (Figure 8). An exogenous increase in credit demand above its trend creates “excessive” credit growth, which could increase financial stability risks. As expected, the credit demand shock features a positive correlation between volume of credit and lending rates. The macroprudential policy authorities raise the minimum capital requirements to address the credit boom (up to 0.5 percent in the case of the Hawkish stance). In turn, banks accumulate capital—taking advantage of increased earnings driven by above-trend growth in credit—although by less than the rise in minimum capital requirements, leading to

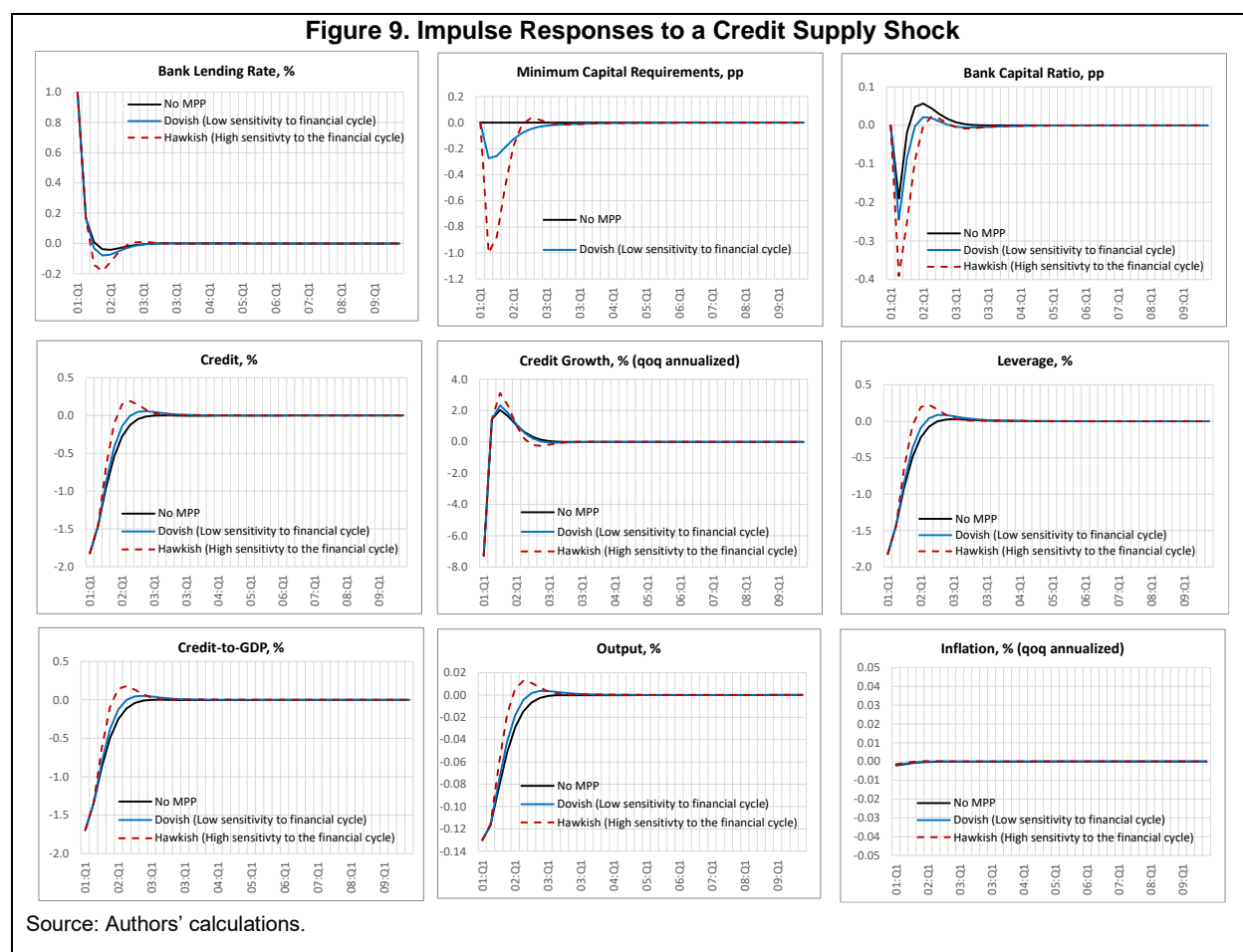
lower capital buffers and higher marginal lending costs for banks. Increased leverage, which translates into the perception of higher credit risk, reinforces these effects. As a result, banks raise their lending rates, putting downward pressure on credit demand and quickly reducing credit growth (which turns negative after two quarters). In this case, credit-to-GDP and credit gaps evolve in the same direction, reflecting the less pronounced effect of the credit boom on output. Because credit shocks do not directly affect inflation, the model is consistent with observing growing credit and output without a significant build-up of inflation as documented in Borio *et al.* (2013, 2014).

Figure 8. Impulse Responses to a Credit Demand Shock



The more aggressive the policy stance, the larger is the initial impact on lending rates and the faster is the convergence speed, but with limited effects on output and inflation. As expected, our results show that higher minimum capital requirements induce a more considerable increase in the lending rate, playing a visible role in mitigating the credit boom. For example, adopting a Hawkish stance—which raises minimum capital requirements by more than 0.5 percentage points at the peak—addresses the credit cycle two quarters earlier than the Dovish stance and four quarters earlier than with an inactive policy. At the same time, as discussed previously, real growth would only be marginally affected due to the low sensitivity of output to interest rates. Adopting a more aggressive stance to address credit demand shocks would then help restore financial stability with no significant implications for the internal macroeconomic stability of the economy.

In the face of an adverse credit supply shock, the macroprudential authority cuts the minimum capital requirements, allowing banks to use their buffers (Figure 9). The shock exogenously increases the marginal cost of lending, hence leading to higher lending rates. Tighter banking regulation, increased intensity of banking distress (for example, due to a drop in bank profitability), or more significant financial frictions (such as from tighter lending criteria due to increased uncertainty) can be captured by this shock. Following the credit supply shock, the lending rate and the volume of credit move in opposite directions. The increase in lending rates puts downward pressure on credit demand. Credit growth falls below its long-term trend, and the credit gap turns negative. The macroprudential policy responds by reducing minimum capital requirements, triggering higher capital buffers and, in turn, lower lending rates. The lower lending rates increase demand for credit, supporting economic activity and eliminating the small negative output gap initially driven by the shock.



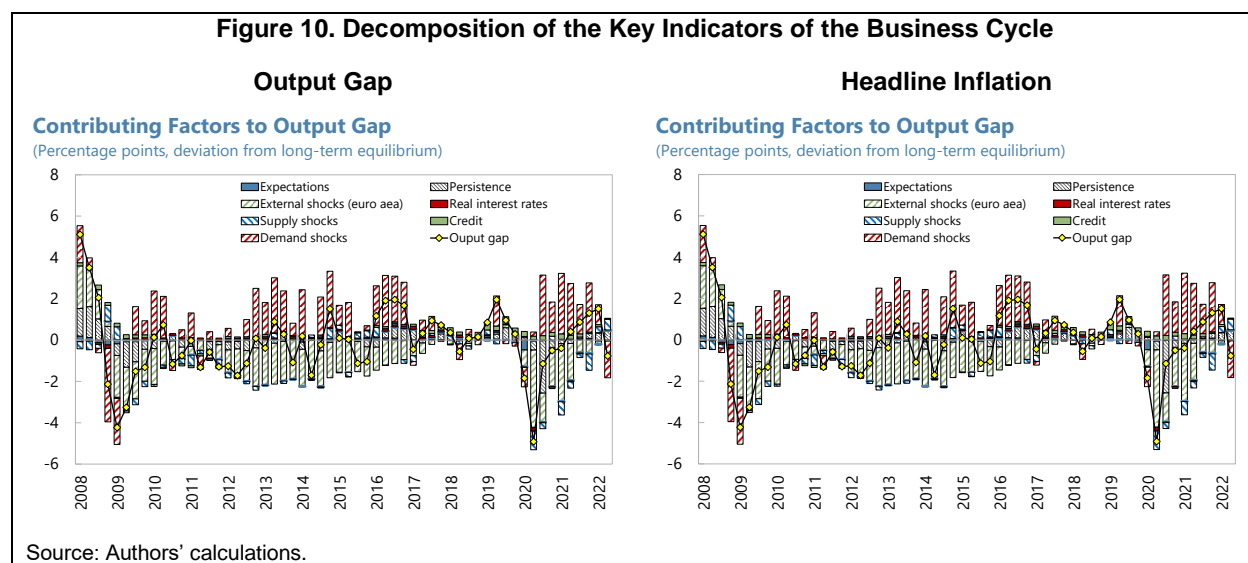
B. Interpretation of Historical Data Using the Model

This section shows how the model helps interpret recent economic developments in Luxembourg, focusing on key indicators of the business and credit cycles. We provide a historical shock decomposition analysis using the Kalman filter for selected macro aggregates covering 2008-2022. We analyzed two groups of indicators to discuss the model's filtration. The first relates to the business cycle part of the model, mainly

focusing on the output gap and headline inflation (Figure 10). The second group relates to the financial sector block, consisting of the aggregate bank credit and real lending rate gaps (Figure 11).

We estimate that the economy has reached a cyclical downturn in mid-2022, driven by unfavorable demand shocks. The model captures well the cyclical position of Luxembourg's economy prior to COVID, with a persistent positive output gap during 2015-2019 due to robust domestic demand. The COVID shock resulted in a (temporary) sizeable negative output gap in 2020, driven by both unfavorable external (i.e., the contraction of the euro area activity) and domestic supply shocks (i.e., due to health-related containment measures). Following the COVID shock, economic activity resumed its expansion, and the output gap became positive due to domestic demand shocks (i.e., the reopening of the economy and the expansionary fiscal policy). Finally, unfavorable demand shocks caused the output gap to have turned slightly negative in mid-2022, indicating a cyclical downturn.

Expectations, cost-push shocks, and robust domestic demand are the main factors driving the post-COVID spike in inflation. The model-based filtration suggests that supply shocks (soaring international food and energy prices which put pressure on domestic prices as well as wage indexation), expectations of continued high inflation, and, to a lesser extent, strong aggregate demand explain the inflationary pressures observed since 2021. More recently, supply shocks and inflation expectations have abated (possibly driven by energy price controls and other subsidies).

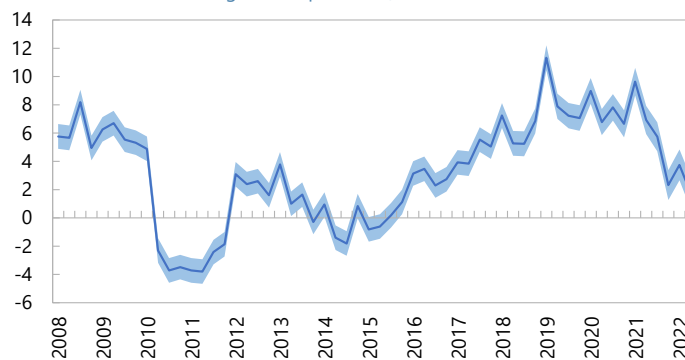


Indicators of the Financial Cycle

By late 2022, the credit cycle was approaching its end, with the credit gap narrowing significantly. The credit gap remained positive for an extended period, driven by continuously low lending rates and credit's underlying persistence. Our estimates indicate that the positive credit gap has narrowed since early 2021. It was almost closed in early 2022 (about 1 percent above its long-term trend), consistent with slower growth of credit to both households and non-financial corporations. The negative contribution of the real lending rate (reflecting the ongoing tightening of the monetary policy stance in the euro area as well as of domestic banks' credit standards) and credit shocks (which capture demand shocks and other credit determinants not explicitly modeled) are offsetting the impact of the credit gap's strong inertia.

Real Credit Gap

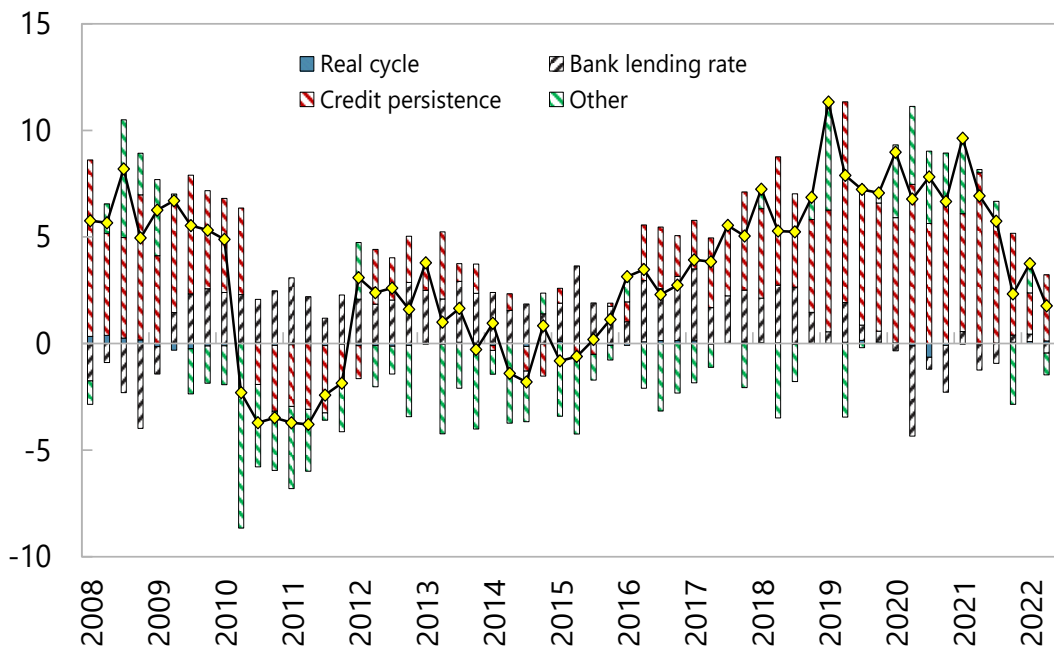
(Percent deviation from long-term equilibrium)



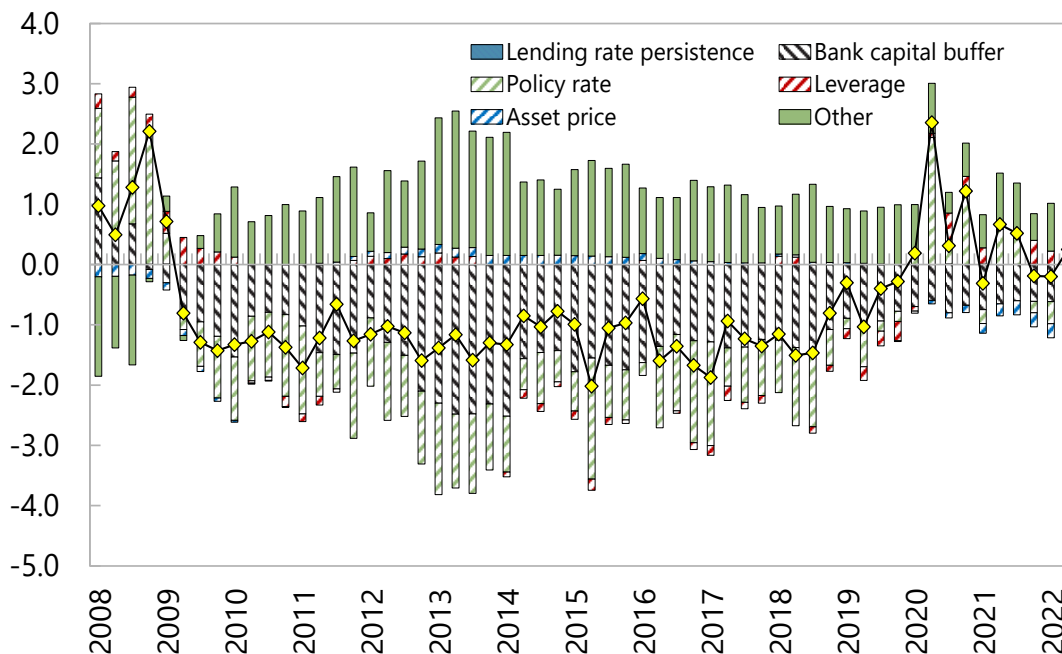
Note: The shaded area corresponds to the confidence band surrounding the filter estimates. Real credit is defined as the credit to resident private non-financial sector extended by domestically-oriented banks; and is deflated by the GDP deflator.
Sources: Authors' calculations

The policy rate and bank capital buffers are important drivers of the lending rate gap, which is estimated to be near its neutral level. During 2012-2020, the lending rate evolved below its long-term equilibrium level, driven by the ECB's accommodative monetary policy stance, pre-existing large capital buffers—partly reflecting the domestic macroprudential stance—and, to a lesser extent, by the positive effect of increasing housing prices on borrowers' collateral and leverage. As the pandemic unfolded, increasing leverage ratios have put upward pressure on the lending rate gap. In contrast, the offsetting effect of the policy rate has declined (consistent with the ongoing tightening in the ECB monetary policy stance). As a result, the lending rate gap was almost closed in mid-2022.

Figure 11. Decomposition of the Key Indicators of the Credit Cycle
Credit Gap



Lending Rate Gap

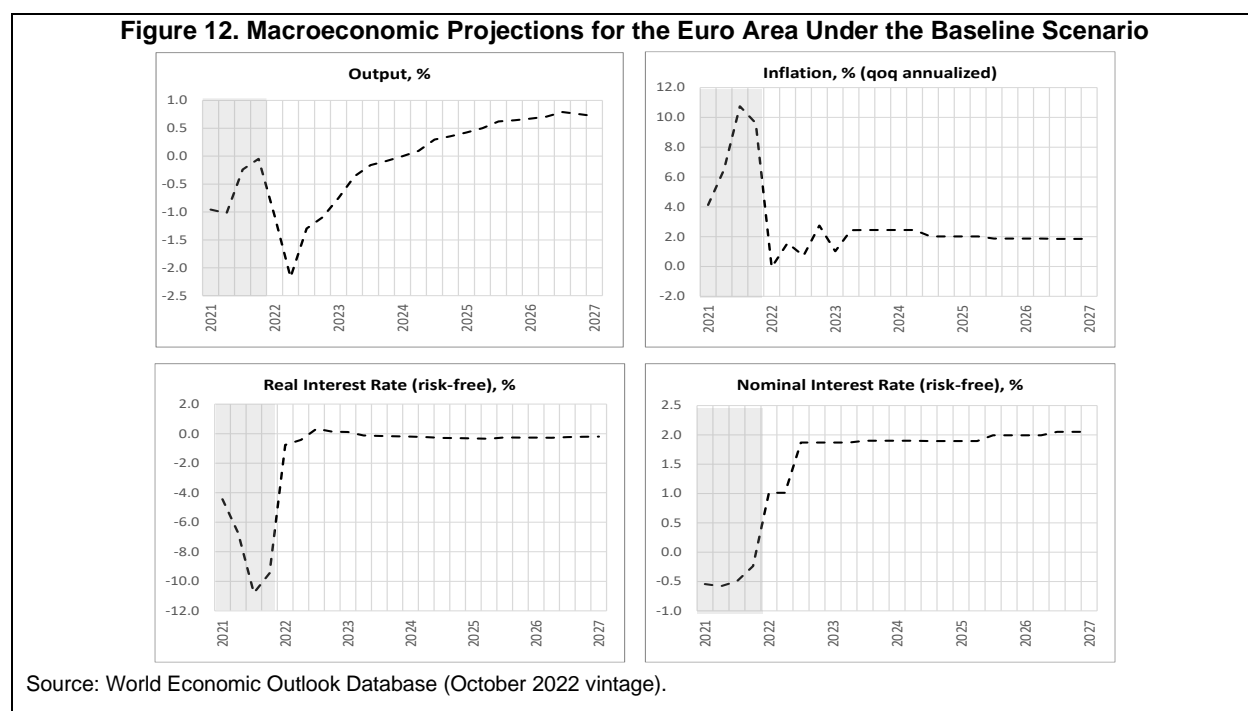


VII. Out-of-Sample Forecasts

This forecasting exercise aims to highlight how the model can facilitate macroprudential policy decision-making. The model can be used to generate forecast paths for Luxembourg's real business and financial cycles. These, in turn, help determine the appropriate macroprudential policy stance, including the target minimum capital requirement consistent with the country's financial stability objectives. We generate quarterly projections for all domestic variables over the medium term (2023-2027) and then assess the appropriate macroprudential policy stance accordingly.

A. Assumptions for the Euro Area

Under the baseline scenario, the short-term outlook points to economic slack, amid a global tightening in financial conditions, followed by a gradual recovery (Figure 12). Our baseline scenario for the euro area is the October 2022 WEO vintage projections. In this scenario, the Euro area was projected to experience a combination of weak growth and high inflation in the short term, driven by higher energy prices, tighter financial conditions, and softer global growth. As a result, the output gap was assumed to remain negative until mid-2024, and monetary policy normalization to proceed steadily (with the ECB policy rate reaching a neutral stance by early 2023).⁴⁷



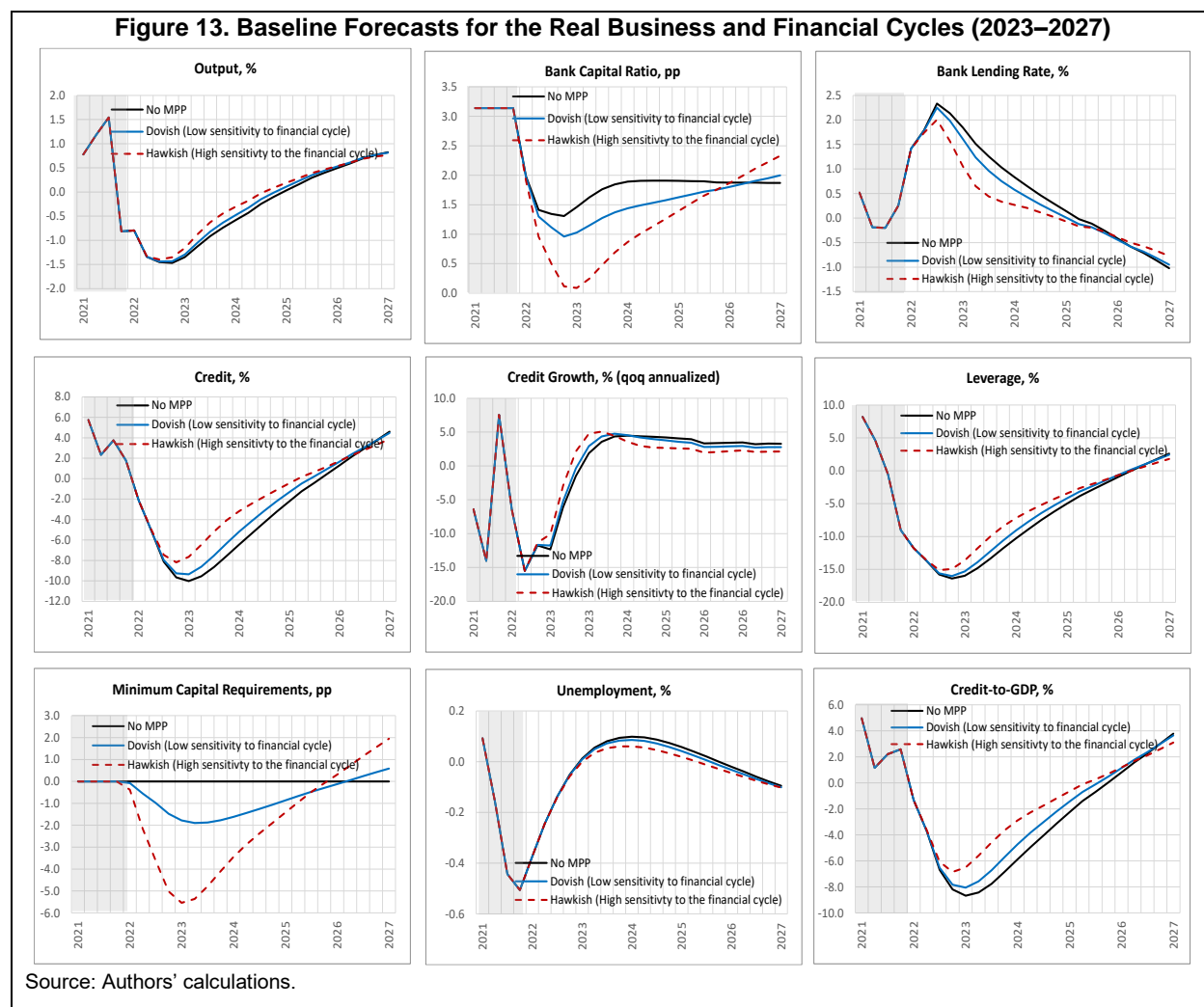
⁴⁷ In reality, the ECB has maintained a tight monetary policy stance until early 2024, although it seems to be approaching the end of the tightening cycle (IMF, 2023).

B. Results

Under the baseline, Luxembourg's business and credit cycles deteriorate significantly, resulting in a loosening of the macroprudential policy stance (Figure 13). Considering the estimated credit gap as of 2022Q2, the model suggests keeping the macroprudential policy stance unchanged. Under the baseline scenario, the model projects some economic slack in the short term, essentially driven by the euro area's weak outlook. The output gap remains negative until the end of 2024 and gradually closes over the medium term. The labor market continues to cool off in this context, with the unemployment gap turning positive by early 2024. Weaker economic activity and increasing lending rates (driven by higher ECB policy rates) would reduce demand for credit, further narrowing the credit gap. *Conditional* on (i) the information set available up to 2022Q2; (ii) the October 2022 WEO projections for the Euro area; (iii) the calibration of the MPP rule; and (iv) the materialization of the projected tightening in financial conditions, the macroprudential authorities would loosen the macroprudential policy stance, reducing the minimum capital requirements by up to 5 percentage points under the most aggressive policy stance.⁴⁸ Even with the 'hawkish' policy reaction to such a big shock as the one caused by COVID, the difference relative to the 'dovish' policy rule in terms of the impact on the real economy (output, unemployment, and inflation) is small.

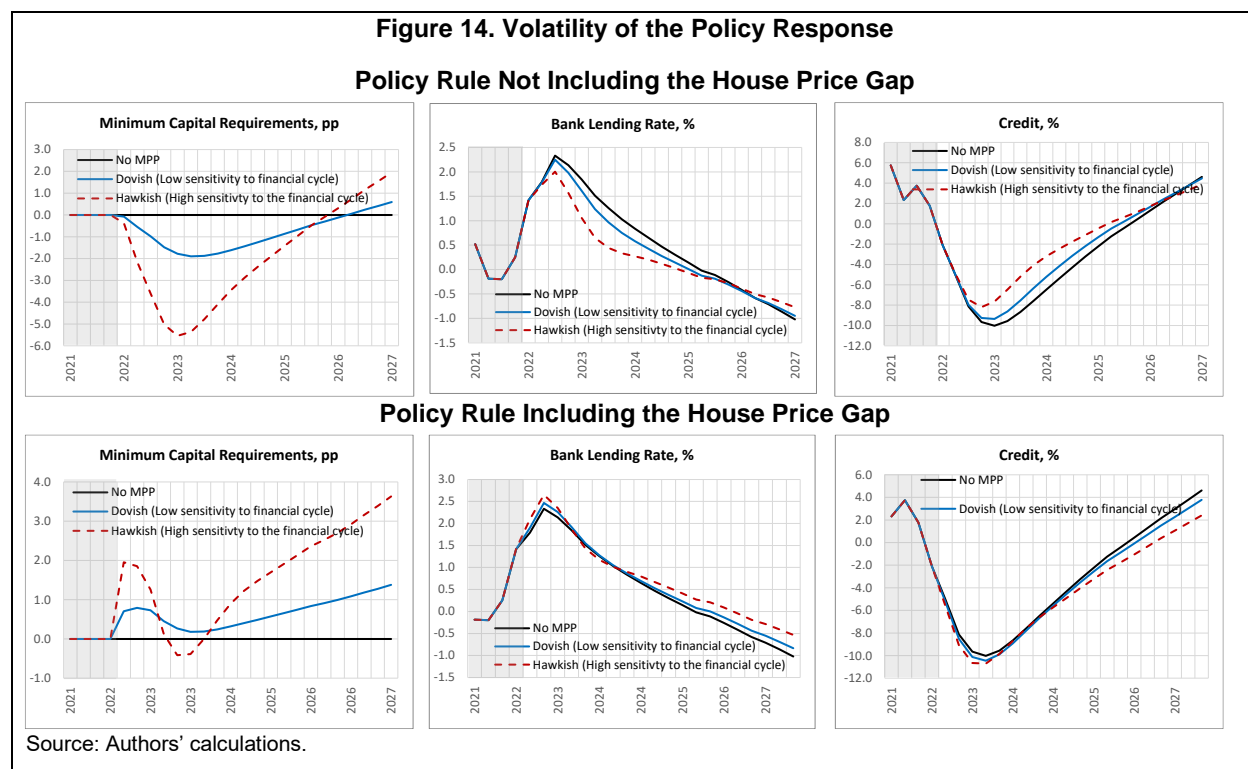
Lending rates decline, and credit recovers, although at a slower pace. Loosening the macroprudential policy stance allows banks to increase their capital buffers, reducing their marginal lending costs and lending rates. A negative leverage gap, mainly driven by the credit cycle downturn, contributes to lower lending rates. As result, the lending rate gap is projected to decline relatively quickly, turning negative by early 2025. Lower lending rates help support credit demand and lead to sustained credit growth over the medium term. Given the strong persistence of credit, the credit cycle would fully recover only over the medium term. During this recovery phase, the macroprudential authorities would adjust the policy stance, gradually increasing minimum capital requirements to ensure that credit expansion remains aligned with the financial stability objectives.

⁴⁸ The forecast of minimum capital requirements is not a commitment to future decisions by Luxembourg's macroprudential authorities. Rather, it is the model-based path if all assumptions materialize as expected (including for the Euro Area) and conditional on the calibration of the weights given to the measures of credit and asset price gaps in the macroprudential policy rule. The model does not impose a lower bound on the CCyB.



The policy rule should be well-designed to avoid undue volatility of the macroprudential policy response (Figure 14). Assuming that developments in the credit and housing markets are equally important for the policy setting, the model initially projects a procyclical policy response (higher minimum capital requirements), followed by some loosening of the policy stance. As of 2022Q2 (latest data point), the house price gap was large (estimated at 15 percent), while the credit gap was almost closed. A policy rule that assigns the same weights to these indicators would imply a tightening of the macroprudential policy stance, further deteriorating the credit cycle. Later, the macroprudential authority loosens the policy stance after the credit gap becomes too small and the housing price gap narrows (due to weaker economic activity and demand for credit). The resulting instability of the macroprudential policy response is undesirable as it exacerbates fluctuations in the credit cycle, potentially heightening economic volatility.⁴⁹

⁴⁹ Adopting a positive neutral CCyB could soften the adverse shocks' impact on credit and economic activity. This would make the macroprudential policy rule less sensitive to assessments of the credit and asset price gaps and avoid unnecessary volatility in the rule.



VIII. Conclusion

This paper incorporates macro-financial linkages and an active banking sector into a canonical semi-structural New-Keynesian model. We analyze the nexus between business and credit cycles and study the role of macroprudential policies in Luxembourg. More specifically, the model extends the multivariate filter approach of Baba *et al.* (2020), incorporating supply and demand for bank loans derived from micro-foundations in Dib (2010), financial accelerator mechanisms, inspired by BGG and KM, and a countercyclical macroprudential policy rule. Its application to Luxembourg, a small open economy with a substantial banking sector and a countercyclical macroprudential rule, provides insights into the interplay between credit and business dynamics. The model performs well to align with recent data and economic developments in Luxembourg.

Results from model simulations underscore the importance of considering macro-financial shocks and their amplification channels. Shocks affecting banks' marginal costs of loan supply and household preferences propagate according to priors to aggregate demand, output, interest rates, and credit volumes. Changes in the countercyclical macroprudential rule exhibit meaningful effects on credit market equilibrium, interest rates, and both business and credit cycles. Quantitatively, our results suggest that a tightening macroprudential stance in Luxembourg prompts a contraction in credit volumes and an increase in lending rates, as expected, but only a relatively modest impact on the real economy. This indicates a favorable trade-off for such policies for Luxembourg. Feeding the model with the 2022 October WEO forecast, we project Luxembourg's business and credit cycles to deteriorate until late 2024.

Annex I. Main Features of the Euro Area Model

The euro area output gap is defined as the deviation of output from its long-term trend ($y_t^e = Y_t^e - y_t^{e*}$), where $Y_t^e \equiv 100 * \ln(GDP^e)$ and GDP^e is the quarterly GDP of euro area. The potential output (y_t^{e*}) follows the following process:

$$y_t^{e*} = y_{t-1}^{e*} + \frac{1}{4} g_t^e + \varepsilon_t^{y^{e*}},$$

where g_t^e is the potential growth that converges toward its steady-state value (g_{ss}^e).

$$g_t^e = (1 - \rho_{ss}^e) g_{t-1}^e + \rho_{ss}^e g_{ss}^e + \varepsilon_t^{g^e}$$

Given that the Luxembourg economy is small, it does not affect the output gap of euro area:

$$y_t^e = \beta_{lead}^e y_{t+1}^e + \beta_{lag}^e y_{t-1}^e - \beta_r^e r_t^e + \varepsilon_t^{y^e}$$

Euro area inflation is driven by the following Phillips curve:

$$\pi_t^e = (1 - \alpha_{lag}^e) \pi_{t+1}^e + \alpha_{lag}^e \pi_{t-1}^e + \alpha_y^e y_t^e + \varepsilon_t^{\pi^e}$$

The nominal interest rate is determined by a Taylor-type monetary policy rule:

$$i_t^e = \gamma_{lag}^e i_{t-1}^e + (1 - \gamma_{lag}^e) [r_t^{e*} + \pi_{t+1}^{targ} + \gamma_{\pi}^e (\pi_{t+4}^{eA} - \pi_{t+4}^{Atarg}) + \gamma_y^e y_t^e] + \varepsilon_t^{i^e},$$

where the ECB aims to set a policy rate (i_t^e) that is close to the equilibrium rate and the announced inflation target ($r_t^{e*} + \pi_{t+1}^{targ}$) while adjusting the rate in response to deviations of the expected annual inflation rate (π_{t+4}^{eA}) from its annualized target (π_{t+4}^{Atarg}) and the output gap (y_t^e).¹

The real interbank rate of euro area (R_t^e) is the difference between the nominal policy rate (proxied by the 3-month EA interbank rate, i_t^e) and expected inflation:

$$R_t^e = i_t^e - \pi_{t+1}^e$$

The real interbank rate gap (r_t^e) is defined as the difference between real interbank rate and its trend:

$$r_t^e = R_t^e - r_t^{e*},$$

where the trend real interbank rate (r_t^{e*}) converges toward a steady state value (r_{ss}^{e*}):

$$r_t^{e*} = (1 - \rho_{r^{e*}}) r_{t-1}^{e*} + \rho_{r^{e*}} r_{ss}^{e*} + \varepsilon_t^{r^{e*}}.$$

¹ The annual inflation is calculated as follows: $\pi_t^{eA} = 1/4 \sum_{i=0}^3 \pi_{t-i}^e$. The inflation target is set to its steady state value: $\pi_t^{etarg} = \pi_{ss}^{etarg}$.

Annex II. Data and Sources

Annex II. Table 1. Data and Sources	
Variable	Source
Luxembourg	
Real GDP	WEO Database (October 2022 vintage)
GDP deflator	WEO Database (October 2022 vintage)
Potential GDP	WEO Database (October 2022 vintage)
Harmonized Index of Consumer Prices	WEO Database (October 2022 vintage)
Unemployment rate	STATEC
Credit granted by the domestically oriented banks to resident households and non-profit institutions serving households	Banque Centrale du Luxembourg
Credit granted by the domestically oriented banks to resident non-financial corporations	Banque Centrale du Luxembourg
Households' mortgage debt to disposable income ratio	Banque Centrale du Luxembourg
Equity and investment fund shares (financial accounts of nonfinancial corporations, liabilities)	Haver Analytics
Debt securities and loans (financial accounts of non-financial corporations, liabilities)	Haver Analytics
Interest rate on loans for house purchase over 5 years initial maturity	Banque Centrale du Luxembourg
Interest rate on loans to non-financial corporations (over 1 and up to 5 years initial maturity)	Banque Centrale du Luxembourg
3-month interbank rate	FRED Database
10-year government bond yield	Global Financial Data
Total capital ratio of domestically oriented banks	Commission de Surveillance du Secteur Financier
Overall capital requirement ratio (including P2R) of domestically oriented banks	Commission de Surveillance du Secteur Financier
Euro area	
Real GDP	WEO Database (October 2022 vintage)
GDP deflator	WEO Database (October 2022 vintage)
Potential GDP	WEO Database (October 2022 vintage)
Harmonized Index of Consumer Prices	WEO Database (October 2022 vintage)
3-month interbank rate: Total for the euro area	FRED Database
Euro area 10-year government benchmark bond yield	European Central Bank

Annex III. Calibration and Estimation

Annex III. Table 1. Calibrated Parameters		
Parameter	Description	Value
ρ_s	Persistence of the trend output growth	0.950
α_y	Sensitivity of inflation to output gap	0.005
g_t^{c*}	Persistence of the trend credit growth	0.700
$\rho_{\gamma,L}$	Persistence of the trend lending rate	0.980
ρ^A	Persistence of the asset price gap	0.800
θ_3	Sensitivity of credit demand to real lending rate	1.800
δ_0	Persistence of real lending rate	0.005
δ_1	Sensitivity of the real lending rate to bank capital buffer	0.195
ψ_1	Persistence of the minimum capital requirements	0.800
ψ_2	Sensitivity of the macroprudential rule to credit gap	[0.000, 0.150]
ψ_3	Sensitivity of the macroprudential rule to credit growth	[0.000, 0.100]
ψ_4	Sensitivity of the macroprudential rule to house price gap	[0.000, 0.150]
ψ_5	Sensitivity of bank capital buffer to minimum capital requirements	0.200
ρ_{k^*}	Persistence of the trend bank capital	0.950
τ_2	Persistence of the unemployment gap	0.800
$\rho_{r_e^*}$	Persistence of the real interbank rate's trend	0.900
ρ_\emptyset	Persistence of the risk premium	0.800
Shocks		
σ^{y^*}	Standard deviation of the shock to potential output	0.001
σ^g	Standard deviation of the shock to potential growth	0.001
σ^{u^*}	Standard deviation of the shock to the equilibrium unemployment rate	0.001
σ^{c^*}	Standard deviation of the shock to trend credit	0.001
$\sigma^{k^{c*}}$	Standard deviation of the shock to trend credit growth	0.009
σ^{k^*}	Standard deviation of the shock to trend bank capital	0.200
σ^A	Standard deviation of the asset price shock	0.020
Steady state		
g_{ss}	Trend output growth	2.500
g_{ss}^c	Trend aggregate credit growth	2.500
$\eta_{ss}^{L^*}$	Non-financial privnon-financial private sector's risk premium	1.500
k_{ss}^*	Trend bank capital ratio	25.000
k_{ss}^{buff}	Long-term bank capital buffer	14.000
u_{ss}	Long-term unemployment rate	5.800
\emptyset_{ss}	Long-term risk premium	0.000
$r_{e,ss}^*$	Long-term Euro Area interbank rate	0.000

Annex III. Table 2. Estimated Parameters

Parameter	Description	Distribution	Prior		Posterior	
			Mode	St. Dev.	Mode	St. Dev. ⁽¹⁾
β_{lead}	Forward-looking expectations on output gap	Beta	0.200	0.100	0.056	0.082
β_{lag}	Persistence of output gap	Beta	0.500	0.150	0.295	0.122
β_{y^e}	Sensitivity of output gap to foreign activity	Gamma	0.700	0.150	0.624	0.142
β_z	Sensitivity of output gap to real exchange rate	Gamma	0.030	0.020	0.017	0.023
β_r	Sensitivity of output gap to real lending rate	Gamma	0.100	0.050	0.075	0.049
β_c	Sensitivity of output gap to real credit	Gamma	0.050	0.030	0.028	0.020
β_π	Sensitivity of output gap to inflation	Gamma	0.200	0.100	0.150	0.101
α_{lag}	Persistence of inflation	Beta	0.500	0.100	0.132	0.044
α_z	Sensitivity of inflation to real exchange rate	Gamma	0.040	0.015	0.053	0.022
θ_1	Sensitivity of credit demand to domestic activity	Gamma	0.100	0.050	0.075	0.033
θ_2	Persistence of credit demand	Beta	0.800	0.100	0.832	0.091
δ_2	Sensitivity of the real lending rate to interbank rate	Gamma	0.950	0.200	0.829	0.228
δ_3	Sensitivity of the real lending rate to aggregate leverage	Gamma	0.050	0.010	0.049	0.008
δ_4	Sensitivity of the real lending rate to housing prices	Gamma	0.020	0.010	0.015	0.008
ρ_{r^L}	Persistence of the trend lending rate	Beta	0.600	0.050	0.575	0.049
$\rho_{k^{act}}$	Persistence of bank capital	Beta	0.300	0.100	0.269	0.097
ψ_6	Sensitivity of bank capital to credit growth	Gamma	0.150	0.100	0.017	0.014
ψ_7	Sensitivity of bank capital buffer to the phasing in of Basel II requirements	Gamma	2.140	0.500	2.030	0.424
ψ_8	Sensitivity of bank capital buffer to the phasing in of Basel III requirements	Gamma	0.950	0.400	0.770	0.314
σ_1	Sensitivity of asset prices to economic activity	Gamma	0.400	0.200	0.233	0.171
σ_2	Sensitivity of aggregate asset prices to house prices	Gamma	0.100	0.050	0.075	0.051
ρ^h	Persistence of the house price gap	Beta	0.950	0.050	0.970	0.078
σ_3	Sensitivity of the house price gap to unemployment	Gamma	0.300	0.200	0.114	0.127
τ_1	Sensitivity of the unemployment gap to economic activity	Gamma	0.220	0.050	0.205	0.035
τ_3	Persistence of growth in trend unemployment	Beta	0.100	0.025	0.112	0.029
Shocks (for gap variables)						
σ^y	Standard deviation of the output shock	Invgamma	1.000	<i>Inf</i>	0.014	0.002
σ^π	Standard deviation of the inflation shock	Invgamma	0.200	<i>Inf</i>	0.003	0.001
σ^u	Standard deviation of the unemployment rate shock	Invgamma	0.250	<i>Inf</i>	0.004	0.001
σ^{CD}	Standard deviation of the credit shock	Invgamma	1.700	<i>Inf</i>	0.026	0.003
σ^{c^*}	Standard deviation of the trend credit shock	Invgamma	0.047	<i>Inf</i>	0.005	0.002
σ^{r^L}	Standard deviation of the lending rate shock	Invgamma	0.300	<i>Inf</i>	0.005	0.001
$\sigma^{r^L^*}$	Standard deviation of the shock to the trend lending rate	Invgamma	0.040	<i>Inf</i>	0.002	0.001
σ^z	Standard deviation of the real exchange rate shock	Invgamma	0.600	<i>Inf</i>	0.009	0.001
$\sigma^{k^{act}}$	Standard deviation of the bank capital ratio shock	Invgamma	0.300	<i>Inf</i>	0.004	0.001
σ^{p^h}	Standard deviation of the house price shock	Invgamma	0.700	<i>Inf</i>	0.010	0.001
σ_\emptyset	Standard deviation of the risk premium shock	Invgamma	0.120	<i>Inf</i>	0.002	0.001

(1) Posterior distributions were constructed using the Metropolis Random Walk Posterior Simulator (based on 500,000 simulated paths).

Parameter	Description	Value
β_{lead}^e	Forward-looking expectations on output gap	0.500
β_{lag}^e	Persistence of output gap	0.550
ρ_{re^*}	Persistence of the real interbank rate's trend	0.050
α_y^e	Sensitivity of inflation to output gap	0.050
Steady state		
g_{ss}^e	Trend output growth	1.200
π_{ss}^{etarg}	Long-term euro area inflation target	1.800
r_{ss}^{e*}	Long-term euro area interbank rate	0.000

Parameter	Description	Distribution	Prior		Posterior	
			Mode	St.Dev.	Mode	St.Dev.
β_r^e	Sensitivity of output gap to real interbank interest rate	Gamma	0.026	0.100	0.154	0.020
ρ_{ss}^e	Persistent of trend output growth	Beta	0.100	0.100	0.043	0.071
α_{lag}^e	Persistence of inflation	Beta	0.300	0.100	0.260	0.038
γ_{lag}^e	Persistence of policy interest rate	Normal	0.750	0.100	0.643	0.039
γ_{π}^e	Sensitivity of policy interest rate to deviations of expected inflation from its target	Normal	1.700	0.100	1.800	0.088
γ_y^e	Sensitivity of policy interest rate to output gap	Normal	0.150	0.100	0.364	0.063
Shocks						
σ_t^{ye}	Standard deviation of the output gap shock	Invgamma	0.120	<i>Inf</i>	0.042	0.022
$\sigma_t^{ye^*}$	Standard deviation of the shock to potential output	Invgamma	0.030	<i>Inf</i>	0.019	0.010
σ_t^{ge}	Standard deviation of the shock to potential growth	Invgamma	0.040	<i>Inf</i>	0.014	0.013
$\sigma_t^{\pi e}$	Standard deviation of the inflation shock	Invgamma	0.140	<i>Inf</i>	0.100	0.052
σ_t^{ie}	Standard deviation of the shock to policy interest rate	Invgamma	0.200	<i>Inf</i>	0.042	0.021
$\sigma_t^{re^*}$	Standard deviation of the shock to real interbank rate trend	Invgamma	0.050	<i>Inf</i>	0.011	0.006

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