1. INTERMEDIATION VERSUS MONEY CREATION FUNCTION IN BANKING: A DSGE PERSPECTIVE

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ABSTRACT

Most macro-financial models consider banks as simple intermediaries of loanable funds between savers and borrowers, ignoring the money creation function of the banking system. Therefore, we address this issue directly by incorporating a mechanism for banks' money creation function as in Jakab and Kumhof (2015, 2019).

This study compares the macro-financial outcomes of the intermediation of loanable funds model of banking and the financing through money creation model and assesses the role of macroprudential policy in the context of a tightening monetary policy environment when banks finance the real economy through money creation. In the context of the DSGE model, we find that the money creation mechanism attenuates the contractionary effects on output from monetary policy tightening compared to the intermediation of loanable funds approach to banking. Furthermore, for both models we find that a tighter macroprudential policy stance helps to attenuate the severity of the monetary policy shock in terms of macro-financial stabilization, suggesting that it may be appropriate to have higher macroprudential capital buffers during periods of tightening monetary policy conditions. However, in terms of welfare the comparison is more complicated.

Keywords: *DSGE, banks, financial intermediation, money creation, monetary policy, Macroprudential policy.*
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1. INTRODUCTION

The 2007-2008 global financial crisis (GFC) demonstrated the important role of the banking sector in amplifying and prolonging economic crises. Consequently, macroeconomic models have increasingly incorporated banks to better assess their role during crisis times[1]. However, the way banks are introduced in these models matters for the analysis of the interactions between the banking sector and the rest of the economy. In particular, the most common modelling framework in the literature considers banks as intermediaries of loanable funds. This is the so-called intermediation of loanable-funds approach to banking. Under this approach, bank loans to borrowers are assumed to originate from the accumulation of savings or loanable funds by savers. Therefore, the intermediation chain starts with savers' deposits being collected by banks and then ends with the lending of those funds by banks to borrowers. The intermediation of loanable-funds framework is somewhat misleading as it ignores the fact that, in the modern economy, banks create deposits through lending[2]. Moreover, as argued by Jakab and Kumhof (2015), many of the unresolved issues in macro-financial economics (e.g., understanding the co-movement of bank assets and debt, amplification of financial and business cycles via the banking sector) are linked to the use of the intermediation of loanable funds (ILF) model of banking. These authors explain that model economies based on the intermediation of loanable funds are entirely fictitious as such institutions simply do not exist in the real world. In fact, they show that models based on this framework do not adequately capture the lending activities of banks.

There is an emerging stream of the academic literature that highlights the provision of financing as the key economic function of banks. In practice, this implies that banks create new monetary purchasing power through loans to borrowers who simultaneously become depositors (Jakab and Kumhof (2015, 2019), McLeay *et al.* (2014a, 2014b), Faure and Gersbach (2022)). More specifically, whenever a bank extends a new loan to a borrower, it creates a new loan entry in the name of that borrower on the asset side of its balance sheet, and simultaneously creates a new (and equal-sized) deposit entry on the liability side of its balance sheet, also in the name of the same borrower. The bank therefore creates deposits in the act of lending through a pure bookkeeping transaction that involves no intermediation. This framework is called the money-creation approach to banking (Faure and Gersbach (2022).

Incorporating these insights into the DSGE models remains one of the main challenges facing macro-financial modellers. Nevertheless, there exist a few DSGE models that include the money creation approach to banking (i.e., financing through money creation (MC) models). To the best of our knowledge, only the works of Jakab and Kumhof (2015, 2019) and Faure and Gersbach (2022) have developed DSGE models that incorporate and subsequently investigate the money creation framework. By comparing the outcomes of the ILF and FMC models, Jakab and Kumhof (2015, 2019) show that the ILF models provide relatively poor empirical predictions compared to the money creation models and that these latter models amplify the effects of shocks compared to the former. Faure and Gersbach (2022) find that, in the absence of uncertainty, both the intermediation of loanable funds and money creation models yield the same goods allocation and, therefore, under these conditions using the former approach does not imply any loss of generality.

Despite the fact that the money creation approach to banking is relatively new in the DSGE literature, the rather small number of existing studies does not investigate how the money creation function of banks interacts with macroprudential policy. The modern money creation process by banks through extensive

[1] See for example, Gerali *et al.* (2010), Christiano *et al.* (2014), Boissay *et al.* (2013), Gertler and Karadi (2011), Gertler and Kiyotaki (2011), Clerc *et al.* (2015), De Walque *et al.* (2010), among others.

[2] See McLeay *et al.* (2014b) for more details on the money creation process in the modern economy.

possibilities to extend credit, as an unexplored facet of the banking system by regulators, could pose risks to financial stability. A model that will trace out the main channels of such an approach of banks should be welcome for analysing the macroprudential policy implications. Therefore, our contribution to the literature in the context of the current study explores the interaction between macroprudential policy and the money creation function of banks, which is a sparse topic in the literature.

Specifically, our work explores the role of the macroprudential policy in a DSGE model that incorporates the money creation function of banks. The research question addressed is whether the money creation model and the intermediation of loanable funds model could yield similar outcomes. In particular, we analyse the role of macroprudential policy in the money-creation framework. In other words, we assess the effectiveness of macroprudential policy in a money-creation framework.

To this end, we build two realistic DSGE models. The first model includes banks as intermediaries of loanable funds (i.e., the ILF model) and the second model considers banks as money creators with no intermediation function (i.e., the MC model). In the modelling framework, our models are closest to those developed by Jakab and Kumhof (2015, 2019) but are much more tractable as, by introducing financial frictions through a costly enforcement mechanism (Kiyotaki and Moore (1997)) instead of the costly state verification mechanism (Bernanke, Gertler, and Gilchrist (1999)), they facilitate the assessment of the main channels of shock transmission. In addition, our models integrate both capital and borrower-based macroprudential policy measures and are calibrated using macro-financial data for the euro area.

We compare the two models under the effects of a positive shock on the monetary policy rate in the context of the current tightening in the monetary policy stance. We also assess macroprudential policy where the banking function is modelled with a money creation mechanism. The welfare-based approach is used in our analysis in order to perform a quantitative assessment of the two models.

Our model comparison exercise shows that, following an identical positive shock to the policy rate, the money creation model predicts a much faster contraction in bank lending and a less contractionary effect on output compared to the intermediation model. This suggests that banks' financing through money creation amplifies the effects of the monetary policy shock on bank lending, which is in line with the findings of Jakab and Kumhof (2015, 2019), while it attenuates the effects of the same shock on output. The result on bank lending can be attributed to the fact that banks in the ILF model can only extend loans after obtaining savings that can only be accumulated gradually over time. On the other hand, banks in the MC model can create new money instantaneously and independently of the available quantity of aggregate savings. The effect on output is a consequence of the fact that the MC model implies relatively high lending interest rates, which increase bank profitability and capital in the short run. In addition, the consumption/leisure distortion stemming from transaction costs encourages households to work more in the MC model than in the ILF, contributing to the resilience of output.

Furthermore, we find that a higher macroprudential capital buffer is likely to be effective in dampening the effects of the shock on the macro-financial variables of the economy, mainly due to the positive relationship between loan supply and the level of bank capital (and bank profits). This finding suggests that in a tightening monetary policy environment macroprudential policy mitigates the amplifying effects of bank financing through money creation. A quantitative welfare-based comparison of the different models and alternative macroprudential policy calibrations strengthen these conclusions.

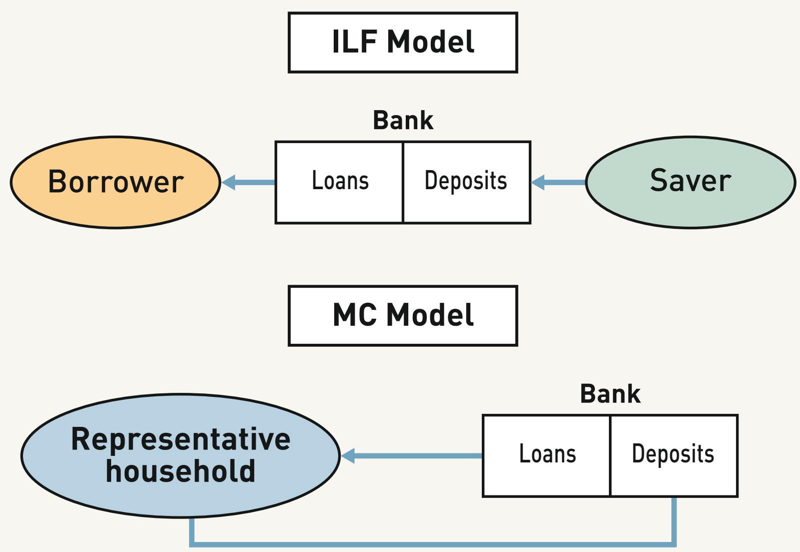
The rest of the paper is organised as follows. Section 2 outlines the two models and Section 3 presents the model calibration. Section 4 analyses the results of the model simulation and Section 5 concludes.

2. THE MODELS

We develop and simulate two versions of DSGE models with banking. The first version consists of the intermediation of loanable funds (ILF) model and the second version is the financing through money creation (MC) model. The main difference between the two models is the set of agents with whom banks interact. We impose that the real steady states of the two models are identical in order to allow for an effective comparison of the two models.

As illustrated by Figure 1, under the ILF model, banks collect deposits from households who save (i.e. savers) and lend them out to households who borrow (i.e. borrowers). Under the MC model, banks interact only with a single representative household in whose name banks simultaneously register both loans and deposits on their books (i.e., a given bank's debtor and creditor are the same household). Therefore, the banking sector intermediates loanable funds between savers and borrowers in the ILF model while it creates new money for a single representative household in the MC model.

Figure 1:
Bank balance sheet in each model



Source: BCL.

We introduce a monopolistically competitive banking sector à la Gerali *et al.* (2010) and assume that banks are subject to a constraint stemming from a risk-weighted capital requirement that translates into an exogenous target for the leverage ratio. We assume that any deviation from this target results in a quadratic cost. Moreover, we model the demand for bank deposits by way of a transactions cost technology, as in Schmitt-Grohe and Uribe (2004). This is essential only for the MC model, but it is also done in the ILF model in order to maintain the symmetry of the steady states. In both models, households consume, work and are subject to a borrowing constraint (i.e., a limit on their loan-to-income ratio).

On the production side, monopolistically competitive non-financial firms produce heterogeneous intermediate goods using labour supplied by households in exchange for flexible wages and capital purchased from households, which are also capital producers. These intermediate-goods-producing firms borrow from banks to finance their capital acquisition and are subject to corporate loan to value ratio limits (i.e., LTV limit). The prices of intermediate goods are set in a staggered fashion à la Rotemberg (1984). Final goods-producing firms, who bundle intermediate goods into final goods, operate in perfectly competitive markets.

Finally, a passive government covers its expenditures through retention of a constant fraction of long-run aggregate production. The interest rate is set by a monetary authority that follows a standard Taylor-type interest rate rule.

2.1 HOUSEHOLDS

As mentioned, the formal difference between the two models comes from the specification of the budgetary constraint on bank clients. In particular, two types of households (i.e., savers and borrowers) characterize the model with intermediation of loanable funds, while the money creation model embeds a single representative household.

A. The intermediation of loanable funds (ILF) model

For this first model, we assume that the economy is composed of two types of households: savers and borrowers. Both types of households derive utility from consumption, $c_{z,t}$, and disutility from the number of hours worked, $n_{z,t}$ and have an identical utility function which corresponds, in real terms, to:

$$E_0 \sum_{t=0}^{\infty} \beta_z^t U(c_{z,t}; n_{z,t}) = E_0 \sum_{t=0}^{\infty} \beta_z^t \left[A_{c,t}(1-a)\ln(c_{z,t} - a.C_{z,t-1}) - \frac{\chi_n n_{z,t}^{1+\gamma}}{1+\gamma} \right] \tag{1}$$

where $z = \{s, b\}$ with s and b, respectively representing borrowers and savers. Current individual consumption depends on lagged smoothed aggregate consumption, $a.\mathrm{C}_{z,t-1}$, of household group z, where the parameter a, denotes the degree of habit formation in consumption for non-durable goods. The parameter χ_n denotes the weight on hours worked and γ is the elasticity of labour supply. All preference parameters that affect the model dynamics, β_z, a, γ, are identical across savers and borrowers, thereby guaranteeing that the steady states of the two models are identical. The equality of discount factors (β_z) among savers and borrowers implies that we abstract from the degree of households' patience. As argued in Jakab and Kumhof (2015), in models where bank liabilities are held for their monetary services rather than as a saving instrument, there is no necessary correlation between the status of an agent as a bank depositor and greater patience. $A_{c,t}$ is a preference shock on consumption and follows an AR(1) process. Aggregate consumption and labour supply in the economy are defined as $c_t = c_{s,t} + c_{b,t}$ and $n_t = n_{s,t} + n_{b,t}$, respectively.

A.1 Savers

In the context of the models, money facilitates consumption and investment-good purchases as in Schmitt-Grohe and Uribe (2004). We assume that the balance of money deposited for consumption and investment purposes, $d_{c,t}$ and $d_{I,t}$ are held exclusively by saver households. We adopt the money demand specification from Schmitt-Grohe and Uribe (2004). Specifically, consumption and investment-good purchases are subject to proportional transaction costs, $s_{c,t}$ and $s_{I,t}$, that respectively depend on households' consumption and investment-based money velocities, $v_{c,t}$ and $v_{I,t}$, such that $v_{c,t} = c_{s,t}/d_{c,t}$ and $v_{I,t} = I_t/d_{I,t}$. The proportional transaction costs evolve as,

$$s_{z,t} = Av_{z,t} + \frac{B}{v_{z,t}} - 2\sqrt{AB} \tag{2}$$

Where $z \in \{c, I\}$ and A and B are the constant transaction cost parameters.

At the beginning of each period t savers are split into consumers/workers/capital holders and capital producers. Capital producers purchase the depreciated capital stock, $q_t K_{t-1}(1-\delta_k)$ at price q_t, from producers of intermediate goods, investment goods I_t from producers of final goods and use resources to pay for monetary transaction costs and real investment adjustment costs $s_{I,t} I_t + G_{I,t}$, where $G_{I,t} = \frac{\zeta_I}{2} I_t \left(\frac{I_t}{I_{t-1}} - 1\right)^2$. They sell the sum of old and new capital $q_t[K_{t-1}(1-\delta_k) + I_t]$ to intermediate goods producers.

The representative saver maximises their expected utility (1) subject to the following real budget constraint:

$$c_{s,t}(1+s_t) + d_t + G_{I,t} = w_t n_{s,t} + \frac{R_{t-1}}{\Pi_t} d_{t-1} + (q_t - 1 - s_{I,t}) I_t + \Lambda_t \tag{3}$$

where the left-hand side of the budget constraint represents the expenditure side: consumption spending, including transaction costs, monetary deposit holdings (i.e., $d_t = d_{c,t} + d_{I,t}$) and investment adjustment costs. The right-hand side disaggregates income. Savers receive the wage rate, w_t, for supplying hours of work and earn R_{t-1} on the risk-free deposit from the previous period, d_{t-1}, which depends on gross inflation, $\Pi_t = \frac{P_t}{P_{t-1}}$. They also receive the net revenue from their investment and dividends from both firms and banks, Λ_t.

The first order conditions with respect to $c_{s,t}$, $n_{s,t}$, $d_{c,t}$, $d_{I,t}$ and I_t are the following:

$$U^c_{s,t} = \lambda_{s,t}(1 + s_{c,t} + v_{c,t} s'_{c,t}) \tag{4}$$

$$w_t = \frac{-U^n_{s,t}}{U^c_{s,t}}(1 + s_{c,t} + v_{c,t} s'_{c,t}) \tag{5}$$

$$\lambda_{s,t}(1 - v^2_{c,t} s'_{c,t}) = \beta \lambda_{s,t+1} \frac{R_t}{\Pi_{t+1}} \tag{6}$$

$$\lambda_{s,t}(1 - v^2_{I,t} s'_{I,t}) = \beta \lambda_{s,t+1} \frac{R_t}{\Pi_{t+1}} \tag{7}$$

$$\begin{aligned} q_t = (1 + v_{I,t} s'_{I,t} + s_{I,t}) + \zeta_I \left(\frac{I_t}{I_{t-1}}\right) \left(\frac{I_t}{I_{t-1}} - 1\right) + \frac{\zeta_I}{2} \left(\frac{I_t}{I_{t-1}} - 1\right)^2 \\ - \beta E_t \left(\frac{\lambda_{s,t+1}}{\lambda_{s,t}}\right) \zeta_I \left(\frac{I_{t+1}}{I_t} - 1\right) \left(\frac{I_{t+1}}{I_t}\right)^2 \end{aligned} \tag{8}$$

where $\lambda_{s,t}$ denotes the Lagrange multiplier with respect to the saver's budget constraint. $U^c_{s,t}$ and $U^n_{s,t}$ are savers' marginal utilities for consumption and labour.

A.2 Borrowers

At period t the representative borrower also maximises their expected utility (1) subject to the following real budget constraint:

$$c_{b,t} + \frac{R_{L,t}}{\Pi_t} l_{h,t-1} = w_t n_{b,t} + l_{h,t} \tag{9}$$

where the borrower spends resources on consumption and loan interest payments and receives the wage, w_t, as revenue from firms and loans, $l_{h,t}$, from banks.

Borrowers are subject to a borrowing constraint:

$$R_{L,t} l_{h,t} \leq \phi_{h,t} w_t n_{b,t} \tag{10}$$

where ϕ_t is the regulatory loan-to-income limit that banks apply to borrowers.

The first order conditions of the borrower with respect to $c_{b,t}$, $n_{s,t}$ and $l_{h,t}$ are combined and summarised as:

$$w_t = \frac{-U_{b,t}^n}{U_{b,t}^c + \phi_{h,t} \mu_{b,t}} \tag{11}$$

$$U_{b,t}^c = \mu_{b,t} R_{L,t} + \beta U_{b,t+1}^c \frac{R_{L,t}}{\Pi_{t+1}} \tag{12}$$

where $U_{b,t}^c$ and $U_{b,t}^n$ are savers' marginal utilities with respect to consumption and labour, and $\mu_{b,t}$ is the Lagrange multiplier with respect to the borrowing constraint.

B. The money creation (MC) model

For this model, we assume that the economy consists of a single representative household that both borrows from the bank and holds money deposits at the bank. This version of the model is a condensed version of the money-creation approach to banking in Jakab and Kumhof (2015, 2019). The preferences of the representative household are identical to (1), after dropping all subscripts z. The household maximises its expected utility subject to the following real budget constraint:

$$c_{s,t}(1 + s_{c,t}) + d_t + G_{I,t} + \frac{R_{L,t}}{\Pi_t} l_{h,t-1} = l_{h,t} + \frac{R_{t-1}}{\Pi_t} d_{t-1} + w_t N_t + (q_t - 1 - s_{I,t}) I_t + \Lambda_t \tag{13}$$

From the left-hand side of the budget constraint, the household consumes with the transaction costs (s_t)[3], holds deposits at the bank and pays investment adjustment costs and the interest rate on loans from the bank. The right-hand side of the budget constraint shows that households borrow from banks, earn gross interest on deposits and receive wages, as well as the net value of their investment and any profits from firms and banks (Λ_t).

The representative household is subject to the same borrowing constraint as in the IL model (see equation 10).

[3] While the transaction cost technology is a feature of the ILF model, it is introduced in the MC model in order to make the two models comparable.

The main difference between the ILF model and the MC model is found in the budget constraint of households (banks' customers), where the separate constraints (3) and (9) of the former model become a single constraint (13) in the latter. In the MC Model, deposits and loans are fast-moving variables, created by matching gross positions on the balance sheets of banks, while they are predetermined variables in the ILF Model, representing slow-moving savings.

The first-order optimality conditions for consumption, investment and bank deposits are identical to those of the saver household in the ILF model, while those for loans and labour are identical to the ones of the borrower household in the ILF model, taking into account transaction costs.

2.2 BANKS

In the ILF model, a monopolistically competitive banking sector extends loans to borrowers and collects deposits from savers, while in the MC model banks perform both operations with a single representative household. In addition, the banking sector lends to non-financial firms. Banks balance sheets are subject to an adjustment cost. As in Gerali *et al.* (2010), we assume that the representative bank has a target τ_t for their capital-to-assets ratio (i.e., the leverage ratio) and pays a quadratic cost whenever it deviates from that target. The target can be interpreted as an exogenous regulatory capital requirement that imposes a constraint on the amount of own resources to hold. The existence of a cost for deviating from the target ratio of capital-to-assets τ implies that bank leverage affects credit conditions in the economy.

In the ILF model, the monopolistic banking sector collects deposits, $d_t = d_{c,t} + d_{I,t}$, from households, paying a net interest rate r_t set by the central bank and issues loans $l_t = l_{h,t} + l_{f,t}$ to households ($l_{b,t}$) and intermediate goods producers ($l_{f,t}$) on which it earns the loan net interest rate $r_{L,t}$. In the MC model, the monopolistic banking sector performs a bookkeeping transaction with a lending net interest rate of $r_{L,t}$ and pays r_t for the change in its liabilities that compensates the change on its asset side.

The representative bank's real profits are the loan interest payments minus deposit interest payments as well as the quadratic cost that the bank is assumed to pay for deviating from its target leverage:

$$\Lambda_{B,t} = r_{L,t} l_t - r_t d_t - \frac{\chi}{2} \left(\frac{k_{B,t}}{l_t} - \tau_t\right)^2 k_{B,t} \tag{14}$$

where $k_{B,t}$ is the bank's capital and χ denotes the parameter that captures the sensitivity of the bank's profit, and thus the bank's lending rate, to the penalty cost for deviating from the target capital-to-assets ratio.

The representative bank chooses the optimal loan supply and deposits in order to maximise its real profit (14) subject to the following balance sheet constraint, $l_t = d_t + k_{B,t}$. Solving the maximisation programme leads to the loan net interest rate that would be optimal under perfect competition, to which we add a premium m_b:

$$r_t^L = r_t - \chi \left(\frac{k_{B,t}}{l_t} - \tau_t\right) \left(\frac{k_{B,t}}{l_t}\right)^2 + m_b \tag{15}$$

where m_b is a constant mark-up representing the finance premium assumed in Gambacorta and Signoretti (2014).

Furthermore, bank's capital $k_{B,t}$ is accumulated out of reinvested profits and evolves as follows:

$$k_{B,t}\Pi_t = (1-\delta_B)k_{B,t-1} + (1-\upsilon)\Lambda_{B,t-1} \tag{16}$$

where δ_B is the bank capital depreciation rate (i.e., bank capital used in banking activities) and υ is the parameter governing the bank dividend policy.

2.3 FIRMS

2.3.1 Final good producers

Final good producers operate under perfect competition, buying differentiated intermediate goods, $j \in [0,1]$, which they bundle into final goods, Y_t, via the Dixit-Stiglitz aggregator:

$$Y_t = [\int_0^1 (Y_t(j))^{\frac{\epsilon-1}{\epsilon}} dj]^{\frac{\epsilon}{\epsilon-1}} \tag{17}$$

where ϵ denotes the elasticity of substitution between the various types of goods. Final good producers generate the following demand equation for each intermediate good:

$$Y_t(j) = (\frac{P_t(j)}{P_t})^{-\epsilon} Y_t \tag{18}$$

where $P_t(j)$ is the price of the intermediate good j and P_t is the aggregate price of final goods set as:

$$P_t = [\int_0^1 (P_t(j))^{1-\epsilon} dj]^{\frac{1}{1-\epsilon}} \tag{19}$$

2.3.2 Intermediate good producers

Intermediate good producers operate under monopolistic competition. Assuming perfect symmetry across firms, an intermediate good producer relies on the following technology:

$$Y_t = A_{F,t}\, N_t^{1-\alpha} K_{t-1}^{\alpha} \tag{20}$$

where N_t stands for the aggregate labour supplied in the economy (with $N_t = n_{s,t} + n_{b,t}$ in the ILF model), K_{t-1} is the previous period's physical capital stock and $A_{F,t}$ is an aggregate productivity shock.

Intermediate good producers earn revenues from sales of their differentiated intermediate output minus expenditures on labour services supplied by households in exchange for the wage, w_t. In addition, non-financial intermediate good producers borrow from banks ($l_{f,t}$) and pay off interest plus principal on loans. They also spend on business investment at price q_t. Therefore, the representative firm's real dividend payoff is:

$$\Lambda_{f,t} = (Y_t - w_t N_t) + (l_{f,t} - \frac{R_{L,t-1}}{\Pi_t} l_{f,t-1}) - q_t I_t \tag{21}$$

The representative firm faces the following borrowing (collateral) constraint:

$$R_{L,t} l_{f,t} \leq \psi_{f,t}\, q_{t+1} K_t \tag{22}$$

where $\psi_{f,t}$ is the regulatory limit on the corporate loan to value ratio.

Intermediate good producers enter period t with previously accumulated physical capital stock, K_{t-1}, which evolves according to:

$$K_t = I_t + (1 - \delta_k)K_{t-1} \tag{23}$$

Solving firms' expected discount profit maximisation, subject to the production function (20), the physical capital accumulation equation (23) and the borrowing constraint (22), entails the following first order conditions:

$$q_t = \mu_{ft}\Phi_{f,t}q_{t+1} + \beta E_t\,(\frac{\lambda_{s,t+1}}{\lambda_{s,t}})\,[\frac{\alpha Y_{t+1}mc_{t+1}}{K_t} + q_{t+1}(1 - \delta_k)] \tag{24}$$

$$[\mu_{ft} + \beta E_t\,(\frac{\lambda_{s,t+1}}{\lambda_{s,t}})\,\frac{1}{\Pi_{t+1}}]\,R_{L,t} = 1 \tag{25}$$

$$w_t = (1 - \alpha)\frac{Y_t}{N_t}mc_t \tag{26}$$

Intermediate good producers are subject to Rotemberg price setting. As in Rotemberg (1984), it is assumed that price changes are subject to quadratic price adjustment costs. In period t, intermediate good producer (j) can adjust its price optimally and it does so to maximize its expected discount profit (21) subject to production function (20) and intermediate good demand function (18).

The necessary first order condition implicitly provides the following optimal price for intermediate goods:

$$\begin{aligned} -\epsilon\,(\frac{P_t(j)}{P_t})^{-\epsilon-1}\frac{P_t(j)}{P_t}\frac{Y_t}{P_t} + (\frac{P_t(j)}{P_t})^{-\epsilon}\frac{Y_t}{P_t} - \zeta_P\,(\frac{P_t(j)}{P_{t-1}(j)} - 1)\,\frac{Y_t}{P_{t-1}(j)} + \epsilon.mc_t(j)\,(\frac{P_t(j)}{P_t})^{-\epsilon-1}\frac{Y_t}{P_t} \\ + \zeta_P\beta E_t\,[\frac{\lambda_{s,t+1}}{\lambda_{s,t}}(\frac{P_t(j)}{P_{t-1}(j)} - 1)\,Y_{t+1}\,(\frac{P_{t+1}(j)}{(P_t(j))^2})\,] = 0 \end{aligned} \tag{27}$$

where ζ_P denotes the price adjustment cost parameter.

As perfect symmetry is assumed across firms, they all fix the same price and consequently, the index j can be dropped. Hence, the inflation rate is:

$$\zeta_P\Pi_t(\Pi_t - 1) = \zeta_P\beta E_t\,[\frac{\lambda_{s,t+1}}{\lambda_{s,t}}\Pi_{t+1}(\Pi_{t+1} - 1)\frac{Y_{t+1}}{Y_t}] + (1 - \epsilon) + \epsilon.mc_t \tag{28}$$

2.4 MONETARY POLICY AND GOVERNMENT SPENDING

The central bank sets monetary policy according to a Taylor-type rule.

$$R_t = R^{1-\phi_R}R_{t-1}^{\phi_R}\,(\frac{\Pi_t}{\Pi})^{\phi_\Pi(1-\phi_R)}\,(\frac{Y_t}{Y})^{\phi_Y(1-\phi_R)}\,A_{R,t} \tag{29}$$

where R denotes the steady-state nominal interest rate. ϕ_R denotes the interest rate smoothing parameter. ϕ_Π and ϕ_Y are the weights assigned to inflation and output deviations from their target values. $A_{R,t}$ represents a monetary policy shock following an AR(1) process.

It is assumed that government spending is exogenous and represents a constant fraction of the steady state output, such as $G_t = g\bar{Y}$.

2.5 MACROPRUDENTIAL POLICY

The macroprudential authority holds three macroprudential instruments: the bank capital-to-assets ratio requirement on the loan supply side, household loan-to-income ratio (LTI) and corporate loan to value ratio (LTV) on the loan demand side.

Following Adrian *et al.* (2022), the regulatory bank capital requirement satisfies a countercyclical capital buffer rule exhibiting partial adjustment dynamics of the form:

$$\tau_t = \rho_\tau \tau_{t-1} + (1-\rho_\tau)\tau + (1-\rho_\tau)\chi_\tau(l_t - l) \quad (30)$$

where $0 \leq \rho_\tau < 1$ denotes the degree of persistence of the capital requirement, $\chi_\tau \geq 0$ is the policy response coefficient to growth in total bank loans with respect to its steady state value and τ is the steady state value of the capital-to-assets ratio.

The regulatory limit on household loan-to-income ratios satisfies a partial adjustment rule of the form:

$$\phi_{h,t} = \rho_\phi \phi_{h,t-1} + (1-\rho_\phi)\phi + (1-\rho_\phi)\chi_\phi(l_{b,t} - l_b) \quad (31)$$

where $0 \leq \rho_\phi < 1$ denotes the degree of persistence in the loan-to-income limit, , $\chi_\phi \geq 0$ is the policy response coefficient to the growth of household borrowing with respect to its steady state value and ϕ is the steady state value of the loan-to-income ratio.

As in Adrian *et al.* (2022), the regulatory limit on the corporate loan-to-value ratio satisfies a partial adjustment rule of the form:

$$\psi_{f,t} = \rho_\psi \phi_{f,t-1} + (1-\rho_\psi)\psi + (1-\rho_\psi)\chi_\psi(l_{f,t} - l_f) \quad (32)$$

where $0 \leq \rho_\psi < 1$ denotes the degree of persistence in the limit on the loan-to-value ratio, $\chi_\psi \geq 0$ is the policy response coefficient to growth in corporate borrowing with respect to its steady state value and ψ is the steady state value of the limit on the loan-to-value ratio.

2.6 RESOURCE CONSTRAINT

For the ILF model, the market clearing condition in the goods market is given by:

$$Y_t = c_{s,t}(1+s_{c,t}) + c_{b,t} + I_t(1+s_{I,t}) + G_{I,t} + G_t + \delta_B \frac{k_{B,t-1}}{\Pi_t} + \frac{\zeta_P}{2}(\Pi_t - 1)^2 Y_t + \frac{\chi}{2}\left(\frac{k_{B,t-1}}{l_{t-1}} - \tau\right)^2 \frac{k_{B,t-1}}{\Pi_t} \quad (33)$$

In the money-creation model, the goods market clearing condition is Equation (33) excluding the term $c_{b,t}$.

3. CALIBRATION OF THE MODEL

In order to simulate the model, we set some model parameters using euro area data and set others to values from the broader literature. Table 1 below presents the calibrated values of parameters and time is measured in quarters.

The degree of habit formation in consumption, a, is set to 0.5 in line with the literature (see Lambertini *et al.* (2017), Darracq Pariès *et al.*(2011)). The goods substitution elasticity, ϵ, is fixed at 6, implying a steady-state markup of 20% as in Chen and Columba (2016) and Hristov and Hülsewig (2017). The inverse of the Frisch elasticity is $\gamma = 1$ following Clerc *et al.* (2015).

Steady-state gross inflation, Π, is set to yield an annual inflation rate of 2% for the euro area. We set the household discount factor β at 0.99 and the average steady-state annual risk-free interest rate at 2%, corresponding to euro area data and yielding a steady-state annual real interest rate of 0%. The average annual bank lending rate is calibrated so that the average annual spread between the risk free and bank loan rates is 200 bps, consistent with euro area data. Following Schmitt-Grohé and Uribe (2004), we set the parameter B of the transaction cost technology to 0.01. The parameter A of transaction costs is calibrated to a higher value (0.29) than in Schmitt-Grohé and Uribe (2004) in order to generate a positive steady-state loan flow to borrowers in the ILF model. The parameter defining capital used in banking activity δ_B is endogenously determined at the steady state.

We fix the ratio of capital to loans at 8% according to euro area data, which is also in line with the literature (Jakab and Kumhof (2015, 2019)). The banking leverage adjustment cost parameter, χ, is set to 10 following Gerali *et al.* (2010). The adjustment cost parameter related to goods prices (ζ_P) is set to 400 to yield enough price stickiness. We calibrate the weight of labour disutility ($\mathcal{X}n$) for savers in the ILF model and the representative household in the MC model to 0.8 and the dividend policy parameter (υ) to 5% according to the values in Clerc *et al.* (2015). The weight of labour disutility ($\mathcal{X}n$) for borrowers in the ILF model is endogenously set in the steady state.

The steady-state value of the corporate loan-to-value ratio is calibrated to 100%, assuming that the firm is financed by the bank against the entire value of its physical capital. We set the steady-state loan-to-income ratio to 33% corresponding to the value endogenously obtained in the MC model.

Following Gerali *et al.* (2010), the capital share in the production function (α) and the depreciation rate of physical capital (δ_k) are set to 0.25 and 0.025, respectively. The investment adjustment cost parameter (ζ_I) is calibrated to 10 as in Gerali *et al.* (2010).

The ratio of public spending to GDP is 0.2 and is based on euro area data. The monetary policy rule has a smoothing parameter of 0.8, an inflation response of 2 and an output gap response of 0.4 following Gerali *et al.* (2010). Macroprudential policy response to the growth of total bank loans ($\mathcal{X}\tau$), household ($\mathcal{X}_\phi$) and corporate ($\mathcal{X}_\psi$) borrowing are fixed at 0.1 following to Adrian *et al.* (2022). The degrees of persistence in the macroprudential rules are all set to 0.8 as in Adrian *et al.* (2022).

Finally, we use 0.8 for the AR(1) coefficients of the shocks, as is common in the literature.

Table 1:

Calibration of the model parameters

PARAMETERS	DESCRIPTION	VALUES
β	Discount factor of households	0.99
a	Degree of habit formation in consumption	0.5
A	Parameter of transaction cost function	0.29
B	Parameter of transaction cost function	0.01
γ	Inverse of Frisch elasticity	1
Ψ	Corporate loan-to-value ratio	1
Φ	Household loan-to-income ratio	0.33
τ	Ratio of Capital to loans	0.08
χ	Banking leverage adjustment cost	20
υ	Banks' dividend policy parameter	0.05
α	Capital share in the production function	0.25
δ_k	Depreciation rate of physical capital	0.025
ζ_I	Investment adjustment cost parameter	10
ζ_P	Parameter of goods price adjustment cost	400
ϵ	Goods substitution elasticity	6
χ_n	Weight of labour in the utility	0.8
g	Government spending to GDP ratio	0.2
ϕ_R	Taylor rule smoothing coefficient	0.8
ϕ_Π	Taylor rule coefficient on inflation	2
ϕ_Y	Taylor rule coefficient on output	0.4
χ_τ	Macroprudential policy coefficient on total loan	0.1
χ_Φ	Macroprudential policy coefficient on household loan	0.1
χ_Ψ	Macroprudential policy coefficient on corporate loan	0.1
$\rho_{\tau,\Phi,\Psi}$	Persistence of the macroprudential rule	0.8
ρ_c	AR consumption preference shock	0.8
ρ_f	AR productivity shock	0.8
ρ_r	AR monetary policy shock	0.8

Source: BCL.

4. QUANTITATIVE IMPLICATIONS AND MODEL DYNAMICS

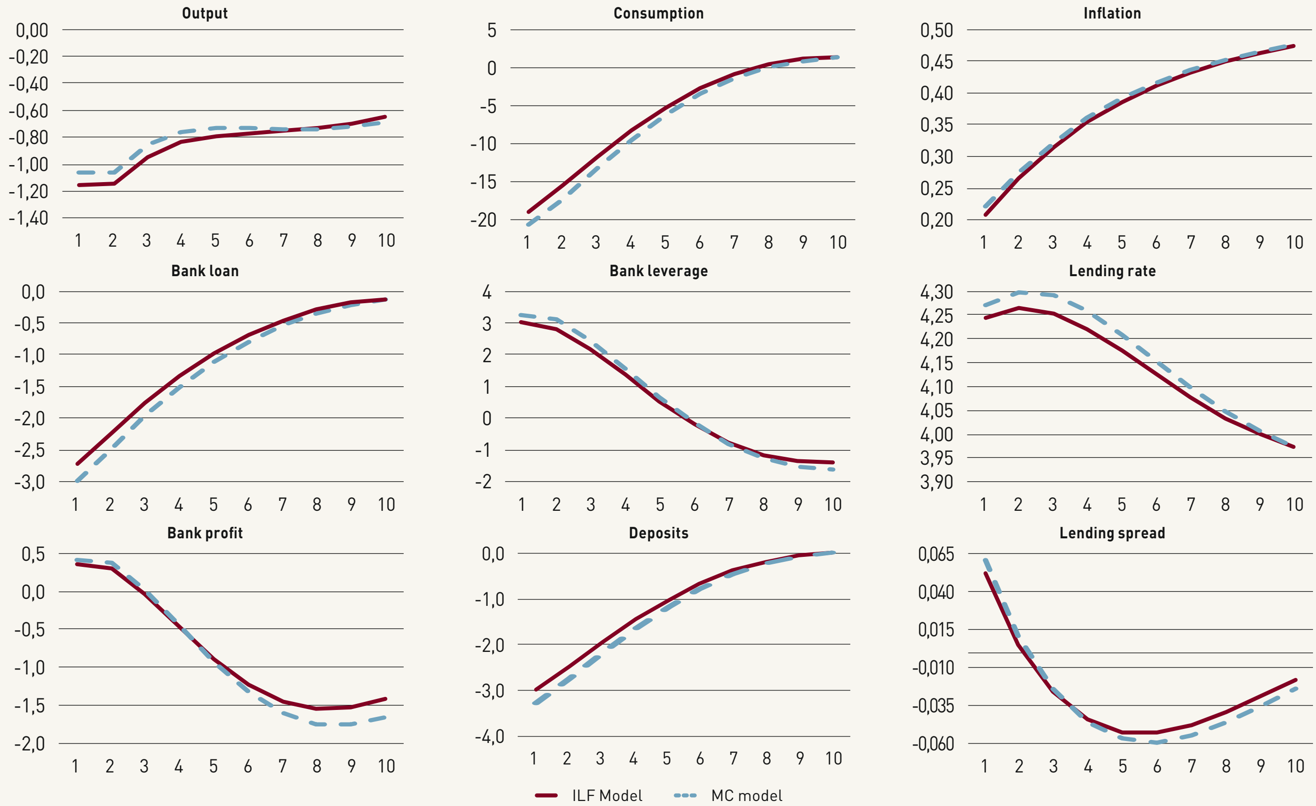
4.1 COMPARISON OF THE INTERMEDIATION OF LOANABLE FUNDS MODEL AND THE FINANCING THROUGH MONEY CREATION MODEL

Figure 2 displays the effects of an unanticipated 50 basis point increase in the monetary policy rate on the main macro-financial variables of the economy.

This shock leads to an increase in the bank lending rate, which, combined with movements in the bank lending spread, immediately improves bank profits in relation to the existing balance sheet and pricing structure (i.e., price effect). As in Gerali *et al.* (2010), this price effect outweighs the decline in bank loans to households and firms (i.e. quantity effect). More specifically, at the time of impact, the bank lending spread increases, which more than offsets the reduction in bank loans. A few quarters later, the spread falls below its steady state level when the marginal effect of deviating from the target capital-to-assets ratio on lending (i.e., the benefit from the bank's capital position) outweighs the change in the policy rate. This compression of the spread causes bank profits to decline after their initial increase.

Figure 2:

Effects of a 50bps tightening of monetary policy on the main macro-financial variables using the ILF and MC models



Source: BCL.

Notes: Time, measured in quarters, is on the horizontal axis. All variables are measured in % deviation from the steady state, with the exception of the lending rate and inflation, which are measured in percentage levels.

Following profits, bank capital and leverage increase in the short-run but decrease several quarters later, in both models. As bank capital increases in the short-run, banks have no incentive to hold deposits and so the level of deposits declines.

The contraction in lending depresses household consumption and firm investment, resulting in a reduction of inflation, which initially falls before converging back to its steady state level (a quarterly value of 0.5 matches the central bank's annual target of 2%). The contraction in lending has a recessionary effect on output, since aggregate demand falls and the real interest rate rises.

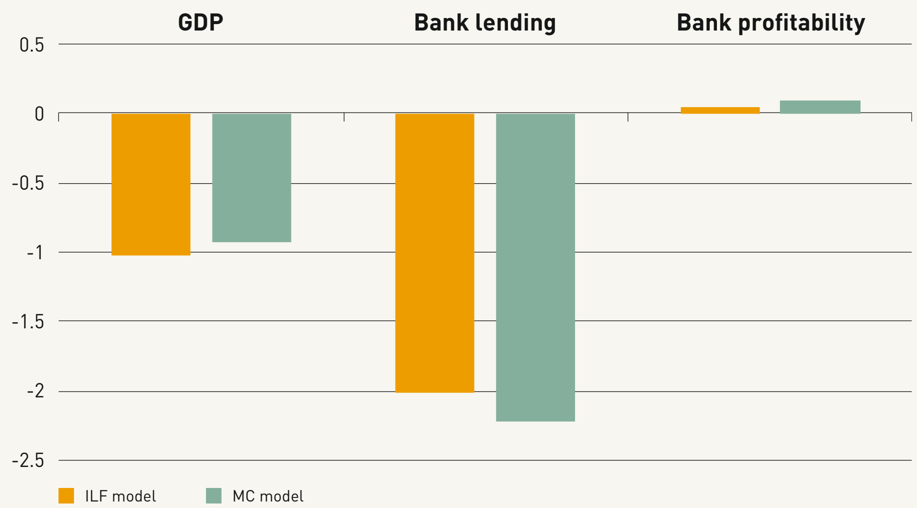
Additional model dynamics are reflected in the impulse responses to monetary policy tightening. Loan supply is positively correlated with the level of bank capital such that it depends positively on bank profits. In other words, an increase in bank profits (and therefore bank capital) leads to a reduction in the lending rate (in the next period) for any given level of lending to the economy.

These responses to monetary policy tightening are in line with those from Gerali *et al.* (2010). They highlight the credit-supply channel created by financial frictions that link the real and financial sides of the economy, as described in Gambacorta and Signoretti (2014).

Comparing the outcomes of the intermediation of loanable funds model to those from the money creation model shows that the latter attenuates the contractionary effects of the monetary policy tightening on output, while it reinforces the effects on other macro-financial variables. In particular, bank loans and household consumption decline more under money creation than under the intermediation of loanable funds. This is explained by the fact that lending flows decline much less under the ILF model than under the MC model, since banks instantaneously reduce their loan supply in the latter while they have to do so gradually in the former model.

More specifically, in the ILF model banks do not contract their lending until they observe a reduction in their deposits. As deposits equal savings from savers and are predetermined variables, lending and deposits cannot jump following the interest rate shock. Moreover, as consumption is the main purpose of household borrowing in our models, consumption decreases less in the ILF model (due to the direct impact of the shock on consumption by borrowers and the indirect effects on consumption by savers). In the MC model, banks face no constraints to adjusting their lending volumes and the increase in the lending rate directly reduces consumption by the representative household, leading to a direct and strong decrease in lending.

Figure 3:
Four-quarter average impact of a 50bps monetary policy tightening (in %)



Source: BCL.

However, output contracts less under money creation than under intermediation of loanable funds, as bank capital and profits increase more under the former. This is because the MC model implies relatively high lending interest rates. In addition, the consumption/leisure distortion stemming from transaction costs encourages households to work more in the MC model than in the ILF, contributing to output growth in the steady state.

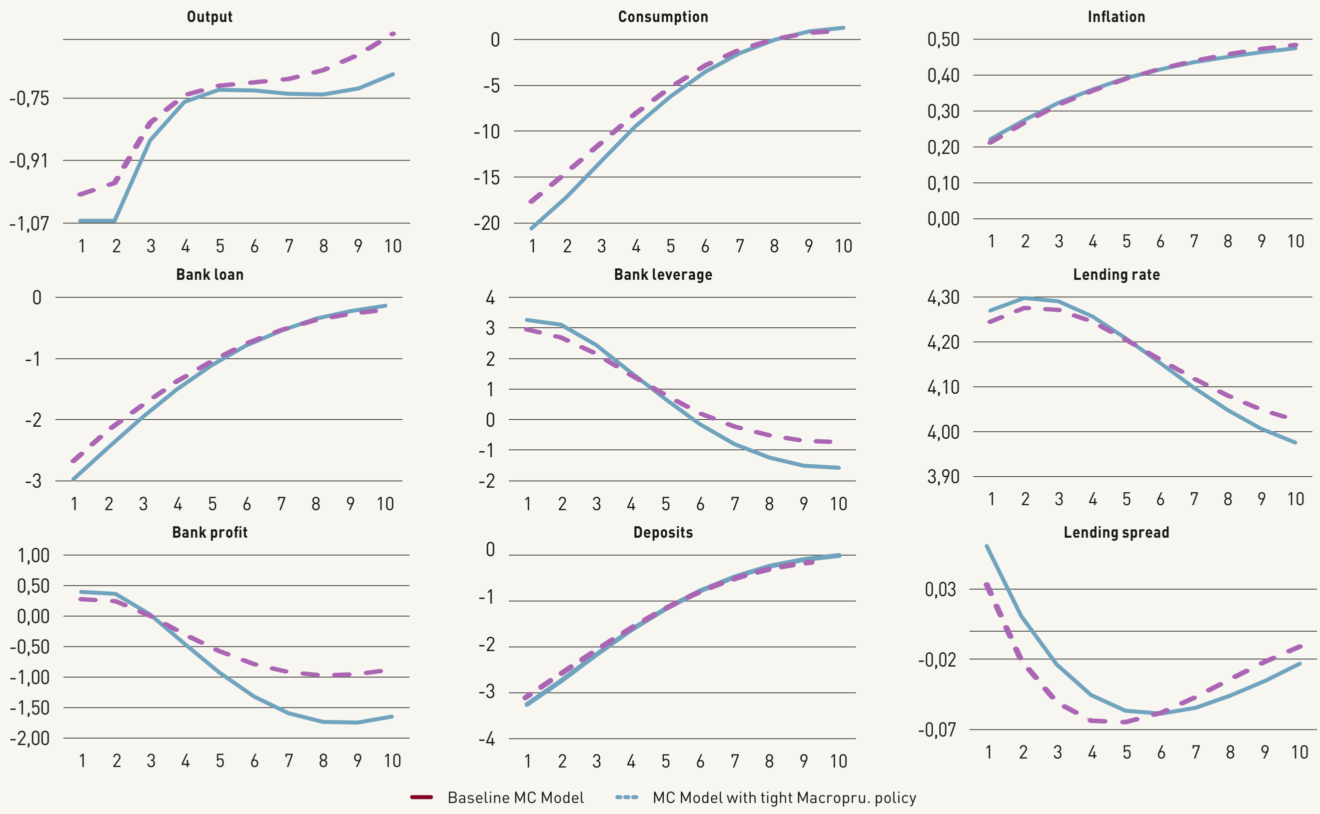
Figure 3 illustrates the one-year average impacts of the 50 basis point increase in the monetary policy rate on GDP, bank loans and bank profitability under alternative model specifications. Over the short-term (one year), GDP decreases on average by 0.94 % in the MC model, which is less than the 1.02 % decrease in the ILF model. In accordance with the impulse responses in Figure 2, bank loans fall, on average, more in the MC model (-2.23 %) than in the ILF model (-2 %). In the short term, the increase in bank profitability is around 0.04 % under the ILF model while it increases about 0.09 % under the MC model.

4.2 INVESTIGATING THE ROLE OF MACROPRUDENTIAL POLICY IN THE MONEY CREATION SETTINGS

In this section, we explore the role of macroprudential policy in our money creation model. We perform a counterfactual analysis by assessing the impact on the main macro financial variables of the economy from choosing alternative targets for the regulatory capital requirement (i.e., the target

Figure 4:

Effects of a tightening monetary policy on the main macro-financial variables using the MC model with and without tight macroprudential policy



Source: BCL.

Notes: Time, measured in quarters, is on the horizontal axis. All variables are measured in % deviations from steady state, except the lending rate and inflation, which are measured in % levels.

capital-to-assets ratio). To this end, we compare two scenarios based on the MC model: a baseline scenario in which the bank's target capital-to-assets ratio is set to its level from the data (i.e., baseline calibration = 8 %) and an alternative scenario where macroprudential policy sets this to a higher level (i.e., policy tightening calibration = 12 %).

The analysis is performed by assuming an exogenous 50 basis point increase in the monetary policy rate. Figure 4 compares the main outcomes of monetary policy tightening in the MC model with the baseline and higher calibration of macroprudential policy.

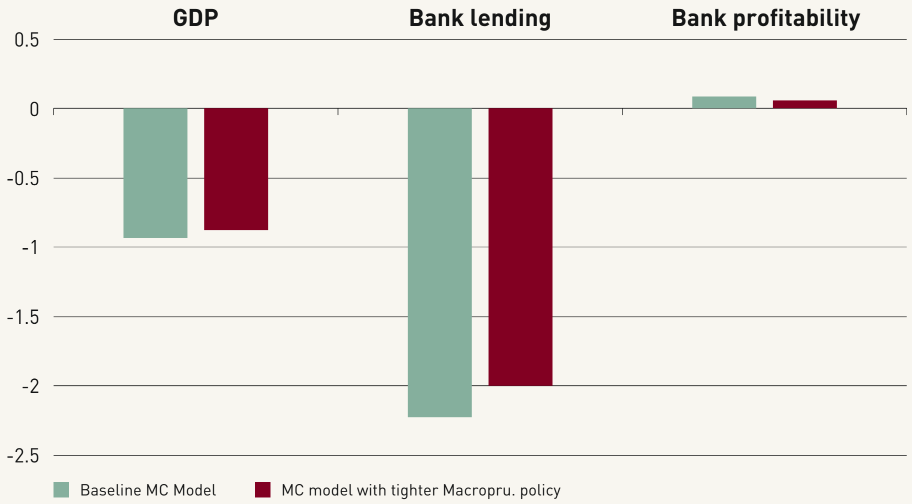
The dynamics of the main variables in the MC model show that a tighter macroprudential policy environment attenuates the contractionary impacts of monetary policy tightening, at least in the short run. In the context of our model, this suggests that the presence of higher capital buffers can attenuate the impact of monetary tightening. The main explanation for this finding is the so-called loan-supply channel mentioned previously. More specifically, the presence of a higher target for the bank leverage position (i.e., a higher bank capital position) reduces the lending rate and spread (which could even decline as shown in Figure 4). In other words, in a monetary policy tightening, resilient banks are likely to increase their lending rates by less than more vulnerable banks. This drives up bank loan supply compared to the scenario with lower capital buffers. Due to this price effect, bank profits increase less under the scenario with a higher capital-to-assets ratio than under the baseline scenario with a lower capital buffer. As a result, bank capital and leverage also increase less under the scenario with higher capital buffers. As bank loans decrease less under the alternative calibration with a high level of capital, the decline in deposits, consumption and output is more limited than in the baseline scenario with a lower capital-to-assets ratio.

For illustrative purposes, Figure 5 shows the one-year averages associated with the 50 basis point tightening of monetary policy under alternative macroprudential policies for the MC model. Figure 5 suggests that the effects on GDP and lending from increasing policy rates are attenuated when the macroprudential policy calibration is tighter (i.e., capital buffers are higher). In particular, under the scenario with a higher capital buffer, GDP declines in the short-term by 0.88 % and bank loans decrease by 2 %, while under the baseline calibration they fall by 0.94 % and 2.23 % respectively.

Bank profitability increases by 0.09 % under the baseline calibration of macroprudential policy, while it only increases 0.06 % under the scenario with the higher capital buffer. The rationale behind these results is that well-capitalized banks attenuate the impact of monetary policy tightening, mainly due to the positive relationship between loan supply and the level of bank capital (and bank profits).

Figure 5:

Four-quarter average impact of a 50 bps monetary policy tightening when macroprudential policy is tighter in the MC Model (in %)



Source: BCL.

4.3 WELFARE ANALYSIS

In order to draw conclusions about the desirability of alternative models and policies, we compare their performance based on welfare criteria. The welfare analysis follows the approach commonly used in the DSGE literature.[4] The individual welfare of households is measured by the conditional expectation of lifetime utility as:

$$W_{z,t} = E_0 \sum_{t=0}^{\infty} \beta_z^t \left[A_{c,t}(1-a)\ln(c_{z,t} - a.C_{z,t-1}) - \frac{\chi_n n_{z,t}^{1+\gamma}}{1+\gamma} \right] \tag{24}$$

In the ILF model, where households are split into two groups, individual welfare (24) is computed separately for each type of household where $z = \{s, b\}$ with s and b standing for borrowers and savers. We define total social welfare as a weighted sum of individual welfare as follows:

$$W_t = (1-\beta_s)W_{s,t} + (1-\beta_b)W_{b,t} \tag{25}$$

where $\beta_s = \beta_b$ as discussed in Section 2.1.A.

In the MC model there is a single representative household, so total social welfare is obtained from a simplified version of Equation (24) after dropping all subscripts, z.

We follow Schmitt-Grohe and Uribe (2007) by computing the conditional welfare of agents using the second order approximation of the model.[5]

To make the results more intuitive, we define a welfare metric in terms of consumption equivalents. This consumption-equivalent welfare measure is the constant fraction of steady-state consumption that households would need in a non-stochastic world in order to yield the same conditional welfare as would be achieved in a stochastic world. A positive value means a welfare gain, which is how much the consumer would be willing to pay to obtain the welfare improvement. A negative value implies a welfare cost, i.e., how much steady-state consumption households would have to sacrifice to reach the same level of deterioration in welfare.

Formally, the welfare loss or gain is given by λ_w:

$$W_t(c_{z,t}; n_{z,t}) = W((1+\lambda_w)c_z, n_z) \tag{26}$$

where variables without subscript "t" denote their steady-state values, c_t, and n_t are aggregate consumption and labour.

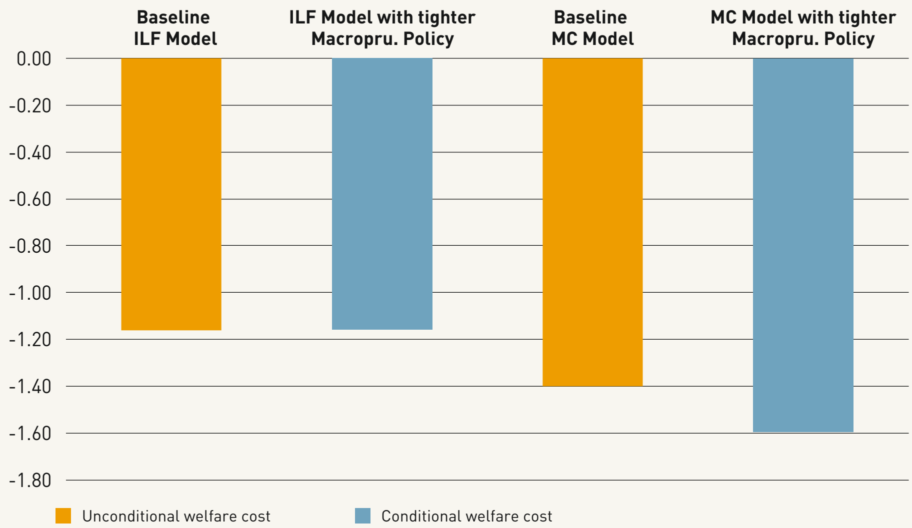
Figure 6 presents the conditional welfare costs (in % of steady-state consumption) following a monetary policy tightening for the different models and macroprudential policies. In line with the above results, the money creation model with the baseline calibration of macroprudential policy displays a higher welfare cost (-1.40 %) compared to the baseline ILF model (-1.16 %). This reflects the dynamics of both consumption and leisure which define the welfare metric. Consumption and leisure decline more under the MC model than under the ILF model, implying a higher welfare cost. Moreover, in accordance with the results from the model dynamics, a higher capital buffer reduces welfare under the MC model as

[4] See among others, Kim and Kim (2003), Faia and Monacelli (2007), Rubio and Carrasco-Galego (2014), Sangare (2019), Schmitt-Grohe and Uribe (2004, 2007).

[5] Second order approximation methods have the particular advantage of accounting for the volatility of variables around their mean levels. See among others Schmitt-Grohe and Uribe (2004).

it implies a greater decline in leisure, which offsets the lower decline in consumption. However, higher capital buffers under the ILF model attenuate the severity of the monetary policy shock in terms of welfare. This is because consumption and labour decrease less with tighter macroprudential policy, owing to reduced loan supply.

Figure 6:
Conditional welfare costs (in % of steady-state consumption)



Source: BCL.

5. CONCLUSIONS

The dominant macro-financial-modelling approach in the literature considers the banking sector simply as an intermediary of loanable funds between non-bank savers and non-bank borrowers. Under this approach, savers' deposits create bank lending in the intermediation process. However, in reality banks create money through their lending operations by creating deposits that require no intermediation from savers. In practice, banks create new monetary purchasing power through loans, with borrowers simultaneously becoming depositors.

This work compares the intermediation of loanable funds model to the money creation model and investigates the role of macroprudential policy when banks are money creators. The effects of a positive shock to the monetary policy rate is compared in the two models in the context of the current monetary policy tightening in the euro area. Macroprudential policy is introduced as a capital requirement, following Gerali *et al.* (2010), by assuming that banks pay a cost if they deviate from a target leverage ratio. Borrower-based macroprudential instruments are also present in our implementation of both models. The first contribution of this study is to construct two realistic DSGE models to explore how the money creation approach to banking affects the macro-model dynamics following monetary policy tightening. The second contribution of this study consists in exploring the role of macroprudential policy in the money creation framework.

Our model comparison exercise shows that an identical positive shock to the monetary policy rate, leads to a much faster contraction of bank lending and much lower contractionary effects on output in the money creation model than in the intermediation of loanable funds model. The explanation is that banks are able to instantaneously reduce their loan supply in the money creation model while they have to do so gradually in the intermediation of loanable funds model. However, output is more resilient to the monetary policy tightening in the money creation model, as bank profitability and capital increase more, and labour supply decreases less, than in the intermediation model. This result suggests that the money creation model amplifies the effects of monetary policy tightening on bank lending while it attenuates the effects of the same shock on output due to the increase in bank capital and the transaction costs on the use of money by households. Furthermore, we find that a macroprudential policy that limits banks' leverage ratio would be effective in dampening the adverse effects of monetary policy tightening, thanks to accumulated capital buffers. More specifically, well-capitalized banks attenuate the impact of a monetary policy tightening mainly due to a positive relationship between loan supply and the level of bank capital. This finding suggests that macroprudential capital buffers may limit the amplification effects a monetary policy shock through money creation.

A quantitative welfare-based assessment of the different models and alternative macroprudential policy settings complete these conclusions. In particular, a monetary policy tightening yields a higher welfare cost under the money creation model compared to the intermediation of loanable funds model. Moreover, a macroprudential policy that implies a higher bank capital position attenuates the welfare cost of a positive monetary policy shock under the ILF model and exacerbates this cost under the MC model.

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2. CLIMATE RISK EXPOSURES OF THE FINANCIAL SECTOR IN LUXEMBOURG AND CLIMATE STRESS TESTING[6]

José Fique*, Max Gehrend◊, Kang-Soek Lee*, Federico Lubello*, Daniel Morell* and Joseph Yapi◊

ABSTRACT

The impact of economic activities on the climate has been constantly increasing over time, creating a situation of urgency in light of the amplification of climate risk and its repercussions, including on the stability of the financial sector. Indeed, climate shocks can lead to rapid and significant depreciations of assets held by financial institutions, thus affecting the stability of the financial system as a whole. It is therefore essential that the various players in the financial sector integrate climate risk in their risk management frameworks and engage in efforts to decarbonise their portfolios. To raise awareness of climate risk and to identify financial stability risks related to climate change, we present an analysis structured in two parts.

In part one, we provide an overview of the exposures of the financial sector in Luxembourg to climate risk. We find that almost half of the corporate exposures of banks and investment funds domiciled in Luxembourg are to carbon-intensive sectors.

In the second part, we conduct a climate stress test for banks and investment funds, the two core components of the financial sector in Luxembourg. Over the horizon of the stress test, we simulate the impact of three climate scenarios (namely, Current Policies, Delayed transition and Net Zero 2050) developed by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) on banks' resilience and on investment funds' net assets. For banks, we explicitly model the evolution of corporate probabilities of default based on a panel data model that includes a set of macroeconomic variables. The simulated probabilities of default under the three scenarios are then used to derive banks' Tier 1 capital ratios. The results indicate that, compared to the Current Policies scenario, the banks in our sample would see their Tier 1 capital ratio stand at 2 percentage points higher under the Net Zero 2050 scenario and 0.6 percentage points higher under the Delayed transition scenario. For investment funds, we regress the growth of net assets of investment funds domiciled in Luxembourg on a set of macroeconomic variables, which we then combine with the above-mentioned climate scenarios to simulate the paths for investment fund net assets. The results indicate that investment fund net assets would be 17.6 % higher under the Net Zero 2050 scenario and 7.4 % higher under the Delayed transition scenario compared to the Current Policies scenario. Hence, the results for banks and for investment funds both suggest that the benefits of policies favouring the transition towards net zero emissions in 2050 clearly outweigh potential costs associated with the transition, for example those stemming from a carbon tax.

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1. INTRODUCTION

It is widely recognized that climate change poses significant and unprecedented challenges to the soundness of the financial system, with the potential to reshape it. Against this background, this study contributes to the debate on the impact of climate-related risks on the economy and financial stability by examining the case of Luxembourg.

Climate-related risks encompass both physical and transition risks. Physical risk refers to the risk stemming from the materialization of nature-related hazards. It includes the economic costs and financial losses resulting from the increasing severity and frequency of extreme weather events that damage physical assets (acute physical risk) as well as longer-term progressive shifts of the climate stemming from global warming, sea level rise and precipitation (chronic physical risk). More severe and frequent extreme weather events could undermine balance sheets of households and firms, and lead to damage of physical assets, increases in defaults, and potential financial sector distress. Transition risk refers to the economic and financial cost of adjustment towards a low-carbon economy. It translates into financial risk for lenders and investors while affecting the profitability of businesses, the wealth of households and the valuation of stranded assets. For instance, the process of reducing the emissions of greenhouse gases (GHG) is likely to dampen all sectors of the economy and affect the value of financial assets. The implementation of climate policies could also lead to a sudden repricing of climate-related risks and stranded assets, which could negatively affect the balance sheets of financial institutions.

Therefore, it is crucial for financial institutions to properly understand climate risks and evaluate their potential impacts. Additionally, supervisors and regulators also need to monitor these risks and take preventive actions. Indeed, the Network for Greening the Financial System (NGFS, 2019) asserts that climate-related risks are a source of financial risk and it therefore falls within the mandates of central banks and supervisors to ensure the financial system is resilient to these risks. The NGFS (2019) also recommends integrating climate-related risks into financial stability monitoring and microprudential supervision. In this context, several central banks and supervisors have carried out climate-related analyses to assess the climate-related risks faced by the financial system. In parallel, climate stress testing has been emerging as an important tool for assessing and managing climate-related risks in the financial sector by quantifying the effects of these risks on the resilience of financial entities such as banks, insurers and investment funds.

In 2022, the European Central Bank (ECB) carried out a climate stress test aiming at deepening the understanding of banks' climate stress-testing framework as well as their level of preparedness. Similarly, several national central banks (NCB) undertook climate risk analyses to assess the exposure of their financial system to climate-related risks. For instance, the Autorité de contrôle prudentiel et de resolution (ACPR, 2021) published the main results of the climate pilot exercise conducted in 2020 by the Banque de France, which aimed at raising awareness of climate change while quantifying the climate-related risks and vulnerabilities to which French financial institutions are exposed. Furthermore, the Bank of England (BoE, 2022) published the results of its Climate Biennial Exploratory Scenario (CBES) carried out in 2021, which aimed at exploring the financial risks posed by climate change for the largest UK banks and insurers. More recently, the US Federal Reserve Board has been conducting, since January 2023, a pilot Climate Scenario Analysis (CSA) exercise aiming at evaluating climate-related financial risks. In particular, this exercise allows for a better understanding of the participating financial institutions' resilience under different climate scenarios, which cover a range of possible climate pathways and associated economic and financial developments. However, the Federal Reserve Board highlights that this exercise differs from regulatory stress tests in that it is exploratory in nature and does not have consequences for bank capital or supervisory implications, even though it also aims to enhance the ability of banks and supervisors to identify, measure, monitor, and manage climate-related financial risks.

In a similar vein, the present study has two objectives. First, it aims to provide an overview of the exposures of the Luxembourg financial sector to climate risk. We find that almost half of the corporate exposures of banks and investment funds domiciled in Luxembourg are to carbon-intensive sectors. This holds for banks' loan and corporate bond portfolios, as well as for investment funds' equity and corporate bond portfolios. Moreover, the ratio of exposures to carbon-intensive sectors to total corporate exposures did not materially decrease over the last years for banks or investment funds, highlighting the need to increase decarbonisation efforts in these two main sectors. Second, our analysis aims to assess the resilience of banks and investment funds in Luxembourg to different climate-related risks. For this purpose, we conduct a climate stress test using three climate risk scenarios developed by the NGFS (2023) to simulate the impacts of climate-related risks on banks' resilience and on investment funds' net assets.

The first scenario consists of an "orderly transition" to net zero greenhouse gas emissions in 2050 (Net Zero 2050). The second is a disorderly scenario, in which transition only starts in 2030 (Delayed transition). The last scenario assumes no further policies are enacted to reduce net emissions beyond what has already been implemented, resulting in a "hot house" world (Current Policies).

In our bank stress test, we use a three-step approach. The first step consists in estimating a panel data model. The corporate probability of default is regressed on a set of macroeconomic variables to assess the sensibility of the probability of default to these variables, which determines the so-called "translation parameters". Then, in the second step, the estimated translation parameters are applied to the NGFS scenarios to get the trajectory of the "stressed" probability of default (SPD). It results in a set of possible trajectories of the stressed probability of default for each selected NGFS scenario. The SPD reflects the creditworthiness of the banks' counterparties given the climate ambitions adopted in the scenarios. Finally, in the third step, the SPD series are used to estimate banks' Tier 1 capital ratios under the three scenarios. For investment funds, we use an auxiliary regression for the growth of net assets of investment funds domiciled in Luxembourg on a set of macroeconomic variables, which is then combined with the above-mentioned climate scenarios to simulate the paths for investment fund net assets.

Turning to the results of the climate stress test, we find that the change in the stressed probability of default underscores not only the urgency of addressing climate change but also the need to act in the appropriate manner. Indeed, in the case where no additional climate policies are implemented, the stressed probability of default is the highest. If the climate policies are implemented in a disorderly manner or lately, the stressed probability of default increases significantly at the time of policy implementation, before decreasing over time. On the contrary, for the more favourable scenario, the stressed probability of default is lower, highlighting the importance of implementing national climate policies in a smooth manner. The results also reveal that, compared to the Current Policies scenario, banks' aggregate Tier 1 capital ratio would be 2 percentage points higher under the Net Zero 2050 scenario and 0.6 percentage points higher under the delayed transition scenario. Regarding investment funds, the results indicate that, compared to the Current Policies scenario, investment fund net assets would be 17.6 % higher under the Net Zero 2050 scenario and 7.4 % higher under the Delayed transition scenario.

The remainder of this analysis is structured as follows. Section 2 provides an overview of Luxembourg banks' and investment funds' exposures to carbon-intensive sectors, illustrating the importance of conducting climate stress tests. This part also presents the regulatory framework and action plan to combat climate change and promote sustainable finance in Europe and Luxembourg, as well as the environmental situation in Luxembourg. Section 3 describes our climate stress-testing model and presents the results for banks and investment funds. Section 4 concludes.

2. CLIMATE RISK EXPOSURES OF THE FINANCIAL SECTOR IN LUXEMBOURG

2.1 ACTION PLANS AND GREENHOUSE GAS EMISSION

2.1.1 Climate action in Europe and Luxembourg

The Paris Climate Agreement[7] is the cornerstone of the global climate action and calls on countries to implement environmental policies to limit global warming to 2 degrees Celsius compared to pre-industrial levels.[8] Limiting global warming to such threshold is imperative if the world is to limit the potential adverse effects of climate risks. Many policies and measures, at both regional and national levels, have been adopted to achieve this goal.

At the European level, the "European Green Deal",[9] published in 2019 by the European Commission (EC), sets out the action plan and roadmap to steer European Union (EU) countries through the environmental transition. It aims to achieve carbon neutrality by 2050 with an intermediate target for 2030 of reducing greenhouse gas (GHG) emissions by at least 55% compared with 1990 levels in a responsible manner. In June 2021, the EU adopted the European Climate Law[10] which enables to revise all relevant climate-related policy instruments for achieving climate neutrality within the Union by 2050.

In Luxembourg, the climate law of 15 December 2020[11] defines the legal and institutional framework for achieving carbon neutrality in Luxembourg by 2050, with an intermediate target of a 55% reduction in GHG in 2030 compared to 2005.[12] Luxembourg's national energy and climate plan[13] for the period 2021-2030 (PNEC) establishes the roadmap for Luxembourg's climate action up to 2030. The PNEC identifies the main fields of action and guidelines for transformation in the sectors most concerned by the fight against climate change and focuses on several dimensions, including decarbonisation, renewable energy, energy efficiency and security of energy supply.

However, the fact that countries are lagging behind in implementing concrete actions is indicative of the gap between the objectives set by the parties at COP 21, when adopting the Paris Agreement, and

7 The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris on 12 December 2015 and entered into force on 4 November 2016. See https://unfccc.int/process-and-meetings/the-paris-agreement for more details.

8 See https://unfccc.int/process-and-meetings/the-paris-agreement for more details.

9 See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en for more details.

10 Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing a framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119.

11 See https://legilux.public.lu/eli/etat/leg/loi/2020/12/15/a994/jo for more details.

12 Other intermediate targets by 2030 include to achieve a 35-37% share of renewable energies in final energy consumption, and to improve energy efficiency by 44%.

13 See https://gouvernement.lu/en/dossiers/2023/2023-pnec.html for more details.

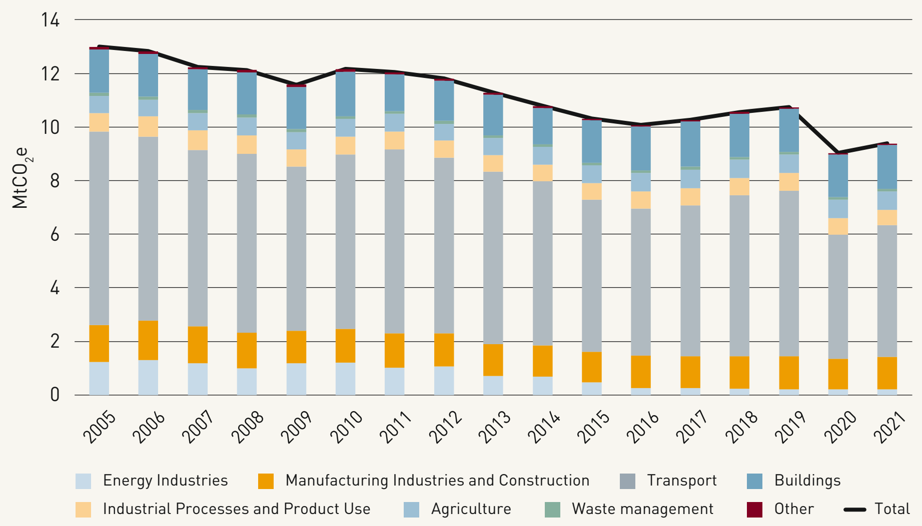
the efforts already made. Indeed, the latest report of the Intergovernmental Panel on Climate Change[14] (IPCC) highlights that the actions carried out to fight climate change remain insufficient. The experts warn of the urgent need to significantly reduce emissions linked to human activity in order to achieve the objectives set by the Paris Agreement.

Achieving all the climate objectives, whether they are set at national level (such as the PNEC) or at European level (such as the "European Green Deal"), requires significant investments not only from all national authorities but also from all actors in the financial system. According to the European Commission,[15] Europe would need additional investments of up to 260 billion euros per year in order to meet the 2030 deadline. The financial sector therefore appears to be one of the key players in achieving carbon neutrality and, in this context, Luxembourg could become a centre of excellence in sustainable finance. In order to achieve this objective, the financial system in Luxembourg must continue to renew itself, in particular by redirecting a significant part of its investments towards sustainable economic activities. This transformation will enable the achievement of a double objective, namely: (i) a more active participation of the financial sector in the fight against climate change (ii) and a reduction of the exposure of banks and investment funds to climate risks, in particular to transition risk.

2.1.2 Greenhouse gas emissions in Luxembourg[16]

Between 2005 and 2021, yearly GHG emissions in Luxembourg fell by almost 3.6 million tonnes of CO_2 ($MtCO_2e$): from 13 $MtCO_2e$ in 2005 to 9.4 $MtCO_2e$ in 2021, i.e. a drop of around 28% (Figure 1).[17] Over the period from 2005 to 2019, this downward trend was less significant, at around 17%. This is due to the exceptional situation of 2020. Indeed, the Covid-19 pandemic and more particularly the lockdown measures in spring 2020 explain the exceptional decrease in GHG emissions for the year 2020. The level of overall GHG emissions dropped from 10.7 $MtCO_2e$ in 2019 to 9.03 $MtCO_2e$ in 2020, a decrease of about 16% over one year. Some sectors that were completely shut down due to containment showed a very significant decrease in GHG emissions. The halting of air transport and the decline in road transport account for the majority of the overall effect. Transport sector emissions experienced a 25% decrease in 2020 compared to 2019 levels. However, there was a minor uptick in 2021, with total emissions increasing around 4% compared to 2020.

Figure 1:
Total GHG emissions in Luxembourg

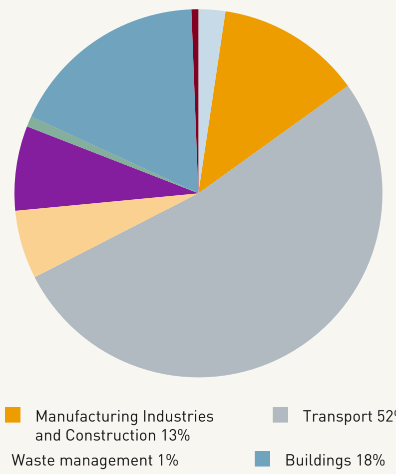


Source: European Environment Agency/Reporting United Nations Framework Convention on Climate Change (UNFCCC).

For more details: https://www.eea.europa.eu/en.

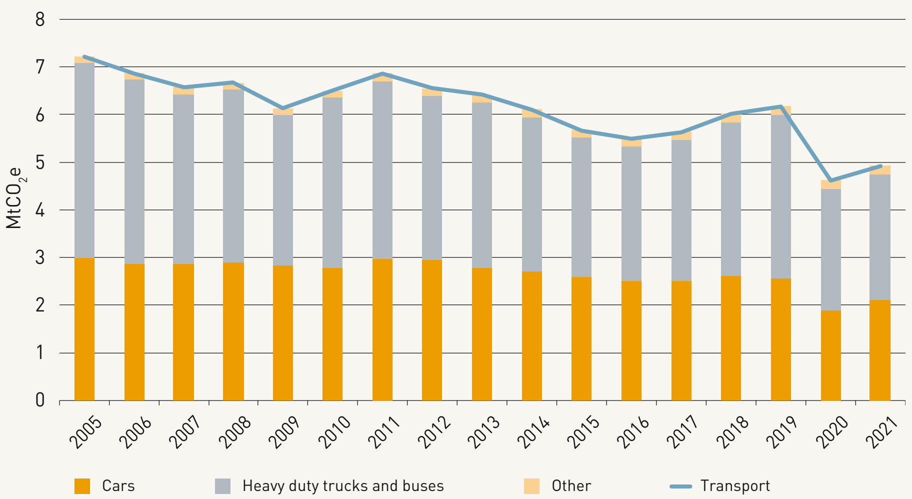
[14] See IPCC reports here: https://www.ipcc.ch/reports/.
[15] See https://ec.europa.eu/commission/presscorner/detail/en/ip_20_17 for more details.
[16] The data used in this section comes from the United Nations Framework Convention on Climate Change (UNFCCC) reporting.
[17] Net emissions, including the Land Use, Land Use Change and Forestry (LULUCF) sector, amount to 8.8 $MtCO_2e$ in 2021.

Figure 2:
Sectoral breakdown of GHG emissions in 2021



Source: European Environment Agency /Reporting UNFCCC.

Figure 3:
Breakdown of GHG emissions in the transport sector



Source: European Environment Agency /Reporting UNFCCC.

Nevertheless, the decline of GHG emissions demonstrates Luxembourg's efforts to reduce GHG emissions in all sectors. GHG emissions in the agricultural sector, nevertheless, increased slightly between 2005 and 2021 from 0.63 $MtCO_2e$ to 0.7 $MtCO_2e$, i.e. an increase of around 11% over the period.[18]

In 2021, 52% of GHG emissions in Luxembourg came from the transport sector (Figure 2), with road transport (mainly cars and heavy trucks) accounting for the majority of GHG emissions (Figure 3). According to the report on the national long-term climate action strategy,[19] 70% of GHG emissions from the transport sector come from the sale of fuel to non-residents.[20] This is likely due to Luxembourg's geographical location (at the crossroads of several European transit routes) and the fuel price differential with its neighbouring countries.

Emissions of the energy industry amounted to 0.22 $MtCO_2e$ in 2021, i.e. 2% of total GHG emissions (Figure 2). This level is explained by the fact that a large part of the electricity consumed in Luxembourg is imported (mainly from Germany), thus counting as GHG emissions in the country of production.[21]

18 This remains relatively low over 15 years.
After 2015, GHG emissions from the agricultural sector stabilised at around 0.7 $MtCO_2e$.

19 See https://gouvernement.lu/dam-assets/documents/actualites/2021/10-octobre/29-strategie-nationale-action-climat/Strategie-nationale-a-long-terme-en-matiere-d-action-climat-octobre-2021.pdf for more details.

20 It is important to note that GHG emissions in the transport sector depend mainly on the amount of fuel sold and the distance travelled. See https://www.ipcc-nggip.iges.or.jp/public/2006gl/french/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf for more details.

21 See the notions of scopes 1, 2 and 3 of the carbon footprint.

Overall, we note that GHG emissions in Luxembourg are following a decreasing trend. Notwithstanding, in order to reach the 2030 objectives, efforts must be pursued and some high-carbon sectors must become more engaged in decarbonising their activities.[22]

2.2 PHYSICAL RISK IN LUXEMBOURG

Physical risks include the risks of natural disasters and extreme events (acute risks) but also more gradual risks such as rising temperatures or sea level rise (chronic risks).

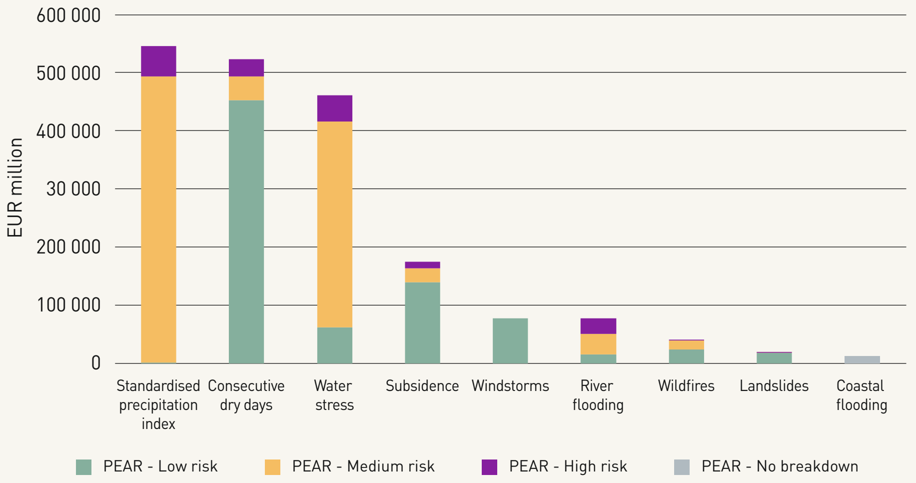
2.2.1 Potential exposure at risk and risk scores

The European Central Bank (ECB) has developed indicators of the financial system's exposure to physical risk.[23] These indicators cover nine acute natural risks, namely coastal flooding, river flooding, wildfires, landslides, subsidence, windstorms and water stress,[24] drought and extreme precipitation conditions. The potential exposure at risk (PEAR) is one of the indicators proposed by the ECB. The PEAR provides information on the share of the portfolios of financial institutions exposed to non-financial corporations (NFCs) located in areas prone to natural hazards. The indicator on risk scores (RS) complements the PEAR. The RS indicator classifies exposures according to risk level categories and assesses the share of the portfolio associated with a specific risk score. The risk score ranges from 0 (no risk) to 3 (high risk). It should be noted that the PEAR is calculated only for RS above zero. For three of the nine indicators (windstorms, landslides, subsidence), only current hazard profiles are available. For river flooding, consecutive dry days, standardised precipitation index, coastal flooding, water stress and wildfires, projections are available up to 2100.

Figure 4 shows the PEAR for each risk score. Two points stand out from this figure. First, the standardised precipitation index (SPI, which captures excessively dry or overly wet conditions), Consecutive dry days (CDD, which captures drought conditions) and water stress indicators exhibit the highest PEAR. Second, for the majority of natural hazards studied, a high share of the PEAR is associated with the lowest risk category. For example, the PEAR associated with windstorms is largely associated with the low-risk class.

Figure 4:

PEAR and RS for Luxembourg



Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.
Note: Projection horizon varies. Scenario 'RCP-8.5' used.

22 For further details see, for example, https://www.eea.europa.eu/en/analysis/indicators/total-greenhouse-gas-emission-trends and https://ccpi.org/country/lux/.

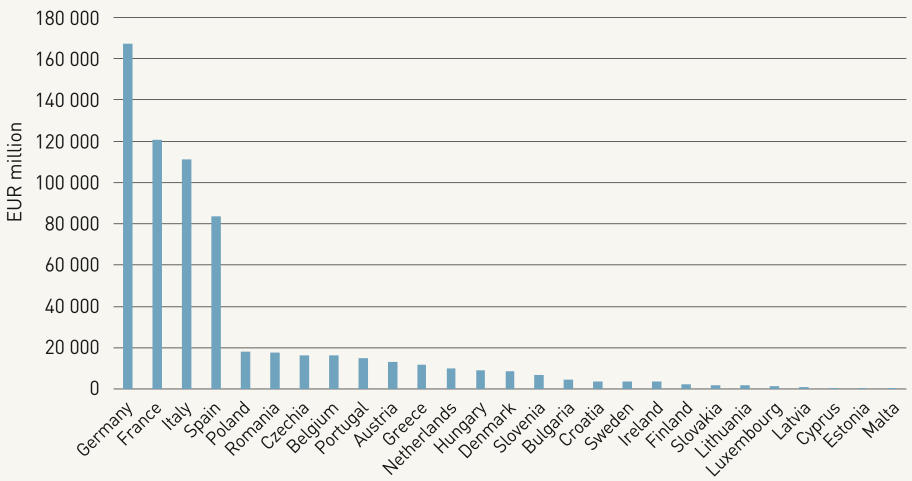
23 See https://www.ecb.europa.eu/pub/pdf/other/ecb.climate_change_indicators202301~47c4bbbc92.en.pdf for more details.

24 Baseline water stress measures the ratio of total water demand to available renewable surface and groundwater supplies. Water demand include domestic, industrial, irrigation, and livestock uses. Available renewable water supplies include the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users. See https://www.wri.org/aqueduct.

However, this is not the case for the SPI and water stress indicators. For these indicators, more than 75 % of the PEAR is assigned to a medium-risk category, while 10 % is assigned to a high-risk category. Therefore, from a physical risk perspective, extreme precipitation conditions and water stress represent the most important threats to the financial system in Luxembourg, both in terms of potential exposure and risk score.

Figure 5:

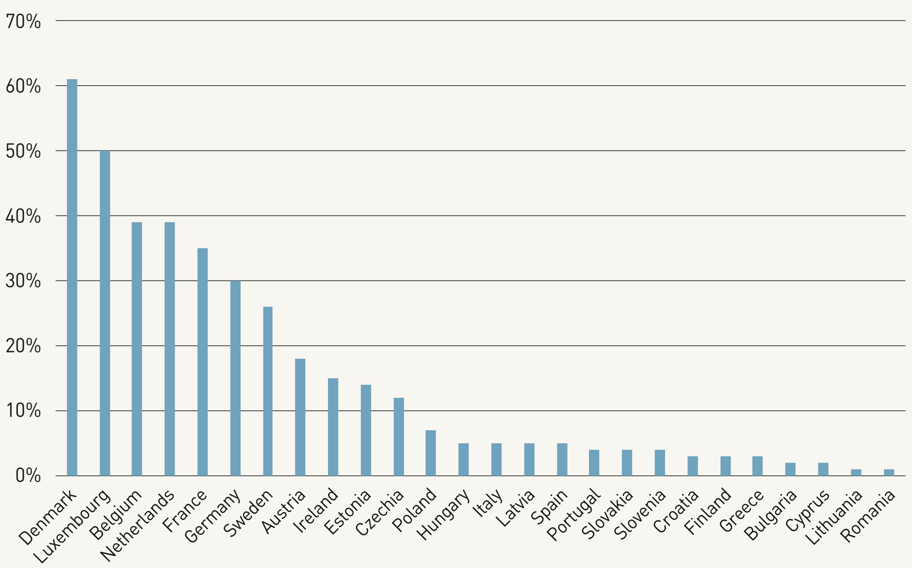
Economic damage caused by weather- and climate-related extreme events in EU member countries (1980-2022)



Source: RiskLayer / European Environment Agency.

Figure 6:

Share of insured losses following weather- and climate- related extreme events in EU member countries (1980-2022)



Source: RiskLayer / European Environment Agency.

2.2.2 Share of losses insured and geographical breakdown of banks' exposures

Despite the wide variations in the data, the economic losses caused by natural hazards in the EU have been steadily increasing since the 1980s. For example, over the period 1980-2022, the losses caused by weather and climate events for the 27 EU Member States amounted to about 650 billion euros.[25] The average loss for all 27 EU Member States was around 24 billion euros. In the same period, the losses for Luxembourg were relatively limited at around 1.25 billion euros. The countries with the largest losses are Germany, Italy, France and Spain respectively (Figure 5). Moreover, a large share of losses in Luxembourg are insured (50 %), which makes it the second best covered country in the European Union in the event of weather- and climate-related extreme events (Figure 6).

With regards to the geographical breakdown of its assets, the banking sector seems to have a limited exposure to physical risk insofar as its exposures are mainly concentrated in geographical areas with low vulnerability to extreme

[25] See https://www.eea.europa.eu/data-and-maps/daviz/economic-damage-caused-by-weather#tab-chart_2 for more details. The data are presented in Euro 2020 values and are from Munich Re.

weather events. The total amount of risk-weighted assets (RWA) of banks in Luxembourg varied slightly around 192 billion euros between December 2015 and December 2018, before rising sharply from 2019 onwards, reaching 256 billion euros in December 2023 (Figure 7a). These exposures are generally located in countries with a temperate climate, and are therefore unlikely to be strongly affected by climate change (Figure 7b). In the fourth quarter of 2023, more than 75 % of the RWA of banks in Luxembourg were located in Europe, including 23 % in Luxembourg and 25 % in the neighbouring countries, namely France, Germany and Belgium while 11 % of the total RWA of banks in Luxembourg were located in Brazil.

Nevertheless, the Luxembourg financial system is not spared from physical climate risks, even if these remain very low. Importantly, its impact increases over time and should not be underestimated. Certain natural risks such as extreme precipitation conditions and water stress should be closely monitored.

Figure 7a:
Risk-weighted assets of banks in Luxembourg

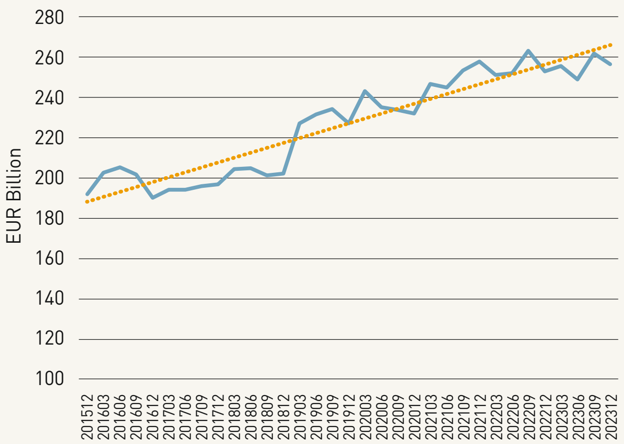
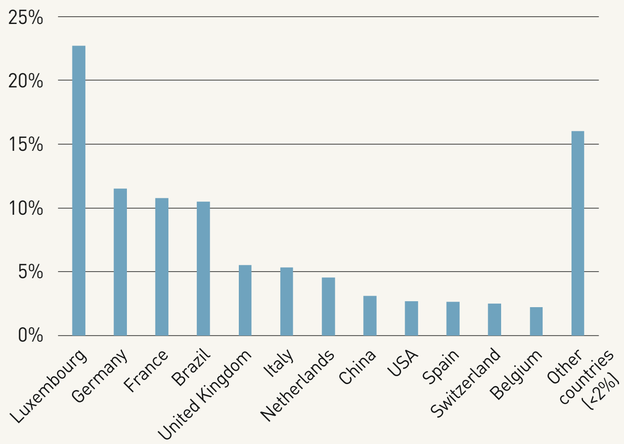


Figure 7b:
Geographical breakdown of RWA of banks in Luxembourg – December 2023



Source: COREP.

2.3 TRANSITION RISK IN LUXEMBOURG

Transition risks refer to the financial impacts on the financial system of a low-carbon and more environmentally sustainable economic model. Energy- and carbon-intensive sectors of activity are those most exposed to transition risks. Indeed, a transition to a low-carbon economy requires these sectors to adapt their business models to new regulations or to the use of new production technologies, thus increasing their innovation and production costs which may affect their profitability and increase their probability of default. As a result, the more the financial system is exposed to carbon-intensive sectors, the greater the transition risk for the financial system. Financial institutions would benefit from shifting their exposures and investments towards greener activities.

2.3.1 Carbon emissions indicators

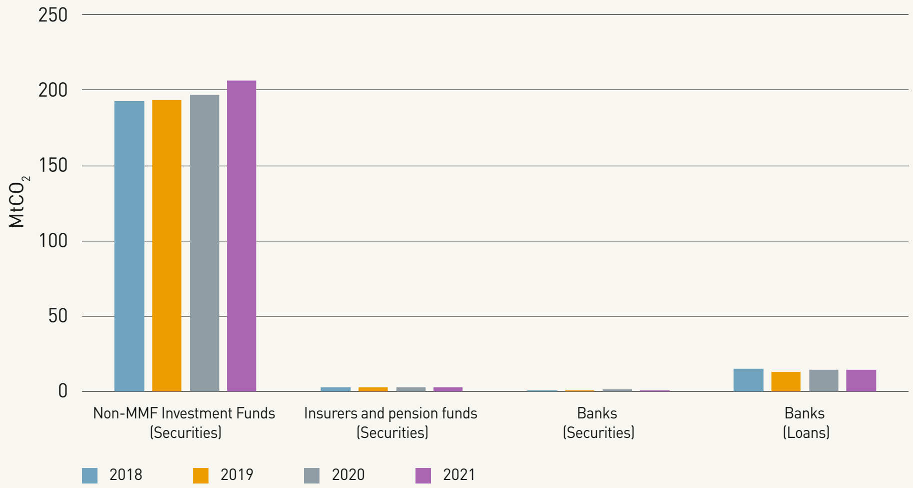
The ECB has developed several indicators to assess the exposure of the financial system to transition risk.[26] These indicators are calculated for different types of financial institutions, namely the banking

[26] See for more details: https://www.ecb.europa.eu/pub/pdf/other/ecb.climate_change_indicators202301~47c4bbbc92.en.pdf.

sector,[27] investment funds and the insurance and pension funds sector. A first category of indicators assesses the extent of financing provided by the financial system to carbon-intensive activities. In other words, these indicators relate the GHG emissions of non-financial corporations (NFC) to the total loan and securities portfolios of financial institutions. Financed emissions and carbon intensity are included in this category.

Figure 8:

Emissions financed in Luxembourg, broken down by financial subsector

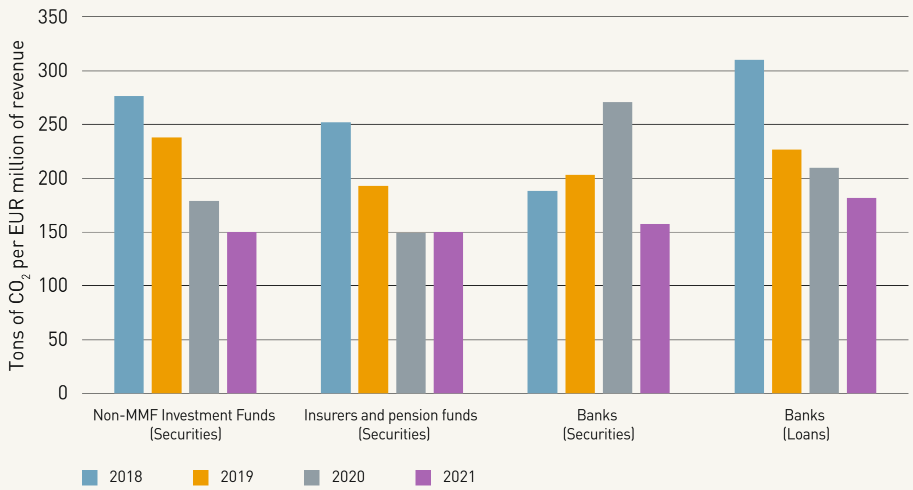


Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.

Figure 9:

Carbon intensity in Luxembourg, broken down by financial subsector



Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.

Financed emissions are the total GHG emissions of a debtor/issuer weighted by the investment held by financial institutions in the total value of the NFC. They allow for an assessment of the magnitude of GHG emissions induced by the financing activities of financial institutions. Figure 8 shows the evolution of financed emissions by Luxembourg's financial institutions between 2018 and 2021. Almost all of the financing of direct emissions by financial institutions in Luxembourg is done through investment funds. Between 2018 and 2021, the Luxembourg investment funds sector financed an average of 197 million tonnes of CO_2. This figure is not surprising considering the size of the investment fund sector in Luxembourg.

Carbon intensity is calculated as the ratio of financed emissions to NFC revenues weighted by the investment held by financial institutions in the total value of the NFC. It expresses financed emissions in terms of the revenue generated by the NFC. Overall, carbon intensity decreased between 2018 and 2021 (Figure 9). The carbon intensity of investment funds fell from 277 tonnes of CO_2 per million euros of revenue to 150 in this period. For insurance and pension funds, the carbon intensity dropped from 252 in 2018 to 150 tonnes of CO_2 per million euros

[27] For the banking sector, a distinction is made between securities and bank loans.

of revenue in 2021. Similarly, the carbon intensity of banks (considering both securities and loans) decreased between 2018 and 2021.

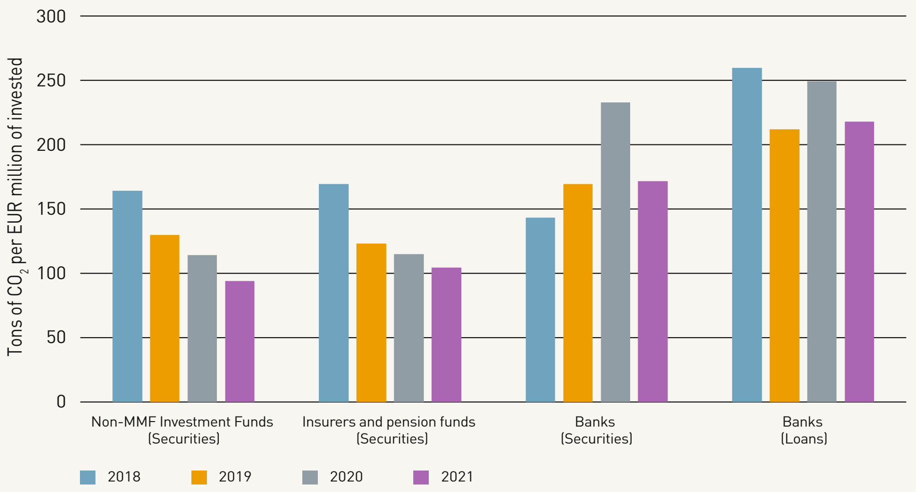
The second category of indicators provides information on the transition risk faced by the financial system by taking into account the exposure of loan and securities portfolios to carbon-intensive economic activities. This category of indicators includes the carbon footprint, which is defined as the financed emissions standardised by the total value of the investment portfolio.

In general, the carbon footprint of non-bank financial institutions declined between 2018 and 2021 (Figure 10). The carbon footprint of investment funds decreased by around 43% (from 164 in 2018 to 94 tonnes of CO_2 per million euros invested in 2021) whereas that of the insurance and pension fund sector decreased from 169 in 2018 to 105 tonnes of CO_2 per million euros invested in 2021 (a decrease of approximately 38%). Conversely, the carbon footprint of the banking sector loan (securities) portfolio decreased (increased) from 260 (143) tonnes of CO_2 per million euros invested in 2018 to 218 (171) in 2021. These dynamics show that changes in the financial system's exposure to transition risk varied across its subsectors depending on the financial instrument considered.

Comparing with its European peers, Luxembourg has the highest financed emissions in the euro area (Figure 11), which follows from the importance of its investment fund sector. However, with regard to the carbon footprint, we note that the exposure of Luxembourg's financial institutions to transition risk is among the lowest in the euro area.

Figure 10:

Carbon footprint in Luxembourg, broken down by financial subsector

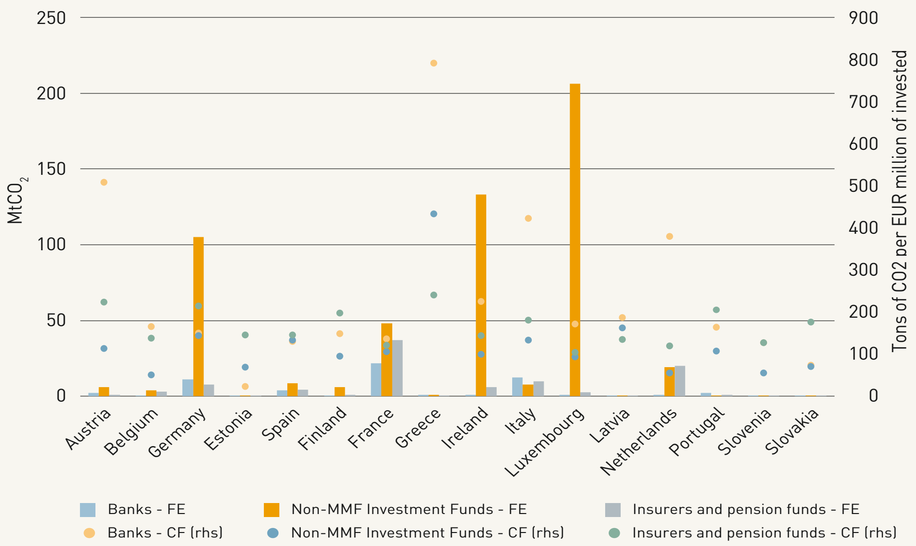


Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.

Figure 11:

Comparison at the euro area level

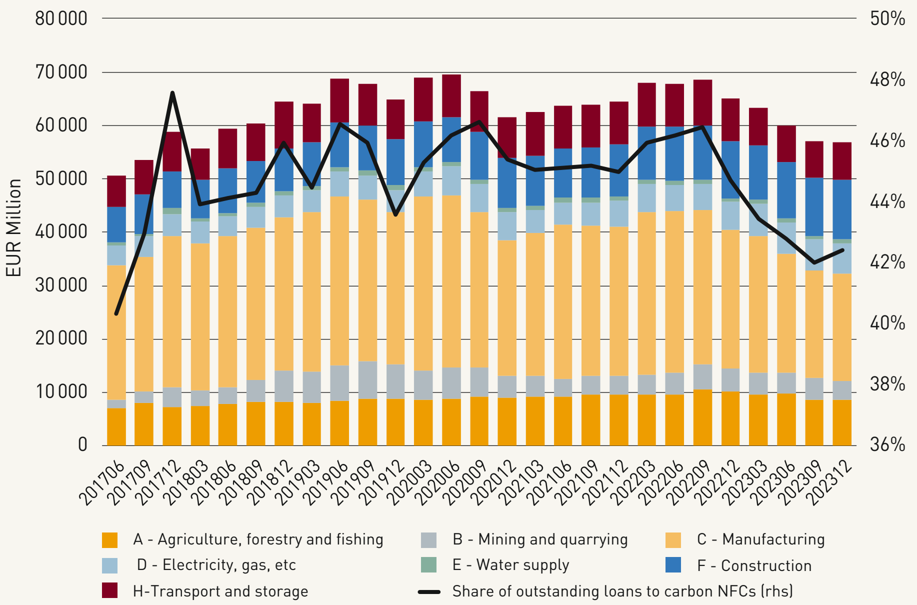


Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.
Note: Data refers to securities portfolios at at 2021. "FE" and "CF" refer, respectively, to "Financed emissions" and "Carbon footprint".

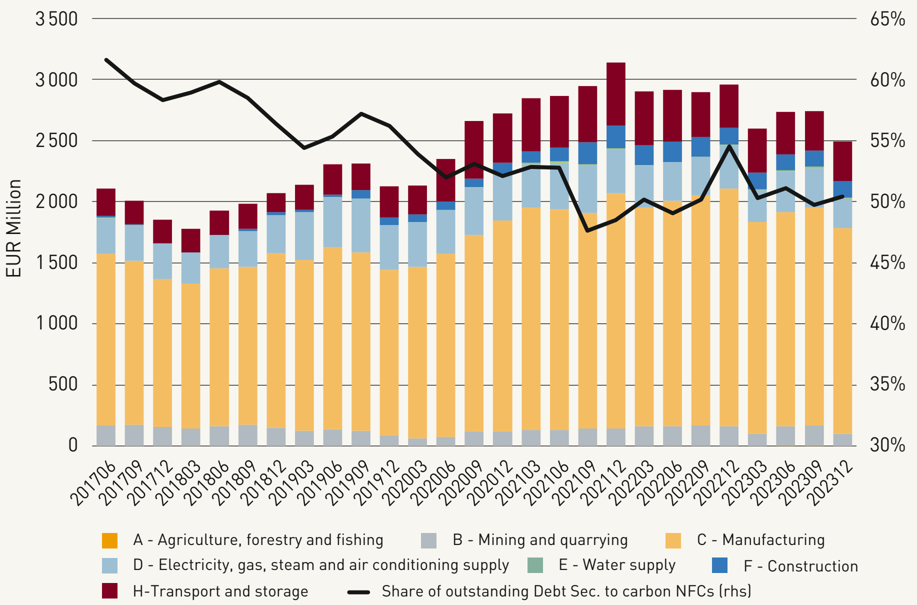
2.3.2 Banks' and investment funds' exposures to carbon-intensive sectors

Figure 12:
Banks' outstanding loans to carbon-intensive sectors



Source: BCL, FINREP.

Figure 13:
Banks' holdings of debt securities issued by carbon-intensive sectors



Source: BCL.

Figure 12 displays banks' outstanding loans to carbon-intensive sectors in absolute amounts and as a share of total outstanding loans to NFCs. It shows an increase in the amounts granted by the Luxembourg banking sector to carbon-intensive economic sectors, from 51 billion euros in the second quarter of 2017 to 57 billion euros in the fourth quarter of 2023. The figure also highlights that the share of banks' outstanding loans to carbon-intensive sectors grows from around 40 % in June 2017 to 42.4 % in the last quarter of 2023, albeit this share has been declining noticeably since the third quarter of 2022. Conversely, the share of carbon-intensive sectors in banks' holdings of corporate debt securities has been broadly declining since the second quarter of 2017 (Figure 13). Additionally, much like in the case of bank lending, manufacturing sectors are the largest recipient of banks' debt securities financing (Figures 12 and 13, and Box 1).

Therefore, Figures 12 and 13 underscore the weight of banks' exposure to carbon-intensive sectors and, consequently, the importance of carrying out climate stress tests for banks.

Box 1 :

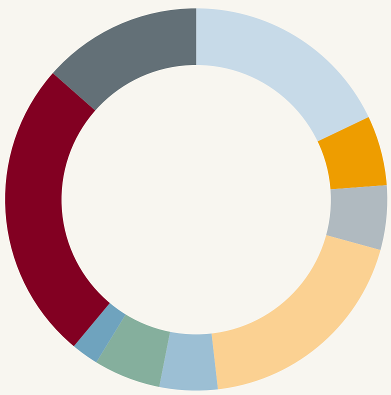
A BREAKDOWN OF DOMESTIC MANUFACTURING EXPOSURES FOR SEVEN LARGE DOMESTIC BANKS

Not only is manufacturing the sector with the highest weight among the carbon-intensive ones in banks' non-financial corporations (NFCs) loan portfolio but it is also a sector with varying degrees of Green House Gas (GHG) emissions amid its constituting sub-sectors. For this reason, this box leverages on AnaCredit to break-down the domestic manufacturing exposures of seven large domestic banks.

As the figures show, for the sample considered, domestic manufacturing exposures are concentrated in three subsectors: i) pharmaceuticals and rubber; ii) food, beverages and tobacco; and iii) basic metals. Therefore, the analysis suggests that the weight of higher emitting industries, namely minerals and basic metals, comprises less than a quarter of the considered banks' domestic manufacturing exposures.

Figure B.1:

Net carrying amount – seven large banks



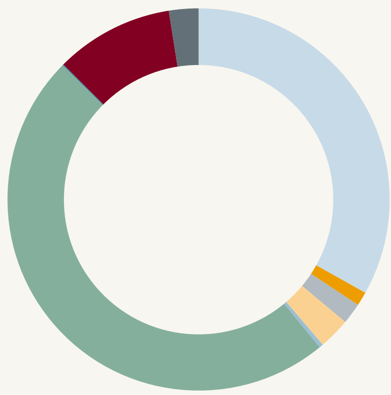
Basic metals 18% | Chemicals 6% | Electronics and machinery 5% | Food, beverages and tobacco 19% | Furniture 5% | Minerals 6% | Motor vehicles 2% | Pharmaceuticals and rubber 25% | Textiles, wood and paper 14%

Source: AnaCredit.

Note: Exposures refer to December 2023.

Figure B.2:

GHG emissions of manufacturing sub-sectors



Basic metals 33% | Chemicals 1% | Electronics and machinery 2% | Food, beverages and tobacco 3% | Furniture 0% | Minerals 48% | Motor vehicles 0% | Pharmaceuticals and rubber 10% | Textiles, wood and paper 3%

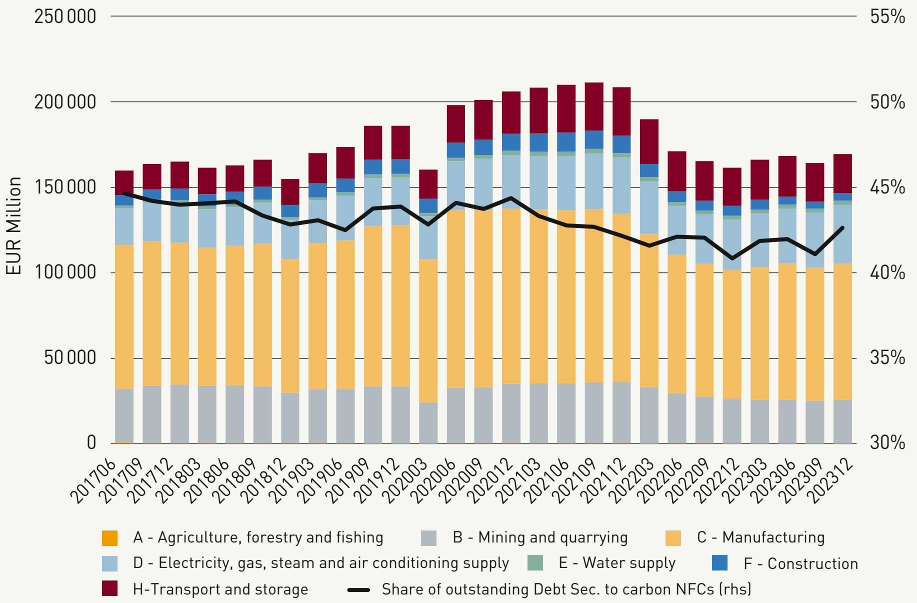
Source: Eurostat.

Note: GHG emissions refer to 2021.

2.3.3 Breakdown of debt securities and equities

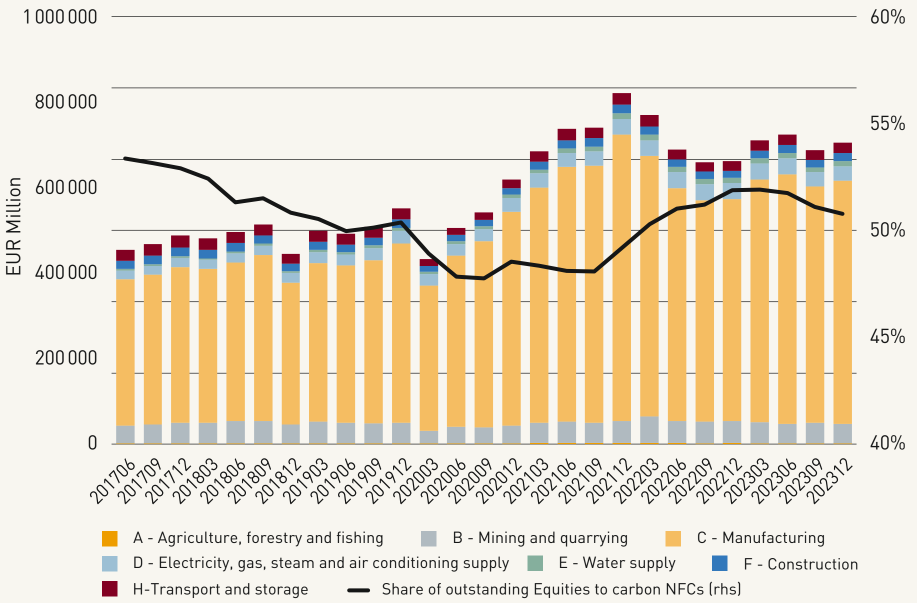
Figures 14 and 15 display the amounts of debt securities and equities issued by carbon-intensive sectors that are held by investment funds, as well as their shares relative to total corporate debt securities and equities held by funds. As for banks, around half of investment funds' corporate exposures are towards NFCs active in carbon-intensive sectors and a large part of these carbon-intensive exposures are towards manufacturing companies (Figures 14 and 15).

Figure 14:
Investment funds' holdings of debt securities issued by carbon-intensive sectors



Source: BCL.

Figure 15:
Investment funds' holdings of equities issued by carbon-intensive sectors

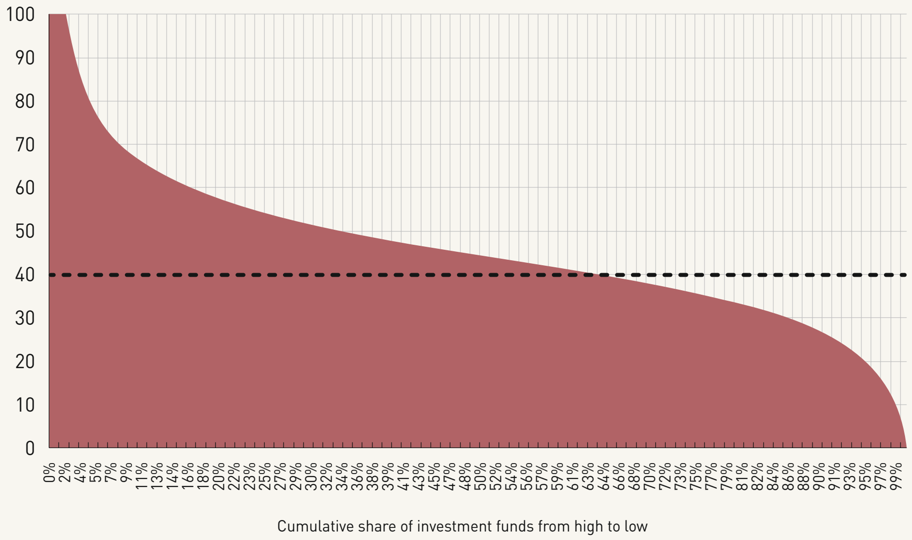


Source: BCL.

In order to understand better investment fund exposures to securities issued by carbon-intensive sectors, the distribution and concentration of these securities in investment funds' NFC portfolios was analysed based on the latest available data (Figures 16 and 17). The analysis of the distribution of the share of carbon-intensive securities in investment funds' NFC portfolios (Figure 16) indicates the weight of securities issued by carbon-intensive NFCs exceeds 40% for around 64% of investment funds, which is substantial. Moreover, a concentration analysis (Figure 17) suggests that these exposures might be quite concentrated, with the top 25% of investment funds holding just over 88% of overall carbon-intensive securities held in investment funds' NFC portfolios.

Figure 16:

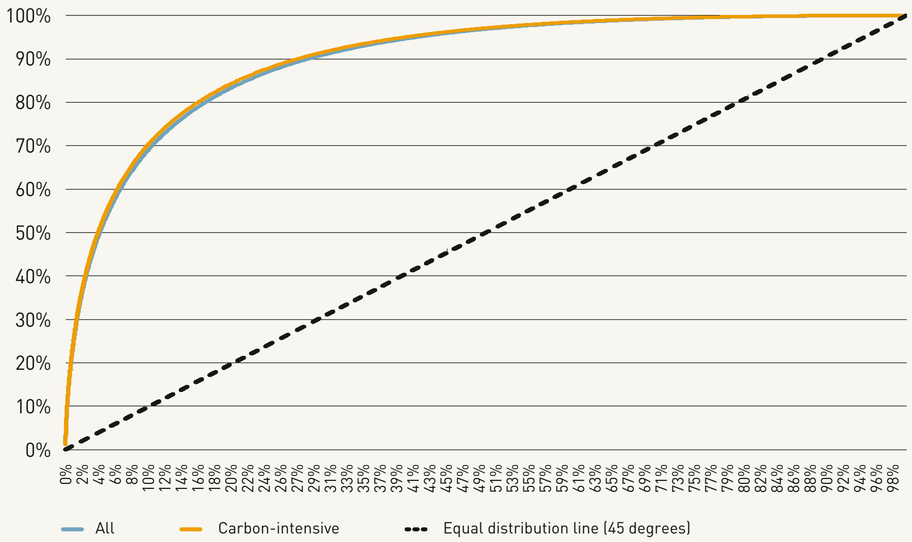
Distribution of securities issued by carbon-intensive NFCs in investment funds' NFC portfolios, December 2023



Source: BCL.

Figure 17:

Concentration of securities issued by carbon-intensive NFCs in investment funds' NFC portfolios, December 2023



Source: BCL.

3. CLIMATE STRESS TEST FOR BANKS AND INVESTMENT FUNDS IN LUXEMBOURG

3.1 OVERVIEW OF PREVIOUS CLIMATE STRESS TESTS

Climate stress testing has emerged as an important tool for assessing and managing climate-related risks in the financial sector by quantifying the exposures of financial entities such as banks, insurers and investment funds to both transition and physical risks.

Several national central banks, such as the De Nederlansche Bank (DNB), the Bank of England, and the Autorité de contrôle prudentiel et de resolution (ACPR) of the Banque de France, have performed stress testing exercises by focusing mainly on transition risk, with physical risk being taken into account only indirectly through the dynamics of macroeconomic variables (Vermeulen *et al.*, 2018; Bank of England, 2019; ACPR, 2020). Additionally, EU-wide climate stress testing exercises have been conducted by European Authorities, namely the European Central Bank (ECB), the European Securities and Markets Authority (ESMA, 2023), and the European Insurance and Occupational Pension Authority (EIOPA, 2022).

Alogoskoufis *et al.* (2021) describe the methodology of the 2021 ECB climate risk stress test under three scenarios ("orderly transition", "delayed transition", and "hot house world").[28] They report the results on the resilience of non-financial corporations (NFCs) and euro area banks to transition and physical risks based on an assessment of the implications of climate risks for the firms and banks by applying a dedicated set of models that capture the specific transmission channels for such risks. This stress test was a pure top-down exercise as it relied solely on internal ECB datasets and models. It is also worth noting that the stress test allowed for transition and physical risks, as well as their mutual interaction over a 30-year time horizon. Overall, the results support the view that there are benefits stemming from an early transition. In particular, the results for banks provide clear evidence of the benefits of an orderly transition as compared with other adverse scenarios: the short-term costs of a green transition are more than compensated by the long-term benefits, while physical risk tends to prevail in the medium-to-long run if climate policies are not implemented.

In 2022, the ECB carried out a climate risk stress test among the significant institutions as its annual stress test in the context of the supervisory review and evaluation process (SREP). As opposed to the 2021 exercise, the 2022 edition was a constrained bottom-up exercise as the participating banks provided their own data and stress projections governed by a common methodology and scenario narratives. The exercise was a learning experience for both banks and supervisors and highlighted a number of key results. First, around 60 % of banks do not yet have a well-integrated climate risk stress testing framework, and most of them envisage a medium to long-term time frame for incorporating physical and/or transition climate risk into their framework. The results also suggest that many banks are not yet accurately accounting for climate risk in their credit risk modelling. Moreover, more than half of banks' income from non-financial corporate customers comes from greenhouse gas-intensive industries. Finally, the results point to the benefits of an orderly green transition as it would lead to lower loan losses compared to disorderly or no transition scenarios.

[28] Under the "orderly transition scenario", climate policy measures are well calibrated and implemented in a timely and effective manner, thus the costs stemming from transition and physical risks are comparatively limited. Under the "delayed transition scenario", policy action is delayed and introduced in 2030 in an abrupt manner, hence transition risks and their associated costs are significant. Additionally, as global warming starts being mitigated only from 2030, this "disorderly transition" scenario also implies the build-up of greater physical risk than what would be the case with an orderly transition. Under the "hot house world scenario", no regulation or policy aimed at limiting climate change is introduced, thus leading to extremely high physical risks. Thus, the costs associated with the transition are very limited, but those related to natural catastrophes are extremely high.

More recently, in September 2023, the ECB published the results of its second economy-wide climate stress test (Emambakhsh *et al.*, 2023). This stress test analysed the resilience of firms, households and banks to three transition scenarios: (i) an "accelerated transition", which brings forward green policies and investment, leading to a reduction in emissions by 2030 in line with the goals of the Paris Agreement; (ii) a "late-push transition", which continues on the current path, but does not speed up until 2026 yet it foresees the Paris-aligned emission reductions by 2030; and (iii) a "delayed transition", taking place on from 2026 onwards but falls short of reaching the Paris Agreement goals by 2030. The results suggest that firms and households would stand to gain from bringing forward the green transition. Regarding banks, these would be exposed to the highest credit risk in face of a sudden, late transition. Moreover, inaction and late transition result in even higher costs and risks in the long run.

However, it is not only in Europe that climate scenario analysis has been increasingly used as a risk-assessment tool. In 2022, the Financial Stability Board, jointly with the Network for Greening the Financial System (NGFS), published a report informed by a survey of FSB and NGFS member authorities on their climate scenario analyses (FSB, 2022). The report shows that the NGFS scenarios at the centre of the financial authorities' climate scenario analysis exercises. Moreover, the respondents note the value of these exercises in raising awareness and developing capabilities and capacity in climate scenario analysis. The results of these analyses tend to suggest that, while the impacts of climate risks can be material, they seem to be concentrated in some sectors but appear to remain contained from the domestic financial system's perspective.

In line with these earlier exercises performed by other central banks and supervisory authorities, we attempt in this section to quantify the impact of different NGFS scenarios on banks and investment funds domiciled in Luxembourg. To this end, we first provide an overview of the climate stress test scenarios we use before describing our modelling approach and presenting the results for banks and investment funds.

3.2 CLIMATE STRESS TEST SCENARIOS

The climate stress test exercise presented here makes use of the latest (i.e. Phase IV) climate reference scenarios developed by the NGFS. These scenarios provide a common framework to assess climate-related risks by exploring the transition and physical impacts of climate change on the way to reaching net zero CO_2 emissions by 2050 globally.[29] The NGFS has defined seven long-term reference scenarios and grouped them into four broad categories, which reflect different degrees of transition risk and physical risk, as well as an intensity that depends on the level of policy ambition, policy timing, regional policy coordination, and technology development. The four scenario categories are "Orderly Transition", "Disorderly Transition", "Too-Little Too-Late" and "Hot House World". More specifically, the "Orderly Transition" category comprises three scenarios, namely "Net Zero 2050", "Below 2°C" and "Low Demand". The "Disorderly Transition" category comprises only one scenario entitled "Delayed transition". The "Hot House World" category comprises two scenarios: "Nationally Determined Contributions (NDC)" and "Current Policies". The "Too-Little Too-Late" category comprises only one scenario entitled "Fragmented World".[30] For the purposes of our climate stress test exercise for Luxembourg banks and investment funds, we focus on three long-term NGFS reference scenarios.

[29] Achieving global net-zero CO_2 emissions by 2050 will require significant investment flows towards clean energy, such that by 2050 renewable and biomass meet 70% of global primary energy needs.

[30] NGFS (2023). NGFS Scenarios for Central Banks and Supervisors. Network for Greening the Financial System. Workstream on Scenario Design and Analysis. November 2023.

The first scenario, "Net Zero 2050", assumes a high level of policy ambition. Policy action is timely (that is, climate-related measures are implemented immediately) and coordinated. The timely manner of implementation allows the policy response of the economy to be smooth. The pace of technology innovation is assumed to be fast, supporting a high rate of adoption of carbon dioxide-removal technologies. In this scenario, transition risk is subdued and physical risk partially mitigated. Global warming is contained at 1.5°C.

The second scenario, "Delayed transition", assumes a slow policy reaction, with climate policies being implemented as of 2030. Until then, annual emissions do not decrease. Strong policy actions are needed to limit global warming below 2°C, at 1.7°C for instance, by setting higher carbon prices. As a result, technological innovation in the green sector develops later, but with stronger intensity. This scenario also assumes a moderate use of carbon-dioxide removal technologies and low regional policy coordination (i.e. countries implement climate policies with different intensities, resulting in a lack of coordination across jurisdictions with respect to carbon pricing and emission targets). This leads to higher transition risk compared to the Net Zero 2050 scenario. The delay in implementing policies leads to a greater increase in temperature and a subsequent rise in the frequency and magnitude of extreme weather-related events. Therefore, compared to the Net Zero 2050 scenario, physical risk is also higher.

The third scenario, "Current Policies", assumes that only currently implemented policies are maintained, without the implementation of any further policies. The lack of global policy ambition results in low variations in regional policies, limited technological development in the green sector and a low use of carbon sequestration technologies. In this scenario, the transition to a carbon-neutral economy is assumed to never take place. As a result, transition risk is negligible (carbon prices do not increase). However, physical risk is high, as it remains unmitigated and worsens due to the adverse physical impacts of extreme weather events on the economy. In this scenario, global warming reaches 2.9°C by end of the century, well above the limit set in COP21.[31]

It is worth noting that compared to the previous vintage (i.e. Phase III), all the latest NGFS scenarios are more disorderly as a result of delays in policy action and of the current geopolitical environment (e.g. consequences to the energy sector stemming from the Russian war in Ukraine).

The NGFS scenarios have been derived by using a suite of models. Integrated Assessment Models (IAM) have been used to derive transition pathways in alignment with different temperature targets. A structural model, suggested by the National Institute for Economic and Social Research model (NiGEM), has been used to produce scenario-conditional economic variables at a jurisdiction-granularity level. NiGEM's output has been used to feed a framework developed by the Banque de France and the ACPR (ACPR, 2020) to obtain NGFS scenario-conditional financial variables such as equity prices and corporate bond spreads.[32] In most cases, the availability of economic variables is at country-level.

Luxembourg is not featured in the NiGEM-based iteration of NGFS scenarios. To overcome this limitation, we use Belgium as a benchmark, given that it is also a small open economy and has important bilateral trade links with Luxembourg. In this context, it is also worth mentioning that the climate

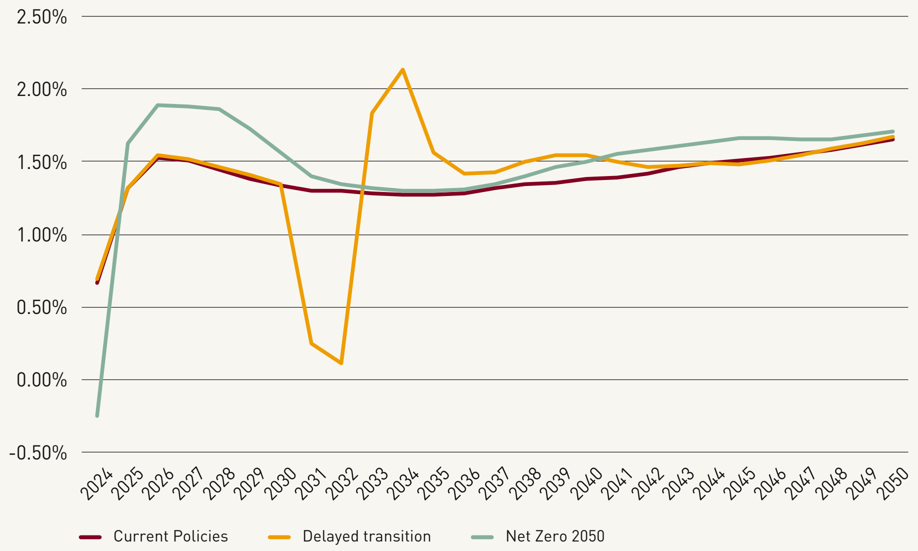
31 COP21 refers to the 21st Conference of Parties held in Paris in 2015, which set to limit global warming to well below 2°C above pre-industrial levels by 2100.

32 Allen *et al.* (2020). Climate-Related Scenarios for Financial Stability Assessment: An Application to France. Working Paper Series no. 774. Economic and Financial Publications, Banque de France.

policies in Luxembourg and the EU are aligned,[33] which supports our choice of another EU country as a benchmark to calibrate Luxembourg macroeconomic variables. In a first step, we conduct separate regressions of Luxembourg macroeconomic variables on the same Belgian macroeconomic variables. In a second step, we apply the regression coefficients resulting from step one to the Belgian NGFS scenarios-conditional variables to obtain NiGEM-based (and NGFS scenario-consistent) economic variables for Luxembourg. The variables are real GDP and equity prices. As an illustration, Luxembourg real GDP growth is shown in Figure 18 below.

Additionally, our modelling approach for banks has a crucial sectoral dimension. Therefore, in order to obtain paths under the three scenarios for sectoral value added for carbon-intensive and non-carbon intensive sectors, we apply scaling factors to aggregate GDP shocks resulting from the sectoral model developed by Frankovic (2022). The approach relies on input-output tables, and accounts for general equilibrium effects that would occur in the event of a rise in carbon prices, including substitution across sectors and energy sources.[34] The sector-level macro-financial variables are used to derive the impacts on probabilities of default (PDs).

Figure 18:
Luxembourg real GDP growth under the three climate scenarios



Sources: NGFS, BCL calculations.

3.3 CLIMATE STRESS TEST FOR LUXEMBOURG BANKS

3.3.1 Methodological approach and data

In this section, we evaluate the sensitivity of banks' corporate portfolios to the climate-related scenarios. Using a three-step methodology, we assess how corporate PDs and Tier 1 capital ratio of banks would evolve given a set of climate-related risks. The first step consists in estimating the relationship between the PDs and a set of macroeconomic and financial variables, in a way that the estimated parameters can be interpreted as "translation parameters". The second step consists in applying the estimated translation parameters to the NGFS scenarios so as to obtain the projections of the stressed

33 In light of the 2050 climate-neutrality objective, Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 foresees that net greenhouse gas emissions are reduced economy-wide and domestically by at least 55% by 2030 compared to 1990 levels. The Luxembourg Loi du 15 décembre 2020 relative au climat et modifiant la loi modifiée du 31 mai 1999 portant institution d'un fonds pour la protection de l'environnement defines the intermediate objective of a 55% emission reduction compared to 2005 levels. Since emission levels in 1990 and 2005 were almost identical in Luxembourg, these intermediate objectives are also equivalent (please see the Stratégie nationale à long terme en matière d'action climat "Vers la neutralité climatique en 2050" for more details on Luxembourg emissions).

34 See the reports of the ECB/ESRB Project Team on climate risk monitoring (2022; 2023).

probabilities of default (SPDs). Finally, the third step consists in simulating the series of Tier 1 capital ratio of banks by combining the projections of the SPDs with some assumed values of loss given default (LGD) and net profit projections under the three scenarios.

To carry out this procedure, we rely on multiple data sources. First, we use the ratio of exposures in default to original exposures as a proxy for the PDs. We use corporate exposures from the Common Reporting Framework (COREP), which are then combined with the sectoral breakdown of banks' loans and advances from Financial Reporting Standards (FINREP) in order to obtain a proxy for corporate PDs for carbon- and non-carbon-intensive sectors.[35] Furthermore, we use sectoral value added and equity price (year-over-year) growth as the main drivers of PDs. Data on sectoral value added is sourced from Eurostat and UNData,[36] while data on equity price growth come from Bloomberg.[37] For the sake of this study, we construct weighted-average bank-specific macroeconomic variables for each bank involved in the analysis. This means that these macroeconomic variables correspond to a weighted-average of each variable across a set of countries, with the weight corresponding to the share of each country's exposure in a given bank's total exposures. As an example, the bank-specific value-added growth for bank k and sector category s (with s either carbon-intensive or non-carbon-intensive) is calculated as follows:

$$VA_{k,s,t} = \sum_{i=1}^{10} \gamma_{i,k,t} * VA_{i,s,t} \qquad (1)$$

where $VA_{k,s,t}$ refers to the bank-specific value added growth associated with bank k for sector category s at time t, $\gamma_{i,k,t}$ denotes the share of country i in bank k's total exposures at time t and $VA_{i,s,t}$ is the value added growth of sector category s of country i at time t. The different weights, γ, of each country i $(i = 1, \ldots, 10)$ are calculated based on ten countries to which Luxembourg banks report the largest corporate exposures: Brazil, China, France, Germany, Italy, Luxembourg, the Netherlands, the United Kingdom, the United States and Switzerland. Our final sample consists of annual data for all variables and spans the period from 2014 to 2023.[38] It includes 21 banks active in Luxembourg, thus covering the main domestically oriented banks, other systemically important institutions (O-SIIs) and significant banks under direct ECB supervision.

We apply a logit transform to the PD, based on the following equation:

$$y = \log\left(\frac{PD}{1 - PD}\right). \qquad (2)$$

Then, we estimate the following regression model:

$$y_{k,s,t} = \alpha_k^s + \delta * y_{k,s,t-1} + \sum_{m=1}^{2} (\beta_m * X_{m,k,t-h}) + \varepsilon_{k,s,t}, \qquad (3)$$

where $y_{k,s,t}$ refers to the logit PD proxy of bank k for sector category s at time t, α_k^s denotes the bank-sector category fixed effect and X_k denotes the two (i.e. $m = 2$) bank-specific macroeconomic variables for bank k.[39] These variables enter the equation as follows: contemporaneous VA (i.e. $h = 0$) while equity price growth with a one-order lag (i.e. $h = 1$).

35 The definition of carbon-intensive sectors is the same as in the first part of this analysis.

36 Since our analysis considers different countries corresponding to the domicile of the key exposures of Luxembourg banks, Eurostat data is used for European countries and UNData for the remaining ones.

37 For more details: https://ec.europa.eu/eurostat/web/products-datasets/, https://data.un.org/ and https://stats.oecd.org/.

38 The starting period is constrained by COREP data availability and the end point is constrained by VA data availability for 2023 for some countries.

39 Note that sectoral VA for the two sector categories is collapsed into a single variable, such that logit PD proxy for bank k and sector category s is regressed against the corresponding weighted average sectoral VA growth rate.

The estimated translation parameters (i.e. $\hat{\alpha}_k^s$, $\hat{\beta}_m$ and $\hat{\delta}$) from Equation (3) are then used to generate the series of SPDs. To do so, we apply the estimated translation parameters to the three NGFS scenarios. More specifically, we use the following equation:

$$\hat{y}_{k,s,t}^{scen} = \hat{\alpha}_k^s + \hat{\delta} * \hat{y}_{k,s,t-1}^{scen} + \sum_{m=1}^{2} (\hat{\beta}_m * NGFS_{k,m,t-h}^{scen}), \tag{4}$$

where $\hat{y}_{k,s,t}^{scen}$ refers to the estimated logit SPD for bank k, sector category under a given NGFS scenario $scen$. $NGFS_{k,m,t-h}^{scen}$ denotes the bank-specific climate scenario variables which we build by multiplying the NGFS-simulated value of each variable m at time $t-h$ by each country i's weight in total exposure of bank k at the end of 2023. As an example, the bank-specific series of equity price growth for bank k is generated by using the following equation:

$$NGFS\ EP_{k,t}^{scen} = \sum_{i=1}^{10} \gamma_{i,k}^{2023} * NGFS\ EP_{i,t}^{scen}, \tag{5}$$

where $NGFS\ EP_{k,t}^{scen}$ denotes the bank-specific path of equity price growth for bank k under NGFS scenario $scen$. $NGFS\ EP_{i,t}^{scen}$ stands for the NGFS-simulated series of equity price growth for country i under NGFS scenario $scen$, and $\gamma_{i,k}^{2023}$ refers to the country i's weight in total exposures of bank k at the end of 2023. By using equation (4), we obtain a time series of logit SPD for each bank k and sector category s under each NGFS scenario $scen$. These series of logit SPD are then reconverted into series of SPD in the normal form by using the following formula:

$$SPD_{k,s,t}^{scen} = \frac{exp^{y_{k,s,t}^{scen}}}{1 + exp^{y_{k,s,t}^{scen}}}, \tag{6}$$

where $SPD_{k,s}^{scen}$ refers to the series of SPD for bank k and sector category s under scenario $scen$ in the normal form, whereas $y_{k,s}^{scen}$ stands for the simulated series of logit SPD for bank k and sector category s under scenario $scen$. The overall SPD is then calculated based on a weighted average of the sectoral SPDs.

3.3.2 Results for corporate probabilities of default

The results of the estimation of Equation (3) are presented in Table 1. We consider two estimation approaches. First, we use the fixed effects (FE) model as a benchmark. However, in order to address the potential bias stemming from the lagged dependent variable (see Nickell, 1981), we also estimate our equation of interest via the bias-corrected fixed effect estimator (LSDVC) put forward by Bruno (2005 a, b) and Kiviet (1995).[40]

The estimated parameter for sectoral valued-added growth is expected to have a negative sign. Indeed, an improvement in sectoral economic conditions is associated with lower corporate PDs. Table 1 shows that the estimated parameters for sectoral value-added growth match the expectations: when the sectoral value-added increases, the logit PD decreases. Consequently, as the logit PDs and the PDs are positively related, an increase in sectoral value-added growth results in a decrease in corporate defaults. Finally, the estimated parameter for equity price growth is negative, meaning higher stock market returns, result in a lower probability of default.

[40] An additional analysis carried out based on GMM estimation yielded qualitatively similar results.

Table 1:

Estimation results

	FE	LSDVC
Logit PD.L1	0.4788***	0.7021***
VA	-0.0706**	-0.1120***
Equity price growth.L1	-0.0150**	-0.0219**
Observations	185	
R2	0.56	

This table reports the estimation results of Equation (3) where the dependent variable is the logit transformation of the probability of default. R2 cannot be derived for the LSDVC model.
**p<0.1; **p<0.05; ***p<0.01*

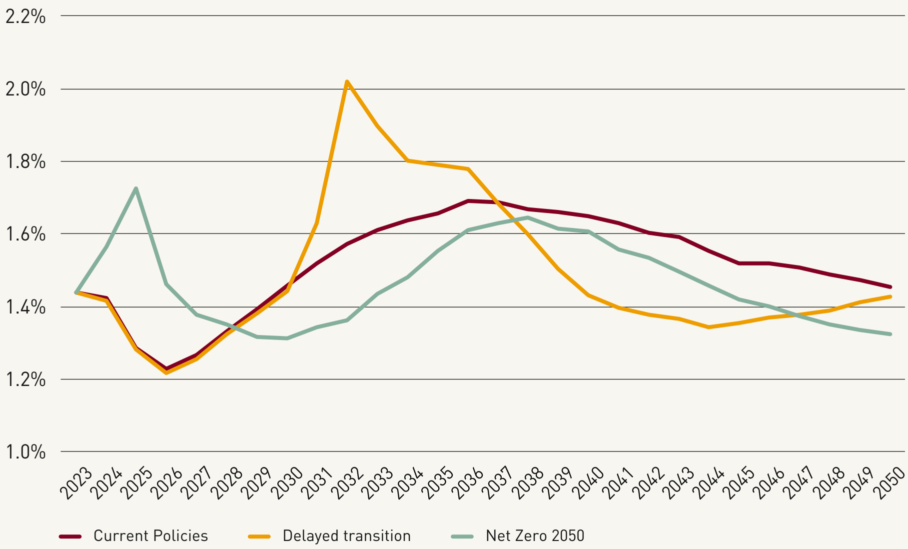
Source: BCL calculations.

Based on the results of the LSDVC estimation and the three NGFS-based scenarios, we simulate the paths for the logit-transformed SPDs for the 2024-2050 period as per Equation (4).

As Figure 19 shows, the SPDs are consistent with the narratives that underpin the scenarios. First, under the Net Zero 2050 scenario, SPDs initially increase due to the immediate implementation and impact of climate-related policies that can result in short-term economic costs. Consequently, until 2028, the SPDs are temporarily higher under the Net Zero 2050 scenario compared to other two scenarios. However, from 2028 onwards, the economy benefits from the early introduction of climate-related policies and this eventually results in lower SPDs relative to the other policy trajectories towards the end of the scenario horizon. Therefore, even if the Net Zero 2050 scenario results in economic costs in the short-term, the underlying policies result in lower economic costs in the long-term, highlighting the need to implement adequate climate policies without delay. Second, there is a significant increase in the SPDs under the Delayed transition scenario that occurs just after 2030. This sharp increase is due to the late introduction of strong policies to limit warming below 2°C., which could potentially lead to disruptions in the banking sector and have an impact on banking profitability through the need for higher provisioning levels. Eventually, SPDs under the Delayed transition scenario decline but still remain above those under the Net Zero scenario, illustrating that later climate policy action, while better than no policy response at all, is still not optimal. Lastly, the costs resulting from inaction are clearly illustrated by the "Current Policies" scenario, which is clearly seen at the end of the scenario horizon where the SPDs are the highest across all scenarios.

Figure 19:

Aggregate corporate SPDs for banks



Sources: COREP, BCL calculations.

Note: The figure shows the median SPD obtained from 5000 bootstrap simulations for each scenario.

3.3.3 Impact on Tier 1 capital ratios

In order to translate the impact of changes in PDs to changes in banks' capital ratios, we complement the SPD projections with an assumption on banks' loss given default (LGD). In line with the first ECB economy-wide climate stress test conducted by Alogoskoufis *et al.* (2021), we assume that the LGD of banks' corporate portfolios increases cumulatively by 0.5 percentage points under the net zero scenario between 2023 and 2050. Under the Delayed transition and Current Policies scenarios, we assume respectively, 1 and 1.5 percentage points cumulative increases between 2023 and 2050.

The SPDs obtained in Section 3.3.2, as well as the LGDs, are used as inputs in the Basel II formula described by the BCBS (2005) in order to obtain capital requirements for corporate exposures. As in Guarda, Rouabah and Theal (2013), the resulting changes in capital requirements for corporate exposures are used to update banks' Tier 1 capital ratios according to Equation 7:

$$Tier\ 1\ capital\ ratio = \frac{K + \Pi}{RWA - 12.5 * E^c * (k_c - k_c^*)} \tag{7}$$

In Equation 7, K denotes banks' Tier 1 capital, Π denotes profits, RWA denotes risk weighted assets, and $\mathrm{E^c}$ denotes corporate exposures. Capital requirements are denoted by k and the superscript asterisk on k denotes capital requirements under the climate scenarios. Since we only take into account changes in PDs and LGDs on corporate exposures to calculate changes in capital requirements, we also restrict ourselves to only considering banks' profits earned on their corporate exposures in Equation 7.

As a first step, we project banks' profits using a fixed-effects panel data model that regresses net profit growth on nominal euro area GDP growth, as in Equation 8 below:

$$Profit\ growth_{it} = a_i + b * EA\ GDP\ growth_t + u_{it}. \tag{8}$$

We obtain a coefficient b that equals 1.121 when estimating Equation 8. Using these results, annual profits are projected for each bank for the 2024-2050 horizon. As a second step, to obtain Π in Equation 7, we multiply the projected profits at the bank level (based on Equation 8) by the ratio of corporate exposures to total exposures. This allows us to proxy bank-level profits earned on corporate exposures and subsequently to calculate banks' Tier 1 capital ratios using Equation 7.

Figure 20 displays the aggregate Tier 1 capital ratio for the banks in our sample under the three climate stress test scenarios described above (i.e. Current Policies, Delayed transition and Net Zero 2050).[41] Overall, the aggregate Tier 1 capital ratio would increase over the long-term, driven by robust net profit growth (Figure 20). In this context, it should be noted that euro area GDP grows under all three scenarios, which drives net profit growth.

[41] It should be noted that the starting level aggregate Tier 1 capital ratio in the climate stress test only applies to the sample considered in this analysis.

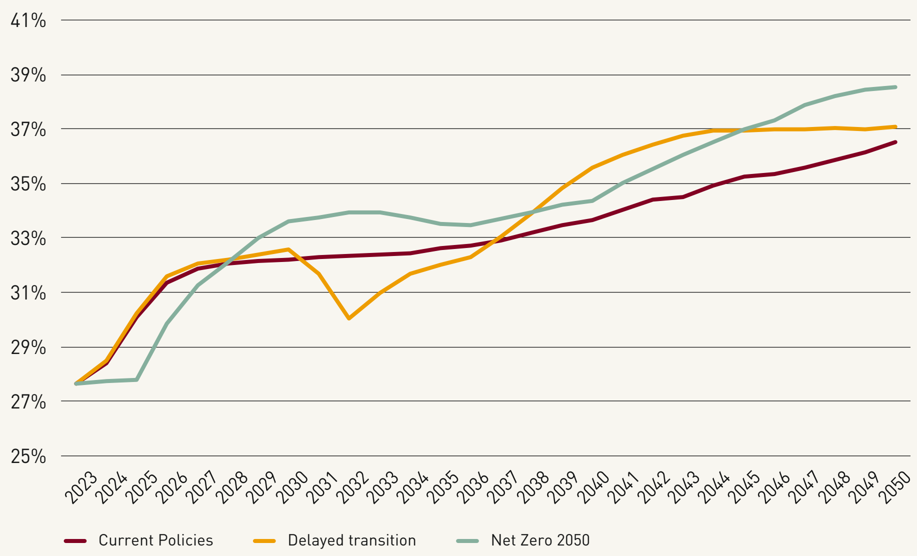
In the short-term, the aggregate Tier 1 capital ratio under the Net Zero 2050 would be lower, albeit still increasing, compared to the other two scenarios reflecting the transition costs incurred in the short-term. However, from 2028 onwards, the aggregate Tier 1 capital ratio would start exceeding that under the Current Policies scenario, reflecting increasing physical risk that is impacting banks' counterparties in the latter scenario. The figure also shows a sharp contraction of the aggregate Tier 1 capital ratio in the early 2030's under the Delayed transition scenario, which follows the increase in corporate PDs driven by heightened transition risk due to the late implementation of climate policies from 2030 onwards.

From 2040 onwards, banks' aggregate Tier 1 capital ratio under the Net Zero 2050 scenario is diverging increasingly from the level under the Current Policies scenario. The difference in Tier 1 capital ratios becomes larger over time, as physical risk continues to materialise under the Current Policies scenario. In 2050, the Luxembourg banking sector's aggregate Tier 1 capital ratio would be 2 percentage points higher under the Net Zero 2050 than under the Current Policies scenario.

Despite the temporary decline in capital ratios under the Delayed transition scenario after 2030, due to the late implementation of climate policies, banks' aggregate Tier 1 ratio would be higher than under the Current Policies scenario over the long-term. Hence, even a late transition would prove beneficial in terms of bank resilience over the long-term, as the aggregate Tier 1 capital ratio under the Delayed transition scenario would surpass the level under the Current Policies scenario from 2037 onwards. In 2050, the aggregate Tier 1 capital ratio would be 0.6 percentage points higher under the Delayed transition scenario than under the Current Policies scenario.

Figure 20:

Aggregate Tier 1 capital ratio for banks



Sources: COREP, FINREP, BCL calculations. Period: 2023-2050.

Note: The starting level aggregate Tier 1 capital ratio in this figure only refers to the banks in the sample used in this analysis.

3.4 INVESTMENT FUNDS

For investment funds domiciled in Luxembourg, we simulate investment funds net asset (year-over-year) growth based on the scenarios paths and the estimates from the following auxiliary regression:

$$IFAG_t = C + IFAG_{t-2} + USRGDPG_t + EARGDPG_t + v_t, \quad (9)$$

where $IFAG_t$ is the growth rate in the net assets of investment funds, $IFAG_{t-2}$ is its lagged value, $USRGDPG_t$ is the United States real GDP growth rate, $EARGDPG_t$ is the euro area real GDP growth rate. This equation is estimated with data sourced from the BCL investment funds statistics (for investment funds' net asset growth)[42] and from the OECD (real GDP growth series) for the period 2000Q4-2023Q4.

Table 2:

Estimation results

	ESTIMATE	STD. ERROR	T-VALUE
IFAG.L2	0.5569***	0.0997	5.586
USRGDPG	3.9109**	1.2402	3.153
EARGDPG	-3.5877***	0.8112	-4.423
C	0.2373	1.8815	0.126
Observations	91		
R2	0.42		

This table reports the estimation results of Equation (9) where the dependent variable is the investment funds net asset growth.
**p<0.1; **p<0.05; ***p<0.01*

Source: BCL calculations.

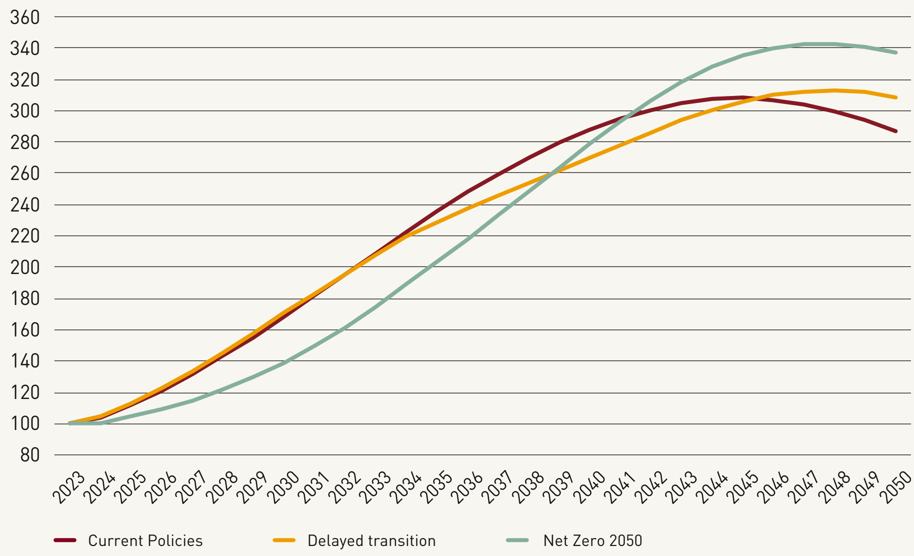
Applying the estimated coefficients to the scenario paths results in the simulated net assets of investment funds domiciled in Luxembourg displayed in Figure 21.

As Figure 21 shows, net assets of investment funds domiciled in Luxembourg under the Net Zero 2050 scenario would exceed those under the Current Policies scenario, reflecting the increasing benefits of timely and adequate policy actions over time. Starting around 2040, the benefits of lower physical risk under the Net Zero 2050 scenario start to outweigh the potential negative impact of heightened transition risk under the same scenario when compared to the Current Policies scenario. Concretely, in 2050, investment fund net assets would be 17.6% higher under the Net Zero 2050 scenario than under the Current Policies scenario.

Figure 21 also illustrates the financial risks arising from only implementing the necessary climate policies from 2030 onwards. Under the Delayed transition scenario, transition risk is much more elevated than under the Net Zero 2050 scenario as policies are implemented in a disorderly manner. As a result, investment fund net assets would remain below those under the Current Policies scenario until 2045. Although investment fund net assets recover thereafter, the level remains below that under the Net Zero 2050 scenario. This suggests that the risks attached to a delayed transition are not temporary. A delayed transition may result in permanently lower investment fund net assets. At the same

[42] Please see Table 13.02 Global situation of undertakings for investment funds. https://www.bcl.lu/en/statistics/series_statistiques_luxembourg/13_investment_funds/index.html.

Figure 21:
Simulated investment fund net assets (Index 2023 = 100)



Source: BCL.
Period: 2023-2050.

time, the figure also exemplifies the benefits of a delayed transition compared to continuing current policies until 2050. In 2050, net assets of investment funds would be around 7.4 % higher under the Delayed transition than under the Current Policies scenario.

4. CONCLUSION

Since 2005 greenhouse gas emissions in Luxembourg have displayed a downward trend, demonstrating the efforts already made by the country to reduce emissions. However, climate risks remain important and are on the rise. The objectives set by the government through the PNEC are ambitious and in line with the environmental challenges. In order to achieve these objectives, the role of the financial sector in financing the ecological transition is essential. Moreover, in addition to financing the ecological transition, the financial sector will have to reduce its exposure to climate risk.

In this respect, the actors of the Luxembourg financial sector seem to have limited exposure to physical climate risk insofar as their exposures are mainly towards less vulnerable geographical areas or from countries with high climate resilience. Nevertheless, extreme precipitation and water stress deserve particular attention. Besides, our analysis shows that the financial sector is materially exposed to transition risk. Indeed, our sectoral study of banks' and investment funds' exposures suggests that the shift in strategies towards low-carbon sectors is still relatively limited, or in some cases inexistent, suggesting that transition risk remains important.

The combination of physical risk and the risks associated with implementing transition policies towards a low-carbon economy is assessed based on three climate scenarios developed by the NGFS. The results of the climate stress test conducted for the Luxembourg banking and investment fund sectors underscore the benefits of an orderly transition towards net zero greenhouse gas emissions in 2050 compared to Current Policies and Delayed transition scenarios.

In terms of resilience, the aggregate Tier 1 capital ratio of the banks in our sample would be 2 percentage points higher in 2050 under the Net Zero scenario than under the Current Policies scenario. Even under a delayed transition, which is sub-optimal compared to the Net Zero 2050 scenario and where the necessary climate policies would be implemented from 2030 onwards, the long-term benefits would clearly outweigh the short-term costs arising from the materialisation of transition risk. Indeed, the aggregate Tier 1 capital ratio of the Luxembourg banking sector would be 0.6 percentage points higher in 2050 under the Delayed transition than under the Current Policies scenario.

The investment fund sector would also benefit from an orderly transition towards net zero emissions in 2050. The results indicate that, compared to the Current Policies scenario, investment fund net assets would be 17.6% higher under the Net Zero 2050 scenario. Under the Delayed transition scenario, the investment fund sector would see, temporarily, lower net assets between 2030 and early 2040s due to transition risk materialisation compared to the Current Policies scenario. However, in 2050, investment fund net assets would be approximately 7.4% higher than under the Current Policies scenario.

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3. HOW DO BANKS AND INVESTMENT FUNDS REACT TO INTEREST RATE SHOCKS? EVIDENCE FROM LUXEMBOURG

Boubacar Diallo[*], Joseph Yapi[◊]

ABSTRACT

This study provides an assessment of how banks and investment funds in Luxembourg react to interest rate shocks and whether there are differences in their respective reactions. We adopt the local projections approach following Jordà (2005) in order to link the response of bank or investment fund balance sheets to both shocks in both short- and long-term interest rates. Results suggest that banks and investment funds react differently depending on whether the shock arises from the short-term interest rate or from the long-term interest rate. More specifically, following shocks to the short-term interest rate total assets contract more among banks than among investment funds. However, the opposite is observed for shocks to long-term interest rates.

We also assess the impact on different types of bank loans such as loans to non-financial corporations (NFCs), loans to households, mortgage loans, interbank loans and loans to other financial institutions (OFIs). We find that the volume of lending to NFCs and OFIs experience a negative and persistent decline following an increase in the short-term interest rate. This finding is consistent with the credit channel of monetary policy transmission.[43]

Finally, to disentangle which types of investment funds might be more affected by increases in the interest rate, we investigate how responses differ across investment funds specialised in the money market, equity, or bonds, as well as mixed funds, real estate funds and hedge funds. Results suggest that investment funds specialised in money market instruments, equities, derivatives and other debt securities with short maturity are more sensitive to short-term interest rate shocks, while investment funds that invest more in long-maturity debt securities tend to be more affected by shocks to the long-term interest rate.

1. INTRODUCTION

The Covid-19 crisis had a global impact on economic activity. Many segments of the economy were almost completely shut down, resulting in supply shortages and major disruptions in the supply chain. This led to an increase in prices, particularly in sectors dependent on shipping. In addition, the war in Ukraine led to a significant increase in energy prices as well as high volatility in energy markets. These developments contributed to a significant and persistent rise in inflation. As a result, many central banks have increased interest rates, ending the period of very accommodative monetary policy. The new macro-financial environment characterized by higher interest rates and inflation may have significant effects on the financial sector. While Luxembourg bank profitability benefitted from higher net interest income, there was also an increase in provisioning.

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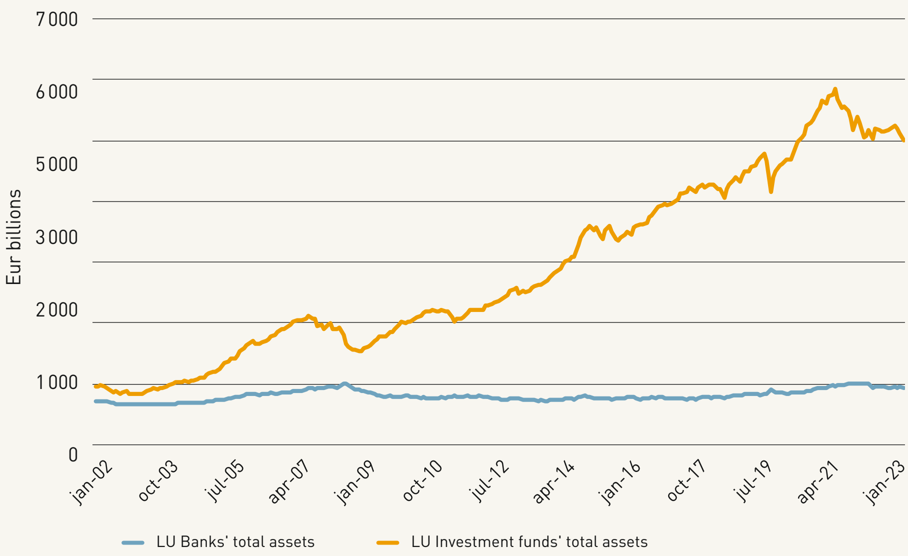
[◊] Joseph Yapi contributed to this study during his previous employment with the Financial Stability and Macroprudential Surveillance Department, Banque centrale du Luxembourg. The views expressed in this study are those of the authors and do not necessarily reflect those of the BCL or the Eurosytem.

[43] Bernanke and Gertler (1995) describe the credit channel as two separate mechanisms, namely the balance sheet (or net worth) channel, which focuses on the impact of interest rate changes on borrowers' balance sheets and income statements, and the bank lending channel that captures the effect of interest rate changes on banks' supply of loans.

Interest rate increases can also affect the value of asset portfolios held by non-banks, in particular bond funds since higher interest rates mechanically affect bond yields. The increase in yields results in valuation losses, also for other assets that are sensitive to interest rates.

Rising interest rates affected total assets of Luxembourg banks and investment funds. With regard to banks, their total assets were 954 billion euros at the end of 2021 but declined to 938 billion euros at the end of 2022, a contraction of -1.62%. Regarding investment funds, total net assets declined 14% from 2021 to 2022 (Figure 1).

Figure 1:
Bank and investment fund total assets in Luxembourg



Source: BCL Statistics.

Investment fund share valuations may also be affected by higher interest rates as funds' debt securities holdings are interest rate sensitive. For example, interest rates and bond prices are inversely related, so when monetary accommodation ends, bond prices decline. In a higher interest rate environment, new bonds are issued at lower prices (i.e. higher yields) and older bonds issued at lower interest rates become less valuable. This is because investors can purchase new bonds with higher interest rates, thereby receiving a better return on investment. The interest rate dynamics can therefore have important valuation effects for funds.

This study assesses how banks and investment funds in Luxembourg have responded to the higher interest rate environment. The assessment adopts two types of interest rate shocks. The first one relates to short-end yield curve shocks and represents changes in the short-term nominal interest rate, while the second focuses on the long-end of the yield curve and is approximated by changes in long-term interest rates (i.e. in 10-year German Bunds). Since the responses to both the short- and long-term rates could be heterogeneous across different asset classes, we explicitly distinguish between the effects on banks and investment funds based on loan counterparties and types of investment fund.

Our analysis adopts the local projections method developed by Jordà (2005). The interest rate shocks are identified using Altavilla *et al.* (2019)'s approach with a focus on changes in high-frequency data around interest rate events. The results highlight that both banks and investment funds' assets are sensitive to interest rates shocks and suggest that bank and investment fund balance sheets contract when monetary accommodation ends. However, banks' and investment funds' balance sheets react differently and depend on whether the shock is to the short- or long-term interest rate. In other words, short- and long-term interest rate shocks result in different impacts on their portfolio exposures. Banks tend to be more impacted by positive short-term interest rate shocks than by long-term rate shocks. More specifically, following a positive short-term rate shock, the decline in the total assets of banks is more pronounced and more persistent than following a positive long-term rate shock.

On the contrary, even if the initial decline in the total assets of investment funds following a positive short-term rate shock is smaller than that for banks, the response of total assets of investment funds following a positive long-term rate shock is more substantial. We also highlight the heterogeneity of responses according to the different counterparty types for bank loans (i.e. loans to households and loans to NFCs) as well as across the different types of investment funds in Luxembourg.

This study has several contributions. First, it provides a comprehensive assessment of the potential risks related to increases in interest rates in Luxembourg for both the banking and investment fund sectors. In this context, the study examines the effects of higher interest rates on the bank lending channel. According to the bank lending channel, higher interest rates will increase the opportunity cost of holding deposits and will reduce bank lending on account of the relative shortfall in funding sources, especially deposits. Several studies support the relevance of the bank lending channel (see for example Altunbas *et al.* (2009) or Holm-Hadulla and Thürwächter (2021)). However, since the increase in the total assets of the non-bank intermediaries over the last decades, the bank lending channel may have become less relevant (Beck *et al.* (2016)).

The literature on the effect of interest rate shocks on non-bank balance sheets is still limited. One strand of the literature explores the risk-taking channel or search for yield behaviour, as in Borio and Zhu (2012). The risk-taking channel relates to a behavior such that, based on following changes in central bank policy rates and a higher risk appetite, investors seek assets and investment strategies that generate higher returns. The data covers the period from 2021 until October 2023 and therefore captures the effects of the recent normalization of monetary policy by major central banks. Our results may therefore help in assessing the effects of tighter financial conditions on the Luxembourg financial sector.

The rest of the paper is structured as follows. Section 2 provides an overview of the literature on the transmission of interest rate shocks to bank and non-bank balance sheets. In Section 3, we present the data and the methodological approach. Section 4 presents and discusses our empirical results and Section 5 concludes.

2. REVIEW OF THE LITERATURE

The literature on the effects of interest rate shocks is divided into two strands. The first, focuses on banks' balance sheet responses to an interest rate shock. The credit channel theory describes how changes in the interest rate may affect borrower and bank behaviour via the external finance premium. According to Bernanke and Gertler (1995), the external finance premium, defined as the difference in cost between funds raised externally through equity or debt and internally generated funds via earnings, plays a key role in understanding the impact of interest rates on economic agents. The credit channel theory covers two transmission mechanisms, namely the balance sheet or net worth channel, which focuses on the potential impact of changes in interest rates on borrowers' balance sheets and income statements, and the bank-lending channel that captures the possible effect of interest rates on banks' supply of loans. The bank-lending channel stipulates that higher interest rates reduce the credit allocated to the economy by banks, which amplifies the interest rate and asset price channels (Bernanke and Blinder (1992), Bernanke *et al.* (1996), Kashyap *et al.* (1993), Kashyap and Stein (1994), Iacoviello (2005), among others). The IMF Global Financial Stability Report of October 2016 entitled "Monetary Policy and the Rise of Non-bank Finance total assets" provides an assessment of the effects of higher interest rates on non-bank assets. The underlying rationale behind this study is that lower interest rates result in households shifting their savings out of bank deposits and into the higher yielding liabilities of investment funds, thereby increasing funds' total assets.

The work of Banegas *et al.* (2016) suggests that when the interest rate is low, there are outflows from equity funds and inflows into bond funds, at least in the case of the U.S. Similarly, Hau and Lai (2016) study the responses of equity and money market funds to changes in interest rates in Europe, finding that investors rebalance their portfolios from money market funds towards equity funds in a low interest rate environment. This finding is in line with Bubeck *et al.* (2018), who show that interest rate shocks lead to large asset price and exchange rate effects with a shift of euro area investors into riskier assets. Kaufman (2020) finds that there is an expansion of investment fund balance sheets following lower interest rates in the U.S.

More recently, Holm-Hadulla *et al.* (2023) find evidence that tighter financial conditions, captured by short-term and long-term interest rate shocks, affect bank and investment fund balance sheets differently. Specifically, for short-term interest rate shocks in the euro area, banks exhibit a slightly swifter and more persistent reaction, while for long-term interest rate shocks, investment funds show a stronger and more persistent decline in their total assets.

While our study also examines bank and investment fund responses to both short-term and long-term interest rate shocks, we focus on for the case of Luxembourg. Additionally, we also disentangle the responses of different types of lending (for example loans to non-financial corporations, loans to households, mortgage loans, interbank loans and loans to other financial intermediaries), as well as several types of investment funds (money market funds, equity, bond, mixed, real estate and hedge funds) to interest rate shocks.

3. METHODOLOGY AND DATA

A. EMPIRICAL METHODOLOGY

This section describes the econometric method used to study the effects of the higher interest rate environment on bank and investment fund balance sheets in Luxembourg. We follow Jordà (2005) and adopt the local projections (LP) method, which is common in the literature. For example, Holm-Hadulla *et al.* (2023) recently study a similar question for euro area banks and investment funds using the LP approach.

The LP approach provides impulse response functions (IRFs) via the estimation of regression models that are robust to misspecification and autocorrelation issues. The model estimated in this study is as follows:

$$\boldsymbol{y}(t+h) = \alpha(h) + \beta(h) * \mathbf{IntRate}(t) + \lambda(h) * \mathrm{X}(\mathrm{t}) + \varepsilon(t+h)$$

with t and h denoting month and horizon of the IRFs with $0 \leq h \leq 24$, respectively. $\boldsymbol{y}$ is the dependent variable, namely the logarithm of total bank and investment fund assets, respectively. $\mathbf{IntRate}$ is the short- and long-term interest rate shocks, and X is a set of Luxembourg specific variables such as real GDP, the GDP deflator , the country level indicator of financial stress (i.e. the CLIFS), the Luxembourg unemployment rate, the Euro STOXX 50 index and the EUR/USD exchange rate, etc. ε is the error term. Additionally, we use the Newey-West standard errors to account for heteroscedasticity and serial autocorrelation. According to Jordà (2005), the Newey-West correction is similar to the Monte Carlo standard errors from VAR models. All the variables enter in logarithms, except interest rates variables, which are in percent. For the control variables, we include many of them with a lag in order to account for endogeneity. We provide more details in the next section.

B. DATA

To investigate banks and investment funds' responses to interest rate shocks, we draw on several sources of data. First, we use data on bank and investment fund balance sheet size (in terms of total assets) from the Central Bank of Luxembourg (BCL).[44] The data for the interest rate shocks come from the euro area Monetary Policy Event-Study Database of Altavilla *et al.* (2019). This dataset is constructed using high-frequency time series to measure changes in interest rates, sovereign yields, stock prices and exchange rates.

We follow Jarocinski and Karadi (2020), Holm-Hadulla *et al.* (2023) and utilize two types of interest rate shocks, which capture both short-term and long-term interest rate shocks. For the short-term interest rate shocks, we use the surprises in 3-month Overnight Index Swap (OIS) rates, as well as surprises in the 10-year German sovereign yields for long-term rate shocks. The 3-month OIS rates are a proxy for the short-term interest rate since these rates directly impact the short-end of the yield curve, while the 10-year German yields are good proxies for the long-term interest rate as they directly affect the long-end of the yield-curve. Making the distinction between short-term and long-term rate shocks allows us to identify the effects on banks and investment funds in Luxembourg at the different interest rate horizons.

To disentangle between interest rate and central bank information shocks as highlighted by Jarocinski and Karadi (2020), we consider only those OIS interest rates and 10-year German yields that are negatively correlated with the surprises in stock prices as measured by the Euro STOXX 50 index.

With respect to control variables, we include real GDP and the GDP deflator for Luxembourg.[45] However, because these two variables are quarterly in frequency, we linearly interpolate them in order to obtain monthly data. In addition, we also use the Country Level Index of Financial Stress (CLIFS) for Luxembourg taken from the ECB's Statistical Data Warehouse (SDW), and the monthly seasonally adjusted unemployment rate from STATEC. As for the lending cost for non-financial corporations (NFCs), we calculate it as the difference between the average of short, medium and long-term interest rates and the 1-month OIS rate in the spirit of Holm-Hadulla *et al.* (2023).

We also control for surprises in the Euro STOXX 50 index and EUR/USD exchange rates. These variables are likely to be relevant for investment funds' inflows and outflows. Indeed, we find that the exposure of the investment fund sector to exchange rate risk is primarily due to the EUR/USD exchange rate as the share of Luxembourg investment fund assets denominated in US dollars represents the majority share of the sector's total assets.[46] Therefore, any depreciation of the euro with respect to the US dollar is likely to result in an increase in investment funds' net asset value (NAV).

44 https://www.bcl.lu/fr/statistiques/series_statistiques_luxembourg/11_etablissements_credit/11_05_Tableau.xlsxhttps://www.bcl.lu/fr/statistiques/series_statistiques_luxembourg/13_fonds_investissement/13_02_Tableau.xls

45 The data come from the Statistical Data Warehouse of ECB using respectively the series: MNA.Q.Y.LU.W2.S1.S1.B.B1GQ._Z._Z._Z.EUR.LR.N and MNA.Q.N.LU.W2.S1.S1.B.B1GQ._Z._Z._Z.IX.D.N

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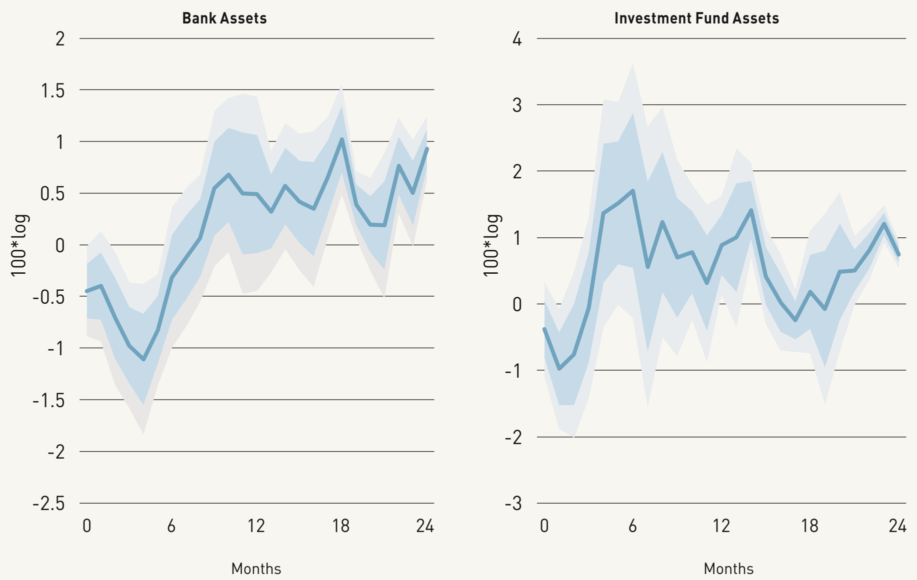
To better understand the effects of interest rate shocks on investment funds, we examine the effect of both the short- and long-term interest rate shocks on different types of investment funds, namely money market funds, equity, bond and mixed funds, real estate funds and hedge funds. We also look at how different types of loans such as loans to NFCs, households, mortgage lending, interbank lending and lending to other financial intermediaries respond to interest rate increases.

Our final sample consists of monthly data for all variables and spans the period from January 2002 to October 2023.[47]

With regard to the selection of the optimal number of lags to be included in the regression models, we apply the Akaike information criterion (AIC), Bayesian information criterion (BIC), and the Hannan and Quinn information criterion (HQIC) lag-order selection statistics. However, the main criterion for selecting the optimal number of lags remains the AIC. We find that for the surprises in the 3-month OIS rates (i.e. the short-term rate shock) the optimal number of lags is 2 according to all three criteria (namely the AIC, SBIC and HQIC). For the surprises in the 10-year German yields, which capture long-term rate shock, the optimal number of lags is found to be 3 based on the AIC. For the logarithm of real GDP and GDP deflator, the optimal number of lags is 4 under all three criteria. For the surprises in the Euro STOXX 50 index and EUR/USD exchange rate, the optimal number of lags is 0 under all criteria. For the variable capturing the level of financial stress in Luxembourg as measured by CLIFS, the optimal number of lags is 4 according to the AIC. Similarly for the lending rate for NFCs, the optimal number of lags is 4 based on the AIC. The next section provides the results.

Figure 2:
Bank and investment fund responses to a 1pp short-term interest rate shock



Source: BCL.
Note: 68 % (blue-shaded areas) and 90 % (gray-shaded areas) confidence bands displayed.

4. RESULTS

A. RESPONSES OF BANKS AND INVESTMENT FUNDS

This section investigates the bank lending and risk-taking channels of interest rate shock transmission in Luxembourg. Figure 2 shows the impulse response functions (IRF) for banks and investment funds following a short-term interest rate shock. Tables 1 and 2 detail the impacts of short- and long-rate shocks on banks and investment funds, respectively. The total assets of banks and investment funds significantly contract after a short-term rate shock. However, there are differences in their responses. First, the initial response of banks

[47] The data is limited until October 2023 because interest rate surprises are not available after this period. However, the model and results will be updated when the Euro Area Interest rate Event-Study will be updated.

is greater than for investment funds. Immediately following a 1 percentage point positive short-term interest rate shock, banks' total assets contract by 0.45 %, corresponding to a contraction of 3 billion euros. In contrast, the immediate response of investment funds is a decline of 0.38 %, corresponding to a contraction of 19.03 billion euros in total assets. Second, a 1 percentage point increase in the 3-month OIS rate results in a maximum decline of 1.11 % of banks' total assets around the fourth month, which corresponds to a contraction of more than 10.44 billion euros. However, for the investment funds, the same shock results in a maximum decline of 0.976 % after 1 month following the short-term interest rate shock. Banks therefore appear to be more adversely affected by an increase in the short-term interest rate compared to investment funds.

Table 1 :

Bank responses to a 1pp short- or long-term interest rate shock

	H = 0	H = 1	H = 2	H = 3	H = 4	H = 5	H = 6	H = 7	H = 8	H = 9	H = 10	H = 11	H = 12
OIS 3 M	-0.45	-0.40	-0.71	-0.98*	-1.11*	-0.83*	-0.32	-0.13	0.07	0.55	0.68	0.50	0.49
	0.27	0.33	0.39	0.37	0.44	0.33	0.41	0.41	0.38	0.46	0.46	0.59	0.57
DE 10 Y	-0.43	0.11	-0.05	-0.31	-0.47	-0.44	-0.55	-0.25	-0.10	0.03	0.30	0.89	0.94
	0.37	0.36	0.35	0.30	0.35	0.49	0.56	0.48	0.48	0.45	0.42	0.46	0.49

	H = 13	H = 14	H = 15	H = 16	H = 17	H = 18	H = 19	H = 20	H = 21	H = 22	H = 23	H = 24
OIS 3 M	0.32	0.57	0.41	0.35	0.65	1.02**	0.39	0.20	0.19	0.77*	0.50	0.93**
	0.36	0.37	0.40	0.46	0.36	0.32	0.20	0.27	0.43	0.28	0.31	0.19
DE 10 Y	0.49	0.35	0.20	0.17	0.38	0.44	0.32	0.00	-0.13	0.16	0.15	0.32
	0.41	0.30	0.42	0.76	1.23	1.17	0.90	0.59	0.61	0.30	0.48	0.53

Note: BCL calculations. Standard errors in parentheses.
**** p<0.01, ** p<0.05, * p<0.1. Newey-West standard errors are in parentheses. Note that all the regression specifications include control variables with their respective lags, namely the logarithm of real GDP and GDP deflator, non-financial corporations' lending rate, the Luxembourg level of financial stress (CLIFS), unemployment rate and the EuroStoxx50 index.*

Table 2 :

Investment fund responses to short- or long-term interest rate shocks

	H = 0	H = 1	H = 2	H = 3	H = 4	H = 5	H = 6	H = 7	H = 8	H = 9	H = 10	H = 11	H = 12
OIS 3 M	-0.38	-0.98	-0.76	-0.06	1.37	1.52	1.71	0.56	1.23	0.70	0.78	0.31	0.88
	0.43	0.55	0.76	0.83	1.04	0.93	1.17	1.28	1.05	0.90	0.62	0.72	0.45
DE 10 Y	0.02	-0.97	-1.48	-1.04	-0.63	-0.73	-0.61	0.07	0.37	0.29	-0.04	0.42	-0.26
	0.55	0.70	0.82	1.05	1.13	0.97	0.93	0.85	0.69	0.59	0.79	0.56	0.65

	H = 13	H = 14	H = 15	H = 16	H = 17	H = 18	H = 19	H = 20	H = 21	H = 22	H = 23	H = 24
OIS 3 M	1.00	1.41**	0.42	0.02	-0.25	0.18	-0.08	0.49	0.51	0.80*	1.20***	0.75**
	0.82	0.44	0.44	0.44	0.29	0.56	0.87	0.72	0.32	0.27	0.17	0.13
DE 10 Y	-0.76	-0.93	-0.51	-0.34	1.45	0.94**	0.09	0.30	-0.83*	0.76**	0.87	1.70*
	0.60	0.87	1.11	1.34	0.89	0.28	0.60	0.83	0.33	0.21	0.53	0.57

Note: BCL calculations. Standard errors in parentheses.
**** p<0.01, ** p<0.05, * p<0.1. Newey-West standard errors are in parentheses. Note that all the regression specifications include control variables with their respective lags, namely the logarithm of real GDP and GDP deflator, non-financial corporations' lending rate, the Luxembourg level of financial stress (CLIFS), unemployment rate, the EUR/USD exchange rate and the EuroStoxx50 index.*

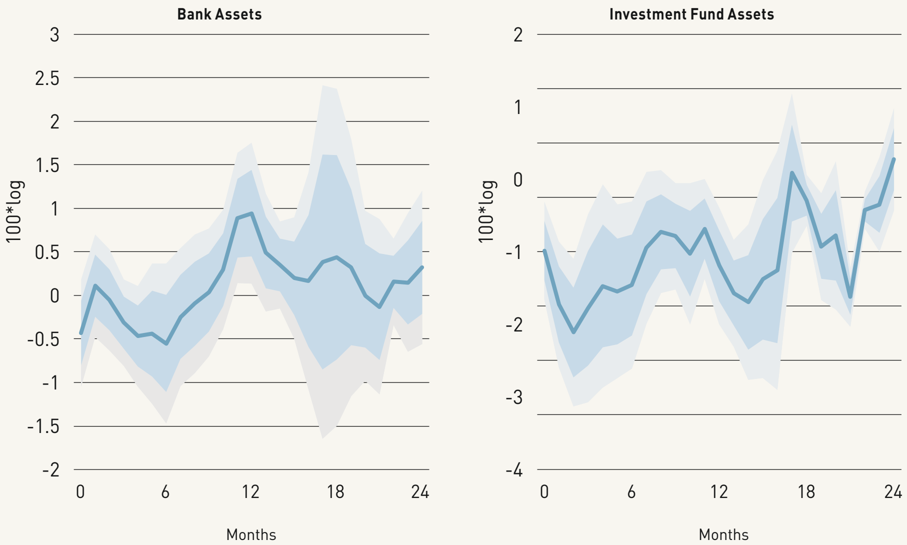
Figure 3 shows the responses of banks and investment funds following a long-term interest rate shock. The results suggest that, compared to banks, investment funds respond more rapidly and are more sensitive to an increase in the long-term interest rate. Following a 1 percentage point positive long-term rate shock, investment funds' total assets contract by a maximum of 1.48 % around the second month after the shock while banks' total assets contract by a maximum of 0.47 % fourth months after the shock.

These results of our analysis are consistent with the literature and underscore the relevance of both the bank lending and risk-taking channels of interest rate transmission. We highlight that both short-term and long-term interest rate shocks have an impact on the banking and the investment fund sectors in Luxembourg. However, as previously mentioned, banks and investment funds react differently to such shocks. Specifically, banks are more sensitive to short-term interest rate shocks, whereas investment funds are more sensitive to long-term interest rate shocks.

The results shown in Figures 2 and 3 highlight some of the key differences in the responses of banks and investment funds to interest rate shocks. These differences may be partly explained by the respective balance sheet structures of banks and investment funds in Luxembourg. Precisely, the asset-side of banks consists primarily of loans, debt securities, and other types of assets, while the asset-side of investment funds' consists of debt securities and other types of assets. On the liability side, banks hold deposits and debt securities, as well as other types of liabilities[48], whereas investment funds mostly hold fund shares on their liability-side. These key differences are important for understanding how banks and investment funds react to interest rate shocks.[49]

Figure 3:

Banks' and investment funds' response to a 1pp shock in the long-term interest rate shock



Source: BCL.

Note: 68 % (blue-shaded areas) and 90 % (gray-shaded areas) confidence bands displayed.

For banks in Luxembourg, interbank loans represent the largest share of banks' assets. The second largest portion of banks' asset composition is customer loans (e.g. loans to households, non-financial corporations (NFCs)) and loans to other financial intermediaries, followed by debt securities. Luxembourg banks are therefore likely to be more sensitive, on average, to a short-term interest rate shock, in line with the credit channel hypothesis. To illustrate the importance of this channel, we examine the responses of different types of bank loans to short-term interest rate shocks.

48 Other types of liabilities refer to bank borrowing from other institutions, including reserves, etc.

49 In the euro area, banks and investment funds operate under different business models. For example, loans comprise more than 60 % of bank assets but less than 10 % for investment funds. However, debt securities make up roughly 40 % of investment fund assets and only 10 % of bank assets. ECB Work stream on non-bank financial intermediation in the euro area: implications for interest rate transmission and key vulnerabilities.

In Luxembourg, investment funds are inclined to allocate their resources in debt securities that have longer maturities, which is likely to enhance the term premium they earn from their bond investments. Consequently, changes in the long-term interest rate that affect the long end of the yield curve are likely to have an impact on the investment fund sector. However, there might be some differences in the effect on funds in Luxembourg depending on the type of investment. We therefore undertake a more granular analysis of funds' responses to interest rate shocks by distinguishing the responses across different types of investment funds.

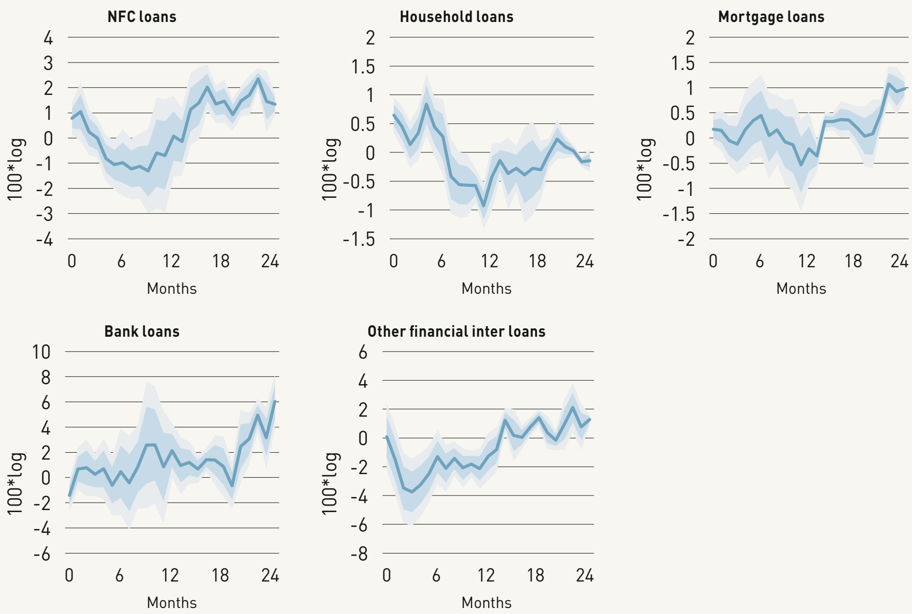
B. HETEROGENEITY OF INTEREST RATE SHOCK RESPONSES ACROSS THE DIFFERENT TYPES OF INVESTMENT FUNDS AND LOAN COUNTERPARTIES

In this section, we examine how investment funds react to interest rate shocks depending on their type. In addition, we also look at how the response of banks following an interest rate shock may affect lending to the different bank loan counterparties.

With regard to banks, Figures 4 and 5 show that banks' lending to the different loan counterparties (i.e. NFCs, household[50] This situation also increases the external finance premium. In addition to an increase in the external finance premium for NFCs and other financial intermediaries tends to contract more than loans to other counterparties. This finding is likely due to the balance sheet structure of Luxembourg banks, which tend to hold a large share of interbank loans followed by loans to NFCs and to other financial intermediaries. Therefore, it is understandable that short-term interest rate shocks primarily affect lending to NFCs and to other financial institutions (OFIs). This decrease in NFCs' lending might also be related to the fact that households cancel or postpone their purchases when interest rates increase, which decrease demand for consumer loans leading to a decrease in demand for goods and services produced by NFCs. Moreover, higher interest rates imply less demand for credit by NFCs, which is partly attributable to the adverse effects on their profits. These results favour the credit channel hypothesis.

Figure 4:

Responses after a short-term interest rate shock according to loan counterparty



Source: BCL.

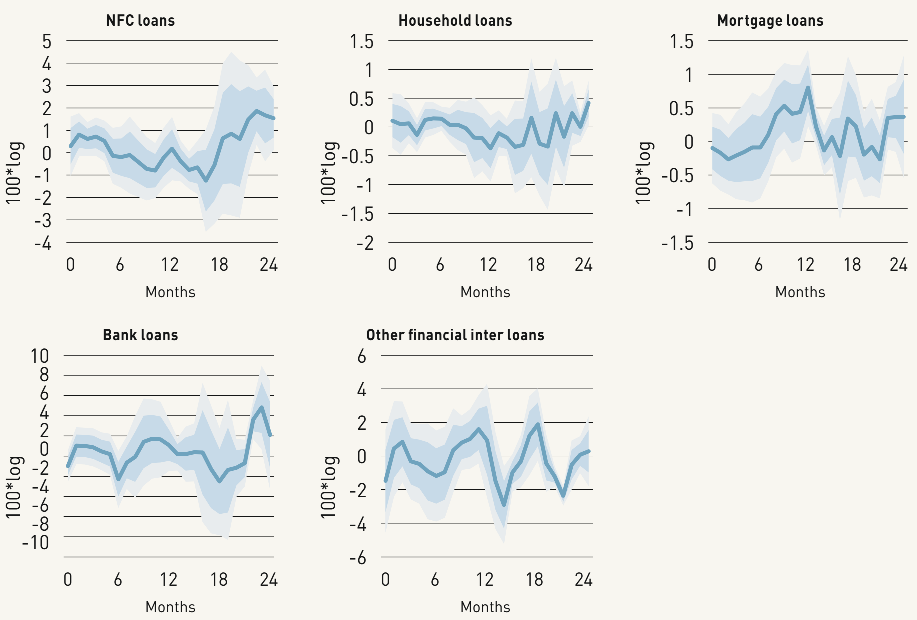
Note: 68 % (blue-shaded areas) and 90 % (gray-shaded areas) confidence bands displayed.

[50] Lending to households consists on consumer loans and other loans. It excludes mortgage loans.

According to Bernanke and Gertler (1995), monetary policy also has an impact on borrowers' financial positions. A tighter monetary policy stance can weaken borrowers' balance sheets in at least two ways. First, to the extent that borrowers have outstanding short-term or floating-rate debt, rising interest rates directly increase debt servicing costs, reducing net cash flows and weakening a borrower's financial position. Second, higher interest rates are also associated with declining asset prices which, among other things, decrease the value of borrowers' collateral. As borrower's net financial position weakens and the value of their collateral diminishes the external finance premium increases, making it harder for them to access credit. Similarly, a tighter monetary policy can have an impact on the supply of bank loans by decreasing the amount of credit allocated to borrowers.[51] This situation also increases the external finance premium. In addition to an increase in the external finance premium for NFCs and other financial intermediaries due to higher interest rates, the balance sheet and banking lending channels, it is important to recall that loans to other financial intermediaries also depend on the broader evolution of financial markets.[52]

Figure 5:

Responses after a long-term interest rate shock according to loan counterparties



Source: BCL.

Note: 68 % (blue-shaded areas) and 90 % (gray-shaded areas) confidence bands displayed.

Regarding long-rate shocks as shown in Figure 5, lending to the various counterparties does not seem to significantly contract following a long-term interest rate shock. It is worth noting that, following a long-rate shock, loans to NFCs tend to contract, but with a lag of more than one year.

Figures 6 and 7 show that investment funds, depending on the type of fund, (i.e. money market, equity, bond, mixed, real estate and hedge funds) react differently to interest rate increases.

[51] In Luxembourg, this process is often due to demand-side factors according to the Bank Lending Survey (BLS).

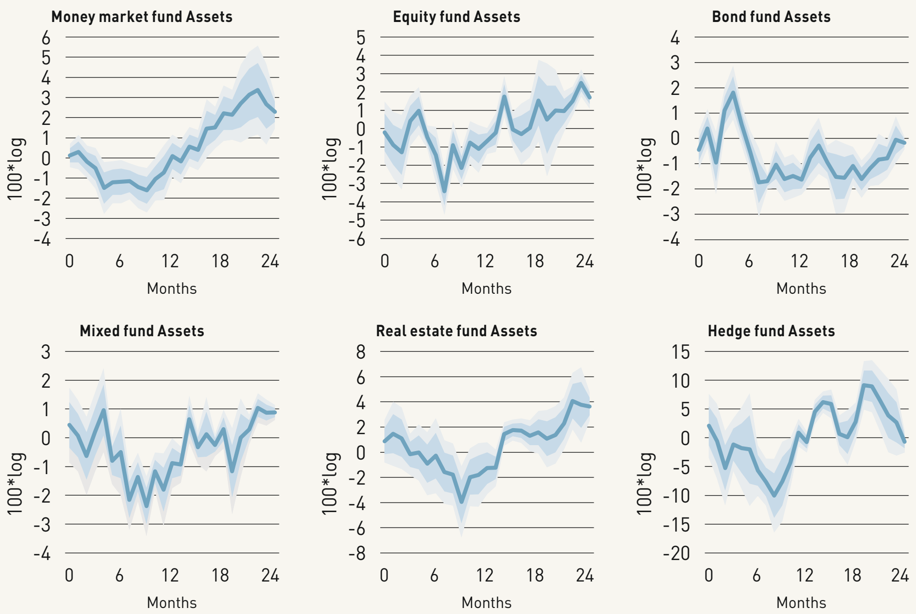
[52] For example, when interest rates increase, it may become more expensive for banks to borrow money, which could lead to higher interest rate pass through on loans to other financial intermediaries. In addition, if banks perceive that the financial markets are becoming less liquid, they may be more hesitant to lend money to other financial intermediaries, which could exacerbate liquidity mismatch.

According to Figure 6, a 1 percentage point increase in the short-term interest rate results in a deeper decline of around 1.74 % and 2.38 % for the total assets of bond and mixed funds, respectively. On the other hand, following a 1 percentage point short-rate increase, the total assets of equity funds, real estate funds and hedge funds decline by a maximum of 3.42 %, 3.94 % and 10 %, respectively. This finding suggests that investment funds that mostly invest in debt securities with longer maturities, such as bond and mixed funds, are less impacted by short-term interest rate shocks. However, funds that invest in equities, derivatives with shorter maturities (such as money market funds, and hedge funds) tend to be more affected by short-rate shocks. Therefore, the results suggest that the more a fund is exposed to short-maturity debt, the more it is likely to be impacted by short-rate shocks.

Figure 7 highlights that, after an increase in the long-term interest rate, equity funds, real estate funds and hedge funds are not materially impacted. However, bond funds and mixed funds experience a significant contraction following shocks to the long-term interest rate.

Figure 6:

Responses after a short-term interest rate shocks according to investment fund types

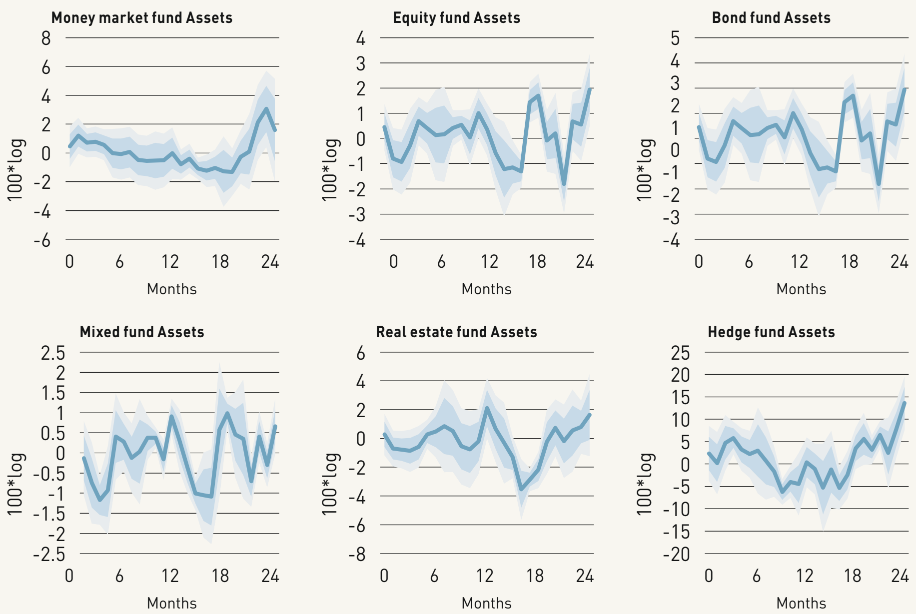


Source: BCL.

Note: 68 % (blue-shaded areas) and 90 % (gray-shaded areas) confidence bands displayed.

Figure 7:

Responses after a long-term interest rate shocks according to investment fund types



Source: BCL.

Note: 68 % (blue-shaded areas) and 90 % (gray-shaded areas) confidence bands displayed.

5. CONCLUSION

The objective of this study was to assess how banks and investment funds in Luxembourg react to interest rate shocks. The study is important from a financial stability perspective given the end of the period of monetary accommodation. The subsequent tightening of financial conditions has been swift and significant as central banks have acted to contain high and persistent inflation. In view of the need to monitor developments in the investment fund sector, and given the amount of total assets under management, assessing how different fund types respond to interest rate shocks is relevant for financial stability in Luxembourg.

This empirical exercise, having used the local projections approach to assess the impact of both short-term and long-term interest rate shocks, suggests that a 1 percentage point increase in the 3-month OIS rate leads to an initial contraction of Luxembourg banks' total assets by 0.45 %, while investment fund assets decline by 0.38 % following the shock. Based on the impulse response functions, the total assets of banks and investment funds decline by a maximum of 1.11 % and 0.98 % four months and one month after the short-term interest rate shock, respectively. However, the impact on banks' assets dissipates approximately eight months after the shock. Banks' total assets then recover with a maximum increase of 1.02 % around eighteen months following an increase in the short-term interest rate. Following a short-term interest rate shock, the decline in the total assets of Luxembourg investment funds fades after three months, with an eventual increase of 1.41 % in total assets after 14 months. This suggests that banks react more strongly to short-term interest rate increases compared to investment funds.

On the other hand, increases in the long-term interest rate, captured by the long end of the 10-year German yield curve, generate a significant contraction in investment funds' balance sheets. The difference between the effects of short and long-term interest rates on bank and investment fund assets can be partly attributed to differences in their balance sheet structure, particularly the composition of the asset side of their balance sheets. More precisely, even if both banks and funds hold debt securities, the presence of loans on the asset side of banks seems to be a key driver of the difference in the responses.

We also undertake a deeper analysis of how banks' lending to NFCs, households, mortgages, banks and other financial institutions and investment funds (by fund type including money market, equity, bond, mixed, real estate and hedge funds) respond to interest rate shocks. Our results suggest that loans to NFCs and to other financial intermediaries are more sensitive to increases in the short-term interest rate, in line with the credit channel hypothesis. In addition, we find that the maturity of securities in which investment funds invest is a determinant of how the different types of investment fund respond to interest rate shocks. More specifically, the more that funds invest in long-term (short-term) securities, the more sensitive they are to longer-term (shorter-term) interest rate shocks.

Finally, the findings outlined in this study confirm that banks and investment funds operating in Luxembourg are less likely to be adversely impacted by interest rate shocks compared to those in other countries as both bank and investment fund balance sheets recover relatively quickly following shocks to the short- and long-term interest rates. In other words, changes in interest rates do not seem to have a material impact on the lending activities of banks, at least on the supply side. Therefore, in an environment of rising rates, the financial sector is expected to continue to fulfill its role in funding the economy. From the borrower's perspective, the results support the interpretation that a decline in lending can primarily be attributed to lower demand for bank loans due to rising interest rates.

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