ESSAYS ON UNCONVENTIONAL MONETARY POLICY

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ABSTRACT

This dissertation studies the synergies and trade-offs between unconventional monetary policy instruments and their interactions with macro-prudential policy. The complementarities between policy tools played a critical role in the monetary response to the Covid-19 pandemic, but they have been overlooked by the literature. My dissertation answers the call by policymakers to fill this knowledge gap undermining unconventional monetary policy (UMP) effectiveness. The first chapter assesses empirically the efficacy of the lending programmes in the context of the Chinese monetary policy. It finds that liquidity injections enhance the policy rate signal and are deployed in coordination with other policy tools — consistent with the European Central Bank's (ECB) experience. The second and third chapters, are theoretical and extend a workhorse DSGE model nesting quantitative easing, negative interest rate policy and forward guidance along two dimensions. The second chapter adds macro-prudential policy to study how the introduction of a countercyclical capital buffer affects the transmission of UMP. Policy simulations show that deploying simultaneously macro-prudential policy and UMP *strengthens* the effectiveness of monetary policy and allows an earlier unwinding of UMP. The third chapter expands the baseline model with central bank lending programmes featuring a collateral policy and a "dual rate system". It aims to analyse the interlinkages generated by the simultaneous deployment of the lending programmes with other UMP tools. Four channels of monetary transmission arise and the chapter offers policy recommendations to capitalise on the *synergies* and mitigate the *trade-offs*. The final chapter estimates the loss in Euro Area potential output due to the Covid-19 crisis using a novel sectoral method. It finds that potential output in 2025 might be 0.8% lower than in the absence of the Covid-19 crisis.

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INTRODUCTION

Since the Global Financial Crisis of 2007-2008, monetary policymakers have operated in a new environment characterised by the proximity to the effective lower bound. In this "new normal", central banks in advanced economies had to develop their framework to keep monetary policy effective.[1] In order to counteract disinflationary pressures close or at the effective lower bound, central banks abandoned the conventional policy rate and engaged with unconventional monetary policy (UMP) tools, previously only rarely deployed. Critically, even when the Global Financial Crisis of 2007-2008 receded, the non-standard tools continued to be used: negative interest rate policy was implemented across Europe for 10 years. More recently, during the Covid-19 crisis of 2020, unconventional instruments grew in their size and breadth of uses: since 2006, the Bank of England's assets to GDP ratio has increased tenfold, while the number of its monetary tools has risen four times (Hauser, 2021a). In short, monetary policy has not returned to the pre-crisis framework: the decline in the equilibrium real interest rate, amongst other factors, threatened the effectiveness of monetary policy, requiring unconventional tools to become conventional.[2]

The adoption of the UMP framework brought in a regime change in central banking: Monetary policy lost its mono-dimensionality — setting only the policy rate — to become multi-dimensional — choosing several instruments to be deployed in combination (Bailey, 2021). This concerted strategy has fuelled strong synergies between the unconventional instruments, enhancing the transmission of the monetary policy stance at the effective lower bound. The European Central Bank's response to the Global Financial Crisis is a case in point: its combined strategy "made [the unconventional tools] so powerful and probably

[1]See the questionnaire for the Treasury Select Committee of the Bank of England Chief Economist Huw Pill (2021a)

[2]In the words of Bernanke (2020): The "old methods won't do". For more detail on the regime change in monetary policy, see (Borio, 2020), (Lagarde, 2020) and (Pill, 2021a).

indispensable within the ECB's multidimensional easing strategy" (Rostagno et al., 2019). Similarly, the ECB approach in response to the Covid-19 pandemic revolved around "three mutually *reinforcing* and *complementary* components [Quantitative Easing, Targeted Longer-Term Refinancing Operations and lender of last resort]" (Schnabel, 2020b).

Despite their growing importance for policymaking, the interactions between non-standard tools have been overlooked by the literature, leaving important knowledge gaps that undermine the design, calibration and communication of monetary policy ((IEO, 2021) and (Pill, 2021a)). In addition, since the complementarities amongst UMP tools become more powerful when space for further easing is limited, the effectiveness of monetary policy depends critically on investigating and conducting research in these unaddressed interlinkages (Saunders, 2020).

The evolution of this new monetary framework coincided with an expansion of macro-prudential instruments. The Global Financial Crisis, in fact, pushed central banks to the effective lower bound — fuelling the adoption of unconventional tools — and, in doing so, crystallised some existing systemic vulnerabilities. The regulatory weaknesses revealed by the crisis led to the development of Basel III and the introduction of higher and countercyclical capital requirements,[3] actively managed with the ultimate goal of mitigating systemic risk. As the regulators' toolbox expanded, the policy environment changed: (unconventional) monetary policy started being conducted synchronously with macro-prudential policy to deliver, respectively, target inflation and financial stability. This obligation of dual delivery inevitably generated significant interlinkages (Laeven et al., 2022). The monetary-macroprudential synergies strengthened during the Covid-19 crisis when 15 major central banks lowered the countercyclical capital buffer to support the supply of credit while engaging in non-standard monetary policy (Aikman, 2020). This dual strategy reflects the approach advocated by former Bank of England Governor Carney (2014) when he announced that the Bank would use its policy tools "in concert" to support the ongoing expansion. Similarly, given the complementarities with monetary policy demonstrated during the Covid-19 crisis, ECB Vice President de Guindos (2021) argued for an increased role in macro-prudential policy of the ECB Governing Council.

[3]Basel III introduced two capital buffers — the capital conservation buffer and the countercyclical capital buffer — and two further requirements: the additional capital for global systemically important banks and the total loss-absorbing capacity requirement.

Despite policymakers' interest, little is known on the interactions between UMP and macro-prudential policy. More broadly, the role of macro-prudential policy in a low/negative environment is still under debate. This knowledge gap generates challenges similar those created by the thin literature on the interactions amongst non-standard monetary tools: uncertainty surrounding the strength of the transmission channels, difficulty in calibrating policy packages and overall, less predictable effects on output and inflation relative to the standard monetary policy framework.

The incomplete understanding of the interactions *amongst* unconventional monetary tools and *between* unconventional monetary tools and macro-prudential policy has consequences beyond the period in which the policy rate is constrained by the zero lower bound. In the short term, as unconventional monetary policy is normalised and the policy rate is increased, the lack of academic research on the interactions makes the net effect of these tools hard to understand and estimate (Panetta, 2022a). In the long term, as the central bank balance sheet is used more actively as a policy tool, not knowing the most effective combination of tools can lead to excessive monetary policy interventions and growing unintended side effects ((Hauser, 2021a) and (Hauser, 2021b)).

The overarching goal of this dissertation is to enhance our understanding of unconventional monetary tools. Taking stock of the existing gap between literature and policy, this dissertation studies the synergies between non-standard monetary instruments and their interactions with macro-prudential policy. For this, it develops a new, unified framework for analysis allowing to disentangle the effects of different tools and their interlinkages. The analysis fills gaps in the literature by shedding light on how the transmission mechanism of unconventional monetary policy works when several instruments are deployed simultaneously, across different states of the world (e.g. level of reserves, collateral used) and economies (China and advanced economies). The insights are applied to policymaking, in order to answer some timely questions, amongst which: Does the simultaneous delivery of multiple tools enhance output stabilisation? Can it generate unwarranted contractionary channels? What does a feasible and useful exit strategy from QE and lending programmes look like? According to the Bank of England, these are some of the questions defining the new directions for central banks' research (BoE, 2022).

The first chapter of this dissertation is empirical and it motivates the following theoretical chapters. The focus is on one specific unconventional monetary instrument — the long-term funding programmes — used by the People's Bank of China (PBoC). Critical for my dissertation, the PBoC deploys its lending programmes simultaneously with a constellation of other monetary tools. The chapter aims to assess the effectiveness of these lending programmes, their implementation in relation to the other instruments and to determine whether China's monetary policy has moved closer to those of advanced economies'. On these grounds, the chapter applies a SVAR model to estimate the effects of an exogenous shock to the PBoC liquidity injections. For this, it follows a methodology used to assess the impact of ECB balance sheet expansion (Boeckx et al., 2017). The chapter finds that PBoC liquidity injections between 2014 and 2019 are effective at enhancing the policy rate signals. This is consistent with ECB experience, confirming that PBoC conduct is increasingly closer to advanced economies'. In addition, monetary policy conducted through the remaining tools demonstrates a high degree of coordination to deliver the central bank's multiple objectives. This evidence is valuable for monetary policymakers engaging in long-term liquidity injections, supporting the ECB "fixed rate full allotment" procedure. However, the lack of detail on the transmission mechanisms at work makes it difficult to translate the synergies between monetary tools into central banks' policy frameworks. This gap calls for a more methodological approach and the development of a more systematic framework for analysis, motivating the following theoretical chapters of the dissertation.

In order to understand the transmission mechanisms fuelling the synergies between unconventional monetary tools I turn to the theoretical model of Sims and Wu (2021). This is one of the few papers building in quantitative easing (QE), negative interest rate policy (NIRP) and forward guidance (FG) in a single framework, allowing direct comparison and analysis of the interlinkages between instruments. The united framework has received attention from policymakers, being welcomed by the Federal Reserve and Bank of England. I chose to build on this contribution because it is highly tractable (allowing different policy simulations) yet rigorous — incorporating prominent frictions from the macro-finance literature. This framework is also useful for explicitly modelling alternative policies and understanding their potential implications. Relying on this new model allows me to expand my research along two dimensions.

First, I focus on the interaction between UMP and macro-prudential policy. Inspired by the concerted monetary-macroprudential response to the Covid-19 crisis, the second chapter extends the model of Sims and Wu (2021) with a countercyclical capital buffer (CCyB) as in Gertler et al. (2012). This enables me to study how the introduction of macro-prudential policy affects the transmission of QE, NIRP and FG. I find that with the introduction of CCyB, QE's transmission mechanism is weakened but NIRP's is strengthened. In addition, the chapter reveals synergies between UMP and macro-prudential policy, making three new, strong cases for the simultaneous deployment of UMP and CCyB: first, using CCyB and QE in unison is more effective at stabilising output than solely relying on QE, allowing UMP to be less aggressive. Second, the powerful interactions between NIRP, QE and CCyB can be used strategically to avoid the reversal interest rate. Third, the concerted deployment of QE and CCyB allows — once the economy is in recovery — to start quantitative tightening earlier than in the case without CCyB and with more policy space to change the normalisation pace without triggering an adverse market reaction. These results confirm the Bank of England's concerted strategy of delivering monetary and macro-prudential policy simultaneously to support the recovery.

Second, answering the call by Bank of England Chief Economist Huw Pill to evaluate non-standard instruments beyond QE, the third chapter adds a long-term lending facility to the model of Sims and Wu (2021). This extension allows me to study the interactions between Central Bank lending programmes and QE, FG and NIRP. The lending programmes feature a collateral policy and a "dual rate system", in the spirit of the ECB strategy during the Covid-19 crisis. I find that the synergies between the lending programmes and the other UMP instruments make three cases for their simultaneous deployment. First, when the lending programmes are deployed simultaneously with QE, synergies — working through the collateral value — and trade-offs — generated by the scarcity of available assets — arise. By setting its collateral policy while engaging in QE, the Central Bank can strengthen the synergies and overcome the trade-offs, improving monetary policy effectiveness. Second, when the lending programmes are deployed simultaneously with NIRP, the dual rate system supports financial intermediaries' net worth. This synergy prevents the economy from hitting the reversal interest rate, again increasing monetary policy effectiveness. Finally, once the economy is in recovery, the smooth, complete, simultaneous unwinding of both QE and the lending programme ensure the most effective normalisation policy. These results offer some of the first policy recommendations on how to design modern lending programmes – understudied thus far, but so important during the Covid-19 crisis to be defined by the ECB as "a central bulwark against the impairment of the bank-based transmission mechanism of monetary policy" (Barbiero et al., 2021).

Finally, the subject of the fourth chapter relates to monetary policy but from the perspective of potential output. Potential output is a notoriously hard but critical variable to estimate for central banks.[4] Misperceptions of potential output, in fact, have profound implications for the conduct of monetary policy and its effectiveness. The urgency to achieve precise potential output estimates increased during the Covid-19 crisis, but the unique nature of the shock — characterised by heterogeneous effects across sectors — limited the scope to use previous frameworks for analysis. This is the reason why in my PhD Traineeship at the European Central Bank I contributed to developing a novel sectoral-level, bottom-up method to estimate euro area potential output and assess the impact of the pandemic on it. The fourth chapter of my dissertation (published as ECB Working Paper 2717 in September 2022) presents the methodology and results of the project. The estimates are based on a supply-demand shock decomposition and are meant to quantitatively support the estimation of scarring effects stemming from the pandemic. The results show that trade and hospitality sectors, amongst others, may suffer a loss in trend output of around 1.4-1.6% by 2025. Aggregate potential output in 2025 might be about 0.8% lower than it would have been without the crisis, and importantly, without support from the Next Generation EU, signalling somewhat larger losses than embedded in the Autumn 2021 forecast of the European.

To conclude, this dissertation is grounded in the new, multi-dimensional framework of monetary policy. The common thread throughout the chapters is the need to reconnect the literature — that has studied monetary tools in an "additive way" — with recent monetary policy — that has emphasised the complementarities and interactions between different instruments. Policymakers at the ECB and Bank of England have made several calls to fill this gap to ensure monetary policy remains effective in the future. This dissertation aims to respond to this by studying the synergies and trade-offs between unconventional monetary instruments and their interactions with macro-prudential policy. The results aim to contribute to

[4] Cœuré, Member of the Executive Board of the ECB, defined it as "a riddle, wrapped in a mystery, inside an enigma".

enhancing the effectiveness of the new monetary policy framework.

Chapter One

The Role of Liquidity Injections: the Case of the People's Bank of China

This chapter assesses the effects of large provisions of short, medium, and long-term liquidity by the People's Bank of China and their role in fuelling China's economic rebalancing.

1.1 Introduction

In 2020 China celebrated the end of the five-year development plan, focused on rebalancing the economy. Ambitious targets set at the beginning of the decade — like doubling of GDP from the 2010 level — were accompanied by a policy push towards a new normal, defined by Premier Li as a "farewell to the unbalanced, uncoordinated and unsustainable growth model" (IMF, 2016). Monetary policy has been instrumental for these goals and its implementation evolved considerably through the years. Most importantly, as the quantity-based operational target grew increasingly ineffective in steering the economy, the People's Bank of China (PBoC) has been promoting a shift towards a market-based interest rate mechanism.

Despite a slow pace of rates liberalisation, the short-term money market rates have become the (unofficial) operational target of the PBoC.

For the change in the operational target to take place, the central bank adopted a structural deficit liquidity management framework, as planned by former governor Guofeng Sun (2015). This is standard monetary policy implementation, in which the central bank generates stable liquidity demand and satisfies it with asset expansions, steering money market rates in line with the policy rate. The PBoC framework fits this description, with only one departure from the standard model: while central bank's liquidity is typically provided by OMOs and a standing facility, the PBoC adds short and, uniquely, *long term* lending facilities. This defining feature of the PBoC toolbox prompted commentators to speculate whether the PBoC adopted ECB Long-Term Refinancing Operations-style instruments (Zhang, 2015), implying a dealer-of-last-resort function.

The chapter shows a larger role played by these long term lending facilities, bringing them at the forefront of PBoC policymaking. This is appropriate as since 2014 they became the main channel to supply base money (PBoC, 2015a) and play a critical role in delivering the multiple final objectives, supporting the rebalancing of the economy. On the one hand, in fact, the lending facilities are employed to stabilise output and promote the interest rate mechanism, shifting to a more efficient allocation of resources. On the other hand, they foster the deleveraging process[1] — by averting funding pressures in the banking system — and accommodate government's policies to restructure loss-making firms — avoiding an "hard landing" in regions affected by overcapacity. By the end of 2019 claims on banks amounted to USD 1.5 trillion but little is known about them. So it is important to understand the exact role played by the lending facilities in recent Chinese monetary policy.

The PBoC lending facilities are present only in three recent papers. Lodge and Soudan (2019) and Funke and Tsang (2019) use them as inputs to build aggregate indexes of PBoC monetary policy stance. Fang et al. (2020) focus on one of them — the Medium-term Lending Facility — and analyse its collateral channel. Critically, however, none of these three papers estimates the impacts of the lending facilities on key macroeconomic variables.

[1]PBoC Monetary Policy Report Q3717: the PBC will employ a number of flexible monetary-policy instruments, and arrange a combination of instruments in properly-paced operations to "shave off mountain peaks and fill valleys" in terms of liquidity so as to maintain its stability and to strike a balance between maintaining liquidity stability and deleveraging.

By focusing on the liquidity injections, the chapter has two main objectives. The first one is domestic: to assess PBoC lending facilities' effectiveness in supporting the economy and their implementation in relation to other monetary instruments. This sheds light on how the PBoC manages the rebalancing of the economy, striking the right balance between growth stability and financial stability. The second one is comparative: to determine whether China's conduct of monetary policy — despite its complexity — has moved closer to advanced economies', like the ECB's. Lending operations have been critical for the Euro Area since the Global Financial Crisis and they are increasingly important in China too, so the chapter investigates if they have similar pass-through and effects. The analysis is particularly interesting because it reveals if the two very different institutions, each with its own distinct institutional framework and history, now operate in a similar fashion.

On these grounds, the chapter applies a SVAR model to estimate the effects of an exogenous shock to the PBoC liquidity injections. In doing so, it follows a methodology used to assess the impact of ECB balance sheet expansion (Boeckx et al., 2017). To analyse the first objective, the chapter estimates the exogenous shock on output, investment, inflation and a monetary policy index that summarises PBoC remaining monetary tools. To investigate the second objective, it is necessary to take into account the effect of central bank's liquidity on credit spreads, so the chapter adds a measure of interbank liquidity risk to the estimation.

The results of the estimation are consistent with the ECB experience. This is surprising because of PBoC complex reaction function and China still being a transition economy with a historically very different approach to monetary policy making. Nonetheless, we find that PBoC liquidity injections are effective as output, investment and the price level increase temporarily. The liquidity spread is compressed, confirming that PBoC conduct is increasingly closer to advanced economies'. Finally, monetary policy conducted through the remaining tools tends to tighten, targeting financial stability risks. This demonstrates the high degree of coordination amongst PBoC monetary tools, employed in unison to deliver the central bank's multiple objectives.

In addition, the chapter draws a policy implication for the ECB. The PBoC use of long-term borrowing facilities, in fact, provides evidence for the ECB to make the Targeted Longer-term Refinancing Operations (TLTROs) a permanent facility, or at least to permanently shift to a "fixed rate full allotment" procedure, without reverting back to auction off fixed amounts of liquidity.

The remainder of the chapter is organised as follows. Section 1.2 presents the institutional framework of the PBoC, setting it apart from the other major central banks. Section 1.3 explains the purposes of the liquidity facilities within the current liquidity management framework. Section 1.4 presents the data and the variable construction. Section 1.5 shows the VAR model and the identification strategy. In section 1.6 the chapter reports the results and draws policy implications. Finally, section 1.7 concludes.

1.2 PBoC Institutional Backdrop

The institutional backdrop is key in understanding the multifaceted contribution of PBoC lending facilities.

The current PBoC operational target is an hybrid one: on one hand the central bank embraces the consensus that the short term interbank rate is the appropriate operational target, and it is increasingly targeting it ((Funke and Tsang, 2019) and (Fu and Wang, 2020)). On the other, it still relies on keeping the growth rates of M2 and AFRE[2] in line with nominal GDP growth to calibrate the monetary policy stance.

The final target is also not clearcut. As enshrined in its statute, the PBoC objective is to deliver stability to the value of the currency, thereby promoting growth. However, due to its setup under the leadership of the State Council, the PBoC has additional objectives in line with the government's quest for employment and social stability (Mehrotra and Sánchez-Fung, 2014).[3] Notably, PBoC's different objectives can be in conflict (Zhou, 2016).

The PBoC achieves its different targets using a conventional toolbox, as defined by [Mishkin, 2019], [4] with one exception: the lending facilities. The chapter's

[2] AFRE, also known as Total Social Financing, is the total amount of financing that the real economy can access via the financial sector during a given period.

[3] Amongst these, former Governor Zhou listed "boosting economic growth, promoting employment, and broadly maintaining balance of payments, promote reform and opening up as well as financial market development". Additionally, the PBoC has strengthened its macro-prudential roles following the 19th National Congress of the CPC in 2017.

[4] As listed by Governor Yi Gang, the PBoC delivers its operation target changing the reserve requirement ratio (RRR), running open market operations and using window guidance. Benchmark lending and deposit rates have lost importance following the 2015 rates liberalisation.

objective is to provide their first assessment. This allows to gauge the extent of PBoC support to the economy, its rebalancing and the move towards an interest rate mechanism.

1.3 The Changing Nature of PBoC Liquidity Management Framework

In order to assess PBoC liquidity injections we need to understand their purpose. Central bank's liquidity injections serve a monetary and a financial stability goal. In the former case, the central bank acts as supplier of liquidity to adjust the quantity of reserves to achieve a price, typically the short term interbank interest rate (Meulendyke, 1998). This is conventional monetary policy implementation. In the latter case, the central bank injects liquidity in the banking system to prevent a liquidity crisis from transforming into a solvency crisis. These two goals are highly intertwined (BIS, 2020) and this chapter argues that PBoC liquidity injections serve both of them.

In fact, the lending facilities were set up to support the shift towards a market-based interest rate mechanism (Gang, 2018). For this transformation to take place, the central bank had to build a liquidity management framework based on a liquidity deficit (Sun, 2015). This came about in 2014 with the end of the twin surplus:[5] as the persistent reduction in FX reserve supply moved the banking sector in a liquidity deficit, the PBoC started to provide base money through assets' expansion, in other words through its lending facilities (see "Claims on banks" in Figure 1.1 below).

In this framework, the reserve requirement ratio (RRR) keeps pressure on the money market, while the PBoC injects short term liquidity through OMOs and Short-term Liquidity Operations (SLO). The standing lending facility (SLF) acts conventionally as the ceiling of the interest rate corridor. The only departure from the conventional model is the supply of *long term* liquidity. This is injected through the Medium-term Lending Facility (MLF), the Targeted Medium-term Lending

[5]A twin surplus is a surplus in the current account and in the capital and financial account. China's structural current account surplus was the result of goods trade surplus, constantly larger than the service trade deficit. The financial account surplus was driven by large capital inflows since 2006, reflecting CNY appreciation. From 2014 onwards the balance of payments would register a current account surplus and a capital and financial account deficit.

Facility (TMLF) and Pledged Supplementary Lending (PSL).[6]

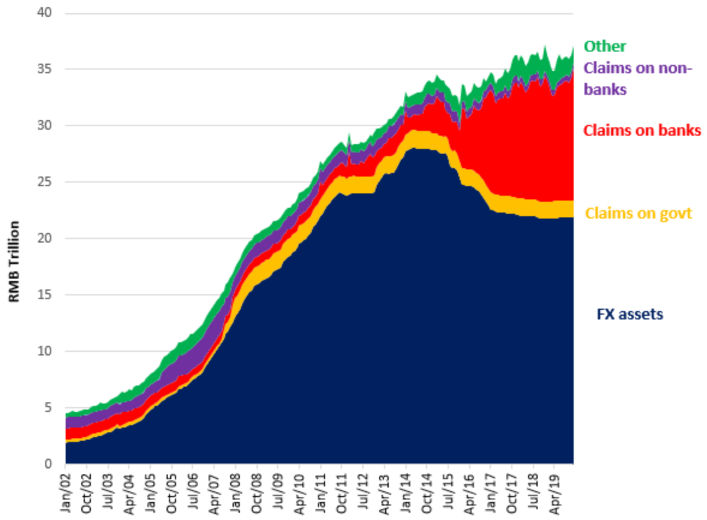


Figure 1.1: PBoC assets.

Source: Datastream.

The mix of monetary policy instruments and maturity structures allows to supply liquidity in a flexible, "elastic" way. Consistent with the PBoC shift towards a market-based interest rate target, the main role of short-term injections is monetary stability: to steer money market rates around the 7-day reverse repo rate ((PBoC, 2016b) and (PBoC, 2016c)). A secondary role is guaranteeing financial stability: as short term liquidity injections smooth out rates volatility (PBoC, 2018), they also facilitate money market operations. This is critical in the Chinese context because the sensitivity toward liquidity conditions has increased as a result of financial deepening (PBoC, 2015b), with medium and small banks increasing significantly their exposure to short-term wholesale funding (IMF, 2017).

Long-term injections are an important channel to provide base money ((PBoC, 2016a) and (PBoC, 2019b)). They depart from the conventional liquidity management framework due to their longer maturity, but they still guide market rates around a policy rate, the long term MLF rate (PBoC, 2016d). In this view, long-term injections are complement to the short term provisions and regular OMOs. Their monetary stability role was strengthened as the MLF rate grew into the floor of

[6] MLF has a maturity of 3month-1year, the PSL 3-5year and the TMLF 1-year but it can be rolled over twice, making the actual term of the TMLF three years.

the market-determined Loan Prime Rate[7] — the lending rate provided to the most creditworthy clients (PBoC, 2019a). In addition to this role, long term financing increases financial stability as it lengthens the maturity of the banks' liabilities and it stabilises credit markets during periods of distress, like in the aftermath of the Baoshang Bank takeover[8]. Therefore, even if these long term liquidity injections were introduced to fill a structural liquidity gap[9] and their architecture resembles the non-standard ECB LTROs, their purpose is not only to substitute an impaired private intermediation during periods of turmoil, but also to steer rates in line with monetary policy objectives. As medium and long term rates are the ones that "really matter for the economy" (Bernanke, 2015), the PBoC has introduced a powerful tool to reduce lending rates, stabilise output and create an environment conducive to supply side reforms ((PBoC, 2016b) and (PBoC, 2016d)).

1.4 Data and Variable Construction

This section presents the selection of the model's variables. The choice was made following Boeckx et al. (2017) and Quint and Tristani (2018), who study the effects of ECB liquidity provisions.

The data are collected from September 2014 — when the Medium-term Lending Facility (MLF) was introduced — until October 2019. The starting date of the dataset is motivated by the fact that before Q4 2014 the PBoC did not use its lending facilities as the main channel to supply base money — a role played by the large FX purchases (PBoC, 2015a). In other words, it would be inadequate to assess the effects of PBoC liquidity injections before 2014 because monetary policy was not implemented following a conventional structural deficit liquidity management framework yet. This reasoning is similar to Boeckx et al. (2017) estimation of ECB's balance sheet policies: they focus only on the period after 2007 because the ECB never used the balance sheet as policy tool before that year.

This chapter includes the following six variables: PBoC liquidity injections, a liquidity spread, an index of monetary policy, output, investment and inflation.

[7]The Loan Prime Rate is calculated adding to the MLF rate a spread, that is the average lending rate provided by 18 commercial banks to their most creditworthy customers

[8]In May 2019, Baoshang Bank was taken over due to credit risks, causing market concerns about the liquidity risks of some small and medium-sized banks (PBoC MPR Q2 2019).

[9]As a result of changes in the balance of payments.

- **PBoC Liquidity Injections.** PBoC liquidity injections to banks are carried on through OMOs and several lending facilities. Hence the chapter uses the aggregate PBoC balance sheet item "claims on banks" presented in Figure 1.1. It includes loans through liquidity facilities, rediscounting, repos and purchases of banks' bonds. The data are collected from Datastream in annual growth rate form.

- **Liquidity spread.** In order to estimate the effects of PBoC lending provisions on credit spreads we need to find a measure of interbank liquidity risk. More in detail, this measure needs to be "unobservable" by the central bank, to ensure that market liquidity risk reacts to monetary policy shocks and not vice versa. In short, PBoC liquidity injections must be orthogonal to the interbank liquidity risk — they cannot react to it. A good starting point is the Chinese equivalent of the spread between Libor and overnight index swap rates (the Shibor-interest rate swap spread) but China's interest rate swap use is infrequent. We could overcome this issue by adopting the spread between the Shibor and Treasury Bond (TB) yield, that is comparable to the US TED spread (Lu et al., 2018). However, the Shibor-Treasury Bond spread doesn't signal liquidity risk only, but also counterparty risk, that would trigger the central bank's intervention (Smith (2012) showed this for Libor-OIS spread). Therefore, following Quint and Tristani (2018) we use a regression analysis to identify the pure liquidity risk component. Using weekly data from September 2014 to December 2019, we regress the Shibor-TB spread on the interbank repo-TB spread and commercial paper-TB spread. The former measures the counterparty risk in the banking sector while the second amongst corporates[10]. All the rates have one month maturity. Figure 1.2 below shows these spreads while the results of the regression are reported in Annex 1 of this chapter. The R^2 is 61%. The residuals of the regression are free from counterparty risk hence we can use them as our variable for liquidity spreads once converted into monthly frequency. The data are downloaded from CEIC database. The provision of "elastic currency" is highly effective in tightening interest rates (Bindseil, 2004), hence we expect a compression of the liquidity spread in response to a shock to PBoC liquidity injections.

[10]We use the AAA-rated commercial paper because, contrarily to the US market, CP in China are all non asset backed (Lu et al, 2018).

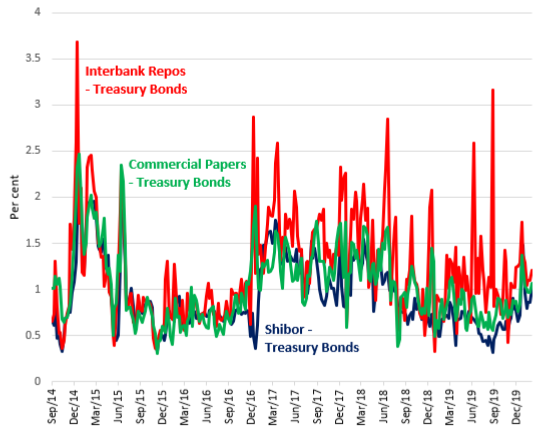


Figure 1.2: Shibor-TB, interbank repo-TB and commercial paper-TB spreads.

Source: CEIC.

- **Monetary Policy Index.** Given that PBoC monetary policy instruments are deployed in unison to achieve multiple objectives (see section 1.2),we need to understand how the central bank's liquidity injections are used in relations to the other tools of monetary policy. Therefore it is convenient to summarise what's left in the PBoC toolbox with one variable. To this end we follow Girardin et al. (2017) and Lodge and Soudan (2019) and construct a Monetary Policy Index, built using the monthly changes of the different tools. The result is a "shadow policy rate". Annex 2 of this chapter explains the construction and it presents the index.

The paper employs three macroeconomic variables to assess the effects of PBoC liquidity injections on the real economy.

- **Output.** To estimate the effects on output, the paper uses the Purchasing Managers' Index (PMI manufacturing). This index is a closely watched indicator of economic activity and the paper uses it because it needs output data with monthly frequency. The PMI is also employed by Fernald et al. (2014) and Breitenlechner and Nuutilainen (2019) as a variable to build an indicator of China's economic activity. Following a central bank liquidity injection, we expect output to accelerate. In fact, as the monetary operation lowers the banks' funding costs, the financial institutions are better positioned to meet the financing demands of the real economy.

- **Investment.** Fixed asset investment (FAI) in infrastructure is used to assess the effects on investment. Infrastructure, in fact, has been a key driver of China's growth (Wilkins and Zurawski, 2014) to the point that local governments engage in infrastructure investment as a policy tool to achieve annual growth targets (Xiong, 2018). We expect investment to increase in response to a central bank liquidity injection. This is due to the lower marginal cost of capital and the banks' improved term structure of liquidity (if it was a long term lending provision).

- **Inflation.** To asses the effect on inflation, the paper uses the Producer Price Index (PPI). This is preferred to the CPI because the latter is highly affected by the food component (Day, 2017). Following Curdia and Woodford (2011), we expect inflation to accelerate following a positive shock to the central bank liquidity injections.

1.5 Model, Identification and Estimation

This section explains the empirical model and the identification strategy, comparing it with the literature.

Following Boeckx et al. (2017), the paper applies a SVAR model to estimate the effects of an exogenous shock to the PBoC liquidity injections on the liquidity spread, the shadow policy rate, output, investment and inflation. This follows a large literature that assesses the macroeconomic impacts of monetary policy shocks, started by Bernanke and Blinder (1992) studying the role of federal funds rate (followed by Bernanke and Mihov (1998); Christiano et al. (1999); Peersman and Smets (2003)). The benchmark model we estimate is the following VAR (2) — the choice of 2 lags of the endogenous variables is informed by the Bayesian Information Criterion (BIC):

$$Y_t = c + B_1 Y_{t-1} + B_2 Y_{t-2} + v_t \tag{1.1}$$

where Y_t is a vector including the six endogenous variables, c is a constant term, B_i are coefficient matrices and v_t is a vector of white noise with covariance matrix Σ.

In order to identify the PBoC liquidity injections shock we use a Cholesky decomposition of Σ. Given that the liquidity spread is allowed to respond contemporaneously to PBoC liquidity injections, the recursive formulation (Cholesky decomposition) is possible only if the innovations in the liquidity spread and in the PBoC liquidity injections are orthogonal to each other. In other words, shocks to the liquidity spreads must not have contemporaneous effects on the PBoC liquidity injections. This condition is satisfied thanks to the construction of the spread variable, signalling "pure liquidity risk" without counterparty risk that would trigger central bank's intervention. Regarding the other variables, the shadow policy rate is allowed to react contemporaneously to PBoC liquidity injections while we assume that output, investment and inflation respond with one period lag. This assumption is common to VAR models studying the effect of monetary policy innovations with monthly estimations (see Bernanke and Blinder (1992 or Christian et al. (1999)). Note that the three macroeconomic variables still have an immediate effect on PBoC decisions. Finally, the Cholesky decomposition yields further orthogonal shocks however the paper doesn't aim to identify them. In the same way of Quint and Tristano (2018), we do not make any claims regarding the effects of the non identified shocks.

In line with Boeckx et al. (2017), we employ a Bayesian method for the estimation of the SVAR model. This approach allows us to incorporate additional information in the estimation process, increasing the precision of the estimates. In light of the relatively short sample period, we set 0.95 as the prior mean for coefficients on own first lag, zero for the others. Following Blake and Mumtaz (2017) we use a Gibbs sampling algorithm to approximate the posterior, imposing a stable draw of the VAR coefficients from its condition posterior.

We note that our identification strategy differs from (Boeckx et al., 2017) that identifies the ECB balance sheet shock using sign restrictions[11]. This method is possible because the ECB reaction function is clear: unconventional monetary policies were taken in reaction to financial turmoil. Indeed the annual growth rate of ECB assets is closely related to a popular indicator of financial stress (CISS) (Boeckx et al., 2017). Contrarily, the reaction function of PBoC liquidity injections is not so unambiguous and changed through time: these operations in fact started in response to changes in the balance of payments and capital outflows but then they continued also during normal market conditions. Hence, without strong, plausible, identifying assumptions, we fall back on the Cholesky decomposition.

[11] The authors disentangle the exogenous shock to the ECB assets from the endogenous response of monetary policy to financial stress imposing that an increase in ECB assets does not increase the CISS.

Our expected results are based on Boeckx et al. (2017) who estimate the effects of an ECB balance sheet expansion. Indeed, we can tentatively draw some similarities between the long-term lending facilities of the two central banks. After June 2014, the focus of the ECB shifted from substituting impaired financial markets — through lending programmes (LTROs) and asset purchases (APP)(Cœuré, 2019) — to support credit growth, strengthening monetary policy transmission using targeted longer-term refinancing operations (TLTROs) (ECB, 2014). Arguably these goals are comparable to the ones driving the PBoC medium and long term lending provisions (MLF, TMLF and PSL). Further similarities arise in terms of borrowing procedure: banks both in the Euro Area and China can borrow as much as they want from the respective central banks, as long as they have enough eligible collateral (this is the "fixed rate full allotment" basis). Finally, banks in the Euro Area and China have both grown reliable on the same source of funding from the central bank: longer-term borrowings now account for almost all of the borrowing from the Eurosystem, and they are increasingly important in China too (BoF, 2019). The main difference is that the TLTRO is a non-standard tool for the ECB, while the MLF, TMLF and PSL sit permanently in the PBoC toolbox. In light of these similarities we expect PBoC liquidity injections to have similar effects to the ECB's: tighter spreads and accelerating economic activity.

1.5.1 PBoC Lending Facility Innovations

Before discussing the impulse responses to a PBoC liquidity shock, we present the time series of the posterior PBoC liquidity injections residuals (Figure 1.3). A rise in the innovations means an expansionary operation, while a decline implies a tightening of the liquidity injections. Comparing Figure 1.3 with the PBoC quarterly Monetary Policy Reports reveals that the posterior residuals match the dates of the liquidity operations. The posterior residuals pick up the large injections that took place in 2015 as a response to capital outflows and slower growth as well as the introduction of daily OMO, one-year MLF (Q2/16) and temporary liquidity support measures (Q1/17). The residuals show a more balanced approach in 2018: this is supported by the Monetary Policy Reports, that highlight a "prudent monetary policy" balancing deleveraging efforts with growth objectives. The impulse responses presented in the next section confirm that the PBoC tools are employed in unison to deliver multiple objectives.

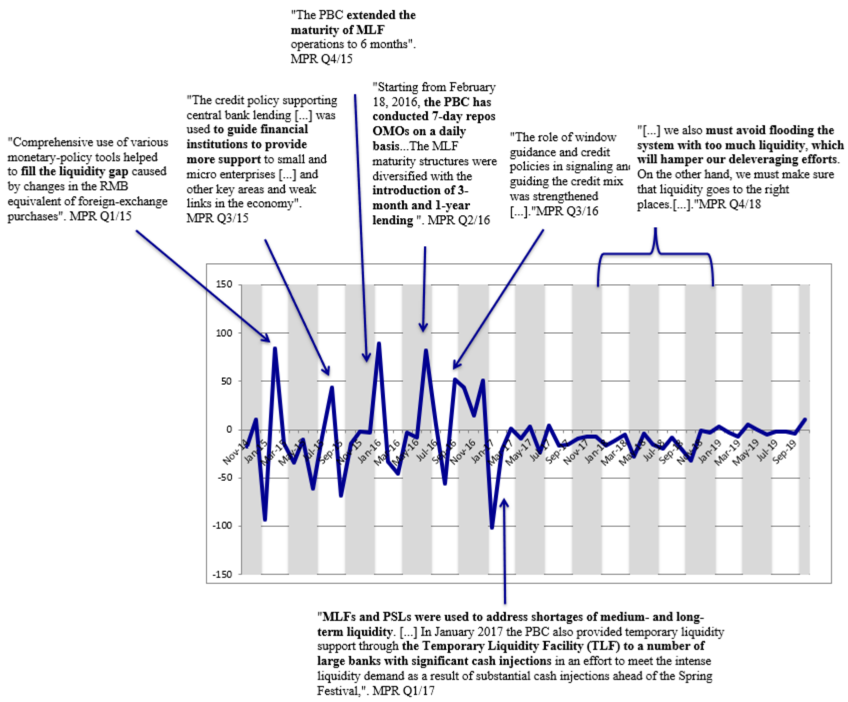


Figure 1.3: Time series of posterior PBoC liquidity injection residuals

1.6 Results

The impulse responses to a one standard deviation PBoC liquidity shock are presented in Figure 1.4 below. The lines represent the median impulse responses of the posterior distribution and the 68% posterior probability of the estimated responses. The exogenous shock takes the form of a 30% yoy increase in the PBoC claims on banks that fades away after about a year. Theoretical expectations (see Curdia and Woodford (2011) and Gertler and Karadi (2011)) indicate that central bank provisions of liquidity lower credit spreads and stimulate economic activity: our findings are consistent with these models.

- **Liquidity spread.** We find that the liquidity spread tightens by 4bps, with the impact lasting less than 5 months. From a policy perspective, the spread compression proves that PBoC liquidity injections stabilise the interbank market, delivering a monetary policy function — stronger policy rate signals — and a financial stability function — they stop the system from sinking into dysfunction. These are important achievements, for three reasons. First, the PBoC needs to anchor volatile interbank rates to strengthen the policy transmission through the interest rate corridor. This supports the flow of credit. Second, ensuring stable interbank rates eases the funding pressures on joint stock, city and rural commercial banks who have increasingly relied on short term funding for their aggressive balance sheet expansion (IMF, 2017). Third, lower liquidity risk allows the large shadow banking sector to deal with its maturity mismatches without triggering liquidity events. The result is similar to Boeckx et al. (2017): they find that the EONIA spread (European Overnight Rate and the ECB's Policy Rate) tightens by 4bps to a positive ECB balance sheet shock and the effect lasts for around 6 months.

Before presenting the effects on the remaining variables, it is helpful to remember the multiplicity of PBoC final objectives. In addition to price stability and financial stability, in fact, former Governor Zhou listed "boosting economic growth, promoting employment, and broadly maintaining balance of payments[...] promote reform and opening up as well as financial market development" (Zhou, 2016). With this in mind we can better assess the effectiveness of PBoC liquidity injections on the remaining variables.

- **Shadow Policy Rate.** We find that the shadow policy rate (monetary policy index) tightens after 5 months. From a policy perspective, the response of shadow rate demonstrates the high degree of coordination amongst PBoC monetary tools, employed in unison to deliver the central bank's multiple objectives. Looking at the sample period, in fact, the higher shadow rate represents the tightening of financial conditions to support the deleveraging campaign (Li, 2016), while the liquidity injections are preemptively carried on to maintain smooth operations in the financial market (PBoC, 2019b). This implies that, should the PBoC avoid tightening, the liquidity injections might have even stronger macroeconomic effects than the ones estimated. Also Boeckx et al. (2017) find that the ECB policy rate tightens after a couple of months since the ECB balance sheet expansion, reflecting the ECB reaction function (output and inflation stabilisation).

- **Investment** Investment reaches 1% yoy growth rate after 8 months, lasting for 2 years. The powerful response is explained theoretically by Cahn et al. (2017) who points to liquidity spread compression as the engine behind the acceleration. From a policy perspective, the significant reaction of investment implies: first that growth during the sample period was still very much investment-driven; second, that the PBoC can rely on an investment-driven boom should it need to boost GDP.

- **Output.** Output (PMI) peaks at 0.4% yoy after 5 months. This result is plausible because it is a fraction of the investment response consistent with the share of investment in GDP. [12] From a policy perspective, the response of output is qualitatively similar to the effect of a typical interest rate cut. Similarl to our result, Boeckx et al. (2017) find that output rises to 0.1% yoy after 9 months.

- **Inflation.** We find inflation (PPI) to have a peak effect at 0.5% yoy after about 8 months. This result is also in line with Boeckx et al. (2017): they find that inflation accelerates to 0.1% yoy after 11 months, broadly following the same path of output.

These results are computationally expensive to estimate so we want to check their sensitivity to a change in the specification. To do this, we omit one variable from the estimation (investment). The results of this exercise are presented in Annex 3 of this chapter. The impulse responses of the liquidity spread, output, inflation and the shadow policy rate are unchanged, confirming the robustness of the results.

[12] Investment as percentage of GDP was 43.03% in 2019. Source: World Bank.

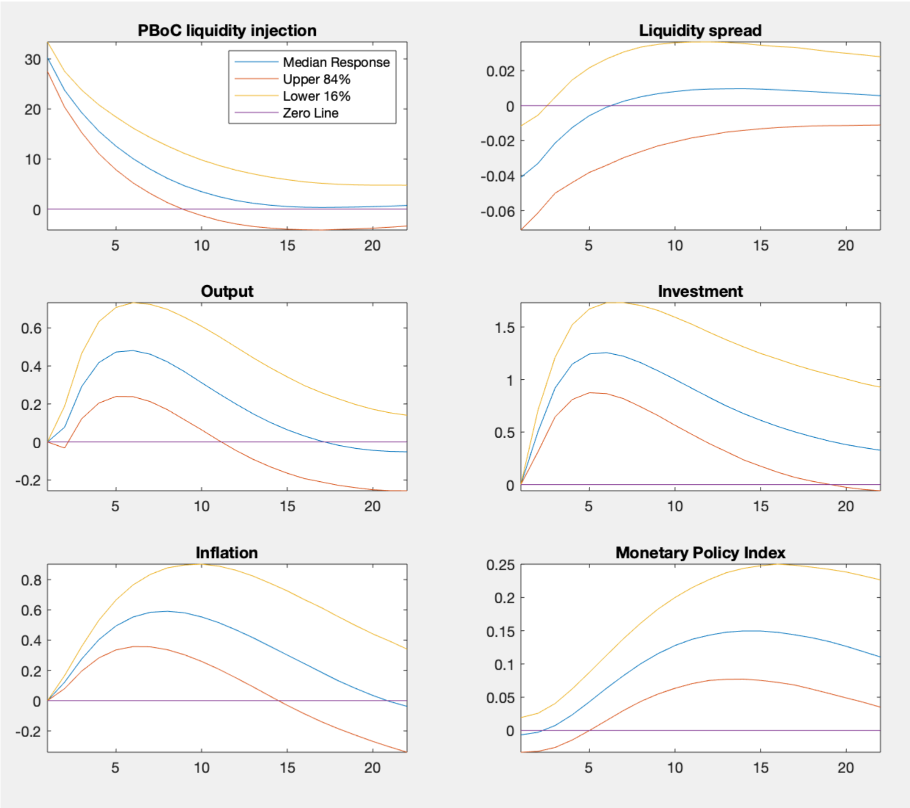


Figure 1.4: Impulse responses to PBoC liquidity injection shock

1.6.1 Policy Implications

The paper draws two policy implications. First, China's conduct of monetary policy is increasingly closer to advanced economies', confirming previous studies (amongst the others, Fu and Wang (2020) and Kim and Chen (2019)). Indeed, PBoC liquidity injections stabilise the interbank market, delivering a monetary policy function — stronger policy rate signals — and a financial stability function — they stop the system from sinking into dysfunction. In short, the recently introduced interest rate-based policy framework is effective in achieving macroeconomic and financial stability objectives.

Second, the paper provides evidence for the ECB to change some aspects of its monetary policy implementation. The ECB launched the third round of TLTRO in March 2019 because stopping the programme meant creating a "congestion effect" as banks would have had to issue large volumes of bonds in a short period of time to replace the central bank' loans, increasing funding costs and hampering credit growth (Praet, 2019). It is plausible to assume that this situation will surface again when the current TLTROs will mature. To avoid "congestion effects" and in light of the similarities with the PBoC long term lending facilities highlighted above, the paper makes the case for transforming the TLTRO into a permanent, conventional facility in the spirit of the PBoC MLF. The interest would be floating, tracking the ECB's MRO. Another policy proposal stems from the observation that the PBoC achieves interest rate targeting allowing banks to determine the size of the monetary base. Hence we propose the ECB to do the same, making the "fixed rate full allotment" procedure permanent, without reverting back to auctioning off fixed amounts of liquidity. This approach in fact would avoid disruptions in the interbank market of the kind experienced in the US during September 2019. This latest proposal is supported also by Whelan (2019) in his Recommendations for the ECB's Monetary Policy Strategy Review to the European Parliament.

1.7 Conclusions

The paper provides a quantitative assessment of PBoC liquidity injections since the lending facilities became the main channel to supply base money. Using a SVAR model, we identify an exogenous shock to the PBoC liquidity injections and estimate its effects on several key variables for China's macroeconomy. We find that the liquidity injections compress liquidity spreads, enhancing the policy rate signals and supporting the flow of credit. This is particularly important in light of the increasing dependence of banks on wholesale funding. We also find that output, infrastructure investment and the price level increase temporarily. Finally, monetary policy conducted through the remaining tools tends to tighten, targeting financial stability risks and economic rebalancing. Overall, PBoC constellation of liquidity injections guide rates, improving funding conditions and supporting economic activity. These results confirm that China's conduct of monetary policy is increasingly closer to advanced economies'.

As far as we know, this is the first attempt in the literature to quantitatively assess the effects of PBoC liquidity injections. Therefore future research will find promising to use a theoretical model to shed light on the transmission mechanism. Another avenue for future research is the estimation of the impacts of the PBoC liquidity injections shocks in the individual provinces.

Annex 1

We use a regression analysis to identify the pure liquidity risk component. Using weekly data from September 2014 to December 2019 we regress the Shibor-TB spread on the interbank repo-TB spread and commercial paper-TB spread.

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	0.16271	0.039236	4.1469	4.4677e-05
x1	0.05445	0.037836	1.4391	0.15123
x2	0.67464	0.052298	12.9	3.2289e-30

Number of observations: 284, Error degrees of freedom: 281
Root Mean Squared Error: 0.234
R-squared: 0.608, Adjusted R-Squared: 0.605
F-statistic vs. constant model: 218, p-value = 7.24e-58

Figure 1.5: Regression results.

Annex 2

The construction of the Monetary Policy Index is carried on in four phases.

- Stage 1. First we select the instruments:
  - The RRR. Banks have different RRR according to their size. Therefore the overall RRR is estimated as 50% RRR for large banks + 25% RRR for medium banks + 25% RRR for small banks.
  - The benchmark lending rate and deposit rate. Even if both have them have been lifted, they are still widely used by banks for pricing.
  - The 7-day reverse repo rate. Since February 2016, the PBC has conducted OMO on a daily basis, and the 7 day reverse repo rate has effectively become the quasi-policy rate, serving as a benchmark for the money market (Wang, 2019).
  - The 7-day Standing Lending Facility. This is the upper bound of the interest rate corridor. The lower bound is the remuneration on banks' excess reserves (absent from our index because unchanged during the sample period).
- Stage 2. We compute a monthly "27 basis-point equivalent" change in the policy rate for each instrument. All the tools have equal weight.
- Stage 3. We include the different changes into a monthly change.
- Stage 4.We cumulate the changes to create the index, starting in September 2014 using the benchmark lending rate in that month as starting point.

Figure 1.6 shows the monthly Monetary Policy Index. This shadow policy rate is characterised by an hiking cycle starting in the second half of 2016: this tighter stance of monetary policy represents the financial deleveraging campaign, implemented to contain the fast growing leverage in the financial sector. A looser monetary policy was implemented since mid 2018. These results are consistent with the monetary policy stance indicator of Funke and Tsang (2019) . Given that the PBoC uses in unison the different monetary tools to achieve multiple final objectives, we expect the shadow policy rate to tighten in response to a central bank liquidity injection. This decision would respond to the financial stability objective, while the liquidity injection would deliver price stability and the growth target.

Figure 1.6: China's Monetary Policy Index.

Source: Datastream.

Annex 3

To run a robustness check we omit investment from the estimation. The impulse responses to a PBoC liquidity injection shock are unchanged from the main results presented in Figure 1.4. This confirms the robustness of the estimation.

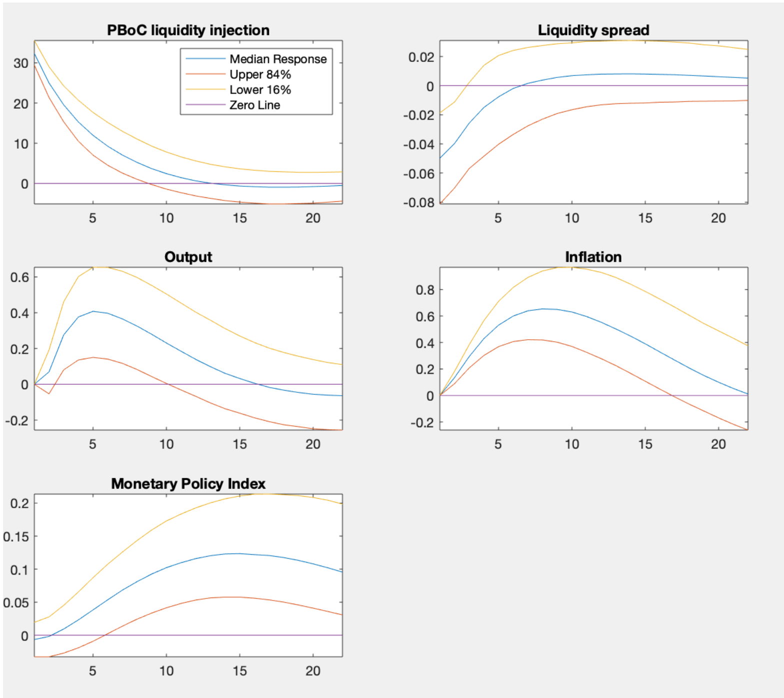


Figure 1.7: Impulse responses to PBoC liquidity injection shock

Chapter Two

The Interaction Between Unconventional Monetary Policy and Macro-prudential Policy

Using a DSGE model, this chapter studies how macro-prudential policy in the form of a countercyclical capital buffer affects the transmission of three unconventional monetary policy instruments: quantitative easing, negative interest rate policy and forward guidance.

"Non-standard policy tools are here to stay: they have evolved to become part of the standard monetary policy armoury."

Huw Pill, Chief Economist of the Bank of England, October 2021

2.1 Introduction

Since 2008 central banks in advanced economies have engaged in unconventional monetary policy (UMP) to deliver on their targets. The constraint imposed by the effective lower bound limited conventional monetary policy (Borio, 2020): nominal short-term rates could not be lowered any further despite disinflationary pressures. Hence central banks have focused on compressing long-term rates and enhancing the transmission of the policy stance through five unconventional tools, used mostly in combination: i) quantitative easing (QE), ii) forward guidance (FG), iii) negative interest rate policy (NIRP), iv) funding-for-lending programmes and, v) yield curve control (YCC).[1]

The Global Financial Crisis of 2007-2008 created challenges not only for monetary policymakers but also for macro-prudential authorities, given the fragilities in the financial system it revealed. In response, there has been an expansion of macro-prudential tools to improve the financial sector's resilience.[2] Amongst these tools, Basel III introduced the countercyclical capital buffer (CCyB): this is an instrument to protect the banking sector from periods of excessive credit growth, often associated with higher systemic risk (BIS, 2010). Given its countercyclical nature, this additional cushion of capital is released during downturns, reducing the risk that capital requirements constrain the supply of credit, weakening the real economy and eventually the banking sector.

More recently, in response to the Covid-19 pandemic, central banks cut the policy rate to the effective lower bound and then resorted to a combination of non-standard monetary tools: between February 2020 and February 2021, 39 central

[1]For a detailed analysis of QE transmission mechanisms, please see Haldane et al. (2016) and Bailey et al. (2020). For a review of FG see Campbell et al. (2012) and across countries see Filardo and Hofmann (2014). For a discussion on NIRP conceptual issues, transmission mechanism and evidence, see Brandao-Marques et al. (2021), Heider et al. (2021), Tenreyro (2021) and de Groot and Haas (2020). For more details on funding-for-lending programmes, see Rostagno et al. (2019) on the ECB's lending programmes and Eberly et al. (2020) on BoE's TFS. For a review of BoJ YCC, see Higgins and Klitgaard (2021)

[2]For a review, see Ampudia et al. (2021).

banks in advanced economies and emerging markets surveyed by BIS, announced 36 lending programmes and 22 asset purchases programmes (Cantú et al., 2021). The unprecedented size of the monetary policy response and the large number of uses of central bank balance sheets caused central banks' assets to surge.[3] At the same time, negative rates were maintained in the same jurisdictions that had deployed them before the pandemic and forward guidance was strengthened, becoming more detailed.[4] Finally, YCC was continued by the Bank of Japan and introduced by the Reserve Bank of Australia (Lowe, 2020).[5] Overall, by offsetting the tight financial conditions, the combination of unconventional tools aimed to support output.[6]

During the Covid-19 crisis monetary tools were complemented by macro-prudential policies aimed at supporting the supply of credit. In particular, 15 major central banks lowered the CCyB — for the first time since the tool had been introduced — and some authorities also restricted dividends (Hardy (2021) and Aikman (2020)). BIS (2021) found that amongst the Basel member jurisdictions that released the CCyB during the pandemic, there is a positive and statistically significant coefficient between CCyB release and loan growth.

This dual strategy begs the question: *How does the implementation of macro-prudential policy in the form of a countercyclical capital buffer change the effectiveness of UMP tools?* In other words, does macro-prudential policy *enhance* or *hinder* the efficacy of UMP? If the introduction of CCyB allows UMP to deliver a higher level of output stabilisation and to be less aggressive, then we can conclude that macro-prudential policy increases UMP's effectiveness.

Policymakers noted that powerful synergies arise when multiple monetary and macro-prudential instruments are used in combination. ECB President Lagarde

[3]For instance, as of September 2021, the Bank of England has accumulated almost GBP1 trillion worth of assets (45% of UK GDP).

[4]For the Fed, see the FOMC statements issued on 15th March 2020 and 16th December 2020.

[5]The RBA started targeting the yield on 3-year Australian Government bonds at around 0.25 per cent.

[6]It is worth mentioning that i) even if UMP had predominantly positive effects, its prolonged use caused side effects (for more details on the negative effects of UMP on market functioning, please read BIS (2019a), while for a theoretical paper on QE addictiveness, see Karadi and Nakov (2021)) and it triggered concerns over the possibility of hitting the reversal interest rate — the turning point when accommodative monetary policy becomes contractionary; ii) as the recovery gains pace, the necessity to unwind central bank's asset purchases — a process known as Quantitative Tightening (QT) — poses critical questions on the new, broader roles of the central bank balance sheets going forward and on the pace of the QT process (Hauser, 2021a).

(2020) highlighted that ECB lending programmes[7] have capitalised on the negative interest rate policy by focusing the negative rates' impulse directly to lenders.[8] ECB Vice President de Guindos (2021) argued for an increased role in macro-prudential policy of the ECB Governing Council, given the complementarities with monetary policy demonstrated during the Covid crisis. Similarly, former Bank of England Governor Carney (2014) announced that the Bank would use its policy tools in concert to support the ongoing expansion. This "concerted effort" caused Ferrero et al. (2017) to question whether we had entered a new era of central banking, one in which monetary policy would focus on interest rate setting and financial stability would deploy macro-prudential tools.[9]

Despite policymakers' interest in understanding these synergies better, the literature has not given a definitive answer. Most papers study the interaction between capital requirements and conventional monetary policy — but not UMP. Those papers that instead include UMP, study the effects of macro-prudential policies on the transmission of a single unconventional monetary tool (Altavilla et al' (2020) and Darracq Paries et al. (2020)). Hence, they do not discover interactions amongst the several instruments and the most effective combination in terms of output stabilisation and policy stance. Overall, the role of macro-prudential policy in a low/negative environment is still under debate.

This chapter focuses on the interaction between three unconventional monetary policy tools — Quantitative Easing, Negative Interest Rate Policy and Forward Guidance — and one instrument of macro-prudential policy — the CCyB. In particular, this chapter fills the gap in the literature by studying theoretically how capital requirements affect the transmission of QE, NIRP and FG in a unified framework. The modelling relies on the tractable workhorse model developed by Sims and Wu (2021) that nests the three non-standard tools. This model is used to incorporate a macro-prudential rule in the form of CCyB.

We make four main contributions. The first one uncovers the transmission of UMP: with the introduction of CCyB, we find that QE's transmission mechanism is weakened but NIRP's is slightly strengthened. The other three contributions reveal synergies between UMP and macro-prudential policy, making three new,

[7]More specifically the targeted longer-term refinancing operations (TLTROs).

[8]Similar complementarities were noted by the external member of the Bank of England MPC Saunders (2020), by the Bank of England Chief Economist Huw Pill (2021a) and by the Governor of the Reserve Bank of New Zealand Orr (2020)

[9]This is a relatively new approach, i.e. complementarity of measures aiming to work together.

strong cases for the simultaneous deployment of UMP and CCyB: i) using CCyB and QE in unison is more effective at stabilising output than solely relying on QE and it allows UMP to be less aggressive — this confirms the Bank of England's concerted strategy of delivering monetary and macro-prudential policy simultaneously to support the recovery (Carney, 2014); ii) UMP has a reversal interest rate, but the powerful interactions between NIRP, QE and CCyB can be used strategically to avoid this reversal rate, increasing NIRP effectiveness. These synergies are particularly important from a policy perspective because central banks that deployed NIRP had already engaged in QE before, so we must take into account the size of the central bank balance sheet when we assess NIRP effectiveness; iii) once the QE programme is over, monetary policy makers must take decisions on the timing of the unwinding of the central bank's balance sheet: we find that if they had deployed QE and CCyB simultaneously, they can start the normalisation process (the so called Quantitative Tightening) earlier and with more policy space to change the tightening pace without triggering an adverse market reaction and a severe economic contraction — this result answers the question by BoE Hauser (2021a) on how the central bank balance sheet going forward should be: "Bigger, broader, faster, stronger?"

Our results are timely and relevant for policymakers. Unconventional monetary policy, in fact, is rapidly becoming conventional (Bernanke (2020), Lagarde (2020) and Schnabel (2021)). This is the result of the decline in the equilibrium real interest rate r* (Negro et al., 2017) and the possible long term consequences of the Covid crisis (Jorda et al., 2020). In a "lower for longer" environment with relatively limited policy space (Saunders, 2020), central banks need to find the most effective monetary policy and macro-prudential policy combination to deliver on their targets. At the same time, the prolonged use of NIRP in some jurisdictions became source of concern as it increased the possibility of hitting the reversal interest rate (Darracq Pariès et al., 2020). Hence, it is important to identify the conditions necessary to avoid accommodative monetary policy from becoming contractionary. Finally, as central banks have started to rein in QE programmes, it is critical to understand the options available should a change to the pace of Quantitative Tightening be needed. Policymakers flagged that these topics "have received limited academic attention" in recent years (Hauser, 2021a): we offer some of the first recommendations.

The remainder of the chapter is organised as follows. Section 2.2 presents a short review of the relevant literature. Section 2.3 explains the main features of the model, focusing on the rich financial sector, especially financial intermediaries and the central bank. Section 2.4 shows the calibration of the model. Section 2.5 presents the quantitative analysis, divided in five parts: first, we simulate a credit shock with conventional monetary policy to explore the mechanisms through which the introduction of CCyB affects output. Second, we simulate three exogenous UMP shocks with and without CCyB to assess how the introduction of macro-prudential policy affects the transmission of QE, NIRP and FG. Third, we make QE endogenous and we simulate a credit shock: this allows us to see the synergies between UMP and CCyB that are triggered when a non-monetary shock hits the economy. Fourth, the paper links QE, NIRP and CCyB, looking for synergies to avoid the reversal rate. Finally, the fifth set of simulations explores different scenarios of central bank's balance sheet unwinding with and without CCyB, to assess the implications of macro-prudential policy for Quantitative Tightening. Finally, section 2.6 concludes.

2.2 A Review of the Literature

This chapter relates to three streams of literature applying DSGE models: the fast growing body of research that studies UMP (including the emerging research on the unwinding of central banks' asset purchases); the literature investigating the interactions between UMP and macro-prudential policy; and finally recent studies on the reversal interest rate.

Kuttner (2018) offers a review of the research on UMP that has been carried out since the Global Financial Crisis. However, the papers applying DSGE models to study UMP introduce the non-standard tools in a piecemeal fashion.[10] Since UMP tools are typically deployed in combination, modelling them in isolation does not enable us to gauge the overall macroeconomic effects nor the synergies amongst them.[11] Our paper, instead, relies on Sims and Wu (2021) that is one of the few papers building in QE, NIRP and FG *in a single framework*. This is an important recent attempt that has received attention from policymakers, welcome by the Fed and BoE. We chose to build on this contribution because it is highly tractable (allowing different policy simulations) yet rigorous — incorporating prominent

[10] For instance Gertler and Karadi (2013) for QE and Wu and Xia (2018) for NIRP.

[11] In response to this challenge, some DSGE models started including shadow rates as indicators of the total accommodation provided by both conventional and unconventional monetary policies (Mouabbi and Sahuc, 2019) — nonetheless, UMP tools were not fully fledged modelled.

frictions from the macro-finance literature. In addition, while most of the UMP literature concentrates on QE, we also focus on the unwinding of central bank's asset purchases, the so called Quantitative Tightening. The scarce evidence of these programmes[12] has resulted in a thin empirical (D'Amico and Seida (2020) and Copeland et al. (2021)) as well as theoretical literature (Karadi and Nakov (2021) and Sims and Wu (2021)), with most of the evidence coming from central banks' speeches.[13] The paper adds to the theoretical literature by showing the important benefits that macro-prudential policy can bring to the QT process.

Papers investigating the interactions between macro-prudential and monetary policy have mostly focused on conventional monetary policy (Beyer et al., 2017). The few papers that instead link macro-prudential policy with UMP do so by analysing the effects only with QE (Darracq Paries et al., 2020). Macro-prudential policy is found to weaken the transmission mechanism of both conventional monetary policy and central banks' asset purchases. Most recently, Darracq Paries et al. (2020) have developed a DSGE model to study the complementarities between macro-prudential policy and NIRP and found that the presence of a reversal interest rate is a novel motive for introducing a countercyclical capital buffer. However, these are *ad-hoc* frameworks, that do not allow the study of interactions nor the comparison of the effects amongst the different non-standard tools and macro-prudential policy. Our paper, instead, is able to assess, in a unified framework, the interrelations between three different UMP tools and macro-prudential policy, introduced as in Gertler et al. (2012).

Finally, our paper relates to the fast growing literature on NIRP and the reversal interest rate. This is a concept developed by Brunnermeier and Koby (2018), indicating that accommodative monetary policy can turn contractionary and reduce lending. Regarding DSGE models for NIRP, Ulate (2021) and Eggertsson et al. (2019) find that negative rates compress banks' profits. Our model includes this channel of transmission but it also adds the interaction with QE and with a countercyclical capital buffer, finding synergies to avoid the reversal rate. This is important from a policy perspective because central banks that deployed NIRP had already engaged in QE before, so we must take this into account when offering policy recommendations.

[12]For more details on the programmes of asset purchases unwinding please read Bis (2019a).

[13]See for instance Bullard (2017) for the Fed and Hauser (2019) and Hauser (2021a) for the Bank of England.

2.3 The Model

Taking the medium-scale DSGE model of Sims and Wu (2021) as baseline, this paper adds macro-prudential policy following Gertler et al. (2012) (GKQ). The main characteristic of GKQ is the possibility for a financial intermediary to raise funds by supplying outside equity to households (as well as deposits). In addition, the bank has its own net worth — accumulated from retained earnings (referred to as inside equity). In short, inside equity can be thought of as common stock and outside equity as subordinated debt. Importantly, the model introduces a funding trade-off between outside equity and deposits: because of its hedging value, the financial intermediary would prefer to increase the fraction of outside equity, but doing so would result in a tighter incentive constraint. While the solution to the trade-off is endogenous, we exploit this friction to introduce a CCyB and assess its effects on the transmission of monetary policy.

There are multiple agents in the model: 1) a representative household; 2) a labour market; production is modelled following a standard framework as in Smets and Wouters (2007) with 3) a capital goods producing firm; 4) a representative wholesale firm; 5) a continuum of retail firms, and 6) a final good firm; in addition there are also 7) a fixed number of financial intermediaries; 8) a fiscal authority; 9) and the central bank which conducts monetary policy and macro-prudential policy. These blocks are presented in the following sections. Annex 5 of this chapter presents the equilibrium conditions.

2.3.1 Households

The utility of the representative household follows equation 2.1 below, with C_t being consumption and L_t labour supply:

$$U_0 = E_t \sum_{t=0}^{\infty} \beta^t \left\{ ln(C_t - bC_{t-1}) - \chi \frac{L_t^{1+\eta}}{1+\eta} \right\} \tag{2.1}$$

Households receive nominal wage MRS_t from selling labour to unions and dividends from holdings in non-financial firms DIV_t as well as from holding banks' external equity $Q_{H,t}H_t$. Each period, households transfer equity X to newly born intermediaries and pay a tax T_t to the government. The budget constraint in nominal terms is the following:

$$P_tC_t + D_t + Q_{H,t}H_t \leq MRS_tL_t + R^D_{t-1}D_{t-1} + R^H_t Q_{H,t-1}H_{t-1} + DIV_t - P_tT_t - P_tX_t \quad (2.2)$$

Maximising with respect to C_t, L_t, D_t and H_t, we find the following:

$$\mu_t = \frac{1}{(C_t - bC_{t-1})} - \beta b E_t \frac{1}{(C_{t+1} - bC_t)} \quad (2.3)$$

The above FOC defines the marginal utility of consumption, μ_t.

$$\chi L_t^{\eta} = \mu_t mrs_t \quad (2.4)$$

The above FOC is the labour supply condition.

$$1 = R^D_t E_t \Lambda_{t,t+1} \Pi^{-1}_{t+1} \quad (2.5)$$

The above is the FOC for deposits.

$$1 = E_t \Lambda_{t,t+1} \Pi^{-1}_{t+1} R^H_{t+1} \quad (2.6)$$

The above is the FOC for external equity.

2.3.2 Labour Market

. The labour market has two tiers: a labour packer and labour unions.

2.3.2.1 Labour packer

The labour packer buys union labour $L_{d,t}(h)$ at $W_t(h)$ and converts it into the labour ready for production, $L_{d,t}$, using a CES technology with elasticity of substitution $\varepsilon_w > 1$:

$$L_{d,t} = \left(\int_0^1 L_{d,t}(h)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dh \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \quad (2.7)$$

The labour packer sells $L_{d,t}$ to production firms at W_t, the aggregate wage. The maximisation problem of the labour packer is the following:

$$maxW_t = \left(\int_0^1 L_{d,t}(h)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dh \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} - W_t(h) L_{d,t}(h) \tag{2.8}$$

The FOC with respect to $L_{d,t}(h)$ is the standard labour demand function:

$$L_{d,t}(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\varepsilon_w} L_{d,t} \tag{2.9}$$

The labour packer sells $L_{d,t}$ to production firms at W_t, the aggregate wage, according to:

$$W_t^{1-\varepsilon_w} = \int_0^1 W_t(h)^{1-\varepsilon_w} dh \tag{2.10}$$

2.3.2.2 Labour Union

Labour unions — indexed by h and subject to Calvo wage rigidity — buy labour from households at MRS_t and sell it to the labour packer. The nominal profit of a labour union is:

$$DIV_{L,t}(h) = W_t(h) L_{d,t}(h) - MRS_t L_t(h) \tag{2.11}$$

Assuming $L_t(h) = L_{d,t}(h)$ and plugging in the demand function 2.9:

$$DIV_{L,t}(h) = W_t(h)^{1-\varepsilon_w} W_t^{\varepsilon_w} L_{d,t} - MRS_t W_t(h)^{-\varepsilon_w} W_t^{\varepsilon_w} L_{d,t} \tag{2.12}$$

Labour unions are subject to Calvo wage rigidity: Each period there is a $1 - \phi_w$ probability (with $\phi_w \in$ [0,1]) that a union can update its nominal wage. At time $t + j$, there is a ϕ_w^j probability that the wage chosen at time t is still valid. Wages that are not changed can be be indexed to lagged inflation at $\gamma_w \in$ [0,1]. Hence, nominal wage at $t + j$ for a non-updating union since t is: $W_t(h) \left(\frac{P_{t+j-1}}{P_{t-1}} \right)^{\gamma_w}$. The maximisation problem of a union that updates its wage at time t choosing a new

$W_t(h)$ is:

$$\begin{aligned}max\mathbb{E}\sum_{j=0}^{\infty}\phi_w^j\Lambda_{t,t+j}\Bigg[\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\varepsilon_w)\gamma_w}W_t(h)^{1-\varepsilon_w}P_{t+j}^{\varepsilon_w-1}w_{t+j}^{\varepsilon_w}L_{d,t+j}\\ -mrs_{t+j}\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\varepsilon_w\gamma_w}W_t(h)^{-\varepsilon_w}P_{t+j}^{\varepsilon_w}w_{t+j}^{\varepsilon_w}L_{d,t+j}\Bigg]\end{aligned} \tag{2.13}$$

The FOC with respect to $W_t(h)$ is:

$$\begin{aligned}(\varepsilon_w-1)W_t(h)^{-\varepsilon_w}\mathbb{E}\sum_{j=0}^{\infty}\phi_w^j\Lambda_{t,t+j}\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\varepsilon_w)\gamma_w}P_{t+j}^{\varepsilon_w-1}w_{t+j}^{\varepsilon_w}L_{d,t+j}=\\ \varepsilon_wW_t(h)^{-\varepsilon_w-1}\mathbb{E}\sum_{j=0}^{\infty}\phi_w^j\Lambda_{t,t+j}mrs_{t+j}\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\varepsilon_w\gamma_w}P_{t+j}^{\varepsilon_w}w_{t+j}^{\varepsilon_w}L_{d,t+j}\end{aligned} \tag{2.14}$$

If we isolate $W_t(h)$ we note that nothing else in equation 2.14 depends on h index: in other words, all the unions that can update, set the same wage. So we can write without h the optimal W_t^*:

$$W_t^*=\frac{\varepsilon_w}{\varepsilon_w-1}\frac{F_{1,t}}{F_{2,t}} \tag{2.15}$$

Where $F_{1,t}$ and $F_{2,t}$ are:

$$F_{1,t}=mrs_tP_t^{\varepsilon_w}w_t^{\varepsilon_w}L_{d,t}+\phi_w\Lambda_{t,t+1}\Pi_t^{-\varepsilon_w\gamma_w}F_{1,t+1} \tag{2.16}$$

$$F_{2,t}=P_t^{\varepsilon_w-1}w_t^{\varepsilon_w}L_{d,t}+\phi_w\Lambda_{t,t+1}\Pi_t^{(1-\varepsilon_w)\gamma_w}F_{2,t+1} \tag{2.17}$$

Knowing that w_t is the aggregate real wage given by 2.10, $f_{1,t}=F_{1,t}/P_t^{\varepsilon_w}$, $f_{2,t}=F_{2,t}/P_t^{\varepsilon_w-1}$ and dividing by the aggregate price level P_t, we obtain real $w_t^*=W_t^*/P_t$ equal to:

$$w_t^*=\frac{\varepsilon_w}{\varepsilon_w-1}\frac{f_{1,t}}{f_{2,t}} \tag{2.18}$$

With:

$$f_{1,t} = mrs_t w_t^{\varepsilon_w} L_{d,t} + \phi_w \mathbb{E}\Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\varepsilon_w} f_{1,t+1} \tag{2.19}$$

$$f_{2,t} = w_t^{\varepsilon_w} L_{d,t} + \phi_w \mathbb{E}\Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\varepsilon_w - 1} f_{2,t+1} \tag{2.20}$$

For the aggregation of the labour market, please see Annex 1.

2.3.3 Modelling long term bonds

The fiscal authority (section 2.3.7) and a representative wholesale firm (subsection 2.3.4.3) issue long term bonds. The long term bonds are modelled as perpetuities with decaying coupon payments following Woodford (2001). The cash flow of coupon payments is 1 in period $t+1$, k in period $t+2$, k^2 in period $t+3$, etc. The new bond's price at time t is Q_t, while the price of the bonds issued at time $t-i$ is $k^i Q_t$, thanks to the decaying coupon payments. The bonds' duration is $(1-k)^{-1}$ and the gross yield to maturity is $Q_t^{-1} + k$. Letting CI_t being the new bonds issued, the total coupon due at period t is:

$$F_{t-1} = CI_{t-1} + kCI_{t-2} + k^2 CI_{t-3} + \dots \tag{2.21}$$

Iterating the above equation we obtain the new bond issuance, critical in the wholesale firm problem (equation 2.42):

$$CI_t = (F_t - kF_{t-1}) \tag{2.22}$$

Finally, thanks to the decaying coupon payments, the outstanding bonds at time t can be written as:

$$Q_t F_t = Q_t CI_t + kQ_t CI_{t-1} + k^2 Q_t CI_{t-2} + \dots \tag{2.23}$$

2.3.4 Production

As in Sims and Wu (2021) there are four types of firms interacting in the model: i) a capital goods producer that creates physical capital $\hat{I}$; ii) a representative wholesale firm that transforms capital and labour into wholesale output; iii) wholesale output is purchased and repackaged by a continuum of retail firms that sell (retail) output to a final good firm; iv) the final goods firm creates a final good combining retail outputs. The main difference from a standard framework is the modelling of the representative wholesale firm that becomes critical in the transmission of unconventional monetary policy.

2.3.4.1 Final Goods Firm

A final goods firm buys and combines retail outputs from retail firms — indexed by f — at $P_t(f)$ and sells it at P_t. For the production of Y_t, the final goods firm uses a CES technology with elasticity of substitution $\varepsilon_p > 1$, creating:

$$Y_t = \left(\int_0^1 Y_t(f)^{\frac{\varepsilon_p - 1}{\varepsilon_p}} df \right)^{\frac{\varepsilon_p}{\varepsilon_p - 1}} \tag{2.24}$$

The maximisation problem of the final goods firm is the following:

$$maxP_t \left(\int_0^1 Y_t(f)^{\frac{\varepsilon_p - 1}{\varepsilon_p}} dh \right)^{\frac{\varepsilon_p}{\varepsilon_p - 1}} - P_t(f) Y_t(f) \tag{2.25}$$

The FOC with respect to $Y_t(f)$ is the below standard retail output demand function:

$$Y_t(f) = \left(\frac{P_t(f)}{P_t} \right)^{-\varepsilon_p} Y_t \tag{2.26}$$

While the aggregate price (price of the final output good) P_t is:

$$P_t^{1-\varepsilon_p} = \int_0^1 P_t(f)^{1-\varepsilon_p} df \tag{2.27}$$

2.3.4.2 Retail firms

Retail firms buy at $P_{m,t}$ and repackage wholesale output $Y_{m,t}$ and sell it to a final goods firm ($Y_{m,t}(f) = Y_t(f)$) at $P_t(f)$.

The profit of a retail firm is:

$$DIV_{R,t}(f) = P_t(f)Y_t(f) - P_{m,t}Y_{m,t}(f) \tag{2.28}$$

Since $Y_{m,t}(f) = Y_t(f)$, we use 2.26 to obtain:

$$DIV_{R,t}(f) = P_t(f)^{1-\varepsilon_p} P_t^{\varepsilon_p} Y_t - P_{m,t} P_t(f)^{-\varepsilon_p} P_t^{\varepsilon_p} Y_t \tag{2.29}$$

Retail firms are subject to Calvo price rigidity: Each period there is a $1-\phi_p$ probability (with $\phi_p \in$ [0,1]) that a retail firm can update its price. At time $t+j$, there is a ϕ_p^j probability that the price chosen at time t is still valid. Prices that are not changed can be indexed to lagged inflation at $\gamma_p \in$ [0,1]. Hence, a price at $t+j$ for a non-updating retail firm since t is: $P_t(f)\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{\gamma_p}$. The maximisation problem of a retail firm that updates its price at time t choosing a new $P_t(f)$ is the following:

$$max \mathbb{E} \sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} \left[P_t(f)^{1-\varepsilon_p} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\varepsilon_p)\gamma_p} P_{t+j}^{\varepsilon_p - 1} Y_{t+j} - P_{m,t+j} P_t(f)^{-\varepsilon_p} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\varepsilon_p \gamma_p} P_{t+j}^{\varepsilon_p - 1} Y_{t+j} \right] \tag{2.30}$$

The FOC with respect to $P_t(f)$ is:

$$\begin{aligned} (\varepsilon_p - 1) P_t(f)^{-\varepsilon_p} \mathbb{E} \sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\varepsilon_p)\gamma_p} P_{t+j}^{\varepsilon_p - 1} Y_{t+j} = \\ \varepsilon_p P_t(f)^{-\varepsilon_p - 1} \mathbb{E} \sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} P_{m,t+j} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\varepsilon_p \gamma_p} P_{t+j}^{\varepsilon_p} Y_{t+j} \end{aligned} \tag{2.31}$$

We denote two variables:

$$X_{1,t} = \sum_{j=0}^{\infty} (\phi_p \beta)^j \frac{\mu_{t+j}}{\mu_t} P_{m,t+j} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\varepsilon_p \gamma_p} P_{t+j}^{\varepsilon_p} Y_{t+j} \tag{2.32}$$

$$X_{2,t} = \sum_{j=0}^{\infty} (\phi_p \beta)^j \frac{\mu_{t+j}}{\mu_t} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\varepsilon_p)\gamma_p} P_{t+j}^{\varepsilon_p - 1} Y_{t+j} \tag{2.33}$$

That written recursively are:

$$X_{1,t} = p_{m,t} P_t^{\varepsilon_p} Y_t + \phi_p \Lambda_{t,t+1} \Pi_t^{-\varepsilon_p \gamma_p} X_{1,t+1} \tag{2.34}$$

$$X_{2,t} = P_t^{\varepsilon_p - 1} Y_t + \phi_p \Lambda_{t,t+1} \Pi_t^{1-\varepsilon_p \gamma_p} X_{2,t+1} \tag{2.35}$$

If we isolate $P_t(f)$, we note that nothing else in equation 2.31 depends on f index, so we deduce that all the retailers that can update their price, will set the same, P_t^*. Hence, 2.31 can be re-written as:

$$P_t^* = \frac{\varepsilon_p}{\varepsilon_p - 1} \frac{X_{1,t}}{X_{2,t}} \tag{2.36}$$

Knowing that $x_{1,t} = X_{1,t}/P_t^{\varepsilon_p}$, $x_{2,t} = X_{2,t}/P_t^{\varepsilon_p - 1}$, $p_{m,t} = \frac{P_{m,t}}{P_t}$ and $p_t^* = P_t^*/P_t$, we obtain:

$$p_t^* = \frac{\varepsilon_p}{\varepsilon_p - 1} \frac{x_{1,t}}{x_{2,t}} \tag{2.37}$$

$$x_{1,t} = p_{m,t} Y_t + \phi_p \mathbb{E} \Lambda_{t,t+j} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\varepsilon_p} x_{1,t+1} \tag{2.38}$$

$$x_{2,t} = Y_t + \phi_p \mathbb{E} \Lambda_{t,t+j} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\varepsilon_p - 1} x_{2,t+1} \tag{2.39}$$

For the aggregation of the retail firms, please see Annex 2.

2.3.4.3 Wholesale firm

The representative wholesale firm follows a Cobb-Douglas production function:

$$Y_{m,t} = A_t (u_t K_t)^{\alpha} L_{d,t}^{1-\alpha} \tag{2.40}$$

Where Y_m is output, $L_{d,t}$ is the labour factor of production, A_t is a productivity variable that follows an AR(1) process, K_t is the stock of firm's capital that is multiplied by u_t, the capital utilisation. K_t is accumulated following the standard law of motion:

$$K_{t+1} = \hat{I}_t + (1 - \delta(u_t))K_t \tag{2.41}$$

Where δ is the depreciation rate. Following Carlstrom et al. (2017) and Sims and Wu (2021), this paper imposes that the representative wholesale firm issues perpetual bonds to buy the fixed fraction $\psi \in [0,1]$ of new physical capital $\hat{I}$. This friction creates the "loan in advance constraint" that is always binding by construction:

$$\psi P_t^k \hat{I}_t \leq Q_t CF_{m,t} = Q_t(F_{m,t} - \kappa F_{m,t-1}) \tag{2.42}$$

With P_t^k being the price of new capital. To impose this binding constraint I assume that the wholesale firm prefers bond issuance over internal funding as its main financing source. While this assumption is not consistent with data if we consider the overall business cycle,[14] it becomes a realistic assumption if we focus on zero lower bound (ZLB) periods — like we do in this chapter: during the Covid-19 crisis, in fact, firms switched to debt, increasing their issuance (Holm-Hadulla et al., 2022). Finally, the wholesale firm's profit (dividend) in real terms is:

$$div_{m,t} = p_{m,t}A_t(u_tK_t)^{\alpha}L_{d,t}^{1-\alpha} - w_tL_{d,t} - p_t^k\hat{I}_t + Q_t\left(\frac{F_{m,t}}{P_t} - \kappa\frac{F_{m,t-1}}{P_{t-1}}\Pi_t^{-1}\right) - \frac{F_{m,t-1}}{P_{t-1}}\Pi_t^{-1} \tag{2.43}$$

Equation 2.43 shows that — while the fraction ψ of new physical capital $\hat{I}$ is funded by debt as per equation 2.42 — the remaining part $(1-\psi)$ is equity financed. In other words, the wholesale firm's profit $div_{m,t}$ are net of the funds necessary to cover $(1-\psi)p_t^k\hat{I}_t$. The wholesale firm maximises equation 2.43 subject to the two constraints of equation 2.41 and 2.42. Taking the first order conditions with respect to $L_{d,t}$, $\hat{I}_t$, u_t, K_{t+1} and $F_{m,t}$ and rearranging (see Annex 3 for more details on first order conditions), we obtain:

$$w_t = (1-\alpha)p_{m,t}A_t(u_tK_t)^{\alpha}L_{d,t}^{-\alpha} \tag{2.44}$$

[14] The pecking order theory of corporate finance states that firms prefer internal financing to debt issuance (de Bondt, 2022).

$$p_t^k M_{1,t} \delta'(u_t) = \alpha p_{m,t} (u_t K_t)^{(\alpha-1)} L_{d,t}^{1-\alpha} \tag{2.45}$$

$$p_t^k M_{1,t} = E_t \Lambda_{t,t+1} [\alpha p_{m,t+1} A_{t+1} K_{t+1}^{\alpha-1} u_{t+1}^{\alpha} L_{d,t+1}^{1-\alpha} + (1 - \delta(u_{t+1})) p_{t+1}^k M_{1,t+1}] \tag{2.46}$$

$$Q_t M_{2,t} = E_t \Lambda_{t,t+1} \Pi_{t+1}^{-1} [1 + \kappa Q_{t+1} M_{2,t+1}] \tag{2.47}$$

$$\frac{M_{1,t} - 1}{M_{2,t} - 1} = \psi \tag{2.48}$$

Where w_t is the real wage, $p_{m,t}$ is the price of wholesale output and p_t^k is the price of new capital. $M_{1,t}$ equals 1 plus the product of ψ and the multiplier of equation 2.42, the loan in advance constraint. Sims and Wu (2021) define $M_{1,t}$ as the "investment wedge". $M_{2,t}$ equals 1 plus the multiplier of equation 2.41 (capital accumulation), and it is defined as the "financial wedge". These wedges are critical for the transmission of QE: asset purchases by the central bank, in fact, raise the price of corporate bonds Q_t, alleviating the loan in advance constraint (equation 2.42) and consequently loosening the capital accumulation constraint, fuelling output. Please see Annex 3 for more details on the role of ψ and the link between short term rates and wholesale firm equity.

2.3.4.4 Capital producer

Unconsumed final output I_t is used by a capital producer to create new physical capital $\hat{I}_t$:

$$\hat{I}_t = \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{2.49}$$

Where $S()$ is an adjustment cost. The new capital is sold to firm at P_t^k. The capital producer's nominal profit is:

$$DIV_{k,t} = P_t^k \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t - P_t I_t \tag{2.50}$$

In real terms ($p_t^k = P_t^k/P_t$), profit becomes:

$$div_{k,t} = p_t^k \left[1 - S\left(\frac{I_t}{I_{t-1}} \right) \right] I_t - P_t I_t \tag{2.51}$$

The maximisation problem then is:

$$max \mathbb{E} \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left\{ p_{t+j}^k \left[1 - S\left(\frac{I_{t+j}}{I_{t+j-1}} \right) \right] I_{t+j} - I_{t+j} \right\} \tag{2.52}$$

And the FOC with respect to I_t is the following:

$$1 = p_t^k \left[1 - S\left(\frac{I_t}{I_{t-1}} \right) - S'\left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] + \mathbb{E}\Lambda_{t,t+1} p_{t+1}^k S\left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \tag{2.53}$$

2.3.5 Financial Intermediaries

The banking sector is made up of a fixed number of financial intermediaries indexed by i. They hold short term reserves and long term corporate and sovereign bonds. They fund themselves through deposits, internal equity and external equity (long term subordinated debt). The banking sector's balance sheet is the following:

$$(1 + \tau_t)(Q_t F_t + Q_{B,t} B_t + RE_t) = N_t + D_t + (1 + \tau_t^s) Q_{H,t} H_t \tag{2.54}$$

Where $Q_t F_{i,t}$ are long term bonds issued by a representative wholesale firm, $Q_{B,t} B_{i,t}$ are long term bonds issued by the fiscal authority, $RE_{i,t}$ are interest-bearing reserves, $N_{i,t}$ is net worth, $D_{i,t}$ are deposits taken from households, $Q_{H,t} H_{i,t}$ is bank's external equity (long term subordinated bonds). The long term bonds are modelled as perpetuities with decaying coupon payments following Woordford (2001), as explained in subsection 2.3.3. We suppose that the government gives banks a subsidy τ^s per unit of outside equity issued and the subsidy is funded by a tax τ_t on total assets. The subsidy is critical to model macro-prudential policy, as explained in section 2.3.6.3. In the simulations without macro-prudential policy, τ^s and τ_t are equal to zero.

Net worth evolves according to:

$$N_{i,t} = (1+\tau_t)(R_t^F - R_{t-1}^d)Q_{t-1}F_{i,t-1} + (1+\tau_t)(R_t^B - R_{t-1}^d)Q_{B,t-1}B_{i,t-1} + (1+\tau_t)(R_{t-1}^{re} - R_{t-1}^d)RE_{i,t-1} + R_{t-1}^d N_{i,t-1} + (1+\tau_t^s)(R_{t-1}^d - R_t^H)Q_{H,t-1}H_{i,t-1} \tag{2.55}$$

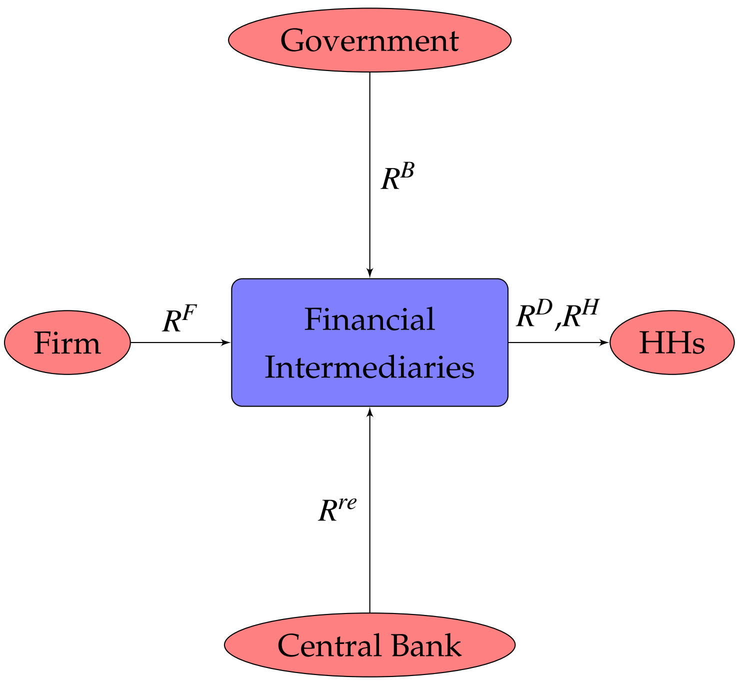
R_{t-1}^{re} is the interest rate on reserves, which is set by the central bank. R_{t-1}^d is the deposit rate. R_t^F R_t^B, R_t^H are the realised holding period returns on private, government and banks' issued bonds:

$$R_t^F = \frac{1+k(Q_t)}{Q_{t-1}} \tag{2.56}$$

$$R_t^B = \frac{1+k(Q_{B,t})}{Q_{B,t-1}} \tag{2.57}$$

$$R_t^H = \frac{1+k_h(Q_{H,t})}{Q_{H,t-1}} \tag{2.58}$$

The following chart shows the financial intermediary's segmented assets and liabilities.



We introduce x_t: the fraction of bank assets funded by outside equity. Formally:

$$x_t = \frac{Q_{H,t}h_t}{Q_t f_t + Q_{B,t}b_t + re_t} \tag{2.59}$$

I obtain the evolution of net worth in real terms dividing by the aggregate price level P_t. Given that $\Pi_t = P_t/P_{t-1}$, equation 2.55 can be re-written as:

$$\begin{aligned} \Pi_t n_{i,t} = (1+\tau_t)(R_t^F - R_{t-1}^d)Q_{t-1}f_{i,t-1} + (1+\tau_t)(R_t^B - R_{t-1}^d)Q_{B,t-1}b_{i,t-1} + \\ (1+\tau_t)(R_{t-1}^{re} - R_{t-1}^d)re_{i,t-1} + R_{t-1}^d n_{i,t-1} + \\ (1+\tau_t^s)(R_{t-1}^d - R_t^H)x_{t-1}(Q_{t-1}f_{t-1} + Q_{B,t-1}b_{t-1} + re_{t-1}) \end{aligned} \tag{2.60}$$

One period forward, that I will use in equation 2.62:

$$\begin{aligned} n_{i,t+1} = \Pi_{t+1}^{-1}\Big[(1+\tau_{t+1})(R_{t+1}^F - R_t^d)Q_t f_{i,t} + (1+\tau_{t+1})(R_{t+1}^B - R_t^d)Q_{B,t}b_{i,t} + \\ (1+\tau_{t+1})(R_t^{re} - R_t^d)re_{i,t} + R_t^d n_{i,t} + \\ (1+\tau_{t+1}^s)(R_t^d - R_{t+1}^H)x_t(Q_t f_t + Q_{B,t}b_t + re_t)\Big] \end{aligned} \tag{2.61}$$

Importantly, outside equity enhances the ability to hedge volatility in net worth, making its issuance attractive to the financial intermediary.

The financial intermediary at time t chooses its balance sheet variables. Its objective is to maximise expected terminal wealth, discounted by $\Lambda_{t,t+1}$, the household's stochastic discount factor. Having survived from t to $t+1$, there is the probability $1-\sigma$ of exiting after $t+1$, $(1-\sigma)\sigma$ of exiting after $t+2$, and so forth. Therefore, the financial intermediary's objective becomes:

$$V_{i,t} = max(1-\sigma)E_t \sum_{j=1}^{\infty} \sigma^{j-1}\Lambda_{t,t+j}n_{i,t+j} \tag{2.62}$$

2.3.5.1 Financial Intermediary's Constraints:

The financial intermediary faces two constraints: i) the agency problem à la Gertler and Kiyotaki (2010) in which financial intermediaries are given the possibility to divert assets — and the fraction of divertable assets depends on the liabilities' composition (Gertler et al., 2012)— ii) and the reserve requirement set by the monetary policymaker.

First Constraint To ensure a constraint on the availability of funds, we allow for the possibility that a financial intermediary can run away with some assets at the end of a period. This leads to the financial intermediary defaulting on its debt and shutting down. In this situation, depositors are able to recover only a fraction of the intermediary's assets (the rest is held by the intermediary), so they will reduce lending, creating a borrowing constraint for the financial intermediary. In addition, following Gertler et al. (2012), it is assumed that the fraction of funds an intermediary can abscond with is dependant on its liabilities' composition. In more detail, this paper assumes that at the margin it is easier to run away with assets funded by outside equity than by deposits. The reason for this is that dividend payments depend on the performance of the intermediary's assets, that is hard for outsiders to track precisely. Deposits, instead, can be withdrawn anytime so they impose more discipline over bank management than outside equity. This friction is critical for the introduction of macro-prudential policy. This paper assumes that having obtained the funds, the intermediary can divert the fraction $\Theta(x_t)$ of assets, with x_t being the fraction of bank's assets funded by outside equity:

$$\Theta(x_t) = \theta_t(1 + \varepsilon(1 + \tau_t^s)x_t + \frac{k}{2}(1 + \tau_t^s)x_t^2) \tag{2.63}$$

To ensure that at the margin it is easier to abscond with assets when outside equity replaces deposits, the paper is calibrated to have $\theta_t(((1 + \tau_t^s)\varepsilon) + ((1 + \tau_t^s)kx_t)) > 0$, as in Gertler et al. (2012). Here θ_t represents a credit shock: as θ_t increases, depositors are able to recover a smaller fraction of the intermediary's assets. Hence depositors reduce lending, creating a borrowing constraint for the intermediary. As intermediation breaks down, the demand for bonds weakens, triggering a fall in assets' value and widening interest rate spreads — dynamics observed in a variety of credit shocks, from the Global Financial Crisis to the "Dash for Cash" of March 2020. As in Sims and Wu ((Sims and Wu, 2021)) we keep θ_t stochastic, following an exogenous AR(1) process:

$$\theta_t = (1 - \rho_t)\theta + \rho_t\theta_{t-1} + s_t\varepsilon_t \tag{2.64}$$

Therefore, depositors will continue to fund an intermediary as long as the intermediary's value V_t is at least as large as the gain it would make by running away with assets, i.e.:

$$V_{i,t} \geq \Theta(x_t)(Q_t f_{i,t} + \Delta Q_{B,t} b_{i,t}) \tag{2.65}$$

Equation 2.65 represents the incentive constraint that in our model is always binding by construction. It suggests that if an intermediary absconds with assets, it keeps the fraction $\Theta(x_t)$ of corporate bonds and the fraction $\Theta(x_t)\Delta_t$ of government bonds. As in Gertler et al. (2012), $0 \leq \Delta \leq 1$, hence it is easier to run away with corporate bonds than government bonds.

Second Constraint This is a reserve requirement. As in Sims and Wu (2021), intermediaries must keep a minimum amount of reserves, proportional to the deposits and decided by the central bank.

$$re_{i,t} \geq \xi d_{i,t} \tag{2.66}$$

This second constraint is necessary to engage in Negative Interest Rate Policy: if the model did not include this requirement, intermediaries would liquidate their negative-yielding reserves, preventing NIRP from being implemented. In most of the simulations this reserve requirement is non-binding — it becomes binding only when the central bank engages in NIRP.

FOCs The paper maximises with respect to f_t, b_t, re_t and x_t. Without any differences amongst financial intermediaries, the FOCs are:

$$E_t\Lambda_{t,t+1}[(1+\tau_t)(R^F_{t+1} - R^d_t) + (1+\tau^s_t)(R^d_t - R^H_{t+1})x_t]\Pi^{-1}_{t+1}\Omega_{t+1} = \frac{\lambda_t}{1+\lambda_t}\Theta(x_t) \tag{2.67}$$

$$E_t\Lambda_{t,t+1}[(1+\tau_t)(R^B_{t+1} - R^d_t) + (1+\tau^s_t)(R^d_t - R^H_{t+1})x_t]\Pi^{-1}_{t+1}\Omega_{t+1} = \Delta\frac{\lambda_t}{1+\lambda_t}\Theta(x_t) \tag{2.68}$$

$$E_t\Lambda_{t,t+1}[(1+\tau_t)(R_t^{re}-R_t^d)+(1+\tau_t^s)(R_t^d-R_{t+1}^H)x_t]\Pi_{t+1}^{-1}\Omega_{t+1}=-\frac{\omega_t}{1+\lambda_t} \tag{2.69}$$

$$E_t\Lambda_{t,t+1}[(1+\tau_t^s)(R_t^d-R_{t+1}^H)(Q_tf_t+Q_{B,t}b_t+re_t)]\Pi_{t+1}^{-1}\Omega_{t+1}=-\frac{\lambda_t}{1+\lambda_t}\Theta'(x_t)(Q_tf_t+\Delta Q_{B,t}b_t) \tag{2.70}$$

With:

$$\Omega_t=1-\sigma+\sigma\Theta(x_t)\phi_t \tag{2.71}$$

λ_t and ω_t are the Lagrangian multipliers of, respectively, the incentive constraint (equation 2.65) and the reserve requirement (equation 2.66). Setting up the financial intermediary in this way generates an endogenous capital constraint and a funding trade-off.

Endogenous Capital Constraint If an asset offers excess returns, we would expect financial intermediaries to increase the demand for that asset until the excess returns are eliminated. However, if financial intermediaries face a borrowing constraint, they cannot fund additional asset purchases and excess returns remain. In short, interest rate spreads widen if there are "limits to arbitrage" (Gertler and Karadi, 2013).

In this paper, the "limits to arbitrage" are triggered by the incentive constraint: since this constraint binds in every simulation ($\lambda_t > 0$), the value of the assets that an intermediary can hold is equal to a factor ϕ_t of net worth:

$$Q_tf_{i,t}+\Delta Q_{B,t}b_{i,t}=\phi_tn_{i,t} \tag{2.72}$$

Equation 2.72 implies that during a crisis, as net worth shrinks, the demand for assets falls, lowering assets' prices and widening spreads (excess returns). In equilibrium, ϕ_t is determined according to:

$$\phi_t=\frac{1+\lambda_t}{\Theta(x_t)}E_t\Lambda_{t,t+1}\Omega_{t+1}\Pi_{t+1}^{-1}R_t^d-\frac{\omega_tre_t}{\Theta(x_t)n_t} \tag{2.73}$$

We define ϕ_t as the highest assets to net worth ratio that the intermediary can hold without breaching the incentive constraint. With the incentive constraint binding — a situation that arises when the central bank engages in conventional monetary policy, QE and forward guidance — ϕ_t depends inversely on $\Theta(x_t)$: As the intermediary's incentive to abscond with assets increases, depositors reduce lending. When the reserve requirement constraint binds — a situation that arises when the central bank engages in negative interest rate policy (NIRP) — ϕ_t becomes less negative as $\Theta(x_t)$ increases. Intuitively, external equity helps to mitigate the loss generated by having the interest rate on reserves lower than the interest rate on deposits. We will explore this mechanism in the policy subsection below (2.5.2 and 2.5.4).

Funding Trade-off The model introduces a funding trade-off between outside equity and deposits. If the financial intermediary increases the fraction of assets funded by external equity, it increases its net worth (equation 2.61). This matters when the incentive constraint binds (equation 2.72), as the bank will be able to intermediate more assets, avoiding interest rate spreads to widen as much as in the case with lower net worth. In other words, the "downward leverage spiral" is avoided (Brunnermeier and Pedersen, 2009). However, by construction, replacing deposits with outside equity increases the intermediary's incentive to divert funds. This tightens the incentive constraint as depositors become less willing to fund the intermediary (equations 2.63 and 2.65). The solution to the trade-off is endogenous, but we exploit this friction to introduce the countercyclical capital buffer (section 2.3.6.3).

2.3.6 The Central Bank

2.3.6.1 Conventional Monetary Policy

There are several ways of modelling conventional monetary policy. The most straightforward one to take at the outset is a simple Taylor rule. It is important to understand the properties of the model in the case of conventional monetary policy: This will help to form a benchmark response against which to compare unconventional monetary policy.

The central bank sets the short-term policy rate R_t^{tr} according to the following

Taylor rule.

$$lnR_t^{tr} = (1-\rho_r)lnR^{tr} + \rho_r lnR_{t-1}^{tr} + (1-\rho_r)[\phi_\pi(ln\Pi_t - ln\Pi) + \phi_y(lnY_t - lnY_{t-1})] + s_r\varepsilon_{r,t} \quad (2.74)$$

With R^{tr} and Π being steady state values of the policy rate and the inflation target. In standard times, the central bank sets the interest rate on reserves equal to the underlying policy rate R_t^{tr}, and the reserve requirement (equation 2.66) is not binding:

$$R_t^{tr} = R_t^d = R_t^{re} \quad (2.75)$$

To implement the zero lower bound (ZLB), we impose that the deposit rate and interest rate on reserves are equal in the following way:

$$R_t^d = R_t^{re} = max(1, R_t^{tr}) \quad (2.76)$$

2.3.6.2 Unconventional Monetary Policy

We are interested in analysing three different tools of unconventional monetary policy, these are: Quantitative Easing, Negative Interest Rate Policy and Forward Guidance. We follow Sims and Wu (2021) for their modelling.

Quantitative Easing. QE is modelled as purchases by the central bank of corporate and sovereign bonds, respectively $F_{cb,t}$ and $B_{cb,t}$, financed through the issuance of reserves held by banks. As a result, the central bank balance sheet takes the following form:

$$Q_t F_{cb,t} + Q_{B,t} B_{cb,t} = RE_t \quad (2.77)$$

QE has real effects because — when the enforcement constraint binds (equation 2.65) — it eases the constraint by changing the composition of banks' assets. In other words, the central bank swaps bonds for reserves: in doing so, it swaps assets that are not perfectly recoverable in case of bank default (bonds) with assets that are perfectly recoverable (reserves), easing the constraint (Sims and Wu, 2021).

As a result, banks can buy more bonds, these purchases compress the excess return on corporate bonds and increase their price, incentivising firms to invest and overall increasing aggregate demand.

For now, we impose real bond holdings to follow an exogenous process (they will become endogenous in section 2.5.3):

$$f_{cb,t} = (1-\rho_f)f_{cb} + \rho_f f_{cb,t-1} + s_f \varepsilon f \tag{2.78}$$

$$b_{cb,t} = (1-\rho_b)b_{cb} + \rho_b b_{cb,t-1} + s_b \varepsilon f \tag{2.79}$$

Where $f_{cb,t}$ and $b_{cb,t}$ are steady state central bank's holdings of corporate and government bonds, with $0 < \rho_f < 1$ and $0 < \rho_b < 1$. The central bank can purchase bonds either in normal times (when the ZLB is not binding and the conduct of monetary policy follows equation 2.74) or when the policy rate is constrained by the ZLB (equation 2.76).

Forward Guidance. FG is modelled as a negative shock to the policy rate R_t^{tr} when the ZLB constraint is binding. Since the policy rate must be non-negative, the MP shock signals lower interest rates on reserves and deposits once the ZLB constraint is not binding anymore. This modelling choice reflects policy actions: when central banks hit the ZLB, they started communicating — and in some cases also promising — the future path of policy rates. Typically they delivered a "lower for longer" message (Bernanke, 2020), that would move the public's expectations, lowering long-term yields and easing financial conditions, thus enabling more lending, investment and increasing aggregate demand.

Negative Interest Rate Policy. NIRP is modelled by i) allowing the interest rate on reserves to become negative,[15] and ii) by imposing the deposit rate to remain positive, e.g. not crossing the ZLB. This methodology reflects the set up of the jurisdictions that adopted NIRP, in which the deposit rate was non-negative, despite bank's being charged a negative interest rate on reserves (Schnabel, 2020a). Formally:

$$R_t^d = max(1, R_t^{re}) \tag{2.80}$$

[15] For this the reserve requirement in equation 2.66 needs to be binding otherwise banks would not hold reserves.

$$R_t^{re} = R_t^{tr} \tag{2.81}$$

Equation 2.80 binds only when NIRP is deployed. In the model, NIRP is transmitted to the economy through two opposing channels. *First, the forward guidance channel*: cutting the interest rate on reserves now implies lower deposit rates once the ZLB stops becoming binding. Consequently, expectations of a "lower for longer" environment kick in, putting downward pressure on long term yields and raising corporate bond prices. This mechanism eases the firm's loan in advance constraint, fuelling investment and aggregate demand. The FG channel is therefore expansionary and — given that it implies an actual reserve rate cut rather than just a message — it is more effective than a forward guidance announcement.[16]

The second channel through which NIRP is transmitted to the economy is the banking channel: having the interest rate on reserves lower than the interest rate on deposits is comparable to having a tax on the bank's net worth (equation 2.55). A lower net worth tightens the financial intermediary's constraint. With banks unable to purchase as much debt, bond yields increase and their prices fall, tightening the firm's loan in advance constraint, thus slowing investment and aggregate demand. The banking channel is therefore contractionary.

As long as the FG channel is stronger than the banking channel, NIRP is expansionary. If instead the FG channel is weaker, NIRP becomes contractionary: in other words, the economy hits the reversal interest rate. This is the turning point when accommodative monetary policy turns contractionary.[17] This chapter analyses the reversal interest rate and the interaction with the CCyB in section 2.5.4.

2.3.6.3 Macro-prudential Policy

A low capitalised financial system increases the probability of a banking crisis when a shock hits the economy (Manganelli et al., 2011). This weakness is

[16]In practice the use of NIRP has proven controversial. The Fed, for instance, never adopted NIRP — even if Bernanke (2020) suggested to keep a"constructive ambiguity" about its future deployment — for several reasons, amongst which legislation and specific features of the US financial system. For more details, please see FOMC (2019).

[17]The key variables determining the strength of the two channels are the size of the reserves held at the central bank and the level of banking capitalisation. We will explore the interactions between these two variables and NIRP in section 2.5.4.

explained by the "downward leverage spiral"(Brunnermeier and Pedersen, 2009): if financial intermediaries record losses, they sell assets to avoid breaching leverage limits, but the liquidation reduces assets prices, shrinking net worth further, triggering other rounds of sales. The higher the leverage, the larger these fire sales. The vulnerability stemming from high leverage became evident with the Global Financial Crisis of 2007-2008, in which the undercapitalisation of the financial system played an important role in amplifying the initial shock (Flannery and Giacomini, 2015).[18] Basel III rules were introduced in the aftermath of the crisis to address these fragilities to some degree.[19]

The model in this paper has been developed with the aim of trying to replicate these dynamics. The features of this model play different and important roles in representing these dynamics. The main features are: i) an endogenous decision on the quantity of outside equity, critical to mitigate the leverage amplification mechanism; ii) the need for macro-prudential policy; iii) a macro-prudential rule in the form of CCyB. The endogenous decision stems from the funding trade-off between outside equity and deposits (see section 2.3.5.1, first constraint): the financial intermediary would prefer to increase the fraction of outside equity funding — as this would hedge fluctuations in its net worth — but doing so would result in a tighter constraint.[20] Within this setup, the need for a macro-prudential rule arises because, when deciding their funding structure, financial intermediaries do not take into account the resilience of the financial system. In other words, when they decide on the composition of their funding, they do not consider that if they issued external equity in concert, the amplification mechanism in the banking system — the "downward leverage spiral"— would be weakened. For this reason the paper introduces a macro-prudential rule as in Gertler et al. (2012). This allows us to study how the macro-prudential policy affects the transmission of UMP, which is one of the main aims of the current paper.

We suppose that the government gives banks a subsidy τ^s per unit of outside equity issued. The subsidy is funded by a tax τ_t on total assets. Applying this

[18] Chen et al. (2014) finds that "Lehman would have needed an equity capital infusion of USD15 billion in order to reduce probability of default below 5%, given the market conditions of March 2008".

[19] Recent research shows that if a CCyB of 2.5% had been in place in 2007, the recession would have been greatly reduced (Faria-e Castro, 2021).

[20] The financial intermediary's constraint tightens because at the margin it is more difficult to divert assets funded by short term deposits than by outside equity — see section 2.3.5.1.

strategy, the flow of funds constraint for the bank is now given by:

$$(1+\tau_t)(Q_t F_t + Q_{B,t} B_t + RE_t) = N_t + D_t + (1+\tau_t^s) Q_{H,t} H_t \tag{2.82}$$

The effect of the subsidy is to increase the attractiveness of issuing outside equity. The paper imposes that τ^s responds counter-cyclically to output and pro-cyclically to the bond spread ($spread_t$ = $(R^F_{t+1} - R^d_t) + (R^B_{t+1} - R^d_t)$).

$$\tau_t^s = (1-\rho_{mpr})\tau_{ss} + \rho_{mpr}\tau^s_{t-1} - \phi_{mpr}[Y_t - Y_{t-1}] + \phi_{mpr}[spread_t - spread_{ss}] \tag{2.83}$$

While $\tau_t = \tau^s x_t$. In short, the subsidy/tax scheme can be thought as a countercyclical capital requirement (for outside equity issue). Its introduction has real effects, through two channels. First, the subsidy increases the steady state level of x_t. In this way it fulfils a capital requirement's function: once the economy is hit by a shock, and the fall in asset value is amplified by a factor equal to the leverage ratio, the amplification mechanism will be weaker thanks to the additional required capital (lower leverage). Second, x_t varies counter-cyclically, allowing banks to be better capitalised when the shock hits the economy and to ease their borrowing constraint — substituting external equity with deposits — once the recovery takes hold. However, the introduction of the countercyclical capital requirement for outside equity issue comes at a cost, given that a larger x_t tightens the bank's incentive constraint. We will analyse the trade-off at work when UMP is deployed.

Overall, the CCyB makes the economy *less* responsive to shocks: this is what motivates and enables the analysis of UMP and macro-prudential policy.

2.3.7 Fiscal Policy

The government spends G_t and it raises revenues by collecting taxes from households T_t, issuing debt B_t and receiving transfers from the central bank $T_{cb,t}$:

$$P_t G_t + B_{G,t-1} = P_t T_t + P_t T_{cb,t} + Q_{B,t}(B_{G,t} - \kappa B_{G,t-1}) \tag{2.84}$$

Where $\kappa \in [0,1]$ is the decay parameter for coupon payments. Real government bonds $b_{G,t}$ and government spending G_t follow an exogenous AR(1) process. The lump sum transfers from the central bank adjust automatically to make equation 2.84 hold.

2.4 Calibration

Most of the parameters in the model have standard values. The non-standard parameters — associated with the financial sector — are taken from Sims and Wu (2021) and Gertler et al. (2012) and they are listed in Table 2.1 below.[21] This chapter, different from Gertler et al. (2012), models external equity (subordinated debt) in the same way of sovereign and corporate bonds: a perpetuity with decaying coupon payments, that requires the calibration of its duration. Following Sims and Wu (2021) sovereign and corporate bond have the same duration of 10 years while — given that in practice subordinated debt has a lower duration than other bonds — external equity's duration is a quarter. The gross yield to maturity of sovereign bonds is 1.26, of corporate bonds 1.28 and external equity 3.16. We also highlight the importance of τ_{ss}, the steady state external equity subsidy: it regulates the financial intermediaries'capitalisation and — as sections 2.5.2.2 and 2.5.4 show — the degree of output stabilisation and level of the reversal rate depend on its calibration. Finally, to switch between binding/non-binding ZLB constraint, the paper uses the Dynare Occbin toolkit developed by Guerrieri and Iacoviello (2015).

[21] Please see Annex 4 of this chapter for more details.

Table 2.1: Calibrated parameters

Parameter	Value or Target	Description
κ	$1-40^{-1}$	Coupon decay parameter / Bond duration
κ_h	0.3	External equity duration
x	0.15	Steady state external equity ratio
ε	-2	Efficiency gains from having external equity
τ_{ss}	1.3	Steady state external equity subsidy
ψ	0.81	Fraction of investment from debt
σ	0.95	Intermediary survival probability
χ	Leverage = 4	Steady state leverage
Δ	1/3	Government bond recoverability
bcb	0.06	Steady state central bank Treasury holdings
fcb	0	Steady state central bank corporate bond holdings
ρ_θ	0.98	AR credit
ρ_b	0.8	AR central bank Treasury
ρ_f	0.8	AR central bank corporate bonds
ρ_{mpr}	0.8	AR external equity subsidy
ρ_r	0.8	AR Taylor rule
ϕ_π	1.5	Parameter inflation Taylor rule
ϕ_y	0.25	Parameter output Taylor rule
$\overline{b_G}$	0.41	Steady state government debt
G	0.2	Steady state government spending

2.5 Quantitative Analysis

The aim of this chapter is to study how capital requirements in the form of a CCyB affect the transmission of QE, NIRP and FG. In particular, we ask whether the introduction of CCyB *enhances* output stabilisation, allowing UMP to be less aggressive. This section runs five sets of simulations to answer this question and to identify the interactions and synergies amongst the instruments. The results make three new, strong cases for the simultaneous deployment of UMP and macro-prudential policy. The five cases we analyse are:

1. **Conventional MP and CCyB.** In order to understand how conventional monetary policy works in this model, we impose that the ZLB constraint does not bind. Within this setup, we run a credit shock, with and without macro-prudential policy. This simulation is useful to understand the mechanics of the model, the channels of transmissions of the shock and the potential role to be played by macro-prudential policy in the transmission process.

2. **Exogenous UMP and CCyB.** Having understood the mechanics of the model with conventional monetary policy, the paper moves to analyse the interaction between UMP and macro-prudential policy. For this, it runs four different monetary shocks — a conventional monetary policy shock, a QE shock, a FG shock and a NIRP shock — with and without CCyB. By comparing the IRFs, the paper assesses whether the introduction of the CCyB has mitigated or amplified QE, NIRP and FG shocks.

3. **Endogenous UMP and CCyB.** While the previous simulations assessed the transmission of a UMP shock with and without CCyB, what we observe in practice is that an exogenous shock hits the economy and in response to it UMP and CCyB are deployed in unison, like during the Covid-19 pandemic. To simulate the joint response, we impose UMP to be endogenous to the model (CCyB is already endogenous). Within this environment, we run a credit shock, with and without CCyB. The simulation assesses whether an economy that deploys QE and CCyB in concert is more effective at stabilising output than an economy that solely relies on UMP. From this, we highlight implications for the monetary policy stance.

4. **Reversal rate, UMP and CCyB.** The previous analysis investigated the synergies between CCyB and QE, here we widen the focus to include NIRP. The prolonged use of NIRP, in fact, triggered concerns over the possibility of hitting the reversal interest rate — the turning point when accommodative monetary policy becomes contractionary. Against this backdrop, we simulate a NIRP shock to test whether the CCyB and UMP (in the form of QE) can be used strategically to avoid hitting the reversal rate and strengthen the effectiveness of NIRP.

5. **Quantitative Tightening and CCyB.** Finally, we turn to the recovery, when central banks end bonds purchases programmes (QE) and start unwinding their balance sheet, a process known as Quantitative Tightening (QT). Contributing to an emerging literature, we run simulations to understand whether the simultaneous deployment of QE and CCyB during the crisis has implications for QT, in particular its pace and starting date.

2.5.1 Conventional MP and CCyB

To understand the mechanics of the model in its simplest form, this chapter runs a credit shock (rise in θ_t) with and without CCyB when monetary policy is conventional (ZLB constraint is not binding). Figure 2.1 below shows the IRFs. The main result is that the introduction of CCyB (red dotted line) "tames" the financial cycle and makes the economy less responsive to the shock.

The credit shock affects the model through equation 2.65, tightening the bank enforcement constraint. This causes output, investment, and labour input to fall. It also lowers long corporate and sovereign bond prices, and pushes up their excess returns. Inflation falls, triggering the central bank to cut the policy rate. The reason for these movements is the following: with a credit shock, depositors can recover a smaller fraction of an intermediary's assets in the event of bankruptcy, which in turn makes them less willing to lend funds. This tightens the intermediary's balance sheet constraint (it squeezes the banks' balance sheet). Therefore banks cannot buy additional corporate or sovereign bonds. As a result, the price of the bonds falls and their excess return increases (see the IRF of the corporate bond spread), limiting the wholesale firms' ability to fund additional investment, given the loan in advance constraint they face. As such, investment falls, dragging down output.

Importantly, the model with CCyB (red dotted line) achieves a higher degree of output stabilisation than the model without CCyB (black line). This is the result of two dynamics: i) as the banking system is better capitalised (lower leverage), the "downward leverage spiral" is avoided and internal equity (net worth) does not fall as much; ii) the smaller drop in net worth tightens the bank's incentive constraint *less* than in the case without macro-prudential policy, allowing banks to buy *more* corporate or sovereign bonds. This results in a smaller drop in the bonds' price, avoiding the firms' loan in advance constraint from binding as much as in the case without macro-prudential policy. As such, investment contracts by 0.04%, less than in the case without CCyB (0.07%), resulting in a smaller aggregate contraction.

These results are aligned with the literature: as in Gertler et al. (2012) and Darracq Paries et al. (2020), the introduction of CCyB reduces aggregate volatility and weakens the monetary transmission.

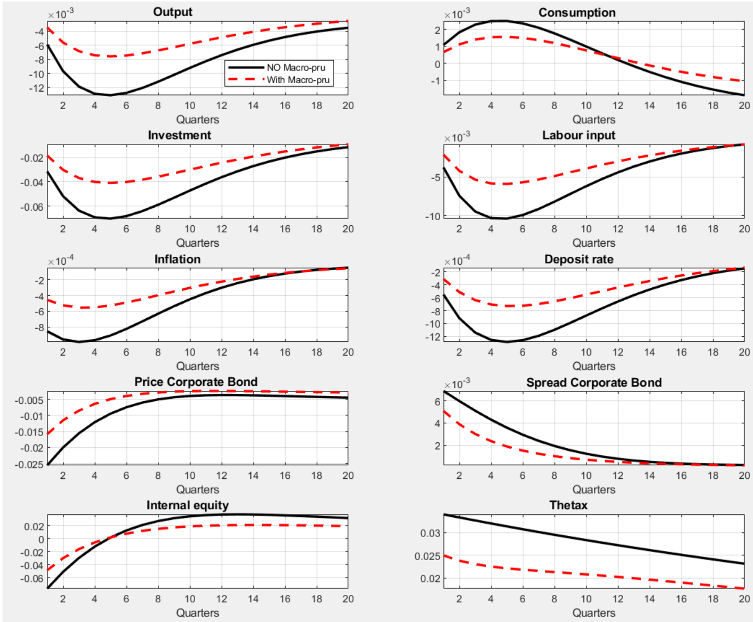


Figure 2.1: Impulse responses to a credit shock (shock to θ)

2.5.2 Exogenous UMP and CCyB

The aim of this chapter is to understand the interaction between UMP and macro-prudential policy: in other words, how the transmission of QE, NIRP and FG is affected by the introduction of CCyB. For this, the simulations in Figure 2.2 make the ZLB constraint binding: this is necessary because UMP is deployed only when short term rates hit the effective lower bound. To make the ZLB constraint binding and then assess the transmission of UMP, the paper follows the three-step procedure of Sims and Wu (2021): first, it simulates credit shocks with 1.5 standard deviations in each period from 1 to 6, pushing the economy to the ZLB;[22] second, it simulates again the same sequence of six credit shocks and in the additional seventh period it simulates four different monetary policy shocks — a standard policy rate cut, QE, FG, NIRP; third, it takes the difference between the second and the first simulations. The exercise is repeated activating the CCyB. Note

[22]In the model, the ZLB constraint dictates that the short-term Taylor rule rate R_t^{tr} cannot go below its steady state set at 1% in gross terms (this is the steady state interest rate on reserves). To implement this occasionally binding constraint we use the Dynare Occbin toolkit developed by Guerrieri and Iacoviello (2015): anytime the Taylor rule rate goes below the steady state interest rate on reserves (making the ZLB constraint binding), the toolkit switches to a different model in which we impose the rate on reserves equal to 0. In this model, the deposit rate equals the interest rate on reserves. Differently, in the case of NIRP implementation, when the Taylor rule rate goes below the steady state interest rate on reserves, the Occbin toolbox switches to a model in which the interest rate on reserves follows the (now negative) Taylor rule rate but the deposit rate remains stuck at 0 (see equations 2.80 and 2.81).

that the ZLB becomes binding in period 4, but simulating the monetary policy shock in period 5 instead of 7 doesn't change the results — please see Annex 6 for more details. In addition, agents do not anticipate that the central bank will engage in UMP, hence there are not precautionary savings, lengthening the time spent at the ZLB (Swarbrick, 2021). This is due to the construction of the ZLB with the Occbin toolbox preventing agents to incorporate the probability of the regime switching from above the ZLB (non-binding constraint) to the ZLB (binding constraint).[23] The resulting IRFs are presented in Figure 2.2 below: the left-hand side represents the IRFs without CCyB (we turn off the subsidy τ_t^s and tax τ_t) and the right-hand side with CCyB. Each line represents a different monetary policy tool: conventional monetary policy is the solid blue line, QE is the orange-dotted line, NIRP is the yellow-dotted line and FG is the purple-dotted line. The unconventional monetary policy shocks (QE, NIRP and FG) on the left-hand side are calibrated to replicate the increase in output produced by the standard policy rate cut. Hence the left-hand side chart of Figure 2.2 can be used to estimate how much UMP is needed to achieve the same results of a conventional policy rate cut (Sims and Wu, 2021). Output, investment, and consumption are deviations from the steady state in percentage terms; inflation and interest rates are in annualised percentage points; the central bank's balance sheet size is expressed relative to steady state output.

2.5.2.1 Results Without Macro-prudential Policy

The conventional policy rate shock (LHS) is -1% decline of the Taylor rule rate. Once the shock hits the economy, it results in a 0.75% decline in the rate (solid blue line in Figure 2.2) because of the endogenous reaction to inflation and output growth (Taylor rule, equation 2.74). The policy rate cut supports an expansion: output accelerates by about 0.5%, investment three times as much, and inflation is also higher at 0.5%.

The QE shock (LHS) implies corporate bonds purchases by the central bank for an equivalent increase of its balance sheet by 4% relative to annualized steady state output (orange-dotted line in Figure 2.2). In the model this takes the form of a shock seven times the shock on the policy rate. The bond purchases trigger a contraction of -0.3% of the nominal long yield, deeper than any other monetary

[23]For more details on Occbin's properties and alternative methods to include occasionally binding constraints, please see: Guerrieri and Iacoviello (2015), Eggertsson et al. (2021) and Swarbrick,2021.

instrument. Compared with the effects from the other monetary tools, the effects of QE on output are less persistent and those on consumption are much weaker.[24]

The NIRP shock (LHS) is shock to the Taylor rule of -2.4% (yellow-dotted line in Figure 2.2). However, consistent with the endogenous Taylor rule reaction to accelerating inflation and output growth, the NIRP shock on impact results only in a -2% decline in the Taylor rule rate (see IRF titled TR rate).

The FG shock (LHS) is a shock of -2.2% to the Taylor rule (purple-dotted line in Figure 2.2). As in the NIRP case — and consistently with the endogenous Taylor rule tightening to accelerating inflation and output growth — the FG shock results on impact in a smaller Taylor rule rate decline: -2%. Note that FG is effective even if at the ZLB the policy rate does not fall into negative territory. The effectiveness is generated by the negative shock to the Tylor rule that keeps the policy rate — and therefore also the deposit rate — lower for longer (see Annex 7). Relative to the scenario in which monetary policy is unconstrained by the ZLB and the policy rate falls by 0.75% (solid blue line), FG is less effective as it requires a shock to the Taylor rule more than twice as large to generate the same output expansion. This is because with a standard policy rate cut the deposit rate is affected immediately, while with FG it is affected only when ZLB is not binding anymore.[25]

The main difference between NIRP and FG is that in the NIRP case the policy rate (interest rate on reserves) follows the Taylor rule rate in deeply negative territory while in the FG case it is stuck at the ZLB. In terms of effectiveness, as observed by Sims and Wu (2021), FG's effect on output is slightly stronger than NIRP's (in fact the shock is bigger for NIRP: -2.4% NIRP shock vs -2.2% FG shock). This is because a negative policy rate has also contractionary effects since it is a tax on banks' net worth, that tightens the financial intermediaries' constraint.

Overall, the (calibrated) similar effect on output is driven by the real long term interest rate, whose compression — due to central bank asset purchases with QE and to expectations of "lower for longer" with NIRP and FG — is the key transmission mechanism of monetary policy.

[24]Sims and Wu (2021) explain this outcome by pointing at the deposit rate, key for the household Euler equation, but not affected by QE.

[25]This is true also for NIRP, requiring a Taylor rule shock of 2.4% vs to generate the same output expansion that conventional monetary policy would achieve with a 1% Taylor rule shock. Sims and Wu (2021) note that if the duration of the ZLB increases, then the shock to FG and NIRP must be larger to obtain a certain output change.

2.5.2.2 Results With Macro-prudential Policy: The Introduction of the CCyB

The introduction of the CCyB has two main effects on the transmission of the monetary shocks: i) it weakens the transmission mechanism of QE and conventional monetary policy; ii) it strengthens slightly the transmission mechanism of NIRP. The following section expands on these two effects further.

Looking at QE and a conventional monetary policy shocks (respectively, orange-dotted line and solid blue line in Figure 2.2), output accelerates by about 0.5% when CCyB is not deployed (LHS), but it expands only by 0.37% when CCyB is introduced (RHS). Mechanically, this happens because the macro-prudential rule rebalances banks' liabilities towards external equity and away from deposits. In practice, the additional capital requirement reduces leverage, weakening the related amplification mechanism.

Focusing on QE, this tool has real effects because it lowers long term rates through two mechanisms: the central bank's large asset purchases and the purchases by financial intermediaries.[26] When CCyB is enacted, the first mechanism keeps on working as described, but the second mechanism is weakened because the macro-prudential rule tightens the bank's balance sheet, limiting their corporate bond purchases. As demand for corporate bonds decreases, so does the firms' ability to fund investment, leading to a smaller acceleration in investment: Investment expands by 2.2% without CCyB, but only by 1.7% when the CCyB is deployed. In other words, even if financial conditions are eased considerably (see the significant decline in nominal long yield), the real effects are weakened because banks cannot buy as many corporate bonds as in the case without CCyB, affecting investment.

The introduction of the CCyB has the opposite effect on NIRP (yellow-dotted line, Figure 2.2), whose transmission is instead slightly strengthened. Output, in fact, accelerates by 0.49% when CCyB is introduced (RHS), compared to 0.48% without CCyB (LHS). Note that if we had calibrated τ_{ss} — the steady state external equity subsidy, that regulates the level of capitalisation — with a higher parameter (for instance 2 instead of 1.3), then output would have expanded more (0.67% instead of 0.49%). The reason why CCyB strengthens the NIRP's transmission mechanism is because CCyB raises the steady state level of x_t, operating like a capital requirement. As a result, banks are better capitalised and the contractionary effect of NIRP (the so called *banking channel*, see subsection 2.3.4.2) is mitigated.

[26] Financial intermediaries enjoy a looser balance sheet constraint after having swapped bonds for reserves with the central bank.

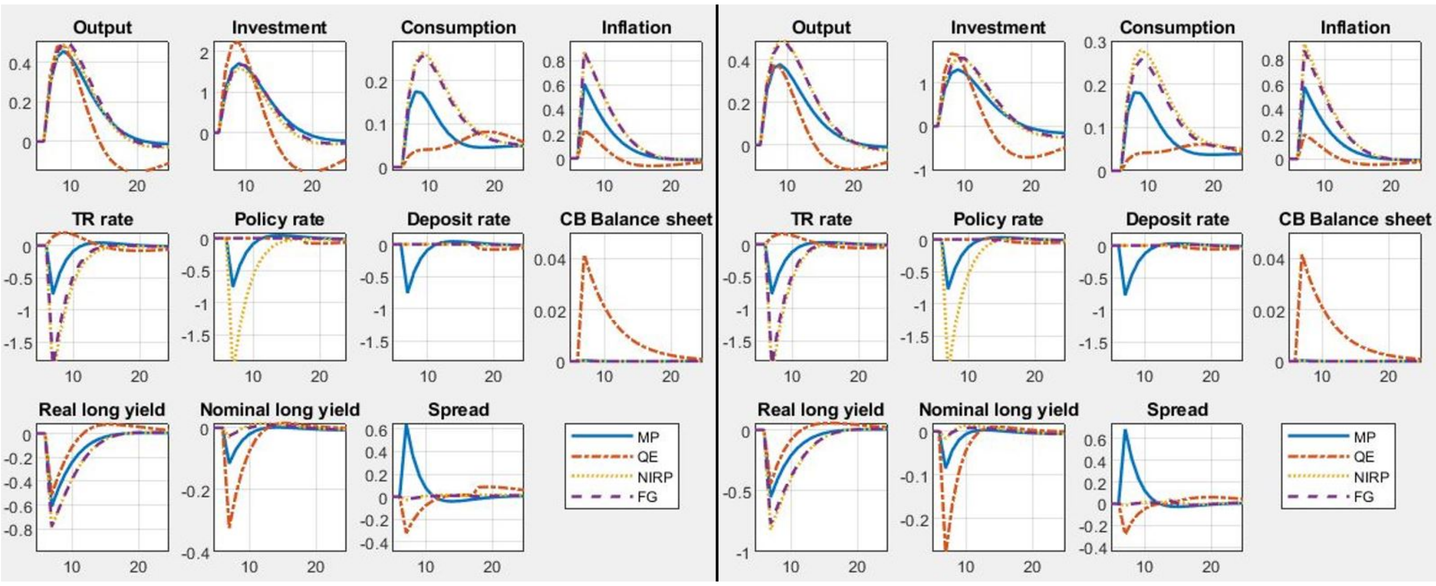


Figure 2.2: Conventional and Unconventional Monetary Policy shocks. LHS: IRFs without macro-prudential policy; RHS: IRFs with macro-prudential policy.

2.5.3 Endogenous UMP and CCyB

The previous section has shown that the introduction of CCyB weakens QE's transmission mechanism and it strengthens NIRP's. However, in practice, both policies are deployed in *unison*: during the Covid 19 crisis, for instance, the CCyB was released by 15 major central banks (already engaging in UMP) to support the supply of credit (Aikman, 2020). This echoes Carney (2014) when he stated that "our policy tools must be used in concert" to explain how the Bank would turn the recovery into a durable expansion.

To analyse the synergies that are triggered once the policies are deployed together and to assess whether monetary stimulus changes when policymakers can make use also of extra capital buffers, this simulation endogenises UMP and CCyB. The CCyB as per equation 2.83, is already able to react to shocks countercyclical. Instead, UMP in the form of QE needs to be modelled. Therefore, leaving behind the exogenous determination of the previous section 2.5.2, we now follow Sims and Wu (2021) and impose that the central bank's corporate bond holdings are set by the Taylor rule reaction function below:

$$f_{cb,t} = (1-\rho_f)f_{cb} + \rho_f f_{cb,t-1} + (1-\rho_f)\Psi_f[\Phi_\pi(ln\Pi_t - ln\Pi) + \Phi_y(lnY_t - lnY_{t-1})] + s_f\varepsilon_{f,t} \quad (2.85)$$

Figure 2.3 below shows the IRFs to a one standard deviation credit shock. To achieve this, the paper follows the same three-step methodology of Sims and Wu (2021) implemented in the previous section: first, it simulates credit shocks with 1.5 standard deviations in each period from 1 to 6, pushing the economy to the ZLB; second, it simulates again the same sequence of six credit shocks adding a further credit shock in period 7 to which monetary policy can react (in section 2.5.2 this additional shock was a monetary policy shock); third, we take the difference between the second and the first simulation. The exercise is repeated activating the CCyB. The resulting IRFs are presented in Figure 2.3 below: the left-hand side represents the IRFs without CCyB (we turn off the subsidy τ_t^s and tax τ_t) and the right-hand side with CCyB. Each line represents a different policy scenario: conventional monetary policy unconstrained by ZLB is the blue-dotted line; monetary policy constrained by the ZLB and the central bank not engaging in UMP is the orange-dotted line; policy rate constrained by the ZLB but the central bank deploys endogenous QE as per equation 2.85 is solid purple line. The left-hand side panels show the IRFs without CCyB and the right-hand side with CCyB.

2.5.3.1 Results Without Macro-prudential Policy

When **conventional monetary policy is unconstrained by ZLB** (blue-dotted line), the credit shock lowers investment by about 7% and output by 1.6%. Inflation also falls and real long yields rise (for a detailed explanation of the dynamics, see section 2.5.1). However, given that the ZLB is not binding, monetary policy can react to the contraction: the policy rate, in fact, is automatically cut by 50 basis points, softening the recession.

With **conventional monetary policy is constrained by the ZLB and unable to use UMP** (orange-dotted line), the recession is deeper: monetary policy is unable to ease financial conditions further to spur aggregate demand. In this situation the central bank has "run out of ammunitions", and investment falls by 15% and output by 3.7% at the peak. Real long yields rise to almost 4%, signalling that the balance sheet constraints for both banks and firms is tighter than in the previous scenario with monetary policy unconstrained by the ZLB.

When **the policy rate is constrained by the ZLB but the central bank deploys endogenous QE** (solid purple line), the IRFs are similar to the case in which the policy rate is allowed to go into negative territory (blue-dotted line): investment falls by about 7% and output by 1.9%. However, in this case the monetary policy response does not come from the policy rate but from the central bank's corporate bonds purchases. The central bank's balance sheet, in fact, grows by about 5% of steady state output at the maximum. The central bank's purchases of corporate bonds ease the intermediary's enforcement constraint because reserves — swapped for bonds — are perfectly recoverable in case of bank's default. As a results banks can buy more corporate bonds, lowering their yields and bidding up their prices. The higher prices ease the firms' loan in advance constraint, preventing investment to fall as much as in the case without monetary policy intervention (compare orange dotted line with solid purple line).

2.5.3.2 Results With Macro-prudential Policy: The Introduction of the CCyB

The introduction of CCyB has two effects: i) it mitigates the slump in the economy in all three scenarios; ii) it allows monetary policy to be less aggressive than in the case without CCyB.

Looking at the case of conventional monetary policy unconstrained by ZLB (blue-dotted line), investment falls by 4% at the peak (7% without CCyB) and the policy rate is cut only by 30 bps (50 bps without CCyB). This smoother response is due to two factors: first, the economy is less leveraged when the shock hits, this causes a smaller drop in net worth and a less tight incentive constraint, overall weakening the amplification mechanism; second, once the recovery takes hold, banks are able to substitute external equity with deposits, shortening their funding maturity. Both these factors ease the enforcement constraint and allow financial intermediaries to buy additional bonds, avoiding yields to rise and firms' constraint to tighten as much as in the case without CCyB. Given that output is stabilised by the CCyB (-0.7% compared with -1.9% without CCyB), the central bank does not have to cut the policy rate as much as in the case without CCyB (30 bps vs 50 bps).

Similarly, in the case with endogenous QE (solid purple line), investment falls by almost 4% (7% without CCyB) and the balance sheet expands by about 1.5% of steady state output at the peak (5% without CCyB). Also in this case the same two factors — a better capitalised banking system and more space on the bank's books — prevent long term yields from rising and financial conditions from tightening as much as in the case without CCyB. As output is more stabilised, the central bank purchases less bonds.

Overall, the IRFs show that deploying UMP and macro-prudential policy in concert is more effective than solely relying on UMP to stabilise output. This confirms the Bank of England's concerted strategy of delivering monetary and macro-prudential policy *simultaneously* to support the recovery (Carney, 2014). Finally, since monetary policy can be less aggressive, UMP side effects (like asset scarcity (BIS, 2019b)) are also reduced.

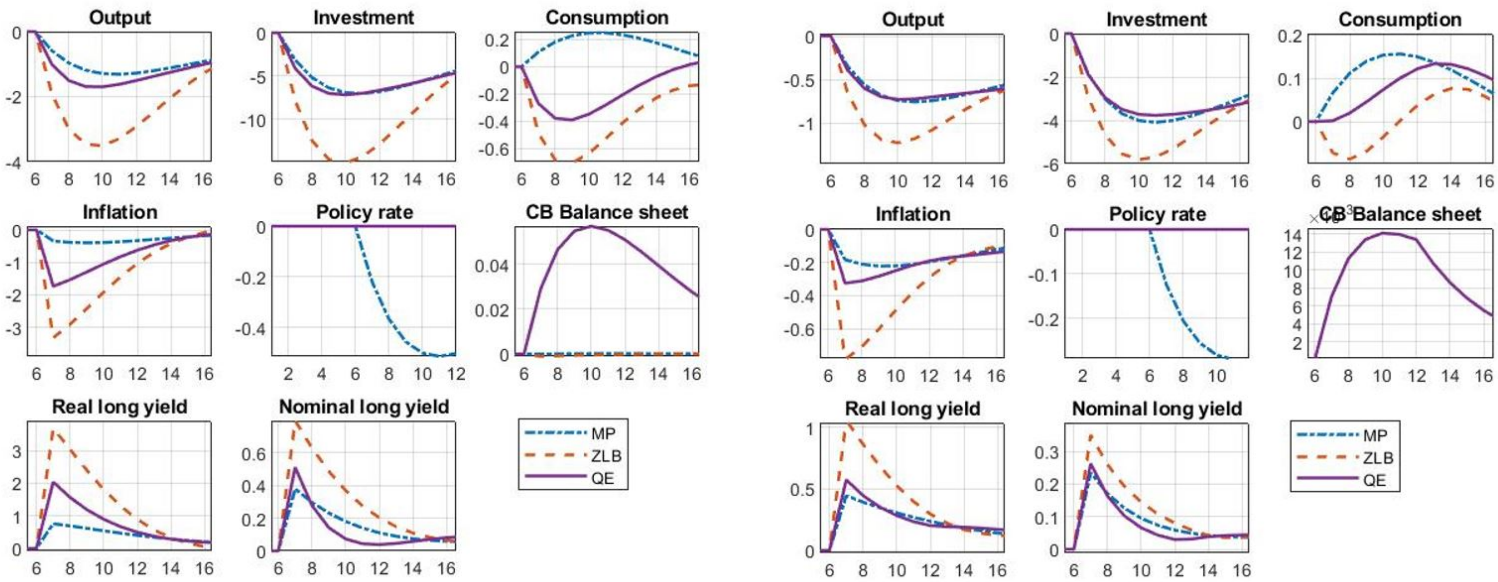


Figure 2.3: Credit shock. LHS: IRFs without macro-prudential policy; RHS: IRFs with macro-prudential policy.

2.5.4 Reversal Rate, UMP and CCyB

The previous analysis has investigated the synergies between CCyB and QE. In this section we widen the focus, including NIRP to the analysis. This is important from a policy perspective because central banks that deployed NIRP had already engaged in QE before, so we must take into account the implications of previous QE policies (size of the central bank balance sheet) when we assess NIRP effectiveness.

The literature has demonstrated the presence of a turning point when accommodative monetary policy can become contractionary and reduce lending: This is the reversal interest rate (Brunnermeier and Koby, 2018). It is triggered by the disconnection between the policy rate and deposit rates, that hurts banks' profitability. In our model, this occurs when NIRP is deployed and the banking channel effect is stronger than the FG channel (see section 2.3.6.2).

Having introduced NIRP in 2014 (ECB), concerns have arisen over the possibility that further monetary loosening could force the banking sector to hit the reversal rate. For this reason it is important to study the conditions that would allow an economy to avoid hitting the reversal interest rate. The literature has shown that large QE programmes hinder the effectiveness of NIRP (Sims and Wu, 2021) and a low capitalised banking sector increases the risk of hitting the reversal rate (Darracq Pariès et al., 2020). However, no framework so far has explored whether there are powerful synergies between NIRP, QE and CCyB to mitigate the reversal interest rate — the aim of this section.

To test whether macro-prudential policy and a strategic use of QE could stop the economy from hitting the reversal rate, we simulate a 100 basis point NIRP shock[27] for: i) three different steady states of the central bank's balance sheet (pre-QE level: 6% of GDP; US after QE3: 25% of GDP; Euro area in 2018 Q4: 38% of GDP, this is as in Sims and Wu (2021); ii) three different τ_{ss}, the steady state level of subsidy to issue equity (2; 1.3; 0.9). Note that the higher τ_{ss}, the higher the steady state level of x_t, the more capitalised the financial intermediary.

The IRFs are presented in Figure 2.4 below and three sets of results arise. First, as already pointed out by Sims and Wu (2021), the larger the central bank balance sheet, the less stimulative NIRP becomes. This is because with larger reserves, the negative rate implies a *larger tax* on the bank's net worth, constraining lending ability. Let's consider the left-hand side chart: with $\tau_{ss} = 2$, a 1% NIRP shock leads to a 1% increase in investment when the central bank's balance sheet equals 6% of GDP (orange line). However, the same shock with the same τ_{ss} causes investment to increase by only 0.55% when the central bank's balance sheet equals 38% of GDP (purple line).

[27] The methodology for this is the same of section 2.5.2. Following Sims and Wu (2021), it simulates credit shocks for 6 periods. Then it replicates the simulations but in the seventh period it simulates the NIRP shock. Then it takes the difference between the simulation with the additional NIRP shock and the simulation without it: the resulting IRFs are presented in Figure 2.4 below.

Second, as suggested by Darracq Paries et al. (2020), the lower the banks' capitalisation, the less stimulative NIRP becomes. This is because NIRP entails having the interest rate on reserves lower than the interest rate on deposits (see equations 2.80 and 2.81), a set up comparable to having a tax on bank's net worth. Hence the lower the bank's capitalisation, the more lending is reduced, despite a stimulative monetary policy stance. Let's consider, for example, the orange line: following a 1% NIRP shock, investment increases by 1% with $\tau_{ss} = 2$, by little above 0.6% with $\tau_{ss} = 1.3$ and by roughly 0.55% with $\tau_{ss} = 0.9$.

Third — and this is the contribution of our paper — there are synergies between QE, CCyB and NIRP in relation to the reversal rate: the lower the banks' capitalization and the higher the reserves holdings, the more likely the economy will hit the reversal rate. To see this, let's look at the purple line, representing an economy in which the central bank's balance sheet equals 38% of GDP. Following a 1% NIRP shock, investment increases by just above 0.5% with $\tau_{ss} = 2$, by less than 0.2% with $\tau_{ss} = 1.3$ and it *contracts* by roughly 0.5% with $\tau_{ss} = 0.9$. Note that — keeping $\tau_{ss} = 0.9$ — if the bank's balance sheet equalled 6% of GDP (orange line), investment would have *increased* by roughly 0.55%. Overall, a NIRP shock of 100 bps, pushes the low capitalised, QE-fuelled economy (purple line with $\tau_{ss} = 0.9$) *across* the reversal rate – making a new strong case for macro-prudential policy and for strategically deploying NIRP and QE.

We conclude that when calibrating NIRP to avoid hitting the reversal interest rate, both bank's capitalisation and reserve holdings matter. We echo Sims and Wu (2021) in flagging that the timing of UMP is important as well: since the larger the reserves, the less stimulative NIRP becomes, the model suggests to first employ NIRP (when reserves are still small) and then QE (that by construction increases reserves). This is the opposite of what monetary policymakers, notably in the Euro Area and Japan, have done. The policymakers' choice on the timing of the instruments imply, through the lens of this model, that during the Covid-19 crisis the economy could have hit the reversal interest rate if NIRP had been cut further.

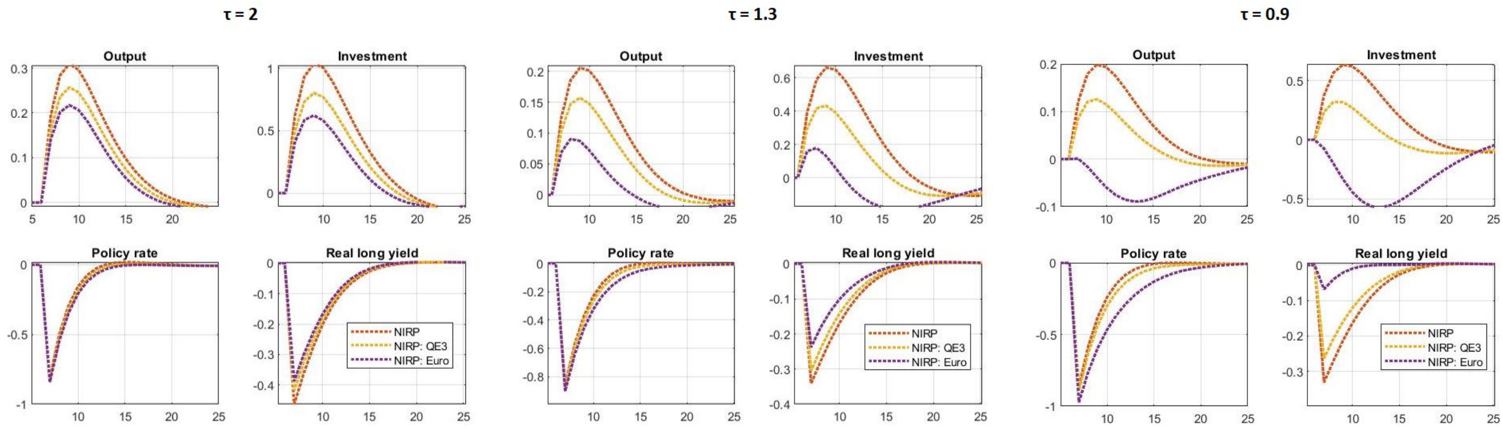


Figure 2.4: NIRP shock with different central bank's balance sheet sizes and different τ_{ss}.

2.5.5 Quantitative Tightening and CCyB

The previous sections have analysed the interactions between UMP and macro-prudential policy to stabilise output when the ZLB constraint is binding. This section takes a step further and it focuses on the synergies between UMP and CCyB when the economy is recovering and the central bank needs to rein in the monetary stimulus. The results make two new strong cases for the simultaneous deployment of QE and CCyB.

Quantitative Tightening (QT) is the unwinding of the central bank's balance sheet, after the bond purchases programme is over. Balance sheet normalisation — both its pace and announcements — move asset prices, with consequences for the real economy. The 2013 taper tantrum made this clear: following an announcement in May 2013 by former Federal Reserve Chair Ben Bernanke that the Fed would start reducing its asset purchases "in the next few [FOMC] meetings" (USCongress, 2013), the bond market reacted sharply, as investors sold off bonds. The 10-year US Treasuries' yield rose from 2% in May 2013 to around 3% in December, causing higher mortgages rates in the US and balance of payment stress in emerging markets (Davies, 2021).

Since the taper tantrum, the conventional wisdom amongst monetary policymakers has been that a quick, immediate unwinding of the central bank's balance sheet creates large repricing movements, tightening the financial conditions excessively, slowing down the real economy. Instead, carrying forward a large balance sheet — replacing the securities that mature to keep a constant balance sheet's size — was thought to have no effects on the recovery path.

Contrary to this general view, Sims and Wu (2021) find that, if the central bank carries forward a large balance sheet, the recession would be deeper than in the case of immediate unwinding (even though output would grow slightly faster once the economy moves away from the ZLB). From these results, they offer a policy recommendation: plan early and communicate clearly the whole balance sheet's path. The feasibility of this advice might be undermined by the data-dependency nature of monetary policy, that critically requires room for manoeuvre if new information warrants changes to the original QT plan. This section, building on Sims and Wu (2021), finds that the simultaneous deployment of QE and a Countercyclical Capital Buffer (CCyB) provides this crucial policy space, and it allows to start the normalisation process earlier than in the case without CCyB.

Following Sims and Wu (2021), Figure 2.5 shows the IRFs to credit shocks in periods 1-7, without CCyB (LHS, in which we turn off the subsidy τ_t^s and tax τ_t) and with CCyB (RHS). The orange dotted line represents an economy in which monetary policy is constrained at the ZLB (the interest rate on reserves and the deposit rate are stuck at the ZLB) and it cannot use UMP. The purple line represents the IRFs when the central bank adopts QE and it unwinds the balance sheet through a QT programme that follows the real bond holdings exogenous process of equation 2.78. In this setting (purple line), the autoregressive parameter ρ_f is equal to 0.8: this can be thought as "smooth QT". The yellow dotted line represents the IRFs when the central bank adopts QE but it unwinds the balance sheet through an immediate QT process — ρ_f is equal to 0. Finally, the green dotted line represents the IRFs when the central bank adopts QE however it does not implement QT, it carries forward a large balance sheet without unwinding it — ρ_f is equal to 1.

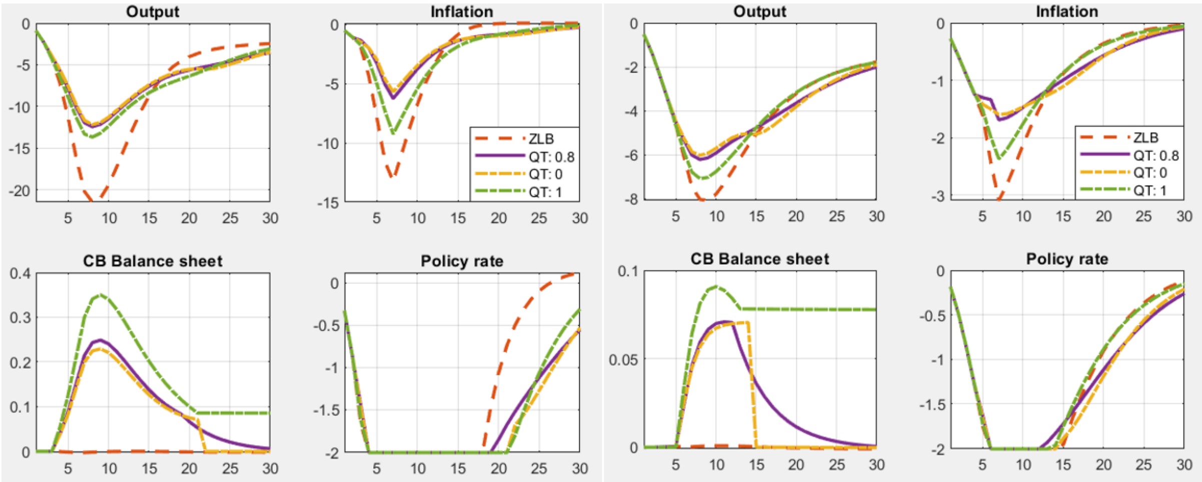


Figure 2.5: Different paces of Quantitative Tightening. LHS: IRFs without macro-prudential policy; RHS: IRFs with macroprudential policy

2.5.5.1 Results Without Macro-prudential Policy

The IRFs without CCyB reveal that QE followed in period 21 by no unwinding of the balance sheet (green dotted line) fuels a deeper recession and deflation than QE followed (again in period 21) by a quick, full normalisation of the balance sheet (yellow dotted line). Note that in the former case the central bank's balance sheet expands up to 34% of steady state output, while in the latter only to 22%. This difference in outcomes was revealed by Sims and Wu (2021), who explain it pointing to firms' expectation of the QT process: if firms expect a quick QT, then they will invest before QT, when the conditions are more favourable. This supports output. If instead they expect the central bank to carry forward a large balance sheet without unwinding it, then they will spread their investment across many periods, and this does not support a quick recovery.

2.5.5.2 Results With Macro-prudential Policy: The Introduction of the CCyB

The IRFs with CCyB show that the credit shock is mitigated, thanks to a less leveraged banking sector.[28] This has two implications. First, since the shock is mitigated, QE is less aggressive than in the case without CCyB and, most importantly for this note, QT can start earlier. Let's look at the case of immediate balance sheet normalisation (yellow line): when CCyB is activated (RHS) the unwinding starts in period 15; while, when CCyB is not activated (LHS), the

[28] Please see sections 2.5.1 or 2.5.3 to see why the introduction of a CCyB mitigates a credit shock.

unwinding starts in period 21. The same is true should the central bank decide to avoid normalising its balance sheet (green dotted line). Second, deploying CCyB alongside QE provides more policy space to the monetary authority than relying only on QE: if the quick unwinding of the balance sheet — the suggested best option by Sims and Wu (2021) — is not possible because economic conditions have changed, then policymakers would still be better off in the scenario with CCyB (RHS) because they would be able to carry forward a big balance sheet with still a smaller output contraction (-7%) than in the best case — quick unwinding — without CCyB (-12%, LHS).

Overall, deploying QE and macro-prudential policy simultaneously provides the benefits explored in section 2.5.3.[29] This final section makes two new strong cases for the simultaneous deployment, namely: using CCyB and QE in unison allows to start the normalisation process *earlier* and it grants more policy space to change the tightening pace without triggering an adverse market reaction and a severe economic contraction.

2.6 Conclusions

In this chapter we have developed a theoretical DSGE model to study how macro-prudential policy in the form of countercyclical capital requirement (CCyB) affects the transmission of three unconventional instruments of monetary policy: Quantitative Easing, Negative Interest Rate Policy and Forward Guidance. We found that with the introduction of CCyB, QE's transmission mechanism is weakened but NIRP's is strengthened. In addition, we revealed synergies between UMP and macro-prudential policy, making three new, strong cases for the simultaneous deployment of UMP and CCyB. First, using CCyB and QE in unison is more effective at stabilising output than solely relying on QE, allowing UMP to be less aggressive (smaller asset purchases programmes). This implies that UMP's side effects are reduced. Second, the powerful interactions between NIRP, QE and CCyB can be used strategically to avoid the reversal interest rate, increasing NIRP effectiveness. Third, turning towards the recovery, the concerted deployment of QE and CCyB allows to start Quantitative Tightening earlier and with more

[29]First, deploying UMP and macro-prudential policy in concert is more effective than solely relying on UMP to stabilise output. Second, it allows monetary policy to be less aggressive than in the case without CCyB. Finally, since monetary policy can be less aggressive, UMP side effects (like asset scarcity) are also reduced.

policy space to change the tightening pace than in the case without CCyB. The next chapter extends the model adding the funding-for-lending programmes. This will shed light on additional synergies amongst non-standard instruments of monetary policy.

Annex 1: Labour Market Aggregation

Knowing that $\int_0^1 L_{d,t}(h)dh = L_t$, we can integrate 2.9 across labour unions h and obtain:

$$L_t = L_{d,t} v_t^w \tag{2.86}$$

With v_t^w a measure of wage dispersion:

$$v_t^w = \int_0^1 \left(\frac{w_t(h)}{w_t} \right)^{-\varepsilon_w} dh \tag{2.87}$$

That can be rewritten with Calvo wage-setting as:

$$v_t^w = (1-\phi_w)\left(\frac{w_t^*}{w_t} \right)^{-\varepsilon_w} + \int_{1-\phi_w}^1 \left(\frac{\Pi_{t-1}^{\gamma_w} W_{t-1}(h)}{W_t} \right)^{-\varepsilon_w} dh \tag{2.88}$$

$$= (1-\phi_w)\left(\frac{w_t^*}{w_t} \right)^{-\varepsilon_w} + \Pi_{t-1}^{-\gamma_w \varepsilon_w} W_t^{\varepsilon_w} W_{t-1}^{-\varepsilon_w} \int_{1-\phi_w}^1 \left(\frac{W_{t-1}(h)}{W_t} \right)^{-\varepsilon_w} dh \tag{2.89}$$

$$= (1-\phi_w)\left(\frac{w_t^*}{w_t} \right)^{-\varepsilon_w} + \phi_w \Pi_{t-1}^{-\gamma_w \varepsilon_w} W_t^{\varepsilon_w} W_{t-1}^{-\varepsilon_w} v_{t-1}^w \tag{2.90}$$

In real terms:

$$v_t^w = (1-\phi_w)\left(\frac{w_t^*}{w_t} \right)^{-\varepsilon_w} + \phi_w \left(\frac{\Pi_t}{\Pi_{t-1}^{\gamma_w}} \right)^{\varepsilon_w} \left(\frac{w_t}{w_{t-1}} \right)^{\varepsilon_w} v_{t-1}^w \tag{2.91}$$

Using 2.10:

$$W_t^{1-\varepsilon_w} = (1-\phi_w)(W_t^*)^{1-\varepsilon_w} + \int_{1-\phi_w}^1 (\Pi_{t-1}^{\gamma_w} W_{t-1}(h))^{1-\varepsilon_w} dh \tag{2.92}$$

And dividing both sides by $P_t^{1-\varepsilon_w}$ we obtain:

$$w_t^{1-\varepsilon_w} = (1-\phi_w)(w_t^*)^{1-\varepsilon_w} + \phi_w \Pi_{t-1}^{\gamma_w(1-\varepsilon_w)} \Pi_{t-1}^{\varepsilon_w - 1} w_{t-1}^{1-\varepsilon_w} \tag{2.93}$$

Annex 2: Retail Firms Aggregation

We integrate 2.26 across retail firms, knowing that: $Y_t(f) = Y_{m,t}(f)$, $\int_0^1 Y_{m,t}(f)df = Y_{m,t}$, obtaining:

$$Y_t v_t^p = Y_{m,t} \tag{2.94}$$

where

$$v_t^p = \int_0^1 \left(\frac{P_t(f)}{P_t}\right)^{-\varepsilon_p} df \tag{2.95}$$

v_t^p is a measure of price dispersion and using Calvo pricing:

$$v_t^p = (1-\phi_p)(p_t^*)^{-\varepsilon_p} + \int_{1-\phi_p}^1 \left(\frac{\Pi_{t-1}^{\gamma_p} P_{t-1}(f)}{P_t}\right)^{-\varepsilon_p} df \tag{2.96}$$

$$= (1-\phi_p)(p_t^*)^{-\varepsilon_p} + \Pi_{t-1}^{-\gamma_p\varepsilon_t} P_t^{\varepsilon_p} P_{t-1}^{-\varepsilon_p} \int_{1-\phi_p}^1 \left(\frac{P_{t-1}(f)}{P_t}\right)^{-\varepsilon_p} df \tag{2.97}$$

$$= (1-\phi_p)(p_t^*)^{-\varepsilon_p} + \phi_p \left(\frac{\Pi_t}{\Pi_{t-1}^{\gamma_p}}\right)^{\varepsilon_p} v_{t-1}^p \tag{2.98}$$

Using 2.27:

$$P_t^{1-\varepsilon_p} = (1-\phi_p)(P_t^*)^{1-\varepsilon_p} + \int_{1-\phi_p}^1 \Pi_{t-1}^{\gamma_p(1-\varepsilon_p)} P_{t-1}(f)^{1-\varepsilon_p} df \tag{2.99}$$

$$= (1-\phi_p)(P_t^*)^{1-\varepsilon_p} + \phi_p \Pi_{t-1}^{\gamma_p(1-\varepsilon_p)} P_{t-1}^{1-\varepsilon_p} \tag{2.100}$$

Dividing by $P_t^{1-\varepsilon_p}$:

$$1 = (1-\phi_p)(p_t^*)^{1-\varepsilon_p} + \phi_p \Pi_{t-1}^{\gamma_p(1-\varepsilon_p)} \Pi_t^{\varepsilon_p - 1} \tag{2.101}$$

Annex 3: Wholesale firm

Subject to constraints 2.41 and 2.42, the Lagrangian is:

$$\begin{aligned}\mathbb{L}_{m,t} = \mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} \Bigg\{ & p_{m,t+j} A_{t+j} (u_{t+j} K_{t+j})^{\alpha} L_{d,t+j}^{1-\alpha} - w_{t+j} L_{d,t+j} - p_{t+j}^{k} \hat{I}_{t+j} + \\ & Q_{t+j} \left(\frac{F_{m,t+j}}{P_{t+j}} - \kappa \frac{F_{m,t+j-1}}{P_{t+j-1}} \Pi_{t+j}^{-1} \right) - \frac{F_{m,t+j-1}}{P_{t+j-1}} \Pi_{t+j}^{-1} + \\ & \nu_{1,t+j} \left(\hat{I}_t + (1-\delta(u_{t+j})) K_{t+j} - K_{t+j-1} \right) + \\ & \nu_{2,t+j} \left(Q_{t+j} \left(\frac{F_{m,t+j}}{P_{t+j}} - \kappa \frac{F_{m,t+j-1}}{P_{t+j-1}} \Pi_{t+j}^{-1} \right) \right) - \psi p_{t+j}^{k} \hat{I}_{t+j} \Bigg\}\end{aligned} \tag{2.102}$$

The first order condition with respect to $L_{d,t}$ is:

$$(1-\alpha) p_{m,t} A_t (u_t K_t)^{\alpha} L_{d,t}^{-\alpha} - w_t = 0 \tag{2.103}$$

The first order condition with respect to $\hat{I}_t$ is:

$$-p_t^k + \nu_{1,t} - \psi p_t^k \nu_{2,t} = 0 \tag{2.104}$$

The first order condition with respect to u_t is:

$$p_{m,t} \alpha A_t (u_t K_t)^{\alpha-1} K_t L_{d,t}^{1-\alpha} - \nu_{1,t} \delta'(u_t) K_t = 0 \tag{2.105}$$

The first order condition with respect to K_{t+1} is:

$$\begin{aligned}\mathbb{E}_t \Lambda_{t,t+1} \Bigg[& \alpha p_{m,t+1} A_{t+1} (u_{t+1} K_{t+1})^{\alpha-1} u_{t+1} L_{d,t+1}^{1-\alpha} + \\ & \nu_{1,t} (1 - \delta(u_{t+1})) \Bigg] - \nu_{1,t} = 0\end{aligned} \tag{2.106}$$

The first order condition with respect to $F_{m,t}$ is:

$$\frac{Q_t}{P_t} + \nu_{2,t} \frac{Q_t}{P_t} - \mathbb{E}_t \Lambda_{t,t+1} \left[\frac{1}{P_t} \Pi_{t+1}^{-1} + \kappa \frac{Q_{t+1}}{P_t} \Pi_{t+1}^{-1} + \nu_{2,t+1} \kappa \frac{Q_{t+1}}{P_t} \Pi_{t+1}^{-1} \right] = 0 \tag{2.107}$$

We set $M_{1,t} = 1 + \psi v_{2,t}$ and $M_{2,t} = 1 + v_{2,t}$ and rearranging we obtain the first order conditions presented in the chapter from equation 2.44 to equation 2.48:

$$w_t = (1-\alpha) p_{m,t} A_t (u_t K_t)^{\alpha} L_{d,t}^{-\alpha} \tag{2.108}$$

$$p_t^k M_{1,t} \delta'(u_t) = \alpha p_{m,t} (u_t K_t)^{(\alpha-1)} L_{d,t}^{1-\alpha} \tag{2.109}$$

$$p_t^k M_{1,t} = E_t \Lambda_{t,t+1} [\alpha p_{m,t+1} A_{t+1} K_{t+1}^{\alpha-1} u_{t+1}^{\alpha} L_{d,t+1}^{1-\alpha} + (1 - \delta(u_{t+1})) p_{t+1}^k M_{1,t+1}] \tag{2.110}$$

$$Q_t M_{2,t} = E_t \Lambda_{t,t+1} \Pi_{t+1}^{-1} [1 + \kappa Q_{t+1} M_{2,t+1}] \tag{2.111}$$

$$\frac{M_{1,t} - 1}{M_{2,t} - 1} = \psi \tag{2.112}$$

As specified in the chapter (subsection 2.3.4.3), the constraint that firms must issue bonds to finance investment is always binding by construction (2.42). To impose this binding constraint I assume that the wholesale firm prefers bond issuance over internal funding as its main financing source. While this assumption is not consistent with data if we consider the overall business cycle,[30] it becomes a realistic assumption if we focus on ZLB periods — like we do in this chapter: during the Covid-19 crisis, in fact, firms switched to debt, increasing their issuance (Holm-Hadulla et al., 2022). Hence, keeping ψ constant, the fractions of new physical capital $\hat{I}_t$ funded by debt and by internal equity remain unchanged. However, if ψ was set to zero (meaning that new physical capital would be entirely equity financed), $M_{1,t}$ would equal one and the optimality conditions for utilisation (2.109) and for capital (2.220) would see the friction (loan in advance) disappear, becoming standard FOCs. In addition, QE would lose its effectiveness on the real economy as shown in Figure 2.6 (red dotted line).

Finally, if we want to examine the relationship between short term rates (R_t^d) and wholesale firm's equity, we have to: first, add the dividends of financial

[30] The pecking order theory of corporate finance states that firms prefer internal financing to debt issuance (de Bondt, 2022).

intermediaries, labour unions, capital producer, retail firms and wholesale firm (equation 2.43); second, include the aggregate dividends in the households' budget constraint (in real terms), obtaining the following relationship:

$$C_t + d_t + Q_{H,t}h_t - R^d_{t-1}d_{t-1} - R^H_t Q_{H,t-1}h_{t-1} - mrs_t L_t + X + T_t = div_{w,t} + div_{aggregate,t} \tag{2.113}$$

Where $div_{w,t}$ is the dividend (equity) of the wholesale firm (equation 2.43) and $div_{aggregate,t}$ is the total divided of financial intermediaries, labour unions, capital producer and retail firms.

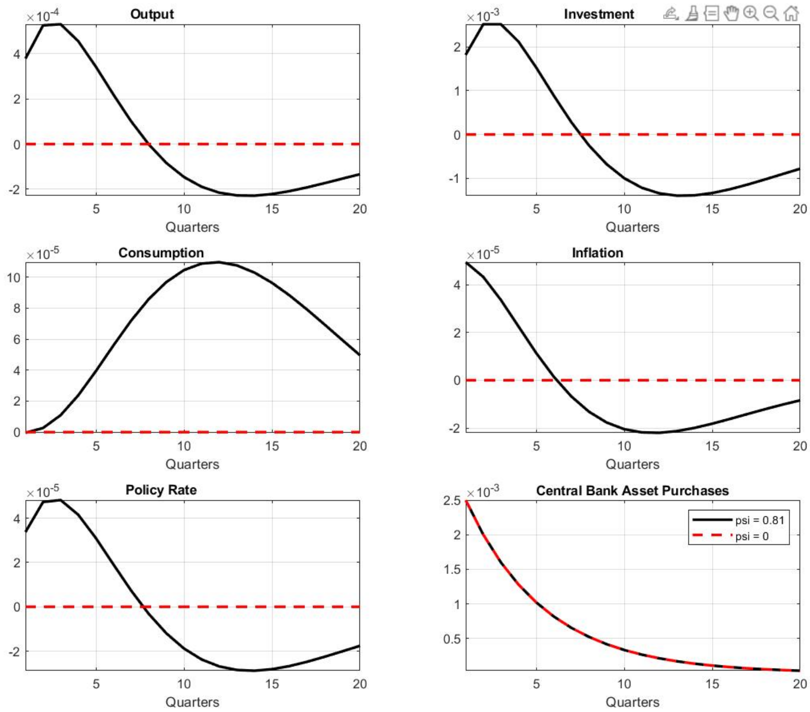


Figure 2.6: IRFs to a QE shock (central bank asset purchases).

Annex 4: Calibrated Parameters

The following non-standard parameters associated with the financial sector are taken from:

Table 2.2: Non-standard calibrated parameters

Parameter	Value or Target	Source
κ	$1-40^{-1}$	(Sims and Wu, 2021)
κ_h	0.3	This paper's calibration
x	0.15	(Gertler et al., 2012)
ε	-2	(Gertler et al., 2012)
τ_{ss}	1.3	This paper's calibration
ψ	0.81	(Sims and Wu, 2021)
σ	0.95	(Sims and Wu, 2021)
χ	Leverage = 4	(Sims and Wu, 2021)
Δ	1/3	(Sims and Wu, 2021)
bcb	0.06	(Sims and Wu, 2021)
fcb	0	(Sims and Wu, 2021)
ρ_θ	0.98	(Sims and Wu, 2021)
ρ_b	0.8	AR (Sims and Wu, 2021)
ρ_f	0.8	AR (Sims and Wu, 2021)
ρ_{mpr}	0.8	This paper's calibration
$\overline{b_G}$	0.41	(Sims and Wu, 2021)
G	0.2	(Sims and Wu, 2021)

Annex 5: Equilibrium Conditions

Households:

$$\Lambda_{t-1,t} = \frac{\beta \mu_t}{\mu_{t-1}} \tag{2.114}$$

$$\mu_t = \frac{1}{(C_t - bC_{t-1})} - \beta b E_t \frac{1}{(C_{t+1} - bC_t)} \tag{2.115}$$

$$\chi L_t^{\eta} = \mu_t mrs_t \tag{2.116}$$

$$1 = R_t^D \mathbb{E}_t \Lambda_{t,t+1} \Pi_{t+1}^{-1} \tag{2.117}$$

$$1 = \mathbb{E}_t \Lambda_{t,t+1} \Pi_{t+1}^{-1} R_{t+1}^H \tag{2.118}$$

Capital producer:

$$\hat{I}_t = \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{2.119}$$

$$1 = p_t^k \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + \mathbb{E}_t \Lambda_{t,t+1} p_{t+1}^k S\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{2.120}$$

Wholesale firm:

$$w_t = (1-\alpha) p_{m,t} A_t (u_t K_t)^{\alpha} L_{d,t}^{-\alpha} \tag{2.121}$$

$$p_t^k M_{1,t} \delta'(u_t) = \alpha p_{m,t} (u_t K_t)^{(\alpha-1)} L_{d,t}^{1-\alpha} \tag{2.122}$$

$$p_t^k M_{1,t} = E_t \Lambda_{t,t+1} [\alpha p_{m,t+1} A_{t+1} K_{t+1}^{\alpha-1} u_{t+1}^{\alpha} L_{d,t+1}^{1-\alpha} + (1 - \delta(u_{t+1})) p_{t+1}^k M_{1,t+1}] \tag{2.123}$$

$$Q_t M_{2,t} = E_t \Lambda_{t,t+1} \Pi_{t+1}^{-1} [1 + \kappa Q_{t+1} M_{2,t+1}] \tag{2.124}$$

$$\frac{M_{1,t} - 1}{M_{2,t} - 1} = \psi \tag{2.125}$$

$$\psi p_t^k \hat{I}_t = Q_t (f_{m,t} - \kappa \Pi_t^{-1} f_{m,t-1}) \tag{2.126}$$

$$Y_{m,t} = A_t (u_t K_t)^{\alpha} L_{d,t}^{1-\alpha} \tag{2.127}$$

$$K_{t+1} = \hat{I}_t + (1 - \delta(u_t)) K_t \tag{2.128}$$

Retail firm:

$$p_t^* = \frac{\varepsilon_p}{\varepsilon_p - 1} \frac{x_{1,t}}{x_{2,t}} \tag{2.129}$$

$$x_{1,t} = p_{m,t} Y_t + \phi_p \mathbb{E}_t \Lambda_{t,t+j} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\varepsilon_p} x_{1,t+1} \tag{2.130}$$

$$x_{2,t} = Y_t + \phi_p \mathbb{E}_t \Lambda_{t,t+j} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\varepsilon_p - 1} x_{2,t+1} \tag{2.131}$$

Labour union:

$$w_t^* = \frac{\varepsilon_w}{\varepsilon_w - 1} \frac{f_{1,t}}{f_{2,t}} \tag{2.132}$$

$$f_{1,t} = mrs_t w_t^{\varepsilon_w} L_{d,t} + \phi_w \mathbb{E}_t \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\varepsilon_w} f_{1,t+1} \tag{2.133}$$

$$f_{2,t} = w_t^{\varepsilon_w} L_{d,t} + \phi_w \mathbb{E}_t \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\varepsilon_w - 1} f_{2,t+1} \tag{2.134}$$

Financial intermediaries:

$$E_t \Lambda_{t,t+1} [(1 + \tau_t)(R_{t+1}^F - R_t^d) + (1 + \tau_t^s)(R_t^d - R_{t+1}^H) x_t] \Pi_{t+1}^{-1} \Omega_{t+1} = \frac{\lambda_t}{1 + \lambda_t} \Theta(x_t) \tag{2.135}$$

$$E_t\Lambda_{t,t+1}[(1+\tau_t)(R^B_{t+1}-R^d_t)+(1+\tau^s_t)(R^d_t-R^H_{t+1})x_t]\Pi^{-1}_{t+1}\Omega_{t+1}=\Delta\frac{\lambda_t}{1+\lambda_t}\Theta(x_t) \quad (2.136)$$

$$E_t\Lambda_{t,t+1}[(1+\tau_t)(R^{re}_t-R^d_t)+(1+\tau^s_t)(R^d_t-R^H_{t+1})x_t]\Pi^{-1}_{t+1}\Omega_{t+1}=-\frac{\omega_t}{1+\lambda_t} \quad (2.137)$$

$$E_t\Lambda_{t,t+1}[(1+\tau^s_t)(R^d_t-R^H_{t+1})(Q_tf_t+Q_{B,t}b_t+re_t)]\Pi^{-1}_{t+1}\Omega_{t+1}=-\frac{\lambda_t}{1+\lambda_t}\Theta'(x_t)(Q_tf_t+\Delta Q_{B,t}b_t) \quad (2.138)$$

$$\Omega_t=1-\sigma+\sigma\Theta(x_t)\phi_t \quad (2.139)$$

$$\Theta(x_t)=\theta\left(1+\varepsilon(1+\tau^s_t)x_t+\frac{k}{2}(1+\tau^s_t)x_t^2\right) \quad (2.140)$$

$$\Theta'=\theta\left(((1+\tau^s_t)\varepsilon)+((1+\tau^s_t)kx_t)\right) \quad (2.141)$$

$$x_t=\frac{Q_{H,t}h_t}{Q_tf_t+Q_{B,t}b_t+re_t} \quad (2.142)$$

$$\phi_t=\frac{Q_tf_t+\Delta Q_{B,t}b_t}{n_t} \quad (2.143)$$

$$(1+\tau_t)(Q_tf_t+Q_{B,t}f_t+re_t)=n_t+d_t+(1+\tau^s_t)Q_{H,t}h_t \quad (2.144)$$

$$\phi_t=\frac{E_t\Lambda_{t,t+1}[(1+\tau^s_t)(R^d_t-R^H_{t+1})(Q_tf_t+Q_{B,t}b_t+re_t)]\Pi^{-1}_{t+1}\Omega_{t+1}\frac{re_t}{n_t}+E_t\Lambda_{t,t+1}\Pi^{-1}_{t+1}\Omega_{t+1}R^d_t}{\Theta(x_t)-E_t\Lambda_{t,t+1}[(1+\tau_t)(R^F_{t+1}-R^d_t)+(1+\tau^s_t)(R^d_t-R^H_{t+1})x_t]\Pi^{-1}_{t+1}\Omega_{t+1}} \quad (2.145)$$

$$n_t = \sigma \Pi_{t+1}^{-1} \Big((1+\tau_t)(R_t^F - R_{t-1}^d) Q_{t-1} f_{t-1} + (1+\tau_t)(R_t^B - R_{t-1}^d) Q_{B,t-1} b_{t-1} + (1+\tau_t)(R_{t-1}^{re} - R_{t-1}^d) re_{t-1} + R_{t-1}^d n_{t-1} + (1+\tau_t^s)(R_{t-1}^d - R_t^H) x_{t-1} (Q_{t-1} f_{t-1} + Q_{B,t-1} b_{t-1} + re_{t-1}) \Big) + X \quad (2.146)$$

Central bank:

$$Q_t f_{cb,t} + Q_{B,t} b_{cb,t} = re_t \quad (2.147)$$

$$T_{cb,t} = (1 + kQ_t)\Pi_t^{-1} f_{cb,t-1} + (1 + kQ_{B,t})\Pi_t^{-1} b_{cb,t-1} - R_{t-1}^{re} \Pi_t^{-1} re_{t-1} \quad (2.148)$$

Monetary policy:

$$lnR_t^{tr} = (1-\rho_r) lnR^{tr} + \rho_r lnR_{t-1}^{tr} + (1-\rho_r)[\phi_\pi (ln\Pi_t - ln\Pi) + \phi_y (lnY_t - lnY_{t-1})] + s_r \varepsilon_{r,t} \quad (2.149)$$

$$R_t^{tr} = R_t^d \quad (2.150)$$

$$R_t^{re} = max(1, R_t^{tr}) \quad (2.151)$$

$$f_{cb,t} = (1-\rho_f) f_{cb} + \rho_f f_{cb,t-1} + s_f \varepsilon f \quad (2.152)$$

$$b_{cb,t} = (1-\rho_b) b_{cb} + \rho_b b_{cb,t-1} + s_b \varepsilon f \quad (2.153)$$

Macro-prudential policy:

$$\tau_t^s = (1-\rho_{mpr})\tau_{ss} + \rho_{mpr}\tau_{t-1}^s - \phi_{mpr}[Y_t - Y_{t-1}] + \phi_{mpr}[spread_t - spread_{ss}] \quad (2.154)$$

$$\tau_t = \tau^s x_t \tag{2.155}$$

$$spread_t = (R^F_{t+1} - R^d_t) + (R^B_{t+1} - R^d_t) \tag{2.156}$$

Fiscal policy:

$$G_t + b_{G,t-1}\Pi_t^{-1} = T_t + T_{cb,t} + Q_{B,t}(B_{G,t} - \kappa\Pi_t^{-1}b_{G,t-1}) \tag{2.157}$$

Aggregate conditions:

$$R^F_t = \frac{1+k(Q_t)}{Q_{t-1}} \tag{2.158}$$

$$R^B_t = \frac{1+k(Q_{B,t})}{Q_{B,t-1}} \tag{2.159}$$

$$R^H_t = \frac{1+k_k(Q_{H,t})}{Q_{H,t-1}} \tag{2.160}$$

$$f_{m,t} = f_t + f_{cb,t} \tag{2.161}$$

$$b_{G,t} = b_t + b_{cb,t} \tag{2.162}$$

$$L_t = L_{d,t} v^w_t \tag{2.163}$$

$$v^w_t = (1-\phi_w)\left(\frac{w^*_t}{w_t}\right)^{-\varepsilon_w} + \phi_w \left(\frac{\Pi_t}{\Pi_{t-1}^{\gamma_w}}\right)^{\varepsilon_w} \left(\frac{w_t}{w_{t-1}}\right)^{\varepsilon_w} v^w_{t-1} \tag{2.164}$$

$$w_t^{1-\varepsilon_w} = (1-\phi_w)(w^*_t)^{1-\varepsilon_w} + \phi_w \Pi_{t-1}^{\gamma_w(1-\varepsilon_w)} \Pi_{t-1}^{\varepsilon_w - 1} w_{t-1}^{1-\varepsilon_w} \tag{2.165}$$

$$Y_t v_t^p = Y_{m,t} \tag{2.166}$$

$$v_t^p = (1-\phi_p)(p_t^*)^{-\varepsilon_p} + \phi_p \left(\frac{\Pi_t}{\Pi_{t-1}^{\gamma_p}} \right)^{\varepsilon_p} v_{t-1}^p \tag{2.167}$$

$$1 = (1-\phi_p)(p_t^*)^{1-\varepsilon_p} + \phi_p \Pi_{t-1}^{\gamma_p(1-\varepsilon_p)} \Pi_t^{\varepsilon_p - 1} \tag{2.168}$$

$$Y_t = C_t + G_t + I_t \tag{2.169}$$

$$lnA_t = \rho_A lnA_{t-1} + s_A \varepsilon_{A,t} \tag{2.170}$$

$$lnG_t = (1-\rho_G) lnG + \rho_G G_{t-1} + s_G \varepsilon G, t \tag{2.171}$$

$$ln\theta_t = (1-\rho_t)\theta + \rho_t \theta_{t-1} + s_t \varepsilon_{\theta,t} \tag{2.172}$$

The above are 59 equations for 59 variables: R_t^B, R_t^F,R_t^{re},R_t^d,R_t^{TR}, Q_t, $Q_{B,t}$, $\Lambda_{t,t+1}$, Ω_t, Π_t, λ_t, ω_t, ϕ_t, re_t, n_t, μ_t, C_t, L_t, mrs_t,w_t^*, $f_{1,t}$, $f_{2,t}$, w_t, $L_{d,t}$, p_t^*, $x_{1,t}$, $x_{2,t}$, $p_{m,t}$, Y_t, $Y_{m,t}$, u_t, K_t, $\hat{I}_t$, p_t^k, $f_{m,t}$,$M_{1,t}$, $M_{2,t}$, I_t, T_t, $T_{cb,t}$, $f_{cb,t}$, $f_{cb,t}$, A_t, G_t, θ_t, f_t, b_t, d_t, v_t^p, v_t^w, $spread_t$, R_t^H, $Q_{H,t}$, h_t, x_t, $\Theta(x_t)$, Θ', τ_t, τ_t^s.

Annex 6: ZLB binding with exogenous UMP and CCyB

To generate Figure 2.2, we first simulate a sequence of credit shocks with 1.5 standard deviations in each period from 1 to 6 in order to push the economy to the ZLB. Figure 2.7 below shows that the ZLB becomes binding in period 4.

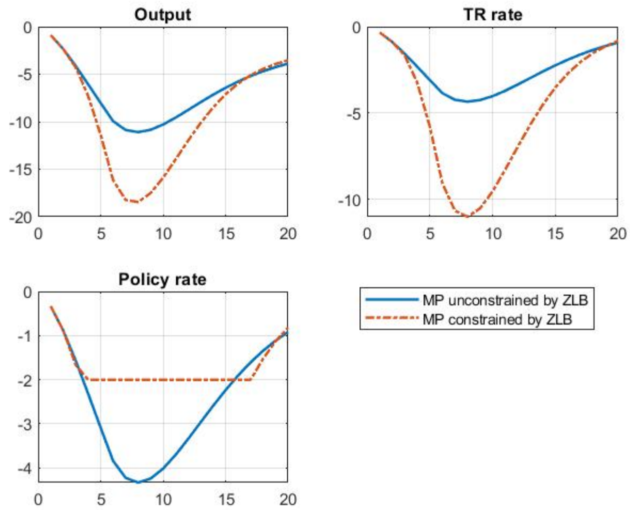


Figure 2.7: A sequence of six credit shocks, with and without the ZLB binding.

If we simulate the monetary policy shock as soon as the ZLB becomes biding (period 5), we obtain the same effects on macroeconomic and financial variables that we obtain in Figure 2.2 in the chapter when the monetary policy shock is simulated in period 7 — please see Figure 2.8 below.

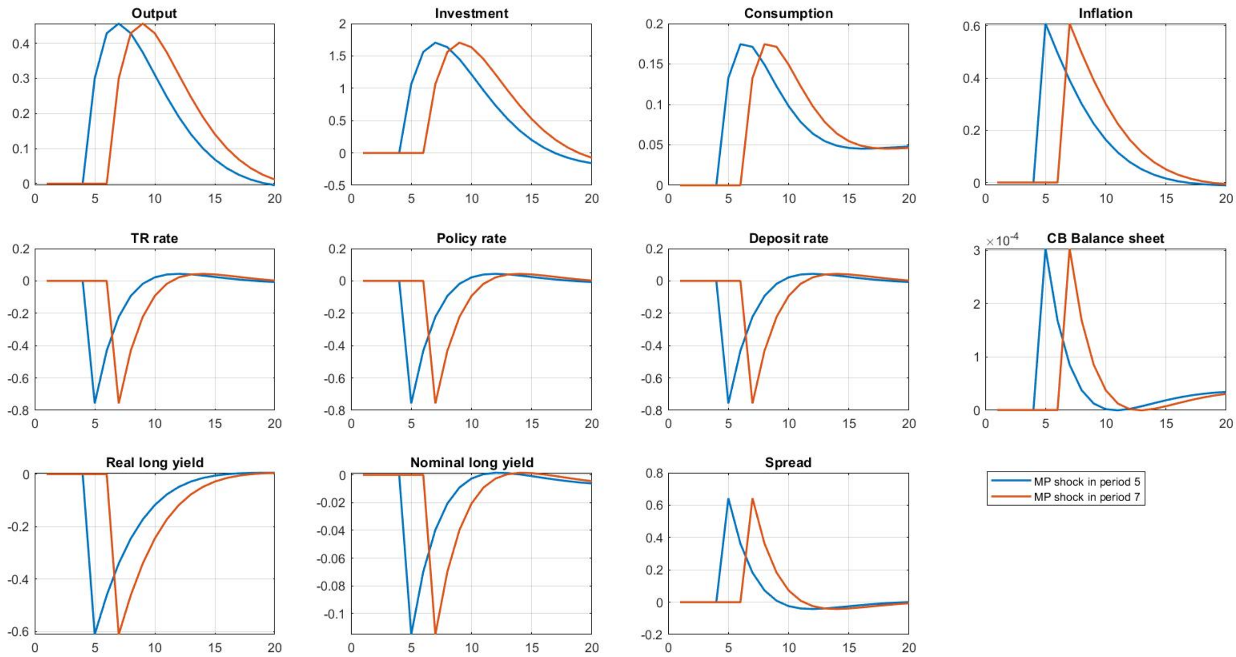


Figure 2.8: MP shock in two different period at the ZLB.

Annex 7: FG effectiveness

We simulate a sequence of credit shocks in periods 1–3 to make the ZLB binding. Then in period 4 we present two scenarios: one in which monetary policy is not constrained by the ZLB and we simulate a conventional Bank Rate negative shock (orange line); another one in which monetary policy is constrained by the ZLB and we simulate a FG shock (blue dotted line). In the latter, the rate implied by the Taylor rule falls, but the policy rate and the deposit rate do not follow. Importantly, the FG shock makes the policy rate and the deposit rate last longer at the ZLB — this is what makes FG effective. However, as noted in section 2.5.2.1, FG is less effective than a conventional monetary policy rate cut: to achieve the same output stabilisation, the Taylor rule rate falls to -8.9% with FG but only -4.2% with conventional monetary policy . This is because with a standard policy rate cut the deposit rate is affected immediately, instead with FG it is affected only when the ZLB is not binding anymore.

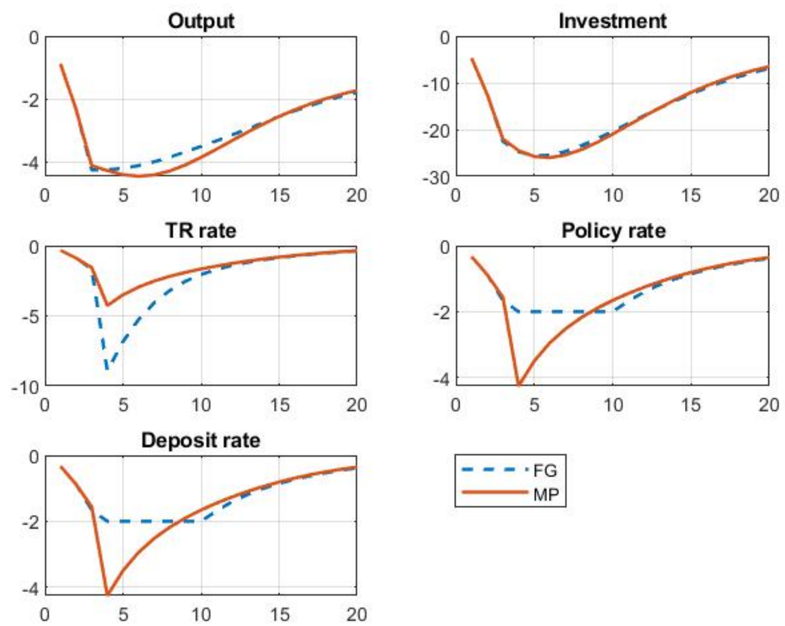


Figure 2.9: Conventional monetary policy shock and FG shock at the ZLB.

Chapter Three

Expanding the Unconventional Monetary Policy Toolbox: Central Bank Lending Programmes

Using a DSGE model, this chapter studies the interactions between Central Bank lending programmes and three other unconventional monetary policy instruments: quantitative easing, forward guidance and negative interest rate policy. The lending programmes feature a collateral policy and a "dual rate system", in the spirit of the ECB strategy during the Covid-19 crisis.

"The anatomy of our response [to the Covid-19 crisis] consists of a carefully calibrated set of three mutually reinforcing and complementary components. The first component relates to broad-based asset purchases [...]. The second component consists of [...] targeted longer-term refinancing operations (TLTROs), as well as a comprehensive set of collateral easing measures. And the third component relates to our traditional role as a lender of last resort."

Isabel Schnabel, ECB Executive Board Member, April 2020

3.1 Introduction

3.1.1 Introduction

The Funding-for-Lending Programmes are long-term, collateralised loans that central banks provide to banks at favourable costs in order to enhance the transmission of the policy stance. Since 2011 the European Central Bank (ECB) and Bank of England (BoE) have used this non-standard tool extensively in response to the severe malfunctioning (in same cases dry-up) of the interbank market.[1] The lending programmes lowered banks' funding costs, spurred lending to the real economy, supported output and helped control inflation.[2] More recently, central banks resorted to lending programmes in response to money market malfunctioning induced by the Covid-19 crisis (Cavallino and Fiore, 2020). Relative to previous liquidity provisions, these programmes featured a *more sophisticated* framework — providing additional degrees of policy freedom[3] — and, critically, they were deployed *simultaneously* with the other unconventional monetary policy (UMP) instruments — generating powerful interactions (Schnabel, 2020b).[4] These

[1] Following the Global Financial Crisis, the ECB in 2011 launched two 3-year Longer-Term Refinancing Operations (LTROs), followed in 2014 by three rounds of Targeted LTROs (TLTROs); the BoE introduced in 2012 the Funding for Lending Scheme (FLS) and in 2016 the Term Funding Scheme (TFS). Critically, the amount that banks could borrow under the TLTROs, FLS and TFS was conditional on their loans to firms and households.

[2] For more details, see Rostagno et al. (2019) on the ECB's lending programmes and Eberly et al. (2020) on BoE's TFS, amongst the others.

[3] For instance, in regard to the ECB lending programme: "The conditional pricing of TLTROs below the deposit facility rate has created additional room for easing funding conditions for banks in a negative interest rate environment and offers an effective backstop against strains in banks' access to market-based funding." (Barbiero et al., 2021)

[4] See Churm et al (2021) for the BoE and Lane (2019) for the ECB.

new, defining characteristics made the lending programmes "a central bulwark against the impairment of the bank-based transmission mechanism of monetary policy" during the Covid-19 pandemic (Barbiero et al., 2021). Nonetheless, little is known by the literature on how to design these types of liquidity provisions (Carpinelli and Crosignani, 2021).

The aim of this chapter is to explore theoretically and to quantify the synergies and trade-offs between the lending programmes and three UMP instruments: quantitative easing (QE), negative interest rate policy (NIRP) and forward guidance (FG). The motivation is threefold. First, the main transmission channel of the lending programmes — to lower banks' funding costs[5] – is different from the transmission mechanism of other UMP tools. Hence, assessing the effectiveness of the current monetary toolkit requires the lending facility to be fully modelled: QE, despite its liquidity channel (Busetto et al., 2022), cannot be taken as proxy for the lending programmes.

Second, while the literature has explored the link between credit supply and central bank's liquidity injections, it has not yet accurately micro-founded the lending programmes to reflect policymakers' choices. In particular, previous theoretical studies do not include the three main features of the framework implemented during the Covid-19 pandemic: i) the collateral policy, defined as changes in collateral needed to access the lending facility,[6] ii) the "dual rate system", that sets the interest rate on the lending facility separately from the policy rate, and iii) the borrowers' duality, allowing not only financial firms but also corporates to borrow from the central bank (e.g. Wall Street vs Main Street Lending Programs). Missing these specific design features, the literature does not capture several channels of monetary policy transmission, hamstringing the validity of the model for policy's purposes.

Finally, so far the literature has analysed the lending programmes, QE, NIRP and FG in a piecemeal fashion. These *ad hoc* frameworks overlook the interactions amongst the instruments [7] providing an incomplete transmission mechanism of monetary policy, again weakening the usefulness for policy analysis.

[5]See Churm et al. (2021) for BoE and Lane (2020b) for ECB.

[6]"Collateral and haircut policies have gone under the radar for a long time, and in any case have been less popular measures of the monetary policy stance than interest rates or quantitative policies. Yet they are not only essential for the correct functioning of the monetary and financial systems (Bindseil et al., 2017), but are also a key instrument to tighten, or loosen, liquidity in the banking system"(Legroux et al., 2018).

[7]The ECB estimates that its QE — the Pandemic Emergency Purchase Programme (PEPP)

In short, as the financial system and the central bank's toolkit evolved, so did the lending programmes: In the words of BoE Hauser (2021b), there is "a new generation of central bank tools aimed at market dysfunction". These modern liquidity provisions are more sophisticated than those following the canonical Bagehot principle,[8] as such they call for a new framework of analysis, necessary to capture the novel channels of transmission. The introduction of a unified framework is one of the main aims of this chapter.

This chapter micro-founds the liquidity injections following the ECB TLTRO and it sets them within the model developed by Sims and Wu (2021) featuring multiple UMP tools: QE, NIRP and FG. *This unified framework allows us to explore and assess the strength of the different transmission mechanisms and interactions*. The modelling contributions are the following: on the financial intermediary's side, we include the possibility to access the central bank lending programme as in Quint and Tristani (2018), subject to a collateral constraint à la Kiyotaki and Moore (1997); on the central bank side, we add the possibility to lend to intermediaries — while deploying QE, NIRP and FG. Mirroring the most recent ECB TLTRO, the central bank toolkit is expanded with three instruments: i) the collateral's haircut, ii) the choice on the assets eligible for collaterals, and iii) the rate applied to the liquidity provisions.

We make five main contributions. First, when deployed in isolation, liquidity injections are as effective as central bank corporate bond purchases and more effective than sovereign bonds purchases in supporting aggregate demand. Given the political economy challenges posed by large QE programmes of corporate bonds,[9] the lending programmes offer an equally effective alternative when the economy hits the ZLB.

Second, when deployed simultaneously, QE and the lending programmes give rise to both synergies that amplify UMP effectiveness and trade-offs that weaken it. The synergies are fuelled by the portfolio rebalancing channel of QE that increases the collateral value, allowing more liquidity injections without using additional

decisions in March and June 2020 and the scaling-up of the Asset Purchase Programme (APP) decided in March 2020 — and long term lending programmes lunched in response to the Covid-19 pandemic added 1.3 percentage points to real GDP growth up to 2022 (Hutchinson and Mee, 2020).

[8]Lending freely, to sound institutions, against good collateral, and at rates higher than those prevailing in normal conditions (Bagehot, 1873).

[9]See the experience of the Bank of England Asset Purchase Facility Schemes: at the end of December 2021 it held GBP875 billion in Gilts and only GBP20 billion in corporate bonds

monetary policy space (no haircut, nor dual rate easing). In other words, when QE and the liquidity provisions work in unison, UMP effectiveness increases. The trade-off surfaces when the central bank, through its asset purchases and (unchanged) collateral requirements, generates a scarcity of available assets (the contractionary scarcity channel). In this case, QE and the liquidity provisions work in opposite directions, weakening UMP effectiveness. BoE (Hauser, 2021b) stated that "we cannot rely on central bank medicine of the scale and duration seen in 2020 every time we see an inflammation [of market dysfunction]": these results are important to design policy interventions carrying fewer costs in terms of central bank balance sheets and mispriced private sector risks.

Third, easing the lending programme's collateral policy while engaging in QE enhances UMP effectiveness, overcoming the scarcity channel. Compared to relying on QE alone, the concerted strategy allows the economy to achieve a higher degree of output stabilisation with a smaller balance sheet intervention. From a policy perspective, this strategy confirms the ECB response during Covid, characterised by "three mutually reinforcing and complementary components": QE, TLTRO with collateral policy and liquidity injections as lender of last resort.

Fourth, deploying simultaneously NIRP and the lending programme with the dual rate strategy enhances NIRP effectiveness. This synergy arises because the dual rate policy mitigates the contraction in banks' net worth induced by NIRP. From a policy perspective, this concerted strategy makes monetary policy more effective: compared to relying solely on NIRP, the dual delivery achieves a higher degree of output stabilisation with a less aggressive implementation of NIRP. This translates into a smaller probability of hitting the reversal interest rate (Lagarde, 2020), the tipping point at which expansionary monetary policy turns contractionary.

Finally, turning towards the normalisation of UMP, we find that the pace of unwinding and the combination of tools that are unwound have significant effects on the performance of the economy during the recession, the recovery and future crises. The most effective strategy is a smooth and complete unwinding of both QE and the lending programme. If this was not possible, QE should be exited quickly and the lending programme carried forward. Compared to never fully unwinding the unconventional stimulus, this strategy leaves the economy less dependent on central bank's interventions and, going forward, more reactive to them, ensuring the effectiveness of future monetary policy decisions. To conclude, the knowledge on the exit from UMP is limited, leaving "policymakers uncertain about the effects of their policy on the economy"(Panetta, 2022b) — my findings offer the first policy recommendations.

The remainder of this chapter is organised as follows. Subsection 3.1.2 and 3.1.3 describe, respectively, the distinctive features and channels of transmission of the ECB TLTRO, deployed in response to the Covid-19 crisis, informing the modelling. Section 3.2 presents a short review of the relevant literature. Section 3.3 explains the main features of the model, focusing on the financial intermediaries and the central bank. Section 3.4 shows the calibration of the model. Section 3.5 presents the simulations above the ZLB, useful to understand the mechanics of the model and to explore the transmission channels of the liquidity provisions. Section 3.6 presents five policy experiments: first, we simulate exogenous UMP shocks, to compare the effectiveness of the different UMP instruments. Second, we simulate exogenous QE shocks to explore synergies and trade-off between QE and the lending programme. Third, we endogenise both QE and the lending programme, allowing the central bank to deploy these instruments simultaneously in response to a credit shock: this experiment replicates the ECB strategy during the Covid-19 crisis. Fourth we study the synergies between NIRP and the dual rate policy of the lending programme, letting the central bank engage with these tools in response to a credit shock. Fifth, we focus on the policy normalisation, studying the effects on output and central bank balance sheet of different tightening paces and combinations of QE/lending programme. Finally, section 3.7 concludes.

3.1.2 The ECB Lending Programmes: Novel, Distinctive Features

This paper micro-founds the lending programmes following the choices of the ECB, a central bank that in response to the Covid-19 pandemic has relied extensively on liquidity injections and developed a highly sophisticated framework. This section presents the characteristics of the ECB Funding-for-Lending Programmes, informing my modelling choices. It is important to fully understand the main features of these programmes because they inform many of the modelling choices made in this chapter.

The ECB in 2019 launched the third round of the Targeted Longer-Term Refinancing Operations (TLTRO III). This decision was taken to avoid "congestion effects" in bank funding markets that would have otherwise materialised because of the need to replace expiring TLTRO II funds (Barbiero et al., 2021). As of June 2021, the

TLTRO III became the largest liquidity injection in the history of the ECB: EUR2.2 trillion were provided to fill the liquidity needs of households and corporates triggered by the Covid-19 pandemic (see Figure 3.1 below). The characteristics of the TLTROs — critical for our modelling — are:

- **Interactions with other unconventional monetary policy tools.** TLTROs are part of a set of *complementary* monetary tools, including QE, NIRP and forward guidance.[10] The ECB found that the TLTROs worked in unison with the broader policy package, generating interactions that enhanced the lending programme's effectiveness (Barbiero et al., 2021).
- In March 2020 the ECB recalibrated the pre-existing TLTRO III as follows:
  - **Collateral policy.** A core element of the ECB's monetary policy response to the coronavirus pandemic has been the easing of the collateral criteria governing the access to the TLTRO. The Governing Council: i) expanded the banks' borrowing allowance under TLTRO III from 30% to 55% of the eligible loan book, thanks to a 20% reduction of collateral haircuts, amongst other measures; ii) enlarged the set of assets eligible for collateral, including: government guaranteed loans[11] as well as assets (and their issuers) that met the collateral eligibility criteria at the beginning of April 2020, regardless of future downgrades. With this decision, the ECB protected credit from any potential vicious cycles. For more detail on the ECB collateral policies during the Covid-19 crisis, please see ECB (2020b) and ECB (2020c).
  - **The "Dual Rate System".** The ECB Governing Council reduced the interest rate applied on TLTROs to a rate as low as -1% until June 2022 for banks fulfilling the lending requirements (ECB, 2020a). This gave rise to the "dual rate system", namely setting the TLTRO interest rate lower than the interest rate on reserves (already negative).[12]

[10]See Rostagno et al. (2019) and ECB (2015).

[11]Allowing banks to receive liquidity against loans covered by the new Euro Area guarantee schemes implemented in response to the Covid-19 pandemic.

[12]In the words of ECB chief economist Lane (2020a): "An important innovation is that, by setting the minimum borrowing rate at 25 basis points below the average interest rate on the deposit facility, we are effectively lowering the funding costs in the economy without a generalised reduction in the main traditional policy rates".

Overall, the TLTROs were "enhanced" along three dimensions: i) the delivery, that became simultaneous with the other UMP tools; ii) the recalibration, that ensured collateral availability; and iii) the pricing, that secured central bank funding at advantageous terms. These three features of the TLTROs played a "key role in preserving favourable bank financing conditions" during the Covid-19 pandemic (Barbiero et al., 2021) and they are fully fledged modelled in our framework.

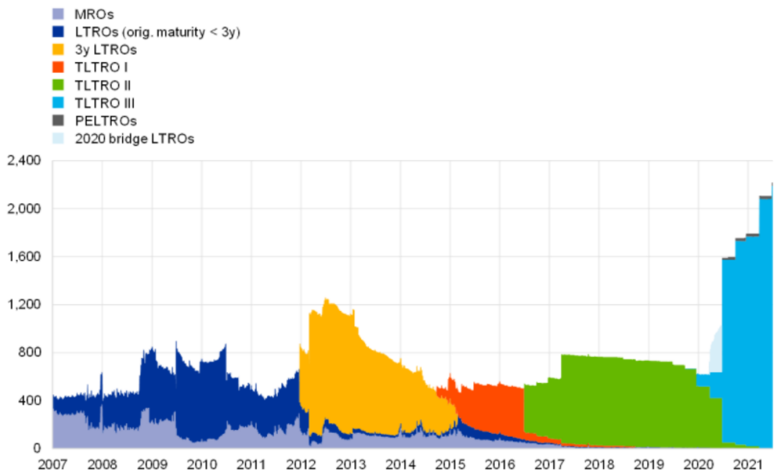


Figure 3.1: Borrowing from the Eurosystem (EUR billion)

Source: ECB Economic Bulletin, Issue 6/2021.

3.1.3 The Lending Programmes' Transmission Mechanisms

The transmission of the "enhanced" liquidity provisions to bank lending works through several channels of transmission, beyond the canonical liquidity channel at work in the Bagehot principle (Bagehot, 1873). Given the key role played by these new transmission mechanisms in supporting credit flow (Barbiero et al., 2021), our model needs to capture them if we want to deliver policy analysis and offer policy prescriptions. Before going into the specific features of the model, it is important to understand how each of these channels work, how they differ and how they may complement or work against each other as a result of different monetary policies.

This section explains four transmission mechanisms of the Lending Programmes that arose during the Covid-19 pandemic and that are at work in our model: i) liquidity channel, ii) collateral channel, iii) "dual rate channel"and iv) scarcity channel.[13]

1. **Liquidity channel**. One of the main functions of banks is to engage in liquidity transformation, as they hold illiquid assets but fund themselves through liquid liabilities (Diamond and Dybvig, 1983). This process is critical to support the flow of credit in the economy. However, it also makes the financial system inherently fragile (Chen et al., 2020): since banks do not hold enough liquid assets to satisfy the immediate withdrawals of all depositors, if funding dries up, financial intermediaries are forced to liquidate their assets through fire sales. As asset prices drop, intermediation breaks down and credit growth stalls. By providing banks funding in periods of market distress — the direct liquidity channel of the lending programmes — central banks prevent market dysfunction, supporting access to credit (Carpinelli and Crosignani, 2021). The ECB distinguishes also an indirect liquidity channel: as banks access the TLTRO, they reduce bond issuances, leading to a decline in bond supply and, consequently, lowering funding costs also for those intermediaries not taking part in the central bank's programme (Barbiero et al., 2021).

2. **Collateral channel.** The provision of central bank's liquidity is granted upon eligible collateral. While this notion is rooted in the canonical Bagehot principle (Bagehot, 1873), the ECB used it to gain three additional degrees of policy freedom. In other words, by changing the eligibility of collateral through three different mechanisms, the ECB increased TLTRO take-up, enhancing the transmission of policy stance. The three novel collateral-based mechanisms are the following, and they are all present in our framework:

   - The *quantity* of the collateral: the haircut. The haircut is a reduction in the value of an asset. In the context of the lending programmes, the haircut — set by the central bank — defines the amount of central bank liquidity the intermediary can borrow by pledging its assets as collateral. A lower haircut translates into more central bank liquidity. Carpinelli and

[13] For completeness, we highlight two additional transmission mechanisms that have been documented by the literature but that are not present in the model: the maturity extension channel (Carpinelli and Crosignani, 2021) and the Liquidity Coverage Ratio channel (Gocheva et al., 2022). The maturity extension channel arises because the central bank lending provisions are longer dated that standard refinancing operations, reducing banks' rollover risk (Carpinelli and Crosignani, 2021). The Liquidity Coverage Ratio (LCR) channel, instead, is triggered when, following central bank liquidity injections, the LCR increases and the financial intermediaries takes actions to reduce it, typically by providing more credit. See Gocheva et al. (2022) and Barbiero et al. (2021).

Crosignani (2021) defined this mechanism as the "collateral relaxation channel".

- The *quality* of the collateral. The central bank can tighten or ease the access to its lending provisions also by changing the set of assets eligible for collaterals. By lowering the collateral's credit quality requirement — in other words, by accepting securities that do not qualify as high-quality liquid assets — the central bank enlarges the pool of assets that can be pledged, fuelling participation in its lending programme. This transmission channel provides leeway to policymakers when credit rating downgrades shrink the pool of eligible assets and their scarcity can impair the effectiveness of the lending programme (ECB, 2020c).
- The *value* of the collateral. In the same way as higher net worth in housing makes it easier for households to borrow,[14] higher value of assets eligible for collateral increases banks' borrowing from the central bank. This is the financial friction of Kiyotaki and Moore (1997) and Iacoviello (2005): credit limits are affected by the price of the collateralizable assets. Policymakers can trigger this collateral-based transmission mechanism by deploying monetary policy tools in unison: for instance, asset purchases increase asset prices, indirectly supporting the value of collaterals, and the lending programme's participation.

3. **The "dual rate channel"**. NIRP is deployed by setting negative interest rate on reserves. However, the inability to pass on negative rates to depositors results in the deposit rate remaining non-negative (Schnabel, 2020a). Critically, this rate dichotomy shrinks Net Interest Margins (NIM), reducing net worth. As banks' capital falls, intermediation slows down: with banks unable to purchase as much debt, bond yields increase, slowing investment and aggregate demand. This is the contractionary channel of NIRP (Sims and Wu, 2021) that, if strong enough, can bring the economy to hit the reversal rate: the turning point when accommodative monetary policy turns contractionary (Brunnermeier and Koby, 2018). In order to alleviate this tightening effect, the central bank can set the interest rate on its lending facility — representing a funding cost for the bank — lower than the interest rate on reserves, alleviating the capital loss resulting from NIRP. As a result, intermediation does not break down, sustaining asset prices and output growth (Lagarde, 2020). This expansionary

[14]Because houses are used as collaterals for loans.

transmission mechanism is the "dual rate channel", observed with interest also by BoE External MPC Member Saunders (2020).

4. **Scarcity channel**. The introduction of the lending programme generates a pent-up demand for assets, especially high quality liquid assets, since they are used as collateral to access the central bank's facility. The pent-up demand for assets affects the availability of collateral, with effects on "prices, rates, and price volatility of assets": this is the scarcity channel first analysed by BIS ((BIS, 2015)). This transmission mechanism is at work in the Euro Area where it is strengthened by the ECB asset purchases, as they further fuel asset demand (Corradin et al., 2017).[15] There is increasing evidence from the literature that this excess demand (not matched by a higher supply of assets) compresses spreads, hurting banks' net worth and monetary policy effectiveness.[16]

To conclude, this section has shown that the "enhanced" lending programmes are transmitted in a more complex, multifaceted way than originally described by the Bagehot principle. In the words of the ECB "The stimulus coming from the enhanced operations was transmitted *above and beyond* the explicit lending criteria ingrained in the programme". Our model of UMP capture all these various transmission channels.

3.2 A Review of the Literature

This chapter relates to three streams of literature applying DSGE models: the studies on UMP and more specifically on the lending programmes; the recent research on the unwinding of UMP; and finally the studies on NIRP and the reversal interest rate.

The papers that study UMP with DSGE models typically introduce the non-standard tools in a piecemeal fashion.[17] This modelling choice does not reflect

[15] See Grandia et al. (2019), Schnabel (2022), Bailey et al. (2020) and BIS (2019a).

[16] Bailey et al. (2020): "market functioning may deteriorate if a central bank's holdings of securities are particularly large compared to outstanding amounts. [...] beyond a given point, central bank purchases of safe assets may reduce the liquidity resilience of the financial system as these assets are no longer available for non-banks to hold". The same message is delivered by Schnabel (2022), Member of the Executive Board of the ECB "[...] years of balance sheet expansion have caused the bond free float in some economies to decline to very low levels. As such, an end to net asset purchases enhances the availability of safe assets that the market requires to function well."

[17] For instance Gertler and Karadi (2013) for QE and Wu and Xia (2018) for NIRP. See Kuttner

policy experience nor policymakers' preferences.[18] Therefore, we contribute to the theoretical literature on UMP by analysing QE, NIRP, FG and the lending programmes *in a single framework*, extending Sims and Wu (2021). Focusing on the lending programmes, there is a burgeoning empirical literature on the effects of the liquidity injections[19] while the theoretical papers have not yet accurately micro-founded the lending programmes to reflect policymakers' choices. Attempts by Quint and Tristani (2018) and Cahn et al. (2017) include only one channel of transmission — the liquidity channel — while Furkan Abbasglu et al. (2019) and Schabert (2015) take a step further including the collateral channel. Building on these papers, we contribute to the lending programmes' literature by adding a channel of transmission that defined the ECB TLTRO during the Covid-19 pandemic — the dual rate channel — and another transmission mechanism at work in the Euro Area, the scarcity channel (Schnabel, 2022). The rich micro-foundations increase the validity of the model for policy purposes.

We contribute also to the recent literature on UMP normalisation. Papers investigating UMP have typically studied the delivery of UMP tools during the easing cycle of monetary policy, avoiding exploring their unwinding during the tightening cycle. The lack of empirical literature on UMP unwinding is due to the scarce engagement of central banks with UMP normalisation: before the current tightening phase, Quantitative Tightening has been attempted only by BoJ in 2006 and the Fed in 2017 (BIS, 2019a). Equally thin is the theoretical literature, with two notable exceptions: Karadi and Nakov (2021) and Sims and Wu (2021). These authors provide policy recommendations on the *pace* of UMP normalisation, but they do not give insights on the *combination* of instruments that are unwound. We show that both the pace of the unwinding *and* the combination of tools that are unwound matters for the performance of the economy during the recession, recovery and future crises.

Finally, this chapter relates to the fast growing literature on NIRP and the reversal interest rate. As presented in the second chapter, the reversal interest rate is a concept developed by Brunnermeier and Koby (2018), indicating that

(2018) for a review of the research on UMP that has been carried out since the Global Financial Crisis.

[18]UMP tools have been deployed simultaneously both during the Global Financial Crisis and the Covid-19 pandemic. In addition, the ECB in its strategy review found that "a combination of instruments is generally more efficient than relying on a single tool" (Altavilla et al., 2021).

[19]Amongst the others, see: Carpinelli and Crosignani (2021), Crosignani et al. (2020) and Garcia-Posada and Marchetti (2016).

accommodative monetary policy can turn contractionary and reduce lending. The theoretical literature has analysed several transmission mechanisms of NIRP, affecting the reversal rate: banks' profits (Ulate (2021) and Eggertsson (2019)), banks' capitalisation (Darracq Paries et al. (2020) and my second chapter) and central bank signalling (Sims and Wu (2021) and de Groot and Haas (2020)). However, little is known about the transmission of NIRP and the implication for the reversal rate when the dual rate strategy is implemented: this monetary policy strategy is analysed empirically only in the recent ECB study by (Barbiero et al., 2022). Our paper fills this gap from a theoretical perspective.

3.3 The Model

This chapter takes the tractable DSGE model of UMP developed by Sims and Wu (2021) — already presented in the previous chapter — as a baseline. We extend it by micro-founding the liquidity injections, modelling them in the spirit of the ECB TLTRO during the Covid-19 crisis. The main changes to the baseline are the following:

- **On the financial intermediary's side**, the possibility to access the central bank lending programme, subject to a collateral constraint;
- **On the central bank's side**, the possibility to lend to intermediaries — while deploying QE, NIRP and FG. Mirroring the most recent TLTRO recalibration of March 2020, the central bank toolkit is expanded with the three instruments described in subsection 3.1.2:
    1. The collateral's haircut,
    2. The choice on the assets eligible for collaterals, and
    3. The rate applied to the liquidity provisions

Having realistically micro-founded the lending programme, we explore the synergies and trade-offs between the liquidity provisions and the other UMP tools.

As already explained in the previous chapter, there are multiple agents in the model: 1) a representative household; 2) a labour market; 3) a capital goods producing firm; 4) a representative wholesale firm; 5) a continuum of retail firms, that sell wholesale output to a final good firm; 6) a fixed number of financial intermediaries; 7) a fiscal authority; 8) and the central bank conducting monetary policy. In the subsections below we present financial intermediaries and the central bank: the two agents that differ from the baseline model.

3.3.1 Financial Intermediary

Using the banking sector of Sims and Wu (2021) as baseline, the paper introduces the lending facility as in Quint and Tristani (2018). The banking sector's balance sheet is the following:

$$Q_t F_t + Q_{B,t} B_t + RE_t = N_t + D_t + H_t \tag{3.1}$$

.

where $Q_t F_t$ are long term bonds issued by a representative wholesale firm, $Q_{B,t} B_t$ are long term bonds issued by the fiscal authority, RE_t are interest-bearing reserves, N_t is net worth, D_t are deposits taken from households, H_t is the central bank liquidity injection. Net worth evolves according to:

$$\begin{aligned} N_t = (R_t^F - R_{t-1}^d) Q_{t-1} F_{t-1} + (R_t^B - R_{t-1}^d) Q_{B,t-1} B_{t-1} + (R_{t-1}^{re} - R_{t-1}^d) RE_{t-1} \\ + R_{t-1}^d N_{t-1} - (R_{t-1}^H - R_{t-1}^d) H_{t-1} \end{aligned} \tag{3.2}$$

R^{re} is the (gross) interest rate on reserves, set by the monetary authority at $t-1$. R^d and R^H are, respectively, the deposit rate and the rate to access the central bank lending programme. R_t^F and R_t^B are the realised holding period returns on private and government bonds.

The financial intermediary's objective is to maximise expected terminal wealth, discounted by $\Lambda_{t,t+1}$, the household's stochastic discount factor. Having survived from t to $t+1$, there is the probability $1-\sigma$ of exiting after $t+1$, $(1-\sigma)\sigma$ of exiting after $t+2$, and so forth. Therefore, the financial intermediary's objective becomes:

$$V_{i,t} = max(1-\sigma) E_t \sum_{j=1}^{\infty} \sigma^{j-1} \Lambda_{t,t+j} n_{i,t+j} \tag{3.3}$$

3.3.1.1 Financial Intermediary's Constraints

The financial intermediary faces three constraints: the agency problem à la Gertler and Kiyotaki (2010), the reserve requirement as in Sims and Wu (2021) and the collateral constraint à la Kiyotaki and Moore (1997).

1. **Enforcement constraint** As in the previous chapter, we impose a constraint on the availability of funds (Gertler and Kiyotaki, 2010) by allowing a financial intermediary to run away with some assets at the end of a period. If the intermediary absconds with assets, it defaults on its debt and it shuts down. Depositors, left with the remaining fraction of the intermediary's assets, become less willing to fund the intermediary, triggering a borrowing constraint. With less funding, the intermediary can fund fewer asset purchases, causing higher excess returns. We model this friction following Quint and Tristani (2018): we impose that the financial intermediary maximizes terminal net worth subject to the following enforcement constraint:

$$V_t \geq \theta(Q_t f_t + \Delta Q_{B,t} b_t - \zeta h_t) \tag{3.4}$$

   According to the above incentive constraint, depositors will continue to fund an intermediary as long as the intermediary's value V_t is at least as large as the gain it would make by running away with assets. If an intermediary absconds with assets, it keeps the fractions θ of corporate bonds, $\theta\Delta$ of government bonds and $\theta\zeta$ of the central bank liquidity provisions. As in Gertler and Kiyotaki (2013), we set $0 \leq \Delta \leq 1$, hence it is easier to run away with corporate bonds than government bonds. As in Quit and Tristani ((Quint and Tristani, 2018)), we calibrate $\zeta = 1$: banks cannot divert assets financed by the liquidity provision of the central bank.

   Finally, θ represents a credit shock: as θ increases, depositors are able to recover a smaller fraction of the intermediary's assets. Hence depositors reduce lending, creating a borrowing constraint for the intermediary. As intermediation breaks down, the demand for bonds weakens, triggering a fall in assets' value and widening interest rate spreads — dynamics observed in a variety of credit shocks, from the Global Financial Crisis to the "Dash for Cash" of March 2020. As in Sims and Wu (2021) we keep θ stochastic, following an exogenous AR(1) process:

$$\theta = (1-\rho_t)\theta_{SS} + \rho_t\theta_{t-1} + s_t\varepsilon_t \tag{3.5}$$

The central bank lending programme works in the opposite direction of a rise in θ: as the central bank injections increase, the enforcement constraint is eased and the intermediary can purchase more assets, thus supporting assets' prices and investment. This mechanism represents the liquidity channel of section 3.1.3.

2. **Reserve requirement constraint** As in Sims and Wu (2021), intermediaries are required to hold a minimum level of reserves that is set by the central bank. The reserve requirement is time-varying and proportional to an intermediary's deposits:

$$re_{i,t} \geq \xi d_{i,t} \tag{3.6}$$

The reserve requirement constraint is included to allow the central bank to engage in NIRP: if the model did not include this requirement, intermediaries would liquidate their negative-yielding reserves, preventing NIRP from being implemented.

3. **Collateral constraint.** The provision of central bank's liquidity is based on eligible collateral. The central bank decides on the quantity (haircut) and quality (asset class) of the collateral. To model these features we include a collateral constraint in the spirit of Kiyotaki and Moore (1997) and Iacoviello (2005). Following Furkan Abbasglu et al. ((Furkan Abbasglu et al., 2019)), the liquidity injection h_t that the financial intermediary receives is constrained by a fraction $\kappa_{b,t}$ of its government bond holdings and a fraction $\kappa_{f,t}$ of its corporate bond holdings:

$$h_t \leq \kappa_{f,t}\frac{Q_{F,t}f_t}{R_t^H} + \kappa_{b,t}\frac{Q_{B,t}b_t}{R_t^H} \tag{3.7}$$

As in Furkan Abbasglu et al. ((Furkan Abbasglu et al., 2019)), the collateral constraint is always binding: this is to ensure the central bank can effectively steer market rates by changing collateral policies setting the haircuts ($\kappa_{b,t}$ and $\kappa_{f,t}$) and by deciding the class of eligible assets (sovereign or corporate bonds). Initially, we keep $\kappa_{b,t}$ and $\kappa_{f,t}$ stochastic, following an exogenous AR1 process (the endogenous cases will be analysed in subsections 3.5.2 and 3.6.3):

$$\kappa_{b,t} = (1-\rho_{b,k})k_{b,ss} + \rho_{b,k}k_{b,t-1} + s_k\varepsilon b, k \tag{3.8}$$

$$\kappa_{f,t} = (1-\rho_{f,k})k_{f,ss} + \rho_{f,k}k_{f,t-1} + s_k\varepsilon f, k \tag{3.9}$$

The inclusion of this constraint has two implications. First, shocks are amplified relative to the baseline model: in fact, when a shock hits the economy, it is propagated not only due to the enforcement constraint (already present in Sims and Wu (2021)), but also due to the changes in value of the collateral. Second, the central bank's toolbox is expanded: policymakers can now use effectively collateral policy, triggering the collateral channel of monetary policy transmission (see section 3.1.3).

FOCs The paper maximises with respect to f_t, b_t, re_t and h_t. The FOCs are:

$$E_t\Lambda_{t,t+1}(R^F_{t+1} - R^d_t)\pi^{-1}_{t+1}\Omega_{t+1} = \frac{\lambda_{1,t}}{1+\lambda_{1,t}}\theta - \frac{1}{R^H_t}\frac{\lambda_{3,t}}{1+\lambda_{1,t}}\kappa_{f,t} \tag{3.10}$$

$$E_t\Lambda_{t,t+1}(R^B_{t+1} - R^d_t)\pi^{-1}_{t+1}\Omega_{t+1} = \Delta\frac{\lambda_{1,t}}{1+\lambda_{1,t}}\theta - \frac{1}{R^H_t}\frac{\lambda_{3,t}}{1+\lambda_{1,t}}\kappa_{b,t} \tag{3.11}$$

$$E_t\Lambda_{t,t+1}(R^{re}_t - R^d_t)\pi^{-1}_{t+1}\Omega_{t+1} = -\frac{\lambda_{2,t}}{1+\lambda_{1,t}} \tag{3.12}$$

$$E_t\Lambda_{t,t+1}(R^H_t - R^d_t)\pi^{-1}_{t+1}\Omega_{t+1} = \zeta\frac{\lambda_{1,t}}{1+\lambda_{1,t}}\theta - \frac{\lambda_{3,t}}{1+\lambda_{1,t}} \tag{3.13}$$

With $\Omega^h = 1-\sigma+\sigma\frac{\partial V_{1,t+1}}{\partial n_{1,t+1}}$. $\lambda_{1,t}$ is the Lagrangian multiplier of the enforcement constraint, $\lambda_{2,t}$ is the Lagrangian multiplier of the reserve requirement and $\lambda_{3,t}$ is the Lagrangian multiplier of the collateral constraint (always binding).

3.3.2 The Central Bank

The central bank is modelled following Sims and Wu (2021). This paper adds to the unconventional monetary policy toolbox a lending facility with the same characteristics of the ECB TLTROs. This addition provides the central bank with three additional degrees of policy freedom,[20] the ability to lower banks' funding costs directly — a unique property of the liquidity provisions, distinctive from the other monetary tools — and the possibility to create synergies with the other UMP instruments.

3.3.2.1 Conventional Monetary Policy

The central bank sets the short-term policy rate R_t^{tr} according to the following Taylor rule:

$$lnR_t^{tr} = (1-\rho_r)lnR^{tr} + \rho_r lnR_{t-1}^{tr} + (1-\rho_r)[\phi_\pi(ln\Pi_t - ln\Pi) + \phi_y(lnY_t - lnY_{t-1})] + s_r\varepsilon_{r,t} \tag{3.14}$$

With R^{tr} and Π being steady state values of the policy rate and the inflation target. In standard times, the central bank sets the interest rate on reserves equal to the underlying policy rate R_t^{tr}, and the reserve requirement is not binding:

$$R_t^{tr} = R_t^d = R_t^{re} \tag{3.15}$$

To implement the zero lower bound (ZLB), we impose that the deposit rate and interest rate on reserves are equal in the following way:

$$R_t^d = R_t^{re} = max(1, R_t^{tr}) \tag{3.16}$$

3.3.2.2 Unconventional Monetary Policy: The Lending Programmes

The baseline model features QE, NIRP and FG.[21] While these three UMP tools are still present in our model, this subsection explains the modelling of the central bank liquidity injections, that the paper introduces mirroring the ECB TLTROs.

With the lending programme, the central bank gains three additional degrees of policy freedom. In fact, it can change the collateral policy — through the haircut and set of assets eligible for collateral — as well as the interest rate it charges on its

[20]The central bank can set i) the collateral's haircut, ii) the assets eligible for collaterals, and iii) the rate applied to the liquidity provisions.

[21]For details on their implementation see Sims and Wu (2021) or the previous chapter of this dissertation.

loans. By setting these policy tools, the central bank may choose to tighten or ease the access to its lending facility, affecting bank financing conditions for households and firms.

- **Collateral Policy.** The central bank decides on:
  - The *quantity* of collateral (haircut) by changing $\kappa_{b,t}$ and $\kappa_{f,t}$.
  - The *quality* of the collateral, by deciding whether to accept only sovereign bonds ($\kappa_{f,t} = 0$), only corporate bonds ($\kappa_{b,t} = 0$) or a mix of sovereign and corporate bonds.

  This chapter makes the collateral policy endogenous by imposing Taylor rules for $\kappa_{b,t}$ and $\kappa_{f,t}$ (see subsections 3.5.2 and 3.6.3).

- **Interest Rate on loans — "dual rate system".** When the ZLB constraint is not binding, the interest rate on the liquidity injection is imposed to be equal to the interest rate on reserves (policy rate): this modelling choice ensures the "favourable terms" of the ECB TLTROs. Instead, when the ZLB constraint is binding and the central bank engages in NIRP, the rate falls below the policy rate. In other words:

$$R_t^h = R_t^{re} - \chi_t \tag{3.17}$$

  Where R_t^h is the interest rate on the lending facility, R_t^{re} is the rate on reserves and χ_t is a spread. When the ZLB constraint is not binding $\chi_t = 0$, when instead the ZLB constraint is binding, χ_t is governed by the following Taylor rule (in the spirit of equation 3.14 governing the policy rate):

$$\chi_t = (1-\rho_\chi)\chi_{ss} + \rho_\chi \chi_{t-1} - \eta_\chi (1-\rho_\chi)[\phi_\pi(ln\Pi_t - ln\Pi) + \phi_y(lnY_t - lnY_{t-1})] + s_\chi \varepsilon_{\chi,t} \tag{3.18}$$

Given the occasionally binding constraint, this chapter uses the Occbin toolkit developed by Guerrieri and Iacoviello (2015) to shift from one regime to the other.[22]

[22] As in Sims and Wu (2021), anytime the Taylor rule rate goes below the steady state interest rate on reserves (making the ZLB constraint binding), the toolkit switches to a different model in

3.4 Calibration

Most of the parameters in the model have standard values. The non-standard parameters — associated with the financial sector — have been taken from Sims and Wu (2021) and Quint and Tristani (2018). The parameters referring to the lending programmes are listed in Table 3.1 below. Amongst these, we focus on the calibration of those governing the collaterals. At the steady state $\kappa_{f,ss}$ is calibrated equal to zero: this is because at the steady state there are not liquidity injections that need corporate bond as collaterals. Instead, the paper calibrates $\kappa_{b,ss}$ at 0.1. This implies that at steady state the lending programmes (for which sovereign bonds are required as collaterals) are still active. We motivate this modelling choice by observing that in March 2019 the ECB introduced the third round of TLTROs to avoid "congestion effects" in bank funding markets that would have otherwise materialised because of the need to replace expiring TLTRO II funds (Barbiero et al., 2021).

Table 3.1: Lending programmes calibrated parameters

Parameter	Value or Target	Description
$\kappa_{b,ss}$	0.1	CB Steady State Fraction of sovereign bond collaterals
$\kappa_{f,ss}$	0	CB Steady State Fraction of corporate bond collaterals
ζ	1	Central bank loans recoverability
χ	0	Steady state spread $R_t^{re} - R_t^h$
$\rho_{b,k}$	0.8	AR sovereign bond collateral
$\rho_{f,k}$	0.8	AR corporate bond collateral
ρ_χ	0.98	AR spread $R_t^{re} - R_t^h$

3.5 Simulations Above the ZLB: Exploring the Transmission Channels

This section presents simulations when the ZLB constraint is not binding. The simulations are useful to understand the mechanics of the model and to explore the transmission channels of the "enhanced" lending programme's, explained in section 3.1.3: i) liquidity channel, ii) collateral channel (working through the

which we impose the rate on reserves equal to 0. In this model, the deposit rate equals the interest rate on reserves and the central bank can use collateral policy. Differently, in the case of NIRP implementation, when the Taylor rule rate goes below the steady state interest rate on reserves, the Occbin toolbox switches to a model in which the interest rate on reserves follows the (now negative) Taylor rule rate but the deposit rate remains stuck at 0.

haircut, asset class eligible for collateral and the value of the collateral), iii) the "dual rate channel", and iv) scarcity channel. This analysis informs the policy simulations of the following section 3.6, allowing to discover synergies and trade-offs amongst the different UMP tools.

3.5.1 Liquidity Channel

Figure 3.2 below shows the IRFs to a one standard deviation positive shock to $\kappa_{b,t}$ in equation 3.8. $\kappa_{b,t}$ is the variable governing the sovereign bond collateral accepted by the central bank's lending programme (the haircut). Output, investment and inflation accelerate, the bonds spreads are compressed and the net worth of the financial intermediary increases. Looking at the central bank's monetary tools, liquidity injections grow and the policy rate is higher. The reason for these dynamics is the following. As the central bank accepts a higher fraction of the value of the sovereign bonds held by the financial intermediary, the liquidity injections increase following equation 3.7. The higher liquidity injections ease the intermediary's incentive constraint (liquidity channel) as per equation 3.4, allowing more bond purchases. The higher demand for bonds compresses bond spreads, easing the wholesale firm's constraint[23] and fuelling investment and output. In addition, the higher asset value (lower spreads) increases the intermediary's net worth (equation 3.2), further allowing more bond purchases and supporting output. The policy rate is hiked following the Taylor rule as in equation 3.14.

[23] For more details on the modelling of the wholesale firm, please see the second chapter or Sims and Wu (2021)

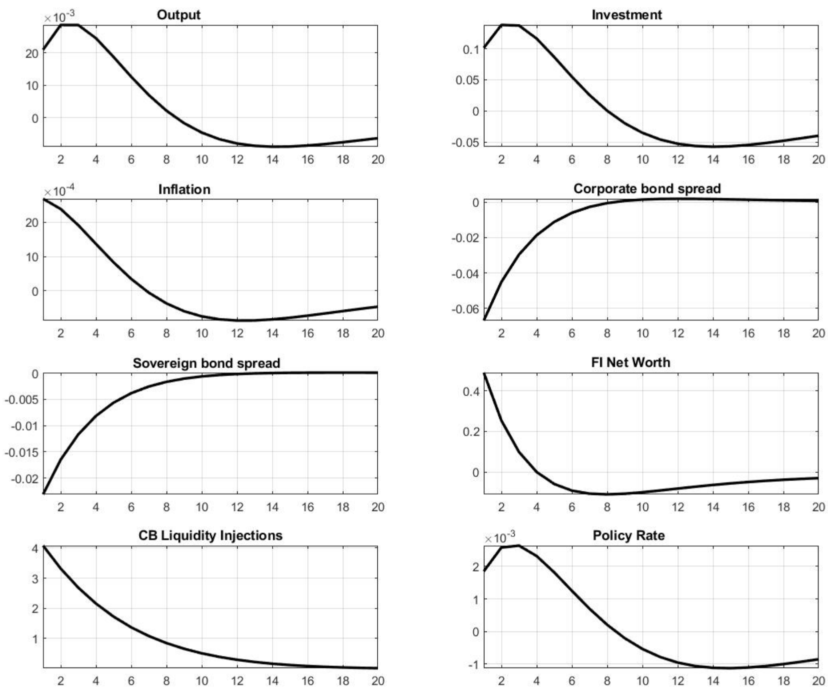


Figure 3.2: Sovereign bond haircut shock ($\kappa_{b,t}$ shock)

3.5.2 Collateral Channel

3.5.2.1 Collateral Policy: Haircut and Asset Class Eligible for Collateral

Figure 3.3 shows the IRFs to a credit shock, without the lending programme (black solid line) and with the lending programme (red dotted line). To have the central bank reacting to the shock changing its collateral policy we make $\kappa_{b,t}$ and $\kappa_{f,t}$ endogenous. In particular, we impose that the central bank increases the *quantity* (haircut) and *quality* (eligible asset class) of the collateral it accepts according to the following Taylor rules:[24]

$$\kappa_{b,t} = (1-\rho_{b,k})k_{b,ss} + \rho_{b,k}k_{b,t-1} - \eta_{b,k}(1-\rho_{b,k})[\phi_{b,k}(ln\Pi_t - ln\Pi) + \phi_{b,k}(lnY_t - lnY_{t-1})] + s_{b,k}\varepsilon_{b,k,t} \quad (3.19)$$

[24]Equation 3.19 and 3.20 follow the methodology used by Sims and Wu (2021) to make QE endogenous. For this, we assume that the central bank's reaction function to inflation and output (represented by the parameters in equations 3.19 and 3.20) is the same for QE and the lending programme.

$$\kappa_{f,t} = (1-\rho_{f,k})k_{f,ss} + \rho_{f,k}k_{f,t-1} - \eta_{f,k}(1-\rho_{f,k})[\phi_{f,k}(ln\Pi_t - ln\Pi) + \phi_{f,k}(lnY_t - lnY_{t-1})] + s_{f,k}\varepsilon_{f,k,t} \quad (3.20)$$

As a result, when the shock hits the economy, there is collateral easing by the central bank that increases the liquidity injections by 9% (see IRF below called CB Liquidity Injections). As a result of the central bank loans, the intermediary's constraint is looser, hence the demand for bonds is higher, which pushes up the prices of bonds, similarly to the previous simulation. The higher bonds' price allows more investment by the firm, dampening the recession. Overall, easing the collateral rules allows more liquidity injections and it helps to stabilise output.

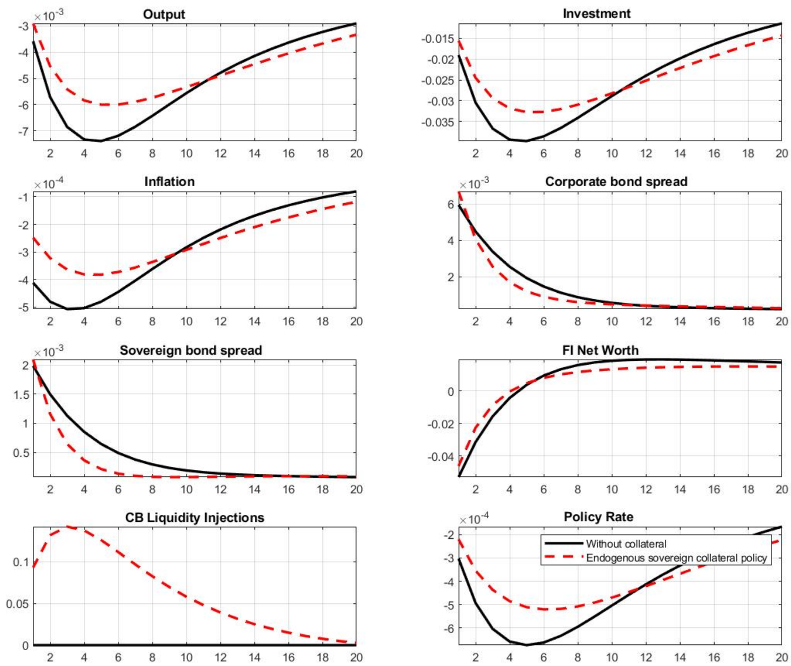


Figure 3.3: Credit shock, with and without endogenous collateral policy

3.5.2.2 Collateral Policy: Asset Value

Figure 3.4 shows the IRFs to a sovereign bond QE shock,[25]without any collateral (black solid line) and with corporate bonds as collateral (red dotted line). QE

[25]Since central bank bond holdings follow exogenous AR(1) processes (see Sims and Wu (2021)), we can use them to simulate a QE shock.

is modelled as central bank's purchases of sovereign bonds financed through the issuance of reserves held by banks. QE has real effects because it eases the constraint by changing the composition of banks' assets. In other words, the central bank swaps bonds for reserves: in doing so, it swaps assets that are not perfectly recoverable in case of bank default (bonds) with assets that are perfectly recoverable (reserves), easing the constraint (see the baseline model of Sims and Wu (2021)). In this simulation the central bank engages only in sovereign bond purchases. At steady state corporate bonds are required as collateral — implying that at steady state there are liquidity injections — but policymakers do not engage in collateral easing.[26] We notice that the use of collateral leads to an amplification of the expansionary effect of QE. This not an unexpected but important result to establish. The reason for the amplification mechanism is the following. As the central bank purchases sovereign bonds, it swaps them with reserves, easing the constraint of the intermediary (equation 3.4) that can now increase its demand for sovereign and corporate bonds, putting upwards pressure on their prices and compressing their spreads. The result is that, even if the central bank purchases only sovereign bonds, ultimately, thanks to the portfolio rebalancing channel of QE (Albertazzi et al., 2021), the price of corporate bonds increases as well. In other words, corporate bond spreads are compressed further: see the IRF below titled Corporate bond spread. The higher corporate bond value allows the wholesale firm to invest more but, critically, it *also* translates into higher collateral value (as per equation 3.7), allowing the intermediary to access more liquidity from the central bank. This loosens further the intermediary constraint, putting upwards pressure on bonds' prices and fuelling output. Overall, this simulation shows that there is an important synergy between QE and lending programme. In section 3.6 this synergy is applied to policy experiments.

[26]This implies that collateral policy is not endogenous: $\kappa_{b,t}$ and $\kappa_{f,t}$ do not follow equations 3.19 and 3.20, instead they are set exogenously according to equations 3.8 and 3.9.

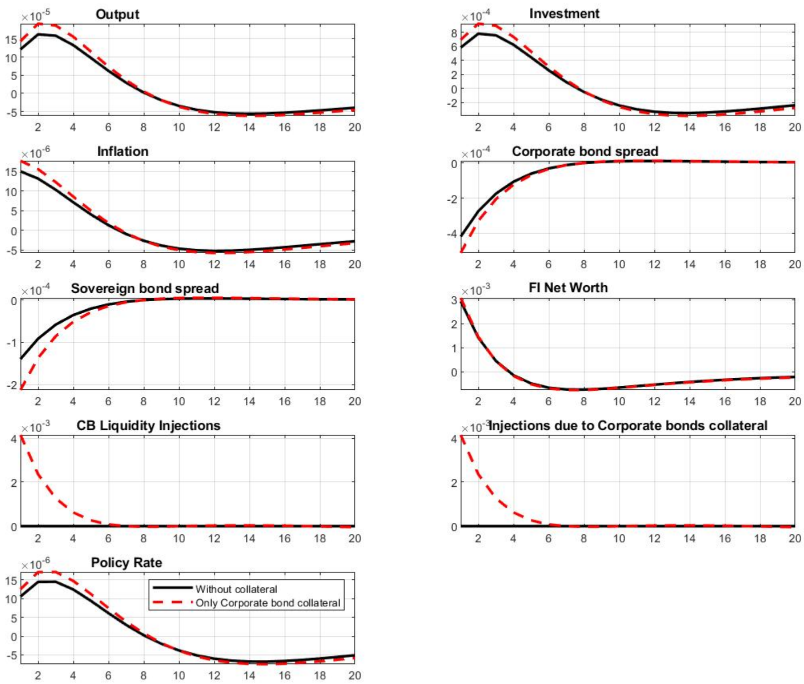


Figure 3.4: QE government bonds shock, with and without collateral policy (corporate bond)

3.5.3 Scarcity Channel

Figure 3.5 shows the IRFs to a sovereign bond QE shock, without any collateral (black solid line) and with sovereign bonds as collateral (red dotted line). As in the previous simulation, the central bank engages only in sovereign bond purchases, it does not use any other UMP tool. However, different from the previous case, at steady state it requires financial intermediaries to hold sovereign bonds (not corporate bonds as was the case in the previous sub-section) as collateral. The supply of sovereign bonds is calibrated: as in Sims and Wu (2021), at steady state the debt-to-GDP ratio is fixed at 41%. We notice that the use of collateral leads to a weaker expansion. The reason for this is the following. If the central bank decides to purchase sovereign bonds and at the same time to accept sovereign bonds for the liquidity injections, there will be a scarcity of sovereign bonds for the financial intermediary to hold. This is signalled by the lower steady state interest rate on sovereign bonds, determined endogenously.[27] Lower interest rates

[27]The interest rate on sovereign bonds without the collateral requirement is 3%, while it is 2.4% when the central bank requires sovereign bonds to be pledged as collateral.

are a hallmark of the scarcity channel (Grandia et al., 2019). At the same time, having sold sovereign bonds to the central bank, now the intermediary has less sovereign bonds to access the lending programme: the liquidity injection falls by 1.5%, tightening the intermediary's constraint and dampening the expansion. Overall, the pent-up demand for assets generated by the central bank gives rise to a scarcity of available assets, thus forming a contractionary channel that weakens the monetary stimulus. This simulation highlights the importance of *coordinating* monetary policy through the different UMP tools since their simultaneous delivery can amplify (see previous simulations) as well as weaken the effectiveness of monetary policy interventions.[28].

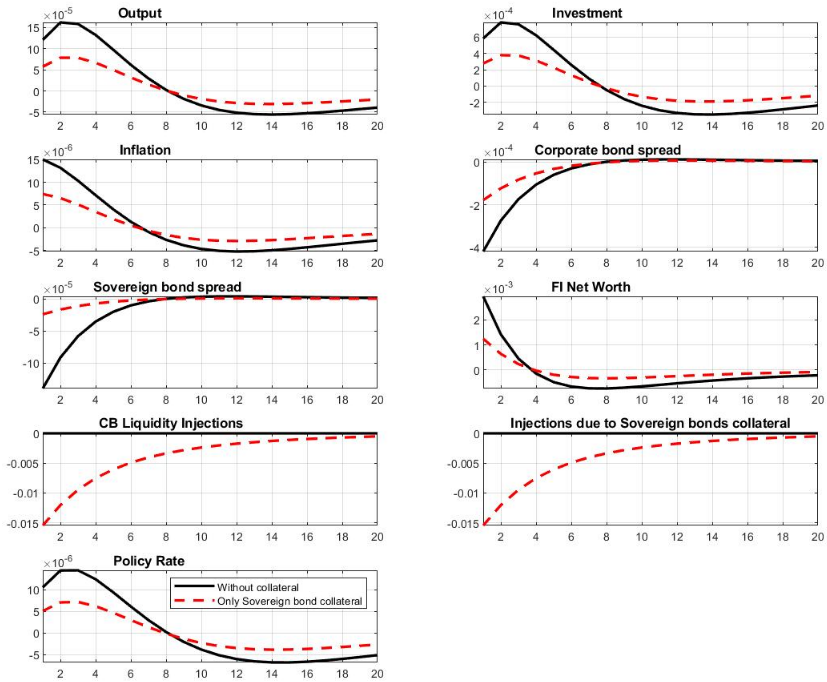


Figure 3.5: QE government bonds shock, with and without collateral policy (sovereign bond)

[28]The importance of complementarities between instruments was highlighted, amongst the others, by Bank of England External MPC Member Saunders (2020) when looking at monetary policy options with a binding ZLB (during the Covid-19 pandemic). Another topic for future work is the timing of the delivery of the different UMP tools.

3.5.4 The Dual Rate Channel

Figure 3.6 shows a one standard deviation shock to the spread between interest rate on reserves and the interest rate on the central bank's loan (see equations 3.17 and 3.18). The shock creates the "dual rate system" (see the IRF below titled "Rate Reserve - Rate Injections"). The IRFs show that output, investment and inflation accelerate. The bonds' spreads are compressed while the intermediary's net worth accelerates. Finally, as the spread between interest rate on reserves and interest rate on central bank's loan widens, the liquidity injections increase (see IRF titled CB liquidity Injections) and the policy rate is hiked following the Taylor rule. The reason for these movements is the following: Having the interest on the lending programme lower than the interest on reserve is similar to having a subsidy on net worth (equation 3.2), hence the financial intermediary accumulates net worth. In addition, the loans from the central bank now are offered at a discount, hence the intermediary will be more willing to access the lending programme. The resulting higher liquidity injections and higher net worth ease the enforcement constraint of the intermediary (equation 3.4), which increases the demand for bonds. This puts downward pressure on bonds' yields, compressing spreads, easing the constraint of the wholesale firm and supporting investment. The policy rate is hiked following the Taylor rule as per equation 3.14. Overall, lowering the intermediary's funding costs without cutting the policy rate is an effective measure to fuel output. In the next section we will study the interaction with NIRP.

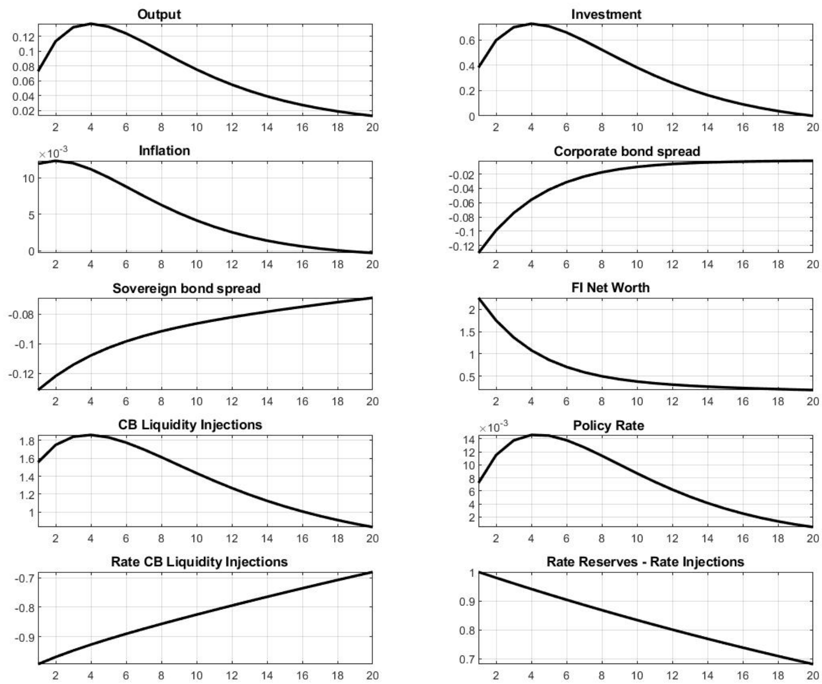


Figure 3.6: Dual rate shock

3.6 Simulations at ZLB: Policy Experiments

This section uses the above described model to analyse the effects of different monetary policies when different tools are utilised on their own and/or in unison with others. This time at the ZLB. The aim here is to disentangle transmission channels, to detect strengths and weaknesses of each policy or combinations of policies between QE, NIRP and lending programmes. We do this by looking at seven different sets of policy simulations. We find that the synergies between the lending programmes and the other UMP instruments make three cases for their simultaneous deployment:

1. When the lending programmes are deployed **simultaneously with QE**, synergies — working through the collateral value — and trade-offs — generated by the scarcity of available assets — arise. By setting its collateral policy, the Central Bank can strengthen the positive interactions and overcome the trade-offs, improving monetary policy effectiveness.

2. When the lending programmes are deployed **simultaneously with NIRP**, the dual rate system supports financial intermediaries' net worth. This synergy prevents the economy from hitting the reversal interest rate, again increasing monetary policy effectiveness.

3. Finally, once the economy is in recovery, the smooth, complete, **simultaneous unwinding** of both QE and the lending programme ensures the most effective normalisation policy.

We draw the above policy conclusions from simulating the following seven experiments:

1. **Exogenous Unconventional Monetary Policy Shocks**. This set of policy experiments assesses the effectiveness of the monetary tools governing the lending programmes — collateral policy and dual rate strategy — relative to the three other UMP tools: QE, NIRP and FG. To do this, we run eight monetary policy shocks. [29] By comparing the IRFs, the paper finds that, if the objective is to find an alternative policy to QE to support aggregate demand when the economy hits the ZLB, then the lending programmes offer another equally effective option. The section also provides guidelines on the timing of the policy delivery: the dual rate policy should be deployed only after easing collateral policy.

2. **Exogenous QE and Exogenous Lending Programmes: Synergies and Trade-offs.** The previous section compared the effectiveness of the lending programmes relative to the other UMP tools when they are delivered *in isolation*. This section, instead, takes stock of recent policy experience during the Covid-19 crisis, and it allows QE and the lending programmes to be delivered *simultaneously*. This is critical to explore the interactions, synergies and trade-off between the monetary instruments, the aim of this chapter. The section finds that UMP effectiveness is amplified if the value of the collateral benefits from the portfolio rebalancing effect of QE (synergy). However UMP can also be weakened if the availability of the collateral worsens due to asset purchases (trade-off).

[29] The exogenous monetary shocks are: Three shocks to the lending programme, representing collateral policy easing and the dual rate strategy, a conventional monetary policy shock, a sovereign bond asset purchases (QE) shock, a corporate bond asset purchases (QE) shock, a FG shock and a NIRP shock.

3. **Endogenous QE and Endogenous Lending Programmes.** The previous simulations study the interactions generated by a QE shock with the lending facility assuming that the central bank does not actively use collateral policy while it is engaging in asset purchases. In other words, the liquidity channel of the lending programme is not activated. Policy experience shows that this is an unrealistic simplification. To reflect policymakers' choices, this subsection makes both QE and the lending programme endogenous in response to a credit shock, introducing the liquidity channel in the simulation and running two policy experiments:

   - **Lending Programme - QE: Trade-off.** Given that the scarcity channel and the liquidity channel have opposite effects, the aim of this subsection is to assess their net effect. We show that the expansionary liquidity channel — generated by endogenising the collateral policy — overcomes the contractionary scarcity channel — generated by the central bank's pent-up demand for sovereign bonds. From a policy perspective, this suggests that the most effective framework to respond to a credit crisis is a combination of sovereign bond purchases and lower haircut on sovereign bonds.
   - **Lending Programme - QE: Synergy.** The portfolio rebalancing channel of QE and the liquidity channel of the lending facility work in unison by easing the intermediary enforcement constraint. This section shows that by engaging in both QE and collateral policy, liquidity injections benefit from QE, allowing the central bank to achieve a higher degree of output stabilisation with a smaller balance sheet intervention.

4. **Endogenous NIRP and Endogenous Lending Programmes: The Dual Rate.** So far the chapter has explored the interactions between QE and the lending programme. This set of policy simulations explores the synergies between NIRP and the lending programme, taking stock of the ECB experience: The dual rate policy, in fact, is implemented when the policy rate is already set negative. To model the ECB decisions this section simulates a credit shock to which the central bank reacts by i) engaging in NIRP, ii) setting the rate on the lending programme *endogenously* below the policy rate, and iii) setting *endogenously* the collateral haircut. We find that the synergies between these tools ensure a higher degree of output stabilisation and prevent the reversal of the interest rate.

5. **Policy Normalisation: Choosing the Tightening Pace and Combination of Instruments.** Having explored the synergies and trade-off arising when the lending programmes are deployed simultaneously with other tools, we now analyse the interactions when the unconventional tools are withdrawn. This set of policy experiments study the effects on output and central bank balance sheet of different tightening pace and combinations of QE/lending programmes. Currently, the knowledge on the exit from UMP is limited, leaving "policymakers uncertain about the effects of their policy on the economy" (Panetta, 2022b). We find that the most effective strategy is a smooth and complete unwinding of both QE and the lending programme. If this was not possible, QE should be exited quickly and the lending programme carried forward.

3.6.1 Exogenous Unconventional Monetary Policy Shocks

The aim of this section is to assess the effectiveness of the monetary tools governing the lending programmes — collateral policy and dual rate strategy — relative to the three other UMP tools: QE, NIRP and FG. To do this, the paper first makes the ZLB constraint binding: this is necessary because UMP is applied only when short term rates hit the effective lower bound.[30] As in the previous chapter, the ZLB constraint dictates that the short-term Taylor rule rate R_t^{tr} cannot go below its steady state set at 1% in gross terms (this is the steady state interest rate on reserves).[31] Once the economy is at the ZLB, the paper assesses the effectiveness of the different monetary tools. Figure 3. 7 below compares the IRFs to eight different monetary policy shocks: three shocks to the lending programme — representing sovereign bond collateral easing (light blue dotted line), corporate bond collateral easing (red dotted line) and dual rate policy easing (dark blue dotted line) — a

[30] To achieve this, the paper follows Sims and Wu (2021) and it simulates credit shocks for 6 periods. Then it replicates the simulations but in the seventh period it simulates the monetary policy shock and then it takes the difference between the simulation with the additional monetary policy shock and the simulation without it, the resulting IRFs are presented in Figure 3.7 below. Output is deviation from the steady state in percentage terms; interest rates are in annualised percentage points; the central bank's balance sheet size is expressed relative to steady state output.

[31] To implement this occasionally binding constraint we use the Dynare Occbin toolkit developed by Guerrieri and Iacoviello (2015): anytime the Taylor rule rate goes below the steady state interest rate on reserves (making the ZLB constraint binding), the toolkit switches to a different model in which we impose the rate on reserves equal to 0. In this model, the deposit rate equals the interest rate on reserves. Differently, in the case of NIRP implementation, when the Taylor rule rate goes below the steady state interest rate on reserves, the Occbin toolbox switches to a model in which the interest rate on reserves follows the (now negative) Taylor rule rate but the deposit rate remains stuck at 0.

policy rate shock (solid blue line), a corporate bond QE shock (orange dotted line), a sovereign bond QE shock (yellow dotted line), a NIRP shock (green dotted dotted line) and finally a FG shock (purple dotted line). The shocks are calibrated to match the same increase in output given by the policy rate cut shock (0.49% in period nine).

First, we focus on the lending programme collateral easing shocks, that are shocks to $\kappa_{b,t}$ and $\kappa_{f,t}$ — respectively, the fractions (haircuts) of sovereign bonds and corporate bonds held by the intermediary that are accepted as collateral by the central bank. The transmission mechanism is the same as in section 3.5.1. We notice that the effectiveness of the liquidity injections is almost the same as corporate bond QE and higher than sovereign bond QE: output increases by 0.49% in all three cases but the central bank balance sheet increases by less than 4% of steady state output with liquidity injections and corporate bond QE while it increases by 14% with sovereign bond QE. The reason for this difference is the following. Purchasing corporate bond from an intermediary in exchange for reserves and increasing its loans from the central bank ease the intermediary's constraint by the same amount (see the incentive constraint in equation 3.4). But, since we assume that an intermediary would find harder to abscond with sovereign bonds than with corporate bonds — a canonical assumption in the literature, see Gertler and Karadi (2013) that finds empirical evidence in D'Amico and Kaminska (2019) — it takes more purchases of sovereign bonds to ease the constraint as much as in the other two cases.

Second, we focus on the lending programme dual rate shock. When the loans from the central bank are limited to 10% of the sovereign bonds held by the intermediary (collateral), the interest rate on the lending programme must fall by more than 6% below the policy rate (stuck at 0%) for output to increase by 0.49%. This is not a policy that can be implemented but we notice (see Annex 1 of this chapter) that if the haircut on the collateral is eased (for instance to 30% of the sovereign bonds held by the intermediary), then the interest rate on the lending programme must fall by 2% below the policy rate (a significantly smaller fall than 6%) to lead to the same output acceleration as the other tools. This shows that our model is in line with policy decisions: the ECB lowered the interest rate on the lending programme to 1% below the policy rate when the share of sovereign *and* corporate bonds pledgeable as collateral was more than 30% of the portfolio holdings.

Overall, there are two takeaway messages from this section. First, liquidity injections are as effective as corporate bond QE and more effective than sovereign bonds QE in fuelling output. Given the political economy challenges posed by large programmes of corporate bond purchases,[32] the lending programmes offer an equally effective alternative to support aggregate demand when the economy hits the ZLB. Second, in order to maintain policy space (e.g. avoid large cuts to the interest rate on the lending programme), dual rate policy should not be deployed before easing the collateral policy.

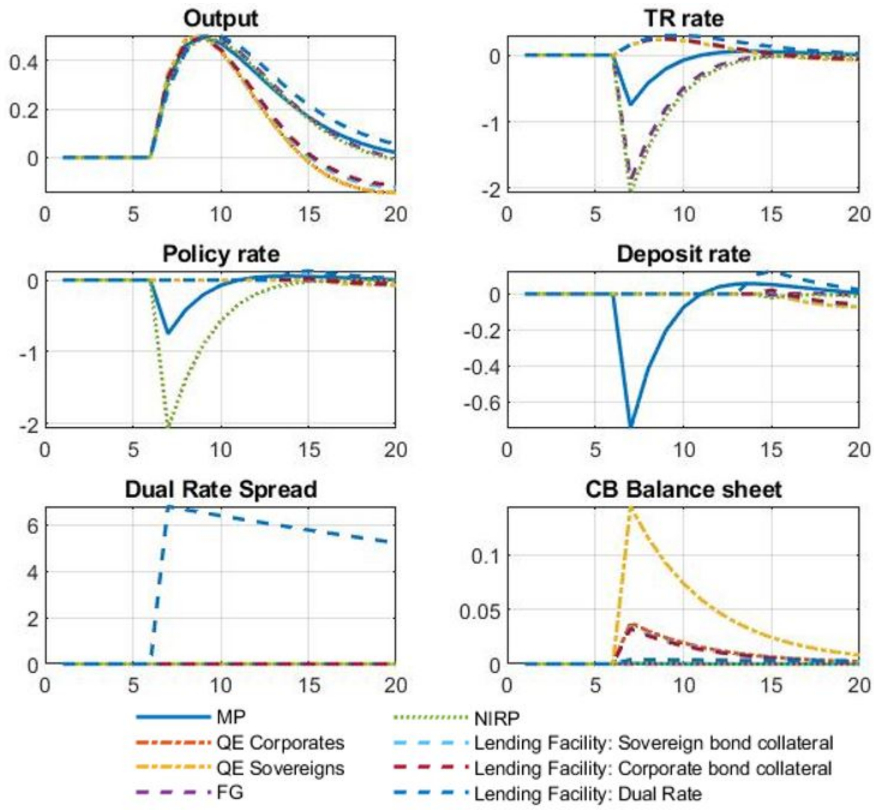


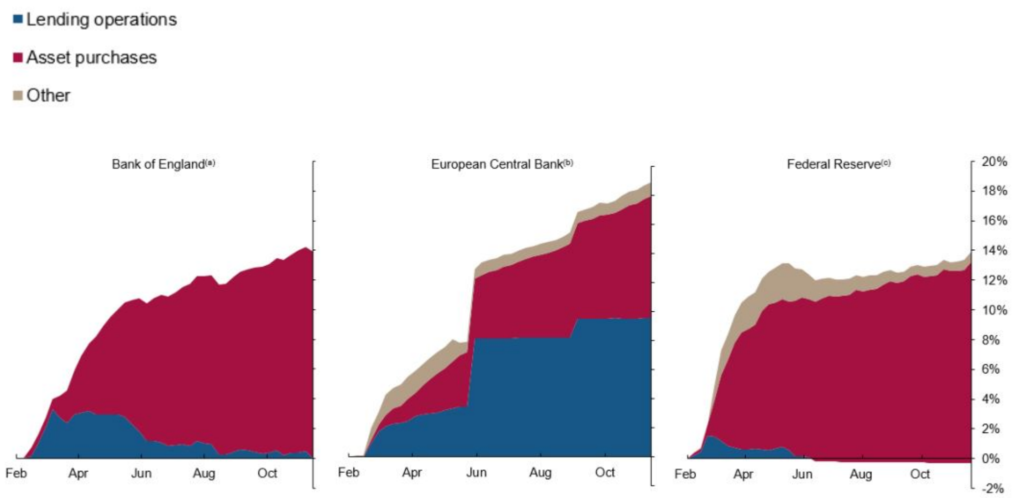
Figure 3.7: Conventional and Unconventional Monetary Policy Shocks

3.6.2 Exogenous QE and Exogenous Lending Programmes: Synergies and Trade-offs

The previous section compared the effectiveness of the lending programmes relative to the other UMP tools when the central bank deliver UMP tools *in isolation*. However, in reality, policymakers deploy UMP *simultaneously*, in

[32]See the experience of the Bank of England Asset Purchase Facility Schemes: at the end of December 2021 it held GBP875 billion in Gilts and only GBP20 billion in corporate bonds

particular the lending provisions are delivered in concert with QE programmes. Figure 3.8 below shows BoE, ECB and Federal Reserve balance sheet policies implemented in response to the Covid-19 pandemic, between February and December 2020. In the case of the ECB, the lending programmes have accounted for about half of the balance sheet increase, with the other half represented by asset purchases programmes (Hauser, 2021b). This concerted strategy is reflected in policymakers' statement: Schnabel (2020b), member of the Executive Board of the ECB, highlighted that "three mutually reinforcing and complementary components" — QE, TLTRO with collateral policy and liquidity injections as lender of last resort — drove the ECB response to the pandemic. Taking stock of the most recent policy experience, this section studies the interactions between QE and the lending programmes.



Sources: Bank of England, Bureau of Economic Analysis, European Central Bank, Eurostat, Federal Reserve Board, ONS and Bank calculations.

(a) Bank of England lending operations shown here: Indexed long-term repo, Contingent term repo facility, US dollar repo operations, Liquidity Facility in Euros, Term Funding Scheme and Term Funding Scheme with additional incentives for SMEs. Bank of England asset purchases shown here: Asset Purchase Facility and Covid Corporate Financing Facility.
(b) ECB lending operations: Lending to euro-area credit institutions related to monetary policy operations denominated in euro. ECB asset purchases: Securities held for monetary policy and other purposes.
(c) Federal Reserve lending operations: Repurchase agreements, Loans and Net portfolio holdings of TALF II LLC. Federal Reserve asset purchases: Securities held outright. Section of chart lying below the zero line from mid-2020 reflects a decline in repo outstanding relative to end-February.

Figure 3.8: Central bank balance sheet responses to the Covid-19 shock during 2020 — Changes in components of central bank balance sheets since end-Feb 2020 (as % of 2019 nominal GDP).

Source: Hauser (2021b)

To document possible synergies and trade-offs between QE and lending programmes we first make the ZLB binding and then we simulate three QE shocks with and without the lending facility's collateral (at the steady state).[33] To be clear, the central bank engages only in asset purchases through its QE programmes, modelled as exogenous shocks. The liquidity injections are the mechanical result of the central bank's requirement at steady state to pledge assets as collateral — in other words, the central bank does not engage either in collateral policy or in dual rate policy. Figure 3.9 below shows the IRFs to the three positive shocks to the central bank's bond holdings.

Baseline model. The IRFs on the left-hand side represent the baseline simulations: at the steady state, there is no collateral requirement. The sovereign and corporate bond QE shocks have been calibrated to match the same output expansion: 0.53% growth in period nine.

Synergy. The charts in the centre shows IRFs to the same QE shocks that generated the left-hand side IRFs. The only difference is that at steady state we impose that the central bank requires corporate bond as collaterals (this implies that at steady state there are liquidity injections). An amplification mechanism is generated thanks to this collateral requirement: in fact, as the central bank purchases sovereign bonds with the QE programme, it not only increases the price of these assets but also indirectly increases the price of the corporate bonds (through the portfolio rebalancing effect). The value of the corporate bonds held by the intermediary is therefore higher and this allows more liquidity injections: the central bank balance sheet is larger when sovereign bond QE is accompanied with corporate bonds as collateral (on the LHS the central bank balance sheet's size is 12% of steady state output while it is 13% in the centre IRFs). Having access to more central bank's loans eases the constraint of the intermediary, fuelling aggregate demand: output accelerates by 0.64% (0.53% on the LHS). In short, the effectiveness of QE can be amplified by exploiting the portfolio rebalancing channel of QE and calibrating the collateral of the lending programme accordingly.

Trade-off. The IRFs on the right-hand side are generated by the same QE shocks that generated the left-hand side (baseline) IRFs. The only difference is that at steady state we impose that the central bank requires sovereign bond collaterals. This implies that there is a pent-up demand for sovereign bonds from the central

[33]To achieve this, the paper follows the same methodology implemented in the previous simulation 3.6.1: first, it simulates credit shocks for 6 periods, pushing the economy to the ZLB; second, it replicates the simulations but in the seventh period it runs a QE shock; third, it takes the difference between the simulation with the additional QE shock and the simulation without it — the resulting IRFs are presented in Figure 3.9 below.

bank, as it buys sovereign bonds through QE and it requires them for the lending programme. The scarcity channel arises: first, the higher demand for sovereign bonds compresses their spreads, hurting the net worth of the intermediary; second, the intermediary has less sovereign bonds to pledge as collateral after having sold them to the central bank, hence it will be able to access less loans. This can be seen from the size of the central bank balance sheet: when sovereign bond QE is accompanied by sovereign bond as collateral, the balance sheet is smaller (on the LHS the central bank balance sheet's size is 12% of steady state output while it is 10% on the RHS). With less loans from the central bank and smaller net worth, the expansionary effect of QE is weakened: output accelerates by 0.23% (0.53% on the LHS). Note that the corporate bond QE shock increases ouput relative to the baseline (collateral effect). Overall, through its unconventional operations the central bank can generate a scarcity of assets that can weaken the transmission of QE. Choosing strategically the collateral of the lending facility prevents the scarcity effect from arising.

Overall, we found that the effectiveness of UMP is amplified if QE and the lending programme are deployed in unison: in other words, the central bank delivers a larger output expansion if the value of the collateral is supported by the asset purchases, allowing more liquidity injections without using monetary policy space (no changes in haircut or in dual rate strategy). However, should the liquidity injections and QE generate a scarcity of available collateral, then the UMP tools will move in opposite directions, weakening the effectiveness of the monetary stimulus.

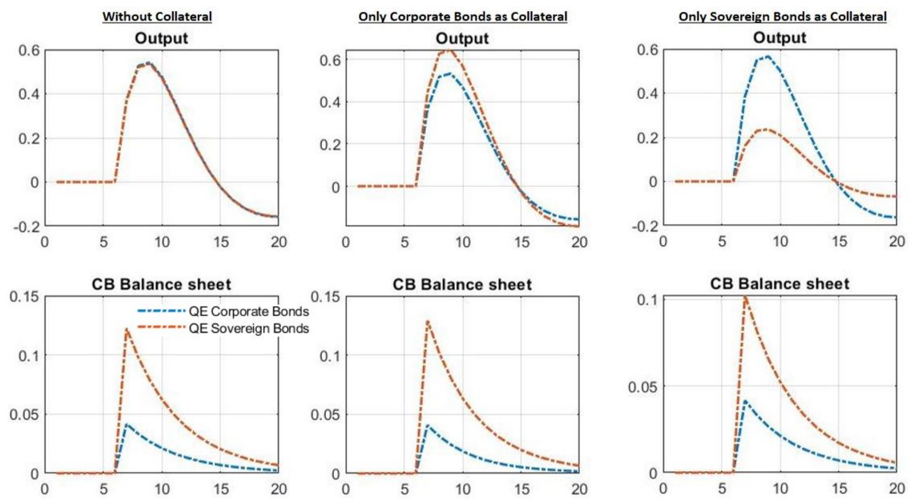


Figure 3.9: QE Shocks, with and without the lending programme's collateral

3.6.3 Endogenous QE and Endogenous Lending Programmes

The previous subsection shows the interactions that a QE shock generates with the lending facility. In particular, it documents the rise of an amplification mechanism — working through the portfolio rebalancing channel of QE — and a weakening mechanism — triggered by the scarcity channel. However, the simulations in subsection 3.6.2 assume that the central bank does not use collateral policy while it is engaging in asset purchases. In other words, the liquidity channel of the lending programme is not activated. This is an unrealistic simplification because, in practice, QE and the lending programme are deployed *in unison* and *in response* to a macroeconomic shock. Indeed, member of the ECB Executive Board Panetta (2022a) states that the ECB has three main tools to adjust the monetary policy stance: the policy rate, QE and the lending programmes.

To reflect policymakers' choices, this subsection makes both QE and the lending programme endogenous in response to a credit shock. By endogenising the lending programme, we introduce the liquidity channel in the simulation. Given that the scarcity channel and the liquidity channel have opposite effects, the first aim of this subsection is to assess their net effect (paragraph 3.6.3.1). The second aim is to assess the extent to which the liquidity channel supports the rebalancing channel, as both channels enhance the effectiveness of monetary policy (paragraph 3.6.3.2).

To make QE endogenous, we follow Sims and Wu (2021) imposing that the central bank's sovereign bond holdings are set by the Taylor rule reaction function below:

$$b_{cb,t} = (1-\rho_b)b_{cb} + \rho_b b_{cb,t-1} + (1-\rho_b)\Psi_b[\Phi_\pi(ln\Pi_t - ln\Pi) + \Phi_y(lnY_t - lnY_{t-1})] + s_b\varepsilon_{b,t} \tag{3.21}$$

In a similar fashion, the collateral policy is endogenised by imposing the following Taylor rules for $\kappa_{b,t}$ and $\kappa_{f,t}$ — the fractions of financial intermediaries' government and corporate bond holdings that can be pledged as collateral to the central bank's lending programme (e.g. haircuts). These reaction functions ensure that when output falls and inflation deviates from its steady state, the central bank engages in collateral policy easing (lower haircut on collaterals), prompting immediately more liquidity injections. The higher take-up of lending provisions eases the financial intermediary constraint (through the liquidity channel), fuelling more intermediation that supports asset prices as well as investment and output.

$$\kappa_{b,t} = (1-\rho_{b,k})k_{b,ss} + \rho_{b,k}k_{b,t-1} - \eta_{b,k}(1-\rho_{b,k})[\Phi_\pi(ln\Pi_t - ln\Pi) + \Phi_y(lnY_t - lnY_{t-1})] + s_{b,k}\varepsilon_{b,k,t} \tag{3.22}$$

$$\kappa_{f,t} = (1-\rho_{f,k})k_{f,ss} + \rho_{f,k}k_{f,t-1} - \eta_{f,k}(1-\rho_{f,k})[\Phi_\pi(ln\Pi_t - ln\Pi) + \Phi_y(lnY_t - lnY_{t-1})] + s_{f,k}\varepsilon_{f,k,t} \tag{3.23}$$

3.6.3.1 Lending programme - QE: Trade-off

Given that the scarcity channel and the liquidity channel have opposite effects on the enforcement constraint of the financial intermediary, the aim of this subsection is to assess their net effect on output stabilisation. We show that the effects of the liquidity channel, generated by endogenising the collateral policy, outweigh the effects of the scarcity channel.

To allow monetary policy to respond endogenously, we simulate an exogenous negative credit shock. Figure 3.10 below shows the IRFs to a credit shock[34] to which the central bank respond in four different monetary policy scenarios: i) without any UMP (blue-dotted line); ii) only endogenous QE: sovereign bonds purchases as per equation 3.21 (solid orange line), iii) only endogenous collateral policy: the haircut on sovereign bonds is set as per equation 3.22 (solid purple line), and iv) endogenous QE and endogenous collateral policy (solid green line).[35] At steady state we impose that the central bank requires sovereign bond as collateral.[36].

We find that when the policy rate is constrained by the ZLB and the central bank is unable to use UMP, output contracts by -1.7% (blue-dotted line). When instead monetary policy can respond to the credit shock with sovereign bonds purchases, the central bank's balance sheet increases to 5.4% of steady state output, mitigating

[34]To achieve this, the paper follows Sims and Wu (2021): first, it simulates credit shocks of 1.5 standard deviations for 6 periods, pushing the economy to the ZLB; second, it runs the simulation a second time adding a further credit shock of 1 standard deviation in period 7,to which endogenous monetary policy responds; third, it takes the difference between the simulation with the additional credit shock and the simulation without it — the resulting IRFs are presented in Figure 3.10 below.

[35]QE and collateral policy are calibrated to achieve the same output stabilisation as a policy rate cut with both κ_f and κ_b at steady state equal to zero.

[36]This implies that at steady state there are liquidity injections equal to 10% of the value of the intermediaries' sovereign bond holdings

the contraction: output falls by -1% (solid orange line). Even if QE is effective at stabilising output, it is not the *most* effective monetary tool because it triggers the contractionary scarcity channel highlighted in subsection 3.6.2. In other words, the sovereign bond purchases, together with the requirement for intermediaries to hold a fraction of sovereign bonds as collateral, generate a pent-up demand for sovereign bonds that *shrinks* the intermediaries' net worth and *lowers* the liquidity injections from the central bank. This deepens the contraction originally caused by the credit shock. To mitigate this self-induced tightening channel, the central bank expands its asset purchases *more* than it otherwise would if the scarcity channel was not present. In this sense, sovereign bonds purchases *by themselves* are not the most effective monetary tool.

If the central bank decides to react to the credit shock only by easing the collateral policy, output falls less than when it deploys QE (purple solid line, -0.9% vs -1%, respectively). The liquidity injections generated by the lower haircut on sovereign bonds increase the central bank balance sheet by 1.5% of steady state output (vs 5.4% generated by QE). In short, collateral easing is more effective than QE: it delivers more output stabilisation with a smaller monetary policy intervention. The reason for the higher effectiveness is due to the different channels of transmission that are at work at the same time: the collateral policy is *fully* expansionary as it works through the liquidity channel (see section 3.5.1) while QE is only *partially* expansionary as it creates the contractionary scarcity channel.[37]

The experience of the ECB during the Covid-19 pandemic shows that monetary policymakers respond to a credit shock by engaging in both QE and collateral easing. In our simulation this implies endogenous sovereign bond purchases and endogenous haircut on sovereign bonds (solid green line). It is this unconventional monetary policy combination that achieves the highest degree of output stabilisation: output falls by only -0.78%, almost a quarter less than when the central bank deploys QE. The mix of liquidity injections and asset purchases increases the central bank balance sheet to 5% of steady state output (5.5% with QE). We conclude that also this policy mix is more effective than solely relying on QE. In other words, the liquidity channel generated by the lower haircut is able to offset the scarcity channel generated by the sovereign bonds purchases.

To conclude, even if QE and collateral policy have the same purpose — to act as a

[37]In addition, by construction of the enforcement constraint in equation 3.4, the effectiveness of liquidity injection is higher than sovereign bonds purchases (as explained in section 3.5.1).

backstop during periods of market malfunctioning (BIS, 2022) — these simulations highlight the different channels of transmission through which they work and the range of outcomes they can potentially lead to. From a policy perspective, we offer two recommendations. First, when liquidity injections with sovereign bonds as collaterals have already been implemented in previous periods, the most effective framework to respond to a credit crisis is a combination of sovereign bond purchases and lower haircut on sovereign bonds. It is this *combination* that will deliver the highest output stabilisation. Second, our simulations discourage engaging solely in sovereign bonds purchases and instead support, as second best option, a greater reliance on lending provisions. Working through the expansionary liquidity channel, it is the lending provisions that will deliver more output stabilisation with a smaller monetary policy intervention than QE.

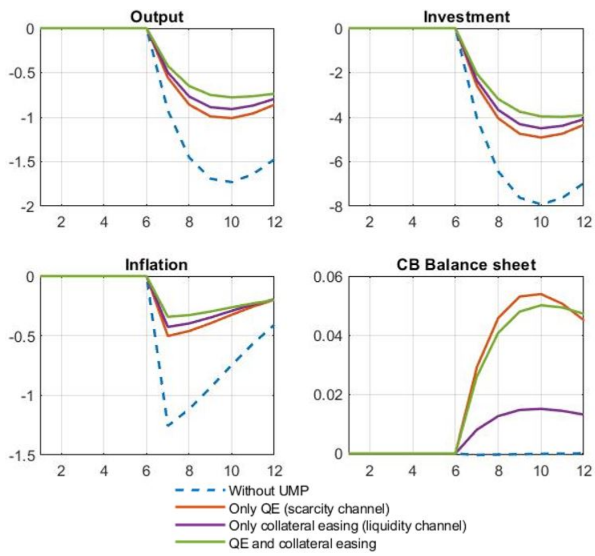


Figure 3.10: Credit shock with endogenous QE and endogenous collateral policy

3.6.3.2 Lending programme - QE: Synergy

This subsection focuses on the amplification mechanism that is generated when the central bank purchases sovereign bonds through its QE programme while requiring corporate bonds as collateral for its lending programme. By endogenesing the collateral policy, this subsection shows that we can exploit the portfolio rebalancing channel of QE to enhance the effectiveness the lending programme.

Figure 3.11 below shows the IRFs to a credit shock[38] in five monetary policy

[38]To achieve this, we follow the same methodology implemented for Figure 10: first, we simulate

scenarios: i) without any UMP (blue-dotted line); ii) only endogenous QE — sovereign bonds purchases as per equation 3.21 — without any collateral requirement at steady state (solid orange line), iii) only endogenous QE with corporate bond required as collateral at steady state[39] (solid purple line), iv) only endogenous collateral policy: the haircut on corporate bonds is set as per equation 3.23 (solid green line), and v) endogenous QE and endogenous collateral policy (solid light blue line).[40]

Our simulations find that when the policy rate is constrained by the ZLB and the central bank does not engage in either QE or lending programmes, output contracts by -1.7% (blue-dotted line). If the central bank responds to the credit shock with sovereign bonds purchases (without having any required collateral at steady state), the central bank's balance sheet increases to 4.9% of steady state output, mitigating the contraction: output falls by -0.9% (solid orange line). As found in the previous policy experiment, QE alone is effective at stabilising output, but it is not the *most* effective strategy. In fact, if the central bank at steady state requires a fraction of the intermediaries' corporate bonds to be pledged as collateral for the lending facility, then the amplification mechanism described in subsection 3.6.2 is triggered. The strength of this mechanism depends on the size of the haircut applied at steady state. In other words, by purchasing sovereign bonds, the central bank indirectly increases the price of corporate bonds (through the portfolio rebalancing channel), allowing more liquidity injections. Since the liquidity injections are more effective at stabilising output than sovereign bond purchases — by construction, as explained in section 3.6.1[41] — the contraction can be mitigated with a less aggressive QE programme. This is the case represented by the purple IRFs: thanks to the collateral requirement at steady state, the central bank is able to achieve the same output stabilisation delivered by QE alone (orange line) but with a smaller balance sheet expansion (4.6% of steady state output vs 4.9%). In this sense, sovereign bonds purchases *by themselves* are not the most effective monetary tool. This is the same conclusion of the previous subsection,

credit shocks of 1.5 standard deviations for 6 periods, pushing the economy to the ZLB; second, we run the simulation a second time adding a further credit shock of 1 standard deviation in period 7, to which endogenous monetary policy responds; third, we take the difference between the simulation with the additional credit shock and the simulation without it — the resulting IRFs are presented in Figure 3.11 below.

[39]This implies that at steady state there are liquidity injections equal to 10% of the value of the intermediaries' corporate bond holdings.

[40]As for the IRFs in Figure 3.10, QE and collateral policy are calibrated to achieve the same output stabilisation as a policy rate cut with both κ_f and κ_b at steady state equal to zero.

[41]See the enforcement constraint at equation 3.4.

but we reach it through a different transmission channel: the portfolio rebalancing channel rather than the scarcity channel.

If the central bank reacts to the credit shock only by easing the collateral policy without engaging in any sovereign bond purchases (green line), its operations work entirely through the liquidity channel. In this case, output falls as much as when the central bank deploys QE but the balance sheet records less than a third of the increase generated by QE. In short, liquidity injections through collateral easing are more effective than sovereign bond purchases, as by construction (section 3.5.1[42]).

Finally, in the spirit of the ECB strategy during the Covid-19 pandemic, we simulate a credit shock to which the central bank reacts using both QE and collateral easing. In our simulation this implies endogenous sovereign bond purchases and endogenous haircut on corporate bonds (solid light blue line). This unconventional monetary policy combination achieves the highest degree of output stabilisation — output falls by -0.8% — with a central bank balance sheet increase of 4.1% of steady state output. This is a smaller balance sheet expansion than when the central bank engages only in endogenous QE and at steady state requires corporate bonds as collateral (solid purple line) — in that case output contracts by -0.9%. Endogenising both instruments is more effective than endogenising only QE because it allows liquidity injections (that by construction are more effective than QE) to substitute sovereign bond purchases. So even if the balance sheet increase is *smaller*, output contracts less because the *composition* of central bank's assets is different. In other words, endogenising both instruments allows the central bank to exploit the portfolio rebalancing channel and enhance the effectiveness of the lending programme.

To conclude, as in the previous subsection, simultaneously deploying the two UMP tools — endogenous QE and endogenous collateral policy — leads to better outcomes than the sum of their parts. This non-linearity is achieved by fuelling the portfolio rebalancing channel of QE. From a policy perspective, our simulations suggest that engaging strategically in QE and in collateral policy can make monetary policy more effective, leading to higher output stabilisation with a smaller balance sheet intervention.

[42]The lending provisions ease the enforcement constraint more than sovereign bond purchases (see equation 3.4) because of the calibration of the parameters Δ (0.3) and ζ (1).

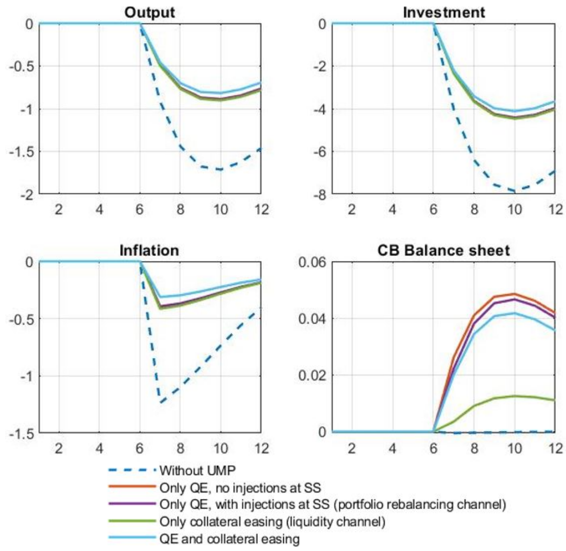


Figure 3.11: Credit shock with endogenous QE and endogenous collateral policy

3.6.4 Endogenous NIRP and Endogenous Lending Programmes: The Dual Rate

In subsection 3.6.1 we simulated an exogenous shock to the rate applied on the lending programme — what we called "dual rate shock" — while the policy rate was set at zero. This setting was convenient to study the effectiveness of having the lending facility rate below the Bank rate, nonetheless it did not reflect policymakers' choices. The experience of the ECB shows that dual rate policy is implemented i) in response to a shock, and ii) when the Bank rate is already set negative. To model the ECB decisions we simulate a credit shock to which the central bank reacts by engaging in NIRP and setting the rate on the lending programme *endogenously* below the policy rate. Following the policy rate (equation 3.14), we endogenize the spread between the lending facility rate R_t^h and the policy rate as per equation 3.18.

Figure 3.12 below shows the IRFs to a credit shock in period seven, when the economy is at the ZLB.[43] We explore four different scenarios to study the synergies and state contingencies of the dual rate policy.

[43]To achieve this, we follow the same methodology implemented for the previous policy experiments: first, we simulate credit shocks of 1.5 standard deviations for 6 periods, pushing the economy to the ZLB; second, we run the simulation a second time adding a further credit shock of 1 standard deviation in period 7, to which endogenous NIRP responds; third, we take the difference between the simulation with the additional credit shock and the simulation without it — the resulting IRFs are presented in Figure 3.12 below.

The first scenario (blue dotted line) is the baseline: this is an economy that engages in NIRP but *not* in dual rate policy and, at steady state, the loans from the central bank are limited to 10% of the value of the sovereign bonds held by the financial intermediaries. In this setting, investment contracts by -4.7% and the net worth of financial intermediaries shrinks by -4.8%. The capitalisation of the intermediaries decreases because of two reasons: first, the fall in assets value (driven by the credit shock), second, the size of the spread between the policy rate and the deposit rate (driven by NIRP). In other words, as the interest rate on reserves falls by more than 30bps and the deposit rate remains at zero, a "tax" on the intermediaries' net worth arises: this is the contractionary "NIRP banking channel" identified by Sims and Wu (2021). Policymakers are aware of this contractionary channel of monetary policy (Lagarde, 2020), potentially triggering the "reversal rate": the tipping point at which expansionary monetary policy (NIRP) becomes contractionary. The liquidity injections record a small increase: as the interest rate on the lending programme follows the policy rate in negative territory, the loans are offered at a discount, becoming more attractive. The dual rate policy is not activated: the spread between the policy rate and the injection rate is set at zero. Note that, relative to the other scenario, this policy choice leads to the deepest contraction.

The second scenario (orange dotted line) introduces the endogenous dual rate policy. It features a central bank that, as in the baseline model, deploys NIRP and, at steady state, it extends loans for 10% of the value of the sovereign bonds held by financial intermediaries. Differently from the baseline model, however, the central bank engages in endogenous dual rate policy, as per equations 17 and 18. The introduction of the dual rate policy takes the form a 800bps spread between the negative policy rate (-0.30%) and the *more* negative rate on the central bank's loans. Relative to the baseline, the dual rate policy mitigates the contraction — investment falls by -4.2% (vs baseline -4.7%) — and it allows to deploy NIRP less aggressively. There are two reasons for these dynamics: first, the intermediaries' net worth does not fall as much as in the baseline (the NIRP contractionary banking channel is weakened); second, the liquidity injections are larger (the negative rate makes them more attractive). In short, the relatively higher capitalisation and liquidity injections ease the constraint of the financial intermediaries, preventing assets' prices and output to fall as much as in the baseline scenario. In addition, the dual rate policy *prevents* the economy from hitting the contractionary reversal interest rate. We conclude that using dual rate policy while deploying NIRP is preferable than relying solely on NIRP.

The third scenario (purple-dotted line) represents an economy highly reliant on the central bank's liquidity injections. The central bank engages in NIRP and endogenous dual rate policy, as in the second scenario. The only difference with the second scenario is that, at steady state, the central bank extends loans for 50% (not 10%) of the value of the sovereign bonds held by financial intermediaries. The reason for simulating this scenario is to avoid lowering into negative territory the interest rate on the lending provision by 800bps below the policy rate as in the previous experiment, as this policy would be unfeasible. As previously found in section 3.6.1, the easier the collateral policy, the less aggressive dual rate policy needs to be: the IRFs show that the liquidity injections increase further (14% vs 1.8% in the second scenario), and the spread between the reserve rate and lending programme rate narrows (440bps vs 800 in the second scenario). As the contraction is mitigated (investment falls by -2.6% vs -4.2% in the second scenario), NIRP is deployed less aggressively, supporting financial intermediaries' net worth. Critically, net worth is *accumulated* thanks to the dual rate policy and the smaller haircut, offsetting the contractionary effects coming from the fall in assets' prices and NIRP. Overall, the third scenario shows that the synergies between NIRP and the lending programme are maximised when the central bank responds — in the words of the ECB during the Covid-19 crisis — "forcefully" to the exogenous shock (Schnabel, 2020b).

Finally, the fourth scenario (green dotted line) represents an economy using NIRP, endogenous dual rate *and* endogenous collateral policy. This combination of policy tools was deployed by the ECB in response to the pandemic: NIRP eased financial conditions, the dual rate strategy supported intermediaries' net worth (hit by NIRP) and the collateral policy improved banks' funding conditions and strengthened the transmission of the dual rate strategy (more funding at favourable terms). To be clear, as in the third scenario, the central bank engages in NIRP, endogenous dual rate policy and, at steady state, it extends loans for 50% of the value of the sovereign bonds held by financial intermediaries. In addition, the collateral policy is decided endogenously by the Taylor-type rule of equation 3.22. The IRFs show that deploying NIRP while *simultaneously* easing the dual rate and collateral policies allows to maintain more room for manoeuvre for the future — the Bank Rate and the rate on the lending facility do not need to be lowered as much into negative territory as in the third scenario — and to deliver a higher degree of output stabilisation.

Overall, this set of policy simulations has shown the strong synergies running between NIRP and the lending programmes. These positive interactions arise because the dual rate policy mitigates the contraction in banks' net worth induced by NIRP. At the same time, easing the collateral haircut enhances the intermediaries' funding conditions and it strengthens the transmission of the dual rate strategy (more funding at favourable terms). These transmission channels keep the economy away from the reversal interest rate (Lagarde, 2020) and they ensure a higher degree of output stabilisation (compared to deploying these tools in isolation). From a policy perspective, these synergies suggest central banks to "go big and go fast" (Bailey et al., 2020) when responding to an exogenous shock with NIRP and lending programmes.

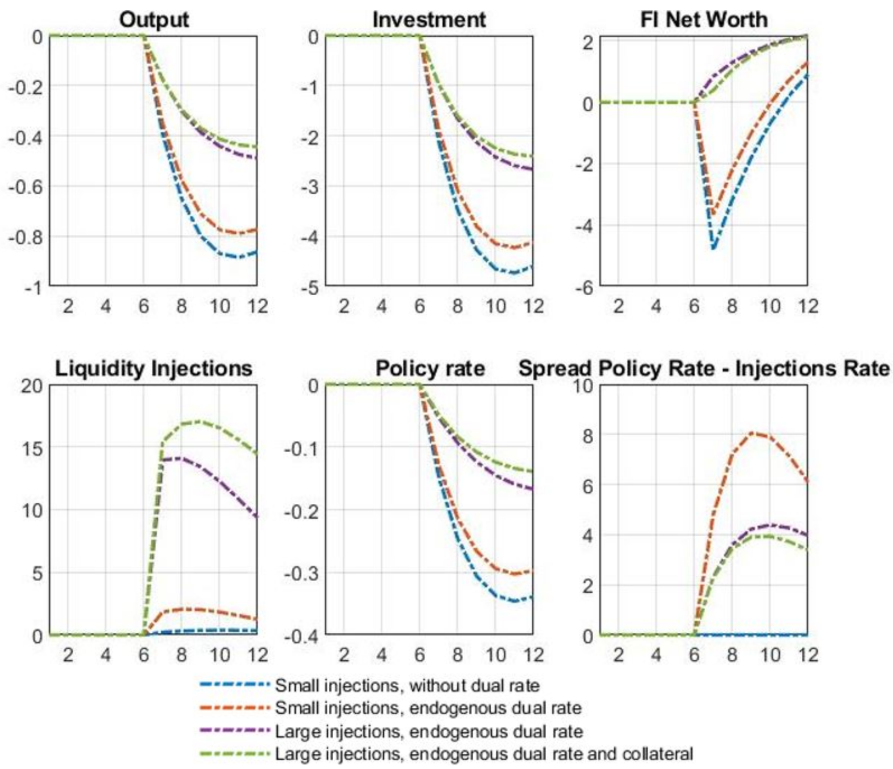


Figure 3.12: NIRP and endogenous dual rate

3.6.5 Policy Normalisation: Choosing the Unwinding Pace and Combination of Instruments

Subsection 3.6.3 found that the most effective framework to respond to a credit crisis is a combination of sovereign bond purchases and lower haircut on sovereign bonds.[44] But how do policymakers eventually exit these two unconventional programmes and normalise the monetary policy stance to achieve their mandate without causing a taper tantrum?[45] Do different unwinding paces and combinations of tools lead to different recoveries and sizes of central banks' balance sheets? If so, is there a way to do this that minimises potential detrimental effects? In short, what does a feasible and useful exit strategy look like? These are the types of questions we aim to answer in this sub-section.

There is a lack of empirical literature on the unwinding of UMP tools. This is mostly due to the scarce engagement of central banks with UMP tightening: before the current normalisation phase, QT has been attempted only by BoJ in 2006 and the Fed in 2017 (BIS, 2019a). Equally thin is the theoretical literature, that focuses mostly on the process of reversing QE — known as Quantitative Tightening (QT, see Sims and Wu (2021) and Karadi and Nakov (2021)). However, these theoretical studies do not capture the interactions with the unwinding of the other UMP tools, hence they do not provide a realistic representation of the normalisation process. Several central banks' documents (BoE, 2021) and some qualitative academic analyses (Forbes, 2021) attempt to overcome this limitation, studying in unison QT and policy rate hikes. This evidence is helpful to inform the sequencing of QT and Bank rate, but its ability to fully represent the normalisation process is hamstrung by the absence of the lending programmes.

Lacking extensive research and policy experience, central banks have adopted gradualism and predictability as their mantra to unwind UMP.[46] Despite the finely balanced tightening strategy — described by BoE Chief Economist Pill (2021b) as "crossing the river by feeling the stones" — the policy normalisation process remains "extraordinarily complex" (Panetta, 2022a). The risks to monetary and financial stability arise from the *pace* and *amount* of tightening as well as the *mix* of policy instruments. A "normalisation tantrum" can in fact be triggered if the unconventional stimulus is unwound:

[44] When liquidity injections with sovereign bonds as collaterals have already been implemented in previous periods.

[45] Following an announcement in May 2013 by former Federal Reserve Chair Ben Bernanke that the Fed would start reducing its asset purchases "in the next few [FOMC] meetings" (USCongress, 2013), the bond market reacted sharply, as investors sold off bonds. The 10-year US Treasuries' yield rose from 2% in May 2013 to around 3% in December, causing higher mortgages rates in the US and balance of payment stress in emerging markets (Davies, 2021).

[46] The importance of a gradual unwinding of UMP was highlighted already in 2017 by the Fed (Ennis and Kirk, 2022) and more recently echoed by the BoE (Bailey et al., 2020), ECB (Panetta, 2022a) and BIS (BIS, 2019a).

- Too quickly, triggering a repricing of market expectations, similar to the 2013 US taper tantrum;
- Too extensively, exacerbating any liquidity gap in the market, as in the US Money Markets in September 2019; or
- Through a tool to which the economy is highly dependent. For instance, the ECB in 2019 did not let its TLTRO programme expire to avoid "cliff effects" — a concentration of payments and maturities at the end of the programme creating stress in funding markets — and instead it announced a new package of funds (TLTRO III).

Our policy experiments and related simulations below focus on two of these risks: the pace of tightening and the mix of instruments.

The aim of the simulation is to study the effects on output and central bank's balance sheet of different tightening paces and combinations of QE/lending programmes. Following Sims and Wu (2021), Figure 3.13 below shows the IRFs to credit shocks in periods 1-7 with endogenous QE and endogenous collateral policy (lending programme) as in equations 3.21 and 3.22, respectively. In other words, the central bank reacts to the exogenous shock by engaging in sovereign bond purchases and by lowering the haircut on sovereign bonds, as in subsection 3.5.3. Both the expansionary liquidity channel and the contractionary scarcity channel arise.[47]. We generate four scenarios of policy normalisation once the ZLB stops binding: first, the solid orange line represents a central bank that unwinds simultaneously QE and the lending programme in a smooth manner — this replicates the gradual and predictable normalisation process envisaged by central banks.[48]

In this setting (purple line), the autoregressive parameter ρ_f is equal to 0.8: this can be thought as "smooth QT". The yellow dotted line represents the IRFs when the central bank adopts QE but it unwinds the balance sheet through an immediate QT process — ρ_f is equal to 0. Finally, the green dotted line represents the IRFs

[47] At steady state we impose that the central bank requires sovereign bond as collateral. This implies that at steady state there are liquidity injections equal to 10% of the value of the intermediaries' sovereign bond holdings

[48] To model this policy strategy, the autoregressive central bank bond holding parameter ρ_b and autoregressive sovereign bond collateral parameter $\rho_{b,k}$ are equal to 0.8 (see Sims and Wu (2021)) — this can be thought as "smooth QT" and smooth exit from the lending programme.

when the central bank adopts QE however it does not implement QT, it carries forward a large balance sheet without unwinding it — ρ_f is equal to 1.

Second, the green dotted line represents the opposite policy choice: the central bank never fully unwinds its lending programmes nor QE, reinvesting continuously the principal payments from maturing bonds.[49] This is the strategy adopted by the ECB before the Covid-19 pandemic. As the side effects of UMP have increased over time (Schnabel, 2022), the ECB as well as other major central banks have taken steps to unwind their balance sheet policies. However, in practice, it may be unfeasible to unwind completely[50] and within the same time frame[51] both policies (QE and the lending programmes), so the next two scenarios present a staggered normalisation strategy. The purple dotted line represents a central bank that ends immediately the lending programmes but it does not unwind QE.[52] The yellow dotted line, instead, represents the opposite case: the lending programme is never completely unwound but the QE programme is exited quickly.[53]

The most effective normalisation strategy is the smooth unwinding of both QE and the lending programme (orange line). In this case, the central bank balance sheet increases the least (27% of steady state output) while achieving the highest output stabilisation (output contracts by -6.7%). However, an inter-temporal trade-off arises as the recovery is slower than in the other three scenarios. The reason for the worst performance during the recovery is due to agents' expectations — the gradual normalisation keeps interest rates low for longer, so agents procrastinate investment decisions, slowing the recovery (Sims and Wu, 2021) — and financial intermediaries' net worth — the gradual unwinding keeps interest rate spreads compressed, hurting net interest margins and consequently intermediation (Karadi and Nakov, 2021).

[49]To model a central bank that carries forward a large balance sheet without unwinding its policies, we set both autoregressive parameters ρ_b e $\rho_{b,k}$ equal to 1.

[50]Both ECB (Panetta, 2022a) and BoE (Bailey et al., 2020) agree that going forward the steady state size of their balance sheets will be larger than before the Global Financial Crisis. For the reasons, see Hauser (2021a)

[51]BoE, for instance, stopped asset purchases in December 2021 and as of June 2022 it has not started the sales of UK government bonds yet, while the deadline for the drawdown period of its lending programme (the Term Funding Scheme with additional incentives for SMEs, (TFSME) was set at October 2021.

[52]This strategy is modelled by setting the QE autoregressive parameter equal to 1 and the lending programme autoregressive parameter equal to 0.

[53]Opposite to the previous case, this strategy is modelled by setting the QE autoregressive parameter equal to 0 and the lending programme autoregressive parameter equal to 1.

Since policy experience shows that the simultaneous, gradual unwinding of both QE and the lending programme is not feasible, we analyse the second best exit strategy: a quick unwinding of QE without a full normalisation of the lending programmes (yellow line). In this case the central bank balance sheet increases more than in the previous scenario (31% of steady state output vs 27%) while delivering almost the same output stabilisation during the recession. In the recovery phase, when the ZLB stops binding, output grows faster. The intuition for these results is the following: the missing normalisation of the lending programme *once the ZLB stops binding* suggests agents spread their investment decisions over time, deepening the crisis *when the ZLB is binding* and requiring a more aggressive monetary policy stance — hence the larger central bank balance sheet. During the recovery, when the ZLB is lifted, the central bank quickly sells sovereign bonds previously purchased through QE: these sales erase the contractionary scarcity effect but they also tighten financial conditions. In period 15, as seen in the output panel of Figure 3.13, the recovery is stalled but the wider interest rate spreads re-build financial intermediaries' net worth faster, supporting asset prices and, consequently, output — hence the better performance during the recovery.

Should the central bank decide to implement the opposite staggered strategy — to end the lending programme quickly but to continue rolling over its sovereign bond purchases over time (purple dotted line) — its balance sheet would increase more (33% of steady state output) and remain *four times larger* than the previous case once the ZLB is lifted. Output would contract more (-7.2%) during the recession, but grow as fast during the recovery.

Despite the good performance during the recovery, this strategy is highly inefficient, for two reasons: first, the scarcity effect generated by the central bank's pent up demand for sovereign bonds persists also after the ZLB is lifted (as QE is never unwound), making large sovereign bonds purchases necessary only to deliver the same output path of the previous strategy. Second, the economy reverts back to steady state with an endogenous scarcity effect that is now stronger than before the central bank's intervention: this implies that even larger sovereign bonds purchases will be needed in the next recession. Echoing Borio (2020), we can also show that the prolonged use of UMP tools exhibits diminishing returns and it might narrow the room for policy manoeuvre in the future. In short, large, permanent central bank balance sheets are not inconsequential as previously thought: they significantly affect the performance of the economy during the crisis

(Sims and Wu, 2021) as well as in future crises. This is an important finding from our policy exercises.

Finally, we analyse the case in which the central bank does not unwind either QE or the lending programme (green dotted line). This is the least effective strategy, as output contracts the most while the central bank balance sheet becomes — and remains — the largest. Two main channels lead to these outcomes: persistent asset scarcity after the ZLB is lifted and agents' expectations of a low for longer environment. The missing normalisation of both UMP tools makes these expectations stronger than in the other simulations, deepening the recession. The severe contraction, however, widens interest rate spreads that quickly rebuild financial intermediaries' net worth, fuelling the fastest recovery amongst our set of policy exercises. Despite the good performance during the recovery, this strategy has long lasting negative consequences: it leaves the economy highly dependent on central bank's interventions — with adverse repercussions on the market ecosystem (BIS, 2019a) — and it endogenises a strong scarcity effect — narrowing the room for policy manoeuvre in the future.

To conclude, the knowledge on the exit from UMP is limited, leaving "policymakers uncertain about the effects of their policy on the economy" (Panetta, 2022b). This section informs the policy debate by showing that the pace of unwinding and the combination of tools that are unwound have significant effects on the performance of the economy during the recession, the recovery and future crises. Our simulations indicate that the most effective strategy is a smooth and complete unwinding of both QE and the lending programme. If this was not possible, QE should be exited quickly and the lending programme carried forward. Compared to never fully unwinding the unconventional stimulus, this strategy leaves the economy less dependent on central bank's interventions and, going forward, more reactive to them, ensuring the effectiveness of future monetary policy decisions.

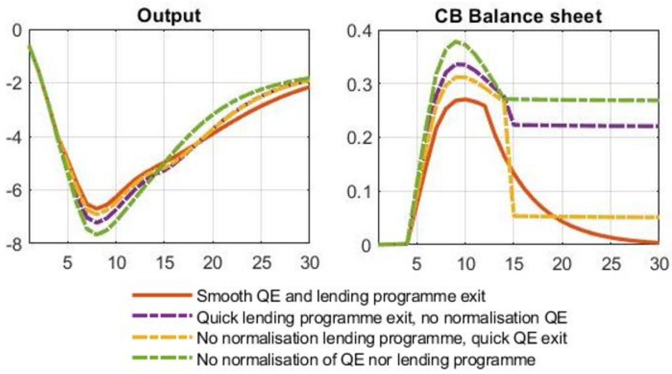


Figure 3.13: Unwinding QE and lending programmes: different paces of normalisation and combinations of instruments

Table 3.2: Different unwinding paces and combinations of tools

Unwinding pace and tools' combination		Output	CB BS*
Smooth QE and lending programme exit	Crisis:**	-6.7%	26.8%
	Recovery:***	-2.9%	1.3%
No normalisation lending programme, quick QE exit	Crisis:	-6.9%	31.1%
	Recovery:	-2.5%	5.1%
Quick lending programme exit, no normalisation QE	Crisis:	-7.2%	33.6%
	Recovery:	-2.5%	22.1%
No normalisation of QE nor lending programme	Crisis:	-7.7%	37.8%
	Recovery:	-2.2%	26.9%

Notes: *Central Bank Balance Sheet size, expressed in percentage of steady state output. **Measured in period 8, at the trough of the cycle.***Measured in period 25. Output is expressed in percentage deviations from the steady state.

3.7 Conclusions

In this chapter we have developed a theoretical DSGE model to study the synergies and trade-offs between the lending programmes and three UMP instruments: QE, NIRP and FG. We found that, when the lending programmes are deployed in isolation, they are more effective than sovereign bonds purchases in supporting aggregate demand. When, instead, the lending programmes are deployed simultaneously with the other UMP instruments, the synergies that arise from the interactions make *three cases for their concerted deployment*. First, when the lending programmes are deployed simultaneously with QE, synergies — working through the collateral value — and trade-offs — generated by the scarcity of available assets — arise. By setting its collateral policy, the central bank can strengthen the positive interactions and overcome the trade-offs, improving monetary policy effectiveness. Second, when the lending programmes are deployed simultaneously with NIRP, the dual rate system supports financial intermediaries' net worth. This synergy prevents the economy from hitting the reversal interest rate, again increasing monetary policy effectiveness. Finally, once the economy is in recovery, the simultaneous, smooth and complete unwinding of both QE and the lending programme ensures the most effective normalisation policy.

Annex 1: Exogenous UMP shocks

Following Figure 3.7, we compare the IRFs to eight different monetary policy shocks once the economy is at the ZLB. The eight monetary policy shocks are: three shocks to the lending programme — representing sovereign bond collateral easing (light blue dotted line), corporate bond collateral easing (red dotted line) and dual rate policy easing (dark blue dotted line) — a policy rate shock (solid blue line), a corporate bond QE shock (orange dotted line), a sovereign bond QE shock (yellow dotted line), a NIRP shock (green dotted dotted line) and finally a FG shock (purple dotted line). The shocks are calibrated to match the same increase in output given by the policy rate cut shock (0.49% in period nine).

30% Haircut on Sovereign Bond

The calibration used for Figure 3.14 below differs from the calibration used in the chapter for Figure 3.7 as the parameter $\kappa_{b,t}$, governing the haircut on sovereign bond, is set at 30% (vs 10% in the chapter). This implies that there are more lending provisions in this Annex's simulation than in the chapter's. The larger liquidity injections ease the financial conditions, as such the dual rate strategy does not need to be applied as aggressively: the interest rate on the lending facility is set 200bps below the policy rate (vs more than 600bps in the chapter's simulation).

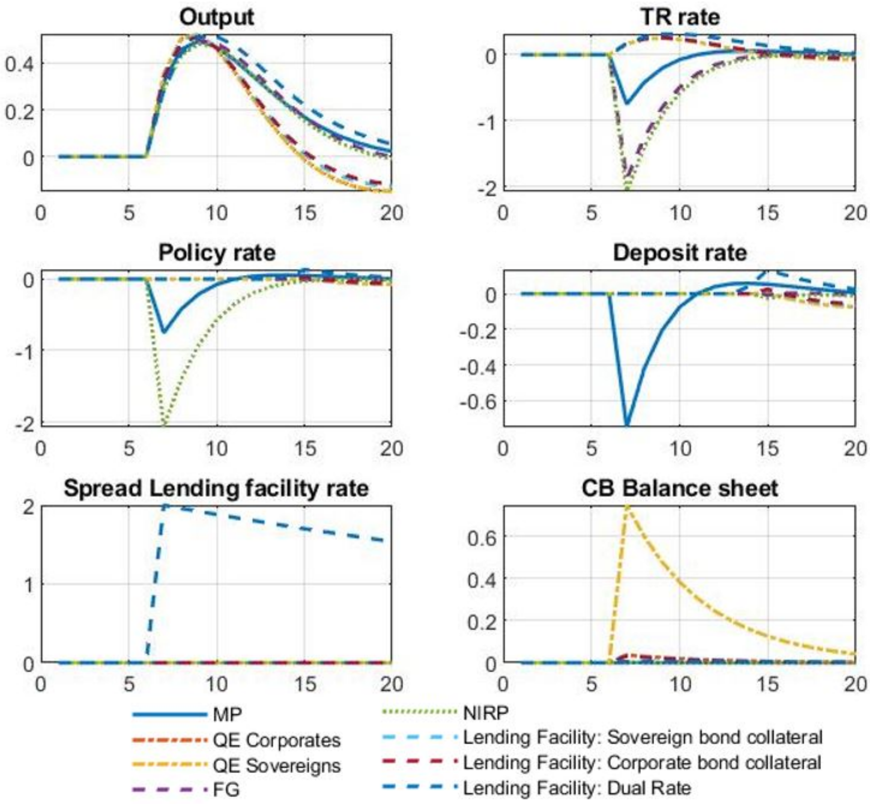


Figure 3.14: Conventional and Unconventional Monetary Policy shocks with 30% haircut on sovereign bond

50% Haircut on Sovereign Bond

Following up on the previous policy experiment, this subsection calibrates the parameter $\kappa_{b,t}$ at 50% — five times larger than the chapter's calibration. The higher liquidity injections make a large cut to the interest rate on the lending facility unnecessary: in Figure 3.15 below the interest rate on the lending facility is set 100bps below the policy rate (vs more than 600bps in the chapter's simulation).

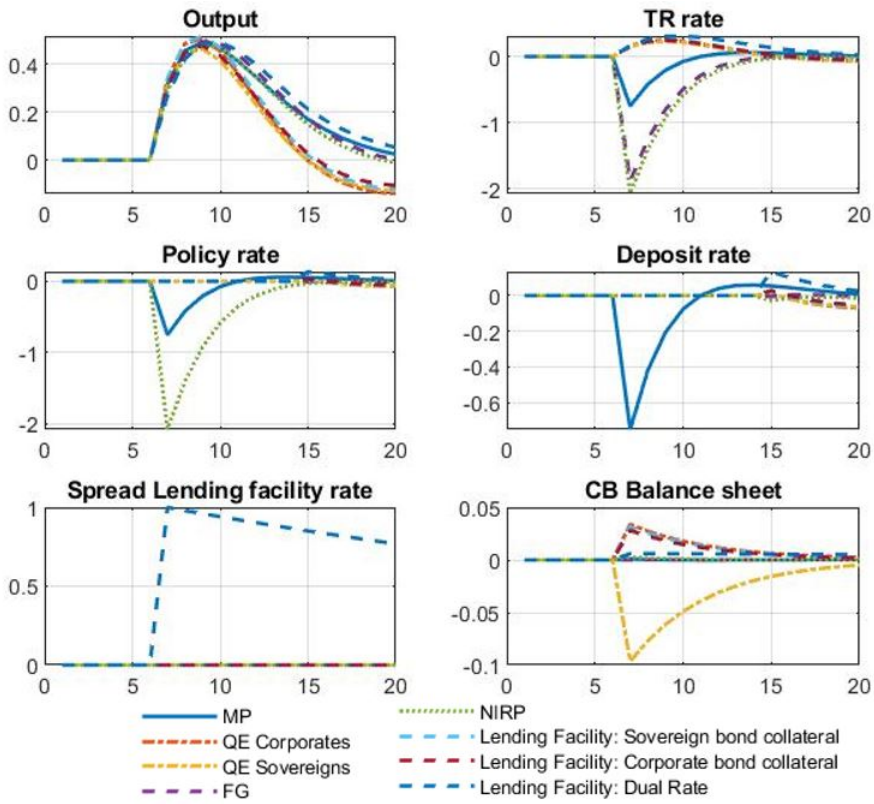


Figure 3.15: Conventional and Unconventional Monetary Policy shocks with 50% haircut on sovereign bond

Chapter Four

The Impact of the Covid-19 Shock on Euro Area Potential Output: A Sectoral Approach

Co-authored with Katalin Bodnár, Julien Le Roux and Bela Szörfi

This chapter presents a sectoral-level, bottom-up method to estimate euro area potential output in order to assess the impact of the COVID-19 crisis on it. The estimates are based on a supply-demand shock decomposition and are meant to quantitatively support the estimation of scarring effects stemming from the pandemic.

What is the degree of scarring from the COVID-19 pandemic?[1] It is of key importance for welfare considerations, fiscal and monetary policies to gauge how much permanent damage to the economy is inflicted by the COVID-19 pandemic. The unique nature of the shock and its policy response, though, limits the scope for

[1]Our analysis is based on the only data available as of 8 March 2022 covering economic developments up to the fourth quarter of 2021. Therefore, the unfolding effects of the Russia-Ukraine war are not estimated in this chapter.

comparison with past crises. Analytically, scarring is most often assessed through the behaviour of potential output. One measure of scarring is simply the expected loss of potential output compared to the pre-crisis path. This can be estimated using data on the total economy. However, focusing on aggregate data overlooks the fact that the COVID-19 crisis has affected sectors very heterogeneously. Sectors that require personal contact and are deemed to be non-essential were seriously affected. This implies that there may be a need for a more fundamental sectoral reallocation of resources which will have costs that may lead to long-term damage, including via hysteresis effects, affecting the aggregate potential growth of the economy.

Studying potential output at the sectoral level allows to cater for this heterogeneity and to attach a narrative-based assessment of possible scarring effects. As there is no well-established methodology to estimate potential output at the sectoral level, this chapter combines state-of-the-art shock-identification methods with COVID-19-specific sectoral resilience metrics to gauge the effect on the growth potential of the euro area economy. Such an approach can be useful to assess the risks around potential output estimates published by international institutions, while it can also be used to assess factor reallocation needs. Going forward, our methodology is also well-suited to assess other sectoral shocks, such as the Russia-Ukraine war which affects first and foremost the manufacturing sector and notably energy-intensive industries, while the COVID-19 mainly affected the contact-intensive services sectors.

We find that, even before the pandemic, the growth of trend output was very heterogenous across euro area sectors. Despite a strong co-movement, trend growth was ranging in 2019 from below 0.5% in sectors such as construction, financial and insurance services or other services to around 4% in the information and communication sector.

In 2020 and 2021, supply shocks played a large role for “other services”, (which includes leisure activities, repairs, personal services like hairdresser, etc.), but they were also significant in “trade, transport and accommodation” and “professional and administrative services”, given the size of the shock. However, the pass-through of these supply shocks to trend output is different across the different sectors and across their potential output contributions (labour, capital and total factor productivity (TFP)).

We support our assessment with the use of a sectoral resilience index (SRI) that gauges how sectors can overcome the COVID-19 shock, depending on their ability to take advantage of teleworking, to innovate and to cover their financial obligations. It shows that information and communication, as well as industry, may have been more resilient to the COVID-19 shock, while trade, transport, and accommodation, as well as other services sectors were much more exposed to its negative effects.

We find that “trade, transport and accommodation”, “industry” and “other services” are likely to experience some scarring, facing a loss in their trend output of approximately 1.6%, 1.4% and 1.4% by 2025, respectively in our baseline scenario.

While potential output estimates are normally surrounded by uncertainty, the sectoral approach points to somewhat lower aggregate potential output growth in 2020 than the Autumn 2021 European Commission (EC) estimates. While the EC estimates 1.0% potential output growth in 2020, the sectoral approach points to a slowdown to 0.7%. In 2021, this gap persists with an estimated potential growth of 1.1% based on the sectoral level approach, against 1.3% in the EC. Various alternative scenarios point to a large uncertainty, and the overall range of estimates points to downside risks.

According to our baseline scenario, the aggregate losses in the level of potential output would amount to over 0.8% by 2025. However, our baseline scenario does not take into account the support provided by the Next Generation EU (NGEU) in the years 2022-2025. Therefore, the losses in our baseline scenario are larger than those projected by the European Commission (no loss in the potential output level), which do take the NGEU into account. The largest contribution to this loss comes from the trade, travel and accommodation sector, which was seriously hit and has a large share in the economy. Some alternative scenarios suggest worse outcomes. It is also shown that the policy response remains very important. In an optimistic policy scenario, the losses could be reversed and there could be even some gains. In our scenario that could be interpreted as if the NGEU support was taken into account (albeit this scenario is not based on the Recovery and Resilience Plans submitted by the EU member states), the loss is more similar to the European Commission’s estimate.

Our results are surrounded by uncertainty. These estimates are based on limited data availability and cannot take sectoral linkages and some aggregate factors into account. Due to the uncertainty around when and how the government support measures will be withdrawn and how persistently consumers have adjusted their behaviour, the scarring effects remain difficult to assess. This notwithstanding, we run a range of robustness and simulation exercises to depict the relevant range of uncertainty, which overall validate our baseline results.

While we aim to outline broad implications from sectoral changes, further work will be needed to detail the extent of resource reallocation among sectors that is or will be initiated given e.g. changing preferences of consumers or the expected strengthening of digitalisation.

4.1 Introduction

The COVID-19 pandemic crisis and the subsequent recovery affected sectors very heterogeneously. Sectors that are considered essential as well as those that can be operated without the risk of spreading the virus could maintain their activity, while those that require personal contact and are deemed to be less essential, were seriously affected. The latter include the so-called recreational services, some of which were found to have responded more strongly to containment measures than other sectors (see Battistini and Stoevsky (2021) and Gunnella et al. (2021)). The recovery has also been uneven, as restrictions have affected sectors differently. In addition, it is still unclear to what degree changes in household and firm consumption patterns are persistent. Indeed, structural changes may have been triggered in some sectors, e.g. transport and tourism, resulting in persistently lower activity than before COVID 19. Furthermore, reallocations of production factors may occur through firm closure and the shift of labour and new investments.[2] In this process, one cannot exclude hysteresis effects having a negative impact on the labour market and long-term growth.

Several indicators confirm the heterogeneity of sectoral developments during the crisis. Across 10 NACE-2 sectors in the euro area, standard deviation of total hours worked, value added and productivity growth rose considerably in 2020 and remained high in 2021, while that of employment growth remained

[2] In that vein, Haltiwanger (2021) highlights a surge in new US business applications, with very uneven developments across sectors and suggesting strong restructuring induced by the pandemic in some sectors.

moderate, reflecting the impact of job retention schemes (Figure 4.1). Even when compared to the global financial and European sovereign crises (GFC), the COVID-19 shock resulted in an abrupt decline in several sectors (Figure 4.2). In 2020Q2, value added dropped the most in other services, followed by trade, transport and accommodation and professional and administrative services. The shocks in these sectors, mainly in other services and trade, transport and accommodation, have been persistent, i.e. activity was in 2021Q4 still well below its pre-shock level.[3]

While potential output is an aggregated concept, it is worth studying its recent developments at the sectoral level, given the heterogeneity described above. Potential output is usually defined as the level of activity that corresponds to the level of output that an economy can generate without excessive inflationary pressures. These concepts are traditionally understood at the aggregate level. However, the heterogeneous impact of the current shock both in terms of its effect on supply versus demand and in terms of the expected persistence calls for a sectoral decomposition of potential output. This may also help understanding the sectoral reallocation needs in the coming years as well as areas of policy action.

[3]Value added and total hours worked by sectors come from quarterly national accounts. The sectoral stock of capital is estimated from the annual national accounts and a forecasting model for the following years (see Annex 1 of this chapter). The sectors are: A – Agriculture, forestry and fishing; BtE – Industry (except construction); F – Construction; GtI – Wholesale and retail trade, transport, accommodation; J – Information and communication; K – Financial and insurance services; L – Real estate activities; MtN – Professional, scientific and technical activities; administrative and support service activities; OtQ – Public administration, defence, education, human health and social work activities ; RtU – Other services.

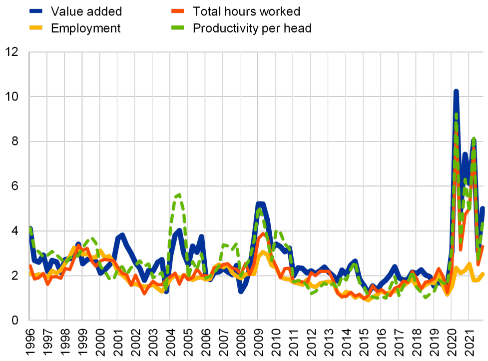


Figure 4.1: Standard deviation of indicators across euro area sectors

Source: Eurostat and own calculations. Notes: standard deviation of annual growth rate of selected indicators by sectors

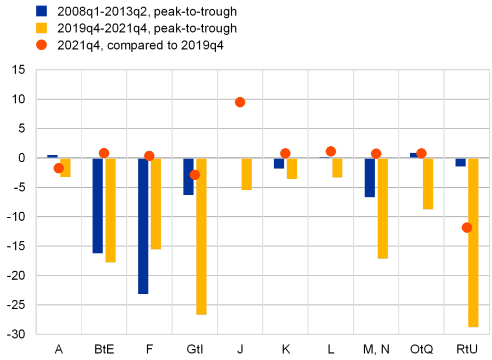


Figure 4.2: Peak-to-trough developments in sectoral value added in the euro area (percentage points)

Source: Eurostat and own calculations. Notes: see footnote 3 for the sector abbreviations.

This chapter develops a sectoral approach to estimate the loss in euro area potential output due to the COVID-19 crisis. There are no standard methods available to estimate potential output from detailed sectoral data.[4] The analysis in this chapter focuses on the euro area as a whole. It applies a bottom-up, production-function sectoral approach, to cross-check estimates of the impact of the crisis on aggregate potential output. It focuses on the medium-term outlook of 5 years following the start of the COVID-19 pandemic. Given the large uncertainty, we develop a baseline and several alternative scenarios using different assumptions. The approach is flexible and can be extended to include further information.

The results show that losses and scarring can be substantial in some severely hit sectors, warranting careful design of policies facilitating the necessary reallocation of resources. Overall, our assessment suggests a higher risk of potential output loss compared to what has been set out by other international institutions. The European Commission (Autumn 2021 Forecast) foresees no loss – and even a gain – in the level of euro area potential output in 2025 in comparison with what was expected before the pandemic, assuming largely a temporary shock of COVID-19 on potential output (Figure 4.16). The IMF (Autumn 2021 WEO) expects much

[4]The few methods that estimate potential output using sectoral data rely on a few sectors. Foerster et al. (2022) on Construction, Nondurable Goods, and Professional and Business Services for the US, while Bundesbank (2007) separate private sector (business sector excluding real estate) and public sector, excluding healthcare, while real estate and healthcare sectors are treated separately.

smaller potential output losses than those following the great financial crisis. In the euro area, the output level in 2024 is expected to be 0.5% lower than projected before the COVID-19 pandemic. Some national institutes have published sectoral estimates of the effect of the current crisis on potential output at the country level. For example, Insee estimates a loss in potential output for France of 1.6% at the end of 2022, based on survey data and using a sectoral decomposition approach.[5]

The remainder of the chapter is organised as follows. Section 4.2 presents the methodology used to estimate and forecast sectoral trend growth. In Section 4.3 we provide the initial conditions for sectoral trend output prior to the crisis. Section 4.4 presents the results on baseline and alternative scenarios and robustness checks and Section 4.5 concludes.

4.2 Methodology

We estimate and project trend growth for 10 NACE-2 level sectors, as presented in the introduction. We split the period between 1996 and 2025 into three distinct phases: 1996 to 2019, 2020-2021, and 2022-2025. The estimation and projection methodologies are explained in detail below and are summarised in Table 4.1.

Table 4.1: Summary of the methodology used for the trend growth estimates in the baseline

Period	TFP and Labour	Capital
1996 – 2019	Hodrick-Prescott filter	Sectoral data, not filtered
2020 – 2021	BVAR and sectoral trend elasticity in baseline. Cross-checking exercise depending on the sectoral resilience index (SRI)	Panel estimation using sectoral value added data, different scenarios depending on the degree of depreciation
2022 – 2025	Gradual convergence to the counterfactual growth. Cross-checking exercise depending on sectoral resilience index (SRI)	Panel estimation using sectoral projection of value added data, depending on the degree of depreciation

[5]See INSEE (2021).

4.2.1 Estimation of Sectoral Trend Output for the Past (1996-2019)

To start our analysis, we estimate past trend output for each sector, using a Cobb-Douglas production function with labour (total hours worked), capital and Total Factor Productivity (TFP) contributions. The aim of this step is to set up some “initial conditions” for the estimations and for the counterfactual scenarios at the sectoral level. Past trend output is estimated for the 10 sectors from 1996 to 2019, using quarterly data.[6]

We carry out the estimation in three steps: First, using sectoral value added, total hours worked and capital stock, we estimate total factor productivity (TFP) using a Cobb-Douglas production function. Second, we use the Hodrick-Prescott (HP) filter to estimate the trend of the labour input and TFP, while sectoral capital stock is not filtered (in line with most production function methods applied at the aggregate level). The smoothing parameter in the HP filter is equal across the ten sectors and is calibrated such that aggregate euro area potential growth is closest to the potential output estimate of the European Commission for the entire period.[7] Third, we combine the trend components of sectoral output, using a Cobb-Douglas production function. Wage share is calculated from sectoral data and it ranges from 4% in the real estate sector to 78% in the public services sector (see Annex 7 of this chapter).

4.2.2 Counterfactual Scenario for the Projection Horizon (2020-2025)

Starting from the past trend output, we derive a counterfactual scenario for all sectors, which is necessary to calculate the losses. We assume that without the COVID-19 shock, trend growth in all sectors would have gradually slowed down somewhat, similarly to the European Commission’s (EC) 2019 Autumn projections. Since these estimates are available publicly only until 2024, for 2025 we make a linear extrapolation of potential output. We calculate the counterfactual scenario for each sector. For this, we assume that the growth rates of trend TFP and of the capital stock would remain at their 2019 level, while the growth rate of trend labour would gradually decrease, reflecting the impact of population ageing. We

[6]We use data from national accounts for sectoral value added and total hours worked. Sectoral capital stock data is taken from balance sheet accounts for non-financial assets (see Annex 1 of this chapter).

[7]In particular, we use a lambda of 37500. The usual lambda of 1600 would result in a less smooth estimate with larger end-point uncertainty.

assume that sectors would be similarly affected by the decline of labour supply due to ageing, and we make sure that the aggregation of the sectoral trend output is equal to the aggregate potential output estimate of the EC for 2020-2025, as estimated in the 2019 Autumn projections.

4.2.3 Estimation of 2020 and 2021 Sectoral Trend Output – Baseline Scenario

Although two years passed since the start of the pandemic, it is still challenging to use standard tools without judgment to assess to what extent the COVID-19-shock affected sectoral trend output in 2020 and 2021. First, while some data are available, some are still missing on the sectoral level (for example, sectoral stock of capital for 2021). Second, statistical filters cannot be used due to the end-point uncertainty. Third, while trend developments are traditionally linked to supply shocks, standard supply-demand shock decomposition methods suffer from methodological challenges, which may result in a distortion when estimating the impact of the shock on trends. The shock decomposition relies on the assumption that prices reflect the relative size of supply and demand, but this may not hold in the pandemic situation as some economic relationships, for example the Phillips-curve have weakened, at least temporarily. In addition, a supply-demand decomposition does not distinguish between temporary and more permanent shocks. If one assumes that the definition of potential output implies smooth fluctuations over time, the temporary part of the supply shock should be excluded.[8] Finally, firms and consumers started to adjust to the shock and the policy measures and can be expected to do so looking ahead, while shocks not closely related to the pandemic occurred in the second half of 2021, making it challenging to assess the impact of the health crisis.

To tackle the above-mentioned issues, we suggest an approach that relies on a supply-demand decomposition, but downscales the size of the supply shock, in order to ignore its temporary part when estimating trend output. We proceed in two related steps. First, we estimate the size of the supply shock using a Bayesian VAR. Second, we derive a metric for the elasticity of sectoral trends to the supply shock and use that to assess trend developments in 2020-2021 (see Annex 2 of this chapter).

[8] Bodnar et al. (2020) discusses the concept of potential output in the COVID-19 crisis.

In the first step, we use a Bayesian Vector Autoregressive (BVAR) model to decompose the change in sectoral value added in 2020 and 2021 to developments related to supply and demand. Similarly to other papers that decomposed sectoral shocks to demand and supply, we start with estimating a BVAR model with sign restrictions and standard stochastic volatility in the error structure and standard setups in the BEAR toolbox.[9] The BVAR is based on two variables: sectoral value added and sectoral value added deflator. The structural identification is based on a sign restriction: a demand shock is considered when the value added and the value added deflator move to the same direction, while in case of a supply shock, they move to opposite directions. We use 4 lags for endogenous variables. We prepare the historical shock decomposition of value added from the second quarter of 1995 up to the last quarter of 2021.

As the BVAR estimation for the supply shock includes both temporary and persistent supply factors, it might overestimate the impact of the COVID-19 shock on trend output. Thus, we consider some additional information on the degree to which the supply shock may affect trend developments. In our baseline setup, we estimate the relationship between trend TFP and labour (estimated using a Beveridge-Nelson decomposition[10]) and the supply shock for 1999-2019 for each sector. For this purpose, at the sectoral level k, we decompose TFP ($tfp_{t,k}$) and labour ($l_{t,k}$) into a cyclical and a trend component, using a Beveridge-Nelson (BN) decomposition[11] over the period 1996q1-2019q4. For any time series y_t, the BN decomposition determines a trend process τ_t and a cyclical process c_t such that: $y_t = \tau_t + c_t$.

For both $tfp_{t,k}$ and $l_{t,k}$, we regress their trend component $\tau_{t,k}$ over the sum of the supply shocks stemming from the BVAR decomposition, over a period of four

[9] We follow the methodology by Bonam and Smadu (2020) and World Bank (2020).

[10] We use a Beveridge-Nelson (BN) filter with standard parameter setups (lag order of 12, backward rolling window of 40, no structural breaks, no smoothing parameter delta). It generally provides a stronger cyclicality in the estimation of trends than a HP filter. This is why we do not use the BN filter to estimate trends over the period 1996-2019. Over the period 2020-2021, assuming a larger degree of cyclicality in potential output growth appears acceptable - this is the hypothesis adopted by the IMF (on the concept of potential output during the COVID crisis, see Bodnar et al. (2020)). Moreover, it is not possible to establish a relationship between supply shocks as estimated in a BVAR and trends as estimated by a HP filter (see Annex 2 of this chapter).

[11] More precisely, the Kamber et al. (2018) modification of the well-known Beveridge and Nelson (1981). The signal-to-noise ratio chosen using the Kamber et al. (2018) is based on an automatic selection procedure which balances the trade-off between fit and amplitude.

quarters.[12] This leads, for each sector k, to:

$$dlog(\tau_{t,k}) = \beta_1 + \beta_2 \sum_{i=t-3}^{t} SUPPLY_{t,i} + \varepsilon_{t,k} \tag{4.1}$$

where $\tau_{t,k}$ represent the trend component of either TFP ($tfp_{t,k}$) or labour ($l_{t,k}$), as filtered by the Beveridge-Nelson filter and $SUPPLY_{t,k}$ is the supply shock as it emerges from the historical shock decomposition of the BVAR and $\varepsilon_{t,k}$ is the residual which follows a normal distribution. Table A2 and A3 in Annex 2 of this chapter present the results of the regressions.

Second, we use the estimated elasticities to estimate the impact of the 2020-2021 supply shock on trend TFP and labour, while capital is assessed separately.

4.2.4 Projection of Sectoral Trend Output for 2022-2025 – Baseline Scenario

In the baseline scenario, we assume that the growth rates of trend TFP and trend labour gradually converge to the counterfactual, and the speed of convergence in 2022-2025 is assumed to be linear. Importantly, an additional assumption is applied, whereby in case of TFP, estimated trend growth rates in 2021-2023 smaller than zero are replaced by zero, to avoid negative trend growth rates in years which are supposed to bring recovery. The projected growth of the stock of capital is explained in Annex 1 of this chapter. In the baseline scenario, trend growth in each sector is equal to the counterfactual by 2025, assuming no losses in terms of growth. Finally, the estimated trends of the components (TFP, labour and capital) are combined using the production function introduced earlier in this Section.

4.2.5 Estimation and Projection of Sectoral Trend Output for 2020-2025 – Cross-checking with the Sectoral Resilience Index

As a cross-checking exercise, we build a sectoral resilience index (SRI) that we use in an alternative scenario to adjust the persistence of the sectoral supply shock (see Annex 3 of this chapter for details on the SRI). The advantage of this index

[12] We tested a large number of specifications for this regression and we selected the most suitable one, providing the best fit and the most significant estimates.

is that it provides information on the components of trend output. However, it is not available as a time series and thus it cannot be checked how it usually co-moves with trend developments. The SRI (Figure 4.3), is based on the share of teleworkable jobs in employment, R&D expenditure, and the interest coverage ratio. All these variables are rescaled, normalised and aggregated using equal weights. In this alternative scenario, the index is used to adjust the share of the supply side shock that is passed on to potential output in 2020-2021 and to differentiate between sectors in terms of the persistence of the shock beyond these two years.

The SRI is strongly correlated with the persistence of the shock up to the last quarter of 2021. For the first two years of the shock, the SRI captures well the heterogenous impact of the shock in terms of its persistence. The correlation between the persistence of the shock and the SRI is strongly positive (Figure 4.4). Even when leaving out the two sectors with the extreme values (information and communication: highest SRI and value added above its pre-crisis level; other services: lowest SRI and value added well below its pre-crisis level), the positive relationship is maintained.

In this alternative scenario, the quarterly sectoral trend growth rates in 2020 and 2021 are estimated with the help of the BVAR results and rescaled with the SRI, differently from the baseline scenario (see above and Annex 2 of this chapter). Over the period 2022-2025, the SRI also helps to calculate the speed of convergence towards the counterfactual.[13]

[13]For the years n =2022 to 2025, labour and TFP trends will change according to the formula:$growth_n = growth_{n-1} + d(growth_{2021} - growth_{2021counterfactual}) XSRI/100)$.

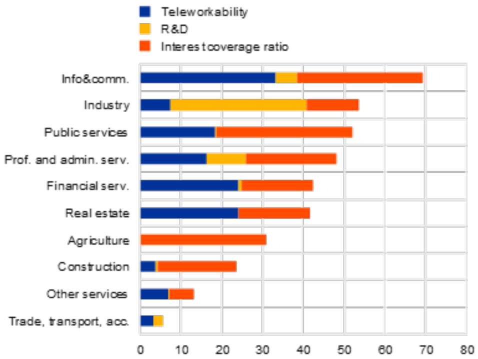


Figure 4.3: The sectoral resilience index (SRI)

Source: OECD, Eurostat and ECB Staff calculations. Note: the SRI is calculated on a scale from 0 to 100. All indicators are rescaled and normalised across the sectors. The SRI is calculated as the weighted average of the sub-components, using equal weights.

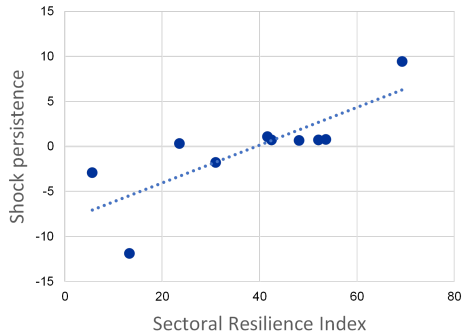


Figure 4.4: The sectoral resilience index (SRI) and the persistence of the shock until 2021Q4

Source: OECD, Eurostat and ECB Staff calculations. Notes: shock persistence is calculated as the percentage difference of sectoral value added in 2021q4 from 2019q4.

4.3 Initial conditions

Our estimates show that past trend growth rates differ widely across sectors. The estimates suggest that trend output growth was decreasing in most of the sectors before and during the global financial crisis (GFC) and it strengthened somewhat after that in many sectors. The exception is the other services, where trend output growth remained low in the aftermath of the GFC. In the entire period up to the COVID-19 shock, trend output growth was the strongest in the information and communication sector, followed by professional and administrative services and industry excluding construction. Trend output growth, however, was weakest in the construction sector, financial services and other services (Figure 4.5). The contributions of labour, capital and TFP also differ considerably across sectors (Figure 4.6). The deviations from the estimated trend output by sector display a clear cyclicality and are in line with the narrative stemming from the macroeconomic environment or sector-specific developments (see Annex 4 of this chapter for a more detailed explanation).

Several factors can be put forward to explain mixed developments in trend growth at the sectoral level in the past. For instance, consumption habits have changed. Households have cut back the share of manufactured goods in their consumer spending over the past decades, in favour of services. Furthermore, spending on services by the manufacturing sector has also increased. This development may result from outsourcing which consists in transferring activities previously carried out by industry (accounting, etc.) to services. It can also reflect a change in relative prices owing to technical progress. The drop in the relative price of ICT products and services as well as the ongoing digitalisation may explain the dynamic of trend output in the information and communication sector. Foreign trade can influence the pace of sectoral trends through different channels: trade specialisation and the nation's net savings.[14] Finally, the trend growth of construction has been low, given the labour-intensity and the low TFP growth, and was even negative after the GFC for several years, reflecting the medium term consequences of the burst of the housing bubble in 2008 after which the labour contribution in the sector declined considerably.

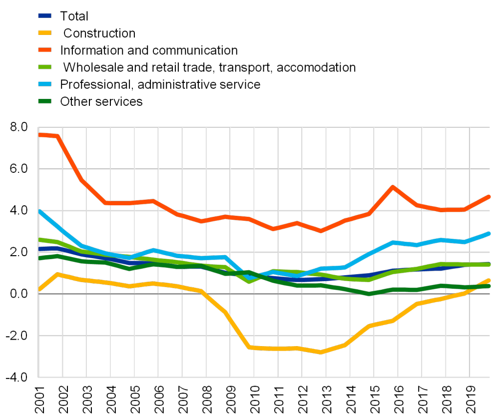


Figure 4.5: Trend growth in selected euro area sectors (annual percentage change)

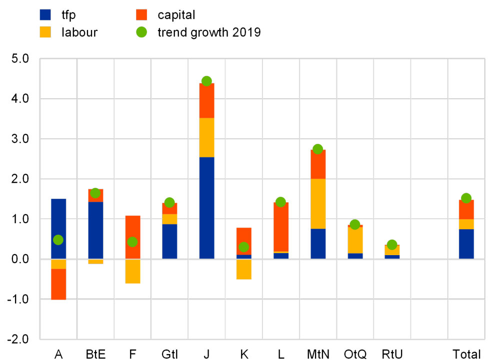


Figure 4.6: Trend growth in euro area sectors in 2019 (annual percentage change)

Source: ECB calculations based on Eurostat. Note: A - Agriculture, forestry and fishing; BtE – Industry (except construction); F - Construction; GtI – Wholesale and retail trade, transport, accommodation; J – Information and communication; K – Financial and insurance services; L – Real estate activities; MtN – Professional, scientific and technical activities; administrative and support service activities; OtQ – Public administration, defence, education, human health and social work activities; RtU – Other services.

[14] For a given net savings level, a country needs to export more or fewer manufactured goods to finance its imports (at the forefront of which we find the energy bill).

4.4 Results

4.4.1 The Estimated Supply Shock by Sectors

The COVID-19 shock affected both demand and supply, albeit to a varying degree, in all sectors. Some papers estimate a heterogenous combination of supply and demand shocks across sectors in 2020, mainly for the US (see for example del Rio-Chanona (2020) and Brinca et al. (2020)). For example, the supply shock is small in essential sectors which were not affected by the closures. Teleworkability is also an important indicator of the degree to which the (labour) supply shock affects the sectors. The share of illegal, immigrant and/or precarious workers also matters: such workers may not be covered by the job retention schemes and are thus not shielded from losing their job, thus, scarring effects may occur with a higher probability; occupational safety and health may also be worse in such sectors and eventually lead to a stronger supply shock in the pandemic.[15] Demand and supply shocks may differ in terms of their persistence (del Rio-Chanona et al., 2020) and therefore it is important to separate them when forecasting sectoral developments. Cirelli and Gertler (2022) use firm-level data and find a persistent negative impact of the COVID-19 shock on firms in the contact-intensive sectors that could not benefit from the situation.

According to our BVAR results, both in 2020 and 2021, demand shocks had a higher role than supply shocks in most sectors (Figure 4.7) (Annex 6 of this chapter includes the quarterly estimates). The negative supply shock was by far the largest in the other services sector, as several activities in the sector were shut down (for example, museums, sports activities, movies, hairdressers), and there was little room to offer these activities online, at least initially. At the same time, firms under lock-down suffer losses in value added but it makes little sense for them to adjust their prices since customers cannot use these services. E.g. even if a movie theatre or sports club cut prices in response to a fall of their output, they are not able to attract more customers since the latter are not allowed to go to these places. Since prices did not fall while activity was lower, the shock is identified as a supply shock.

[15] See the sectoral summaries by ILO (2022).

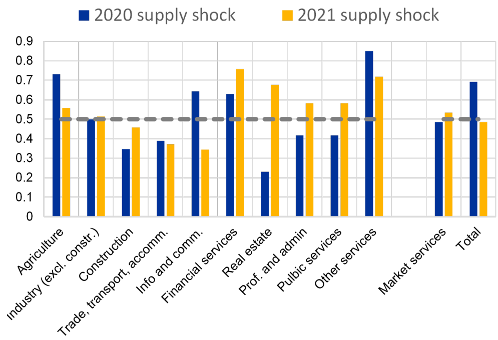


Figure 4.7: The relative share of the supply shock in 2020 and 2021 (percentage)

Source: Eurostat, ECB Staff calculations. Notes: averages of the quarterly estimates.

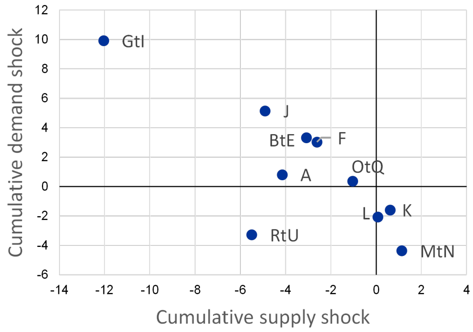


Figure 4.8: Cumulative supply and demand shock by sectors (2020q1-2021q4) (percentage)

Source: Eurostat, ECB Staff calculations. Notes: average of the quarterly estimates.

For the entire period of the pandemic crisis, it seems that supply and demand shocks correlated negatively (Figure 4.8). The cumulative absolute supply shock between 2020q1 – 2021q4 was quite negative in most sectors, but the largest in trade, transport and accommodation, which also experienced a very positive cumulative demand shock during the same period. Smaller shocks with similar signs happened in industry, construction, information and communication, public services, and agriculture. In contrast, the professional and administrative, real estate and financial sectors faced a positive supply and a negative demand shock. The only sector with both a negative supply and demand shock in cumulative terms was other services.

4.4.2 Trend Output by Sectors for 2020-2025 – Baseline Estimation

In the baseline scenario, the most affected sectors are: trade, transport and accommodation (GtI), industry (BtE) and other services (RtU), accumulating an overall loss lying between 1.4% and 1.6% by 2025. In our baseline estimation, the trend growth in those sectors decelerate strongly in the years of the pandemic – sometimes even turning negative – before gradually converging to pre-COVID trends (Figure 4.9). Also, in those sectors, the loss is driven mainly by capital, followed by labour and TFP (Figure 4.10). One cannot resist to make the link between this loss of capital stock to the fast expansion of telework and also of digital businesses at the expense of brick-and-mortar activities, although our methodology cannot ascertain this.

On the other side, the information and communication sector (J) remains the fastest growing sector, with a trend growth close to the counterfactual, thus seeing almost no loss in the baseline. The professional and administrative services (MN) and public services register a sharp decline in 2020 and 2021, followed by a significant boom and see also limited losses, or even a gain, in their level of potential output at the end of 2025.

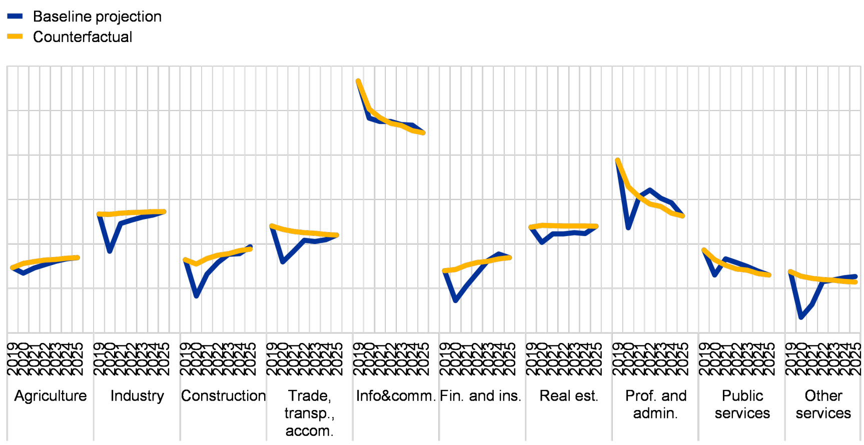


Figure 4.9: Sectoral trend growth projections in the baseline and counterfactual growth (annual percentage growth). Source: own calculations

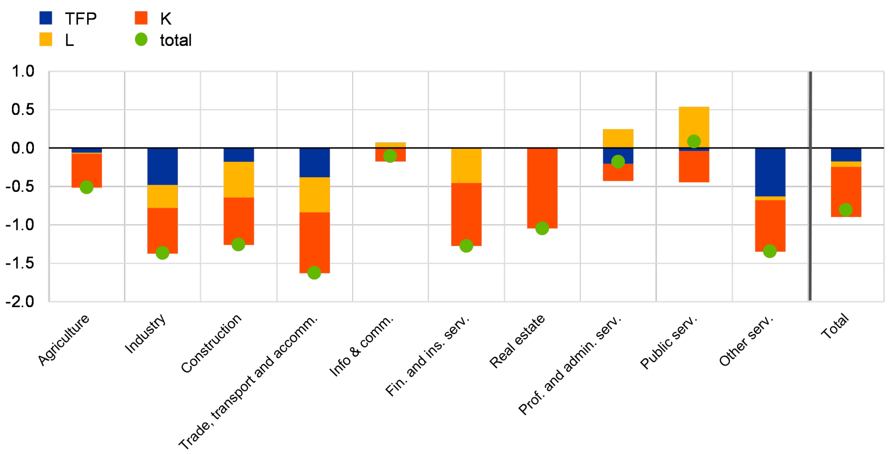


Figure 4.10: Sectoral losses in the level of potential output in the baseline scenario in 2025 (percentage point). Source: own calculations

The aggregation of the sectoral estimates points to a decline of potential growth to

0.7% in 2020 and a rebound at 1.1% in 2021, below the estimate of the European Commission. Figure 4.11 compares the aggregation of the baseline results to the counterfactual scenario and the latest EC projection. The difference between the baseline projections and the 1.0% estimated by the EC reflects some special factors: first, we rely on total hours worked as labour input, which dropped considerably, and we attribute some of this decline to the trend. Second, the EC estimate includes some smoothing due to the application of filters, which is not used in our estimates.

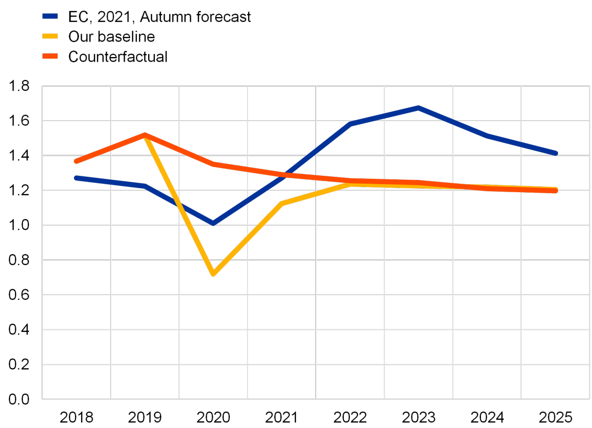


Figure 4.11: The estimated baseline and counterfactual potential output growth (annual percentage growth). Source: European Commission and own calculations

4.4.3 Robustness Scenarios

Due to the uncertainty around the impact of the COVID-19 shock on trend output and the necessarily ad-hoc nature of our assumptions, we use a wide range of robustness scenarios which serve as a cross-check exercise to better grasp the model uncertainty. First, we present a scenario where potential output is estimated using the SRI (see Section 4.2 and Annex 3 of this chapter). Second, we introduce an alternative baseline, in which trend labour is decomposed to trend average hours worked and trend employment, and we keep trend average hours worked unchanged (i.e. we do a linear extrapolation of the trends observed before the pandemic). Third, we test different assumptions on the supply-demand decomposition. Demand shocks might impact trend, mainly via hysteresis effects, and thus the effect on potential output might be larger than shown by the supply shock.[16] At the same time, it is also possible that the supply shock is not properly

[16]Note that there is also a burgeoning theoretical literature on supply and demand interactions (Guerrieri et al. (2020) and Baqaee and Farhi (2020)).

estimated, because information on prices, including deflators, may have been distorted in 2020. Thus, to reflect these two considerations, we use different versions of the BVAR results: using arbitrarily 1.2-times the size of the supply shock in 2020-2021 in one scenario and using 0.8-times its size in another one. Fourth, we assume a stronger capital stock contribution than in the baseline, reflecting the possible impact of the NGEU funds. In this scenario called "NGEU scenario", investment in some sectors (public, construction) follows that of the Broad Macroeconomic Projection Exercise of the Eurosystem (which already partly includes the effect of the NGEU).[17] Furthermore, the adverse effect of the value added losses in our equations is removed after the year 2021 (see Annex 1 of this chapter), reflecting stronger-than currently expected gains in potential output. Finally, we draw a robustness check where the capital stock is much more affected than expected. For this, we assume a stronger degree of losses in value added which affects the investment estimation (see Annex 1), without this being compensated by a drop in the depreciation rate.

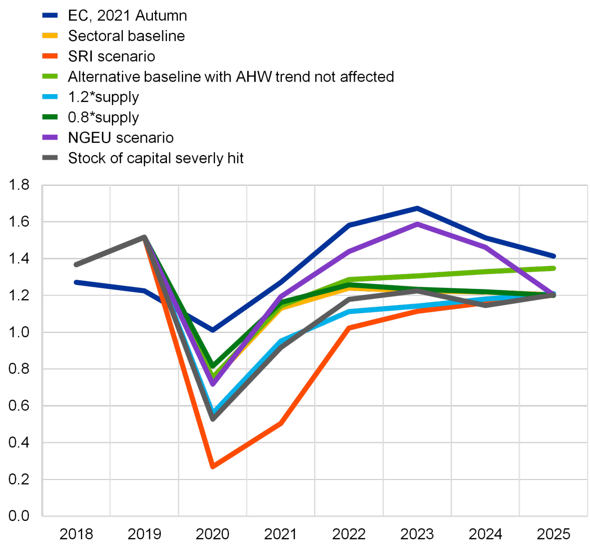


Figure 4.12: Robustness scenarios (annual percentage growth). Source: European Commission and own calculations.

Finally, we take the minimum and maximum of all the scenarios for 2020-2025. This gives us the total range of plausible estimates (Figure 4.13). In some sectors, the best and the worse scenarios evolve closely to the baseline scenario, with limited deviations across scenarios. However, in some sectors the range provided by the

[17]See ECB (2022)

worst and best scenarios is fairly sizeable. This is the case in construction, and in some services sectors. In the construction and the other services sectors, the worst scenarios imply negative trend growth for a protracted period. These scenarios can realise in case the changes in demand seen in the last two years become entrenched and firms shut down after the policies are withdrawn. In the worst scenario, the losses can be considerable, up to -14% in the other services sector and -10% in the trade, transport and accommodation sector. The construction sector may see negative trend growth in the worst scenario, which may be linked to the high sensitivity of its trend growth to the business cycle, but also to the expected impact of the COVID-19 shock on the building of offices. In contrast, in the professional and administrative services sectors, in the information and communication as well as in the public services and industry, trend growth always remains positive, and the difference between the best and worst scenarios are small.

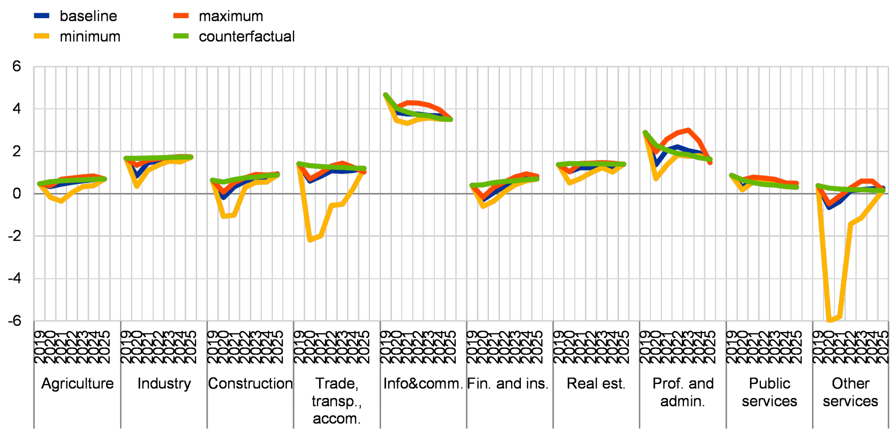


Figure 4.13: Sectoral trend growth rates – minimum and maximum across scenarios (annual percentage growth). Source: own calculations.

Reflecting the estimated range of trend growth, the sectoral losses may also be the largest in the other services and the trade, transport and accommodation sectors. In the worst scenario, the losses are driven by labour and TFP. In the best scenarios, labour may have some positive contribution to the sectoral trend growth rates in certain sectors.

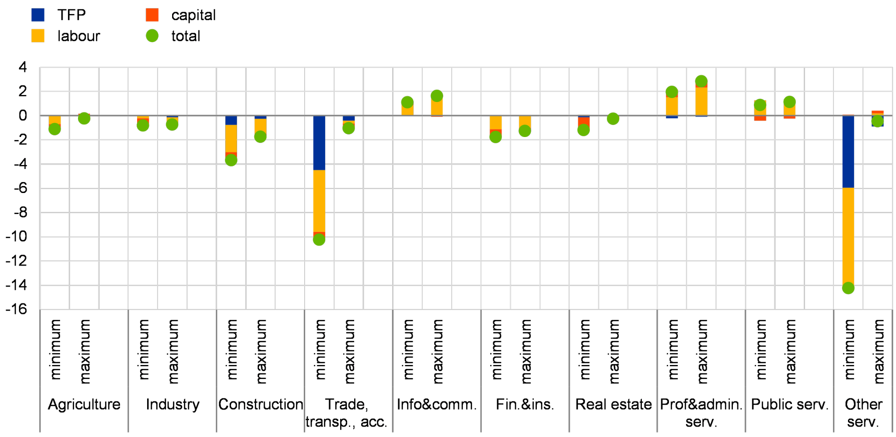


Figure 4.14: Loss in the level of potential output in 2025 in the minimum and the maximum of the range of estimates, compared to the counterfactual path (percentage point). Source: Eurostat, own calculations

The aggregation of the results points to a wide range of potential growth scenarios, with the EC projection being closer to the top of the range. Figure 4.15 and 4.16 show two sets of ranges: the minimum-maximum range of all scenarios and the minimum-maximum range that is calculated using the minimum and maximum of all factors of production across the scenarios. Overall, the results point to the risks tilting to the downside for the EC potential output path. However, they also confirm that policy measures may have the potential to improve the potential output path and moderate the losses. The risks around the estimated losses are also tilted to the downside. In the worst case, the losses can amount to -4% by 2025, while in the best scenario, there are some gains.

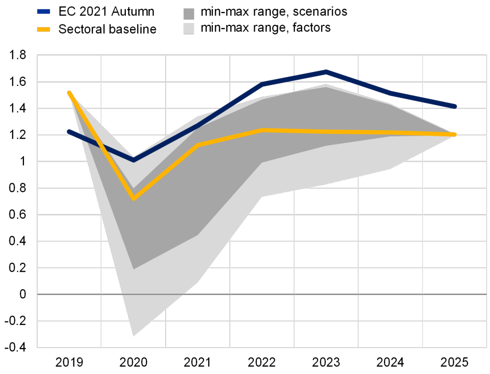


Figure 4.15: Range of aggregate potential growth estimates (annual percentage change)

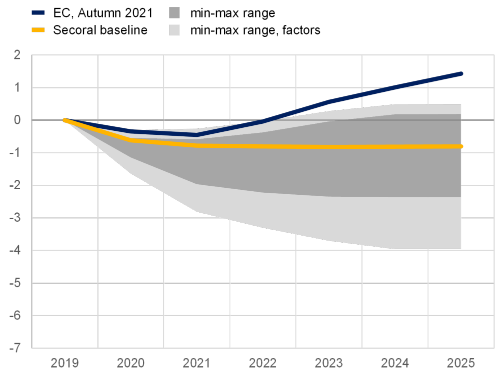


Figure 4.16: Range of the estimated aggregate loss in level (percentage point)

Source: European Commission and own calculations. Notes: the min-max range of factors shows the potential output growth calculated with the minimum/maximum level of the three factors of production across all scenarios.

While some sectors do suffer large losses, the impact of a sectoral reallocation on aggregate potential growth is also expected to be significantly negative in the baseline. In order to calculate the impact of sectoral reallocation, the change in aggregate potential output between 2019 and 2025 is decomposed into a within-sector and an across-sector component. The former assumes no change in the weight of the sectors, while the latter covers the impact due to the change in the weights of the sectors. The data and estimates show that sectors most severely hit by the crisis and suffering the largest losses were relatively slow-growing sectors before the crisis. On the other hand, sectors that are expected to come out of the crisis relatively better and gain weight (information and communication, etc) were and are expected to remain relatively fast-growing sectors. Some creative destruction, i.e. the increase of the relative weight of faster growing sectors may occur, implying that the impact of sectoral reallocation on the level of aggregate potential output (-0.6%) is smaller than the estimated loss in potential output (-0.8%). The relative size of the sectors work towards a negative aggregate impact: the largest sector, public services (O to Q), trade, accommodation and transport (G to I), see a decline in their relative weight, which largely exceed the increase in the weight of the largest sectors (B to E and M to N). This is illustrated on Figure 4.17 for the baseline scenario.

There is hardly any difference between the different scenarios with respect to the degree of reallocation. Overall, all the scenarios point to a slight negative effect of reallocation (Figure 4.18). This is largely due to the fact that the impact of the shock is generally negative on all sectors, except for a minority of smaller sectors.

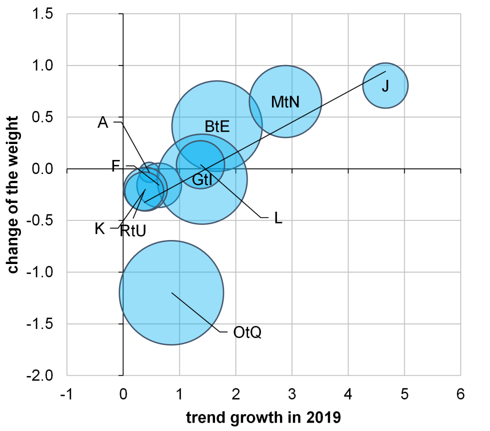


Figure 4.17: The impact of sectoral reallocation on aggregate potential growth in the baseline scenario (percent)

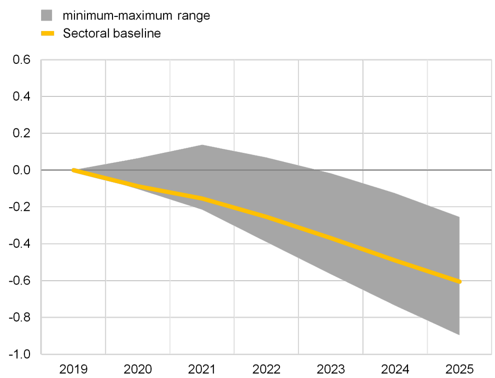


Figure 4.18: The impact of sectoral reallocation on the level of aggregate potential output (percent)

Source: own calculations. Note: the size of the bubbles represents the sector's value added weight in 2019

4.5 Conclusion

This chapter develops a novel approach for assessing potential output at a sectoral level, relying both on a supply-demand shock decomposition and on the elasticity of trend components on the supply shocks. A sectoral resilience index may also help to gauge the trend losses suffered at the sectoral level, through the design of alterative scenarios. Our baseline results point to lower potential growth than the estimates by international institutions, e.g. that of the European Commission's (EC) 2021 Autumn projections or the IMF Autumn 2021 WEO for the euro area, albeit this is partly due to the fact our baseline scenario does not take into account the support from NGEU. In any case, in our baseline scenario, we find that in 2020 and 2021 (i.e. in the years before the NGEU support was effective), potential growth may have been lower than estimated by the EC.

The results described are robust to a battery of alternative assumptions as illustrated by the range of different scenarios. However, our estimates admittedly suffer from some weaknesses. Just like the aggregate potential output estimations, our sectoral estimates are surrounded by a large degree of uncertainty, stemming from model uncertainty, but also from the challenges of assessing trend developments in real time. In addition, our approach cannot take sectoral interlinkages into account. While such effects can be temporary, they may also affect the trends if longer lasting or if induce behavioural changes. Also, we cannot channel in aggregate labour supply effects, which are assessed to limit potential growth looking ahead, and are also expected to have an impact on other components of trend growth (for example, by increasing the need for automation). Sectoral reallocation was found to have explained about 75% of the rise of productivity in Europe (IMF, 2021). Survey results for Belgium suggest that R&D, ICT equipment and computer software and databases increased in the recent period and may lead to higher TFP (NBB, 2021). Similar developments were found in the US (GS, 2021). However, in the lack of detailed sectoral data, this channel could not have been taken into account. Notwithstanding the difficulties to assess scarring effects, this work is of prime importance for policymakers, as it highlights the threat to potential output that was posed by the COVID-19 crisis. It also appears pivotal, in the context of the Ukraine-Russia war which also affects sectors asymmetrically. Depending to a large degree on how and when the government support measures will be withdrawn and how firms and households will adjust to the post-COVID period, scarring effects may be significantly mitigated by well-tailored policy measures. In the same vein, the very high and to a large degree unintended rise of the savings ratio may be persistent or decline, depending on the policy response and the ability to restore confidence. Furthermore, consumption patterns may also change, and could affect trend growth by sectors differently.

Annex 1: Assessing Investment and Capital Stock at the Sectoral Level

The sectoral capital stock series are derived from the balance sheet accounts for non-financial assets. These data, measured in value terms, are available on an annual basis, are broken down into a quarterly frequency and deflated by the total investment deflator. Owing to its low cyclicality property, the capital stock series in the production function is not filtered, as it is commonly done.[18] For the most recent periods, for which data is not available, and over the projection horizon, the capital stock is estimated using a small accelerator-type model.

We estimate sectoral equations linking annual real investment to value added in volume in an error correction model estimated in panel. It includes the main euro area countries (Germany, France, Italy, Spain, Belgium and Austria):

$$dlog(GFCF_{t,i}) = \beta_0 + \beta_1 dlog(VA_{t,i}) - \beta_2(log(GFCF_{t-1,i}) - log(VA_{t-1,i})) + \varepsilon_{t,1} \quad (4.2)$$

The estimation results are summarised in Table A1 and suggest somewhat different elasticities of investment to value added depending on the sector. Although relatively simple, the equations are rather robust and capture relatively well the 2020 period for investment (see Figure 4.19), for which sectoral investment is not yet available, while the total is. Other variables, such as the margin rate or the cost of capital could help to improve the performance of the model, but they are not available at the sectoral level.

The estimation shows that sectors that have been strongly affected by the crisis represent a small share of investment or have a lower than average elasticity of investment to value added (for example arts and entertainment). Conversely, some sectors, which are major contributors to investment, have been less affected by the crisis or their elasticity of investment to value added is higher than average.

Going forward, based on value added losses projections,[19] the sectoral investment

[18] See Toth (2021).

[19] Sectoral value-added losses are derived using an internal ECB methodology based on a cross-country panel VAR model which captures the relationship between the stringency of containment measures and the level of economic activity. See the box entitled: "The impact of containment

as well as the capital stock can be projected until 2024. The depreciation rates, for each country and sector are assumed to follow a linear trend estimated over the past.

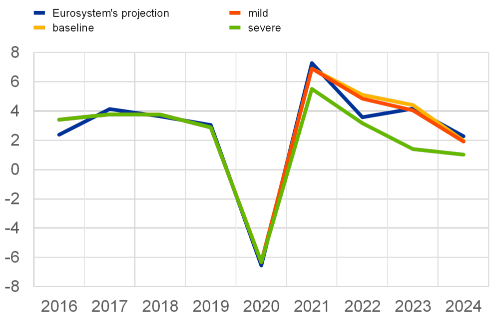


Figure 4.19: Gross fixed capital formation, based on the sectoral projection (annual percentage change)

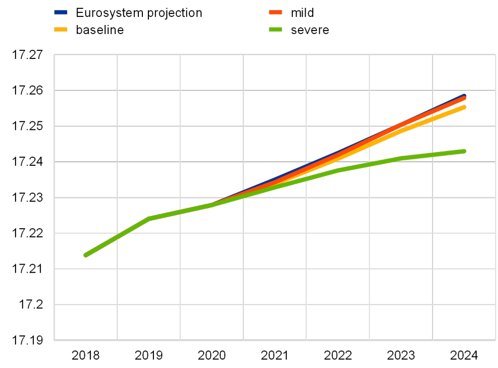


Figure 4.20: Projection of capital stock, based on the sectoral projection (log level)

Source: Eurosystem's March 2022 projection and own calculations.

As regards sectoral capital stocks, they follow a wide range of values, as shown for the baseline scenario in Figure 4.21. These differences stem from a combination of factors: differences in elasticities of investment to value added, difference in projected depreciation rates and differences in projected value-added losses. These differences partly compensate each other, once the capital stock is aggregated.

measures across sectors and countries during the COVID-19 pandemic" (ECB, 2021b). The capital projection scenarios reflect different sectoral value-added paths reflecting the different scenarios (mild, severe, baseline) published by the Eurosystem (ECB, 2021a).

Table A1: Estimation results of equation (2)

	β_0	β_1	β_2
Agriculture	-0.10** (0.01)	-0.15 (0.11)	0.10** (0.01)
Industry (except construction)	-0.32*** (0.11)	0.46** (0.21)	0.24*** (0.11)
Construction	-0.79*** (0.21)	2.25*** (0.41)	0.34*** (0.11)
Wholesale and retail trade, transport, accommodation	-0.50*** (0.11)	1.37*** (0.31)	0.27*** (0.11)
Information and communication	-0.38*** (0.11)	1.05*** (0.31)	0.30*** (0.11)
Financial and insurance services	-0.68*** (0.21)	0.66 (0.41)	0.31*** (0.11)
Real estate activities	-0.03 (0.01)	0.93** (0.41)	0.05 (0.01)
Professional, scientific and technical activities	-0.58*** (0.11)	1.01*** (0.21)	0.25*** (0.01)
Administrative and support activities	-0.98*** (0.11)	3.45*** (0.51)	0.39*** (0.11)
Public administration	-0.16** (0.11)	3.53*** (0.71)	0.07 (0.01)
Arts, entertainment, recreation	-0.11 (0.11)	1.33*** (0.51)	0.05 (0.01)

Note: standard errors are given in parentheses. (*), (**) and (***) denote 10%, 5% and 1% significance level, successively. The regressions include country fixed effects as well as time fixed effects.

In comparison with past trends, the sectors whose capital stock was most affected by the crisis are first the arts and recreational activities, second professional, scientific and technical activities administrative and support services,[20] and third retail, accommodation, and transport. These sectors mainly cover tourism activities. In 2020 and 2021, on average, the capital stock growth in those sectors is estimated to have been between -1.0% and -0.9% lower than in the year preceding the pandemic.

All sectors have seen a slowdown in the growth of their capital stock compared to their pre-COVID trend. However, for some sectors the loss is limited (construction, real estate).

[20]The sector classified as "M-N" include the rental and leasing activity and travel agency activities.

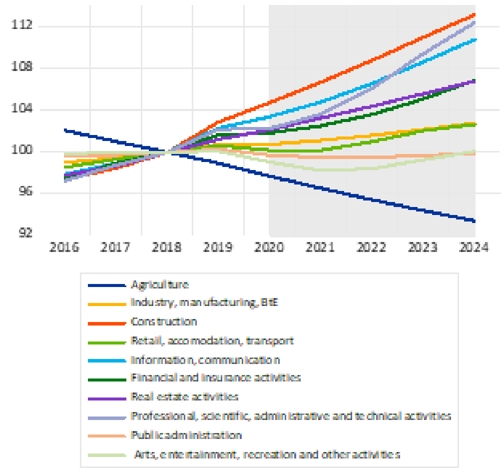


Figure 4.21: Sectoral projection of capital stock (index = 100 in 2018). Source: Eurostat, own calculations.

Annex 2: Estimation of Trend Labour and Total Factor Productivity in 2020 and 2021

For 2020 and 2021, trend TFP and trend labour can then be projected using equation 4.1, presented in Section 4.2 (Estimation of 2020 and 2021). In a few sectors, when the coefficient β_2 is statistically non-significant or shows a wrong sign, we use the elasticity estimated for the total (see Tables A2 and A3 below). Over the projection horizon, the residuals are extended in a way that they gradually revert to their zero long-term average.

For the period 2020-2021, our estimate of potential output growth is based on a Beveridge-Nelson decomposition, which differs from our estimate of past trends calculated with an HP filter. This is due, on the one hand, to the fact that equation 4.2 does not give significant results with a trend estimated from an HP filter and, on the other hand, over the recent period, we can anticipate a greater cyclicality of potential growth, as is the case with the IMF estimates. This is also in line with a BN-type decomposition (Figure 4.22). Finally, over the period preceding the crisis, potential growth as estimated with a BN is fairly close to that estimated with a HP (Figure 4.23 to be compared to Figure 4.6). By way of comparison, an estimate of potential output losses based on an identical methodology, but with a counterfactual calculated with a Beveridge Nelson leads to a loss in potential output of 1.0% by 2025, against 0.8% in our baseline.

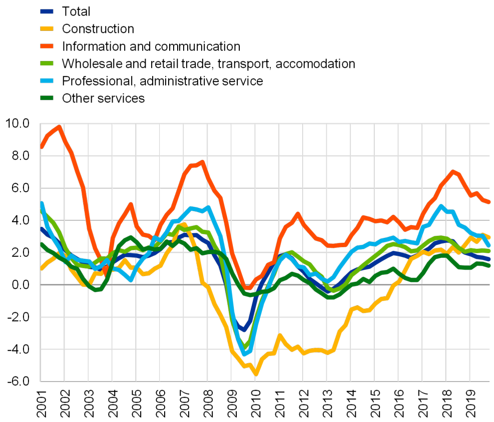


Figure 4.22: Trend growth in selected euro area sectors estimated with a B-N decomposition (annual percentage change)

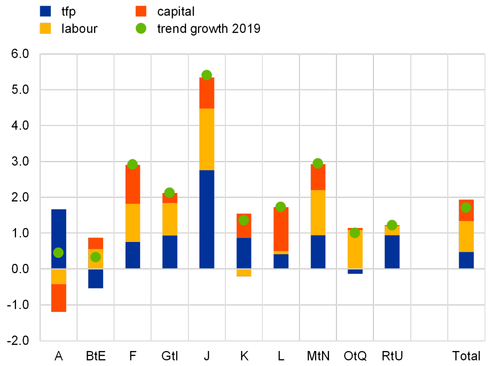


Figure 4.23: Trend growth in euro area sectors in 2019 estimated with a B-N decomposition (annual percentage change)

Source: ECB calculations based on Eurostat. Note: A - Agriculture, forestry and fishing; BtE – Industry (except construction); F - Construction; GtI – Wholesale and retail trade, transport, accommodation; J – Information and communication; K – Financial and insurance services; L – Real estate activities; MtN – Professional, scientific and technical activities; administrative and support service activities; OtQ – Public administration, defence, education, human health and social work activities; RtU – Other services.

Table A2: Estimation results of equation (1) with trend TFP as the dependent variable

	β_1	β_2
A - Agriculture	0.00*** (0.00)	0.21*** (0.02)
BtE - Industry (except construction)	0.00*** (0.00)	0.14*** (0.01)
F - Construction	0.00*** (0.00)	0.09*** (0.02)
GtI - Wholesale and retail trade, transport, accommodation	0.00*** (0.00)	0.10*** (0.02)
J - Information and communication	0.01*** (0.00)	0.16*** (0.02)
K Financial and insurance services	0.00*** (0.00)	0.21*** (0.02)
L Real estate activities	0.00*** (0.00)	0.12*** (0.03)
MtN Professional, scientific and technical activities, administrative and support services	0.00 (0.00)	0.14*** (0.01)
OtQ Public administration, defence, education, human health and social work activities	0.00*** (0.00)	-0.01 (0.01)
RtU Other services	0.00* (0.00)	0.06*** (0.01)
Total	0.00*** (0.00)	0.07*** (0.01)

Note: least-squares regression coefficients with robust standard errors given in parentheses. (*), (**) and (***) denote 10%, 5% and 1% significance level, successively.

Table A3: Estimation results of equation (1) with trend labour as the dependent variable

	β_1	β_2
A - Agriculture	0.00***	-0.02*
	(0.00)	(0.01)
BtE Industry (except construction)	0.00***	0.02**
	(0.00)	(0.01)
F Construction	0.00***	0.15***
	(0.00)	(0.05)
GtI Wholesale and retail trade, transport, accommodation	0.00***	0.02*
	(0.00)	(0.01)
J Information and communication	0.00	0.07*
	(0.00)	(0.04)
K Financial and insurance services	0.00	0.03**
	(0.00)	(0.01)
L Real estate activities	0.00***	-0.39***
	(0.00)	(0.08)
MtN Professional, scientific and technical activities, administrative and support services	0.01***	0.06***
	(0.00)	(0.02)
OtQ Public administration, defence, education, human health and social work activities	0.00***	-0.04***
	(0.00)	(0.01)
RtU Other services	0.01***	0.02*
	(0.00)	(0.01)
Total	0.00***	0.06***
	(0.00)	(0.02)

Note: least-squares regression coefficients with robust standard errors given in parentheses. (*), (**) and (***) denote 10%, 5% and 1% significance level, successively.

Annex 3: Sectoral Resilience Index (SRI)

The three elements of the SRI are mirroring the three different factors of contribution to potential growth:

1. **Share of employees in potentially teleworkable jobs:** being considered as essential, the degree of teleworkability and the reliance on job retention schemes affected the degree of labour input adjustment. Firms in sectors with a high share of teleworkable jobs could maintain their activities without being exposed to the virus. Thus, labour supply is less affected and there is a smaller chance for a deterioration of workers' human capital.[21] Teleworkability was found to be highest in the euro area in information and communication and the smallest in agriculture.[22] This subindex may also be relevant beyond 2020, because it may reflect the overall flexibility of the workforce by sectors and the resilience to containment measures. Teleworkability is mainly linked to labour input.[23]

2. **Research and Development (R&D) expenditure in 2017**: TFP growth is positively associated with R&D expenditure, and TFP may react with a lag to changes in R&D.[24] Thus, by including R&D expenditure in the SRI, we control for the degree to which sectoral TFP may be affected, and we assume that a higher TFP implies higher resilience. Aggregate TFP growth was found to be influenced by within-sector developments in the short run,[25] thus, its projection for the first few years after the shock would be important. R&D expenditure is quite high in industry (excluding construction), while it is lowest in real estate activities.[26]

3. **Percentage of firms whose interest coverage ratio does not fall below unity**:

[21] Bai et al. ((Bai et al., 2021)) find that US firms with a higher pre-pandemic working-from-home index were more resilient to the COVID-19 shock.

[22] Teleworkability is not available for the real estate sector, and we assume that the share of teleworkable positions in this sector is the same as in financial and insurance services.

[23] Physical capital in the sectors with high teleworkability can be adversely affected, for example if firms decide to operate with a smaller office or, looking ahead, without one at all, although this can be counterbalanced by higher housing capital (which appears in the real estate sector) and/or higher TFP. In an extreme case, a firm that decides to operate without premises, where all the employees telework, reduces its stock capital, but not its potential output, as the capital is now provided by the employee. This decrease in the firm's capital stock is then compensated by the increase in its TFP.

[24] See for example Elfsbacka Schmoller and Spitzer (2020) and Fuentes and Moder (2021).

[25] See Furceri et al. ((Furceri et al., 2021)).

[26] Data are taken from the OECD statistical database.

the decline in profits induced by the COVID-19 crisis relative to the business-as-usual scenario can impair firms' ability to service their debt and to invest. This would lead to defaults and insufficient investment, both weakening sectoral potential output.[27] The interest coverage ratio is calculated by dividing a company's earnings before interest and taxes (EBIT) by its interest expense, indicating how easily a company can pay interest on its outstanding debt.[28] It is highest in information and communication and professional and administrative services sectors and lowest in other services. As regards public administration, we assume a 100% interest coverage ratio as we assume the government sector will not face issue in covering its interest payments.

The quarterly sectoral potential growth rates in 2020 are estimated with the help of the BVAR results and the SRI. For trend TFP and total hours worked expressed in log the below formula is used:

$$\bar{x_t}^k = \bar{x_{t-4}}^k + (\bar{x_{t-4}}^k - \bar{x_{t-8}}^k) + (x_t^k - x_{t-4}^k) * bvar_t^k * Max((50 - SRI^k), 0) \tag{4.3}$$ [29]

Where $\bar{x_t}^k$ is trend TFP and trend total hours worked growth in sector k in quarter t, x_t^k is actual TFP and actual total hours worked growth in sector k in quarter t, $bvar_t^k$ is the share of supply shock in sector k in quarter t, stemming from the BVAR introduced previously, and SRI^k is the resilience index of sector k. I.e., potential growth in 2020 depends on to what extent the COVID-shock can be considered as a supply shock, and on how resilient the different sectors are to the shock.

[27] See Chart 3 from Arnold and Nguyen (2020).

[28] Data are taken from OECD (2020). The data for three sectors is missing: i) financial services (this sector is assumed to have the same ratio as real estate); ii) public administration (it is assumed that government will not default); iii) Agriculture, forestry and fishing (since they have not been so impacted by the crisis in terms of annual value added growth rate, we assume they have the same ratio as another low hit sector, Information and communication).

[29] For easier presentational purposes, the formula is in levels. Rearranging it would show that the annual change in potential in quarter t deviates from the annual change in potential in the previous year by the annual change in value added, multiplied by the SRI and the BVAR parameter. This reflects that part of the shock to value added (SRI×BVAR, to be precise) is transmitted to potential output.

Annex 4: Sectoral Trend Output and Output Gap Estimations

This Annex describes the sectoral output gap estimations, calculated as the difference between the sectoral value added and the estimated trends. This serves the purpose of cross-checking the validity of the sectoral trend output estimations through the plausibility of the output gaps.

The sectoral output gaps seem to be plausible, with a strong co-movement and in line with the macroeconomic narrative. All sectors are estimated to have had an open output gap before the global financial crisis, although their magnitudes differed somewhat. After the global financial crisis, the estimated output gaps declined and turned negative for all sectors. The standard deviation of the output gaps differs: it is larger in the more cyclical industry and construction sectors, while it is muted in public services and real estate.

The estimated output gaps are in line with the narratives on the sectoral level also. For example, in industry, the global financial crisis resulted in a large, but quickly closing negative output gap, while trend output continued increasing, as the shock was temporary in the sector. In contrast, in construction, the global financial crisis affected both the trend and the cycle strongly, which sounds plausible, given the important role the overheating in this sector played in the global financial crisis. Trend output in construction declined in one decade by about 16%, while the output gap was also negative for an extended period. In services sectors, there is a strong co-movement in the estimated cycle, albeit with some differences both in the magnitudes and the timing of turning points. The information and communication sector experienced a quick decline of its output gap in 2002, in the aftermath of the .com crisis.

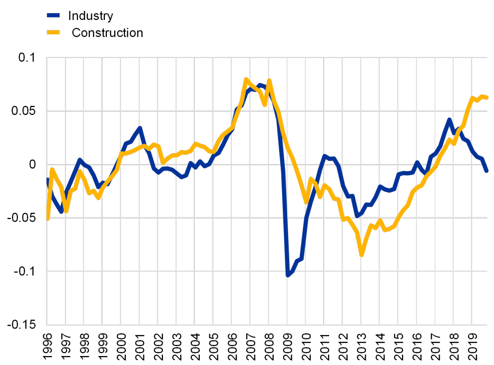


Figure 4.24: Output gaps by sector: industry and construction (pp deviation from trend)

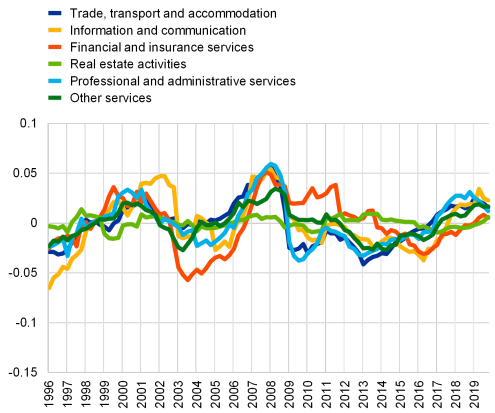


Figure 4.25: Output gaps by sector: services sectors (pp deviation from trend)

Source: Eurostat, own calculations

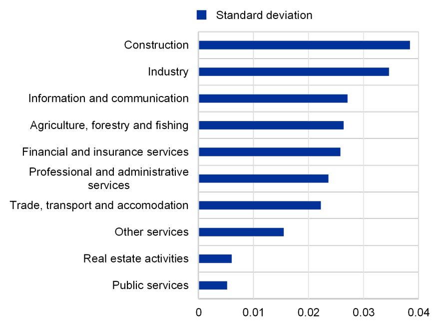


Figure 4.26: Standard deviation of sectoral output gaps. Source: Eurostat, own calculations

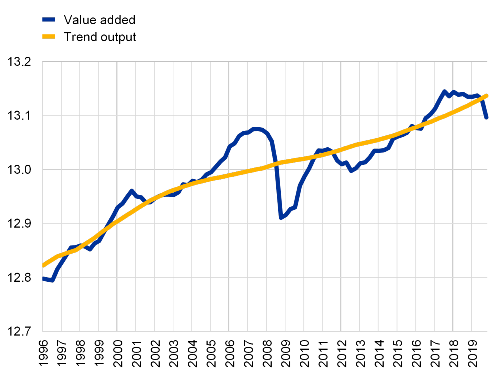


Figure 4.27: Industry: actual and trend output (log levels)

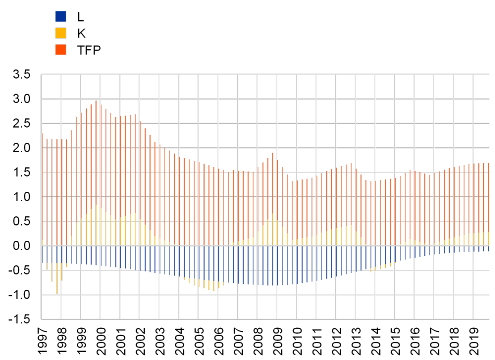


Figure 4.28: Industry: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

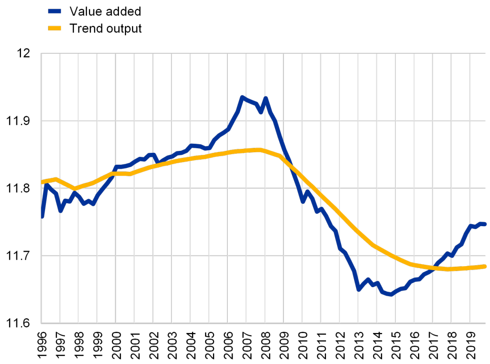


Figure 4.29: Construction: actual and trend output (log levels)

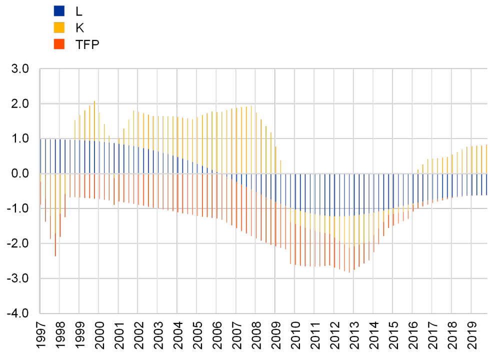


Figure 4.30: Construction: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

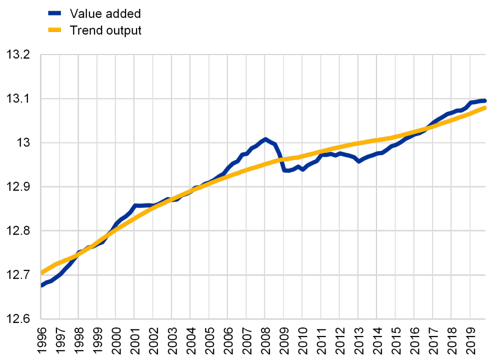


Figure 4.31: Trade, transport and accommodation: actual and trend output (log levels)

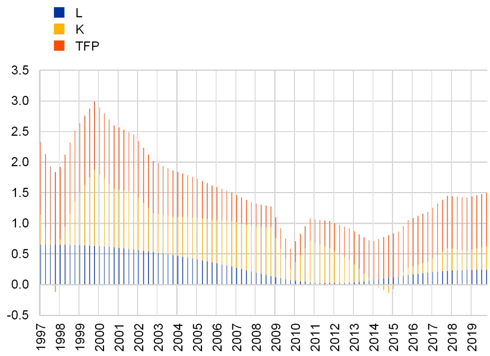


Figure 4.32: Trade, transport and accommodation: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

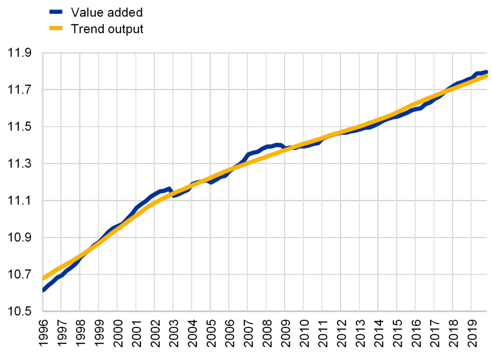


Figure 4.33: Information and communication: actual and trend output (log levels)

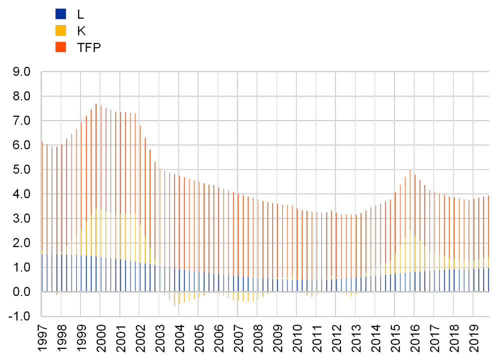


Figure 4.34: Information and communication: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

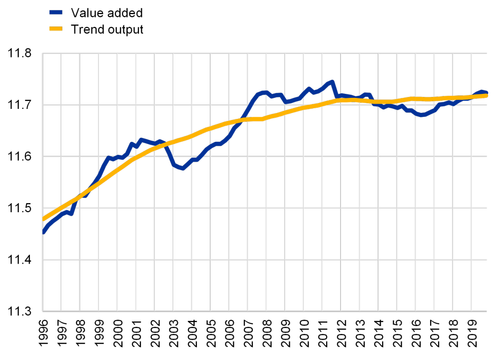


Figure 4.35: Financial and insurance services: actual and trend output (log levels)

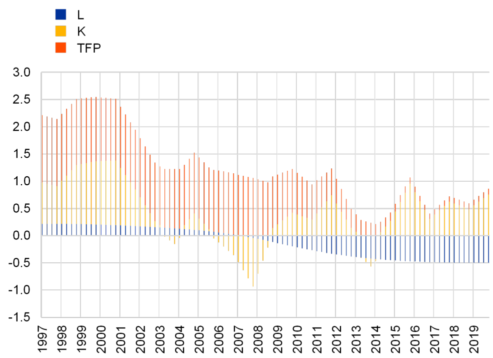


Figure 4.36: Financial and insurance services: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

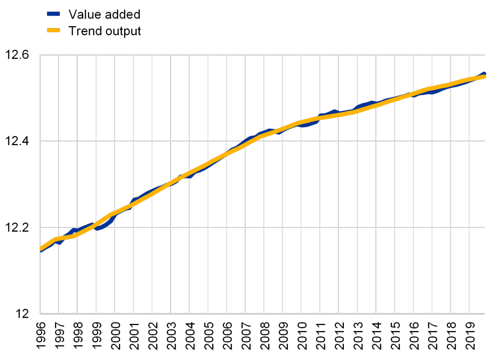


Figure 4.37: Real estate services: actual and trend output (log levels)

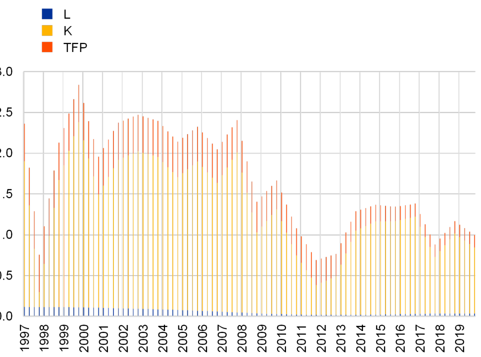


Figure 4.38: Real estate services: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

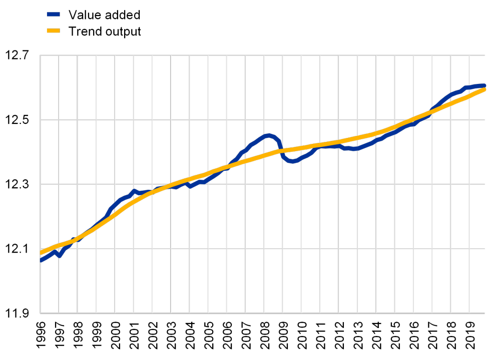


Figure 4.39: Professional and administrative services: actual and trend output (log levels)

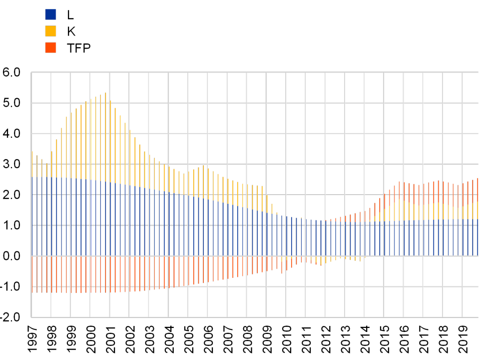


Figure 4.40: Professional and administrative services: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

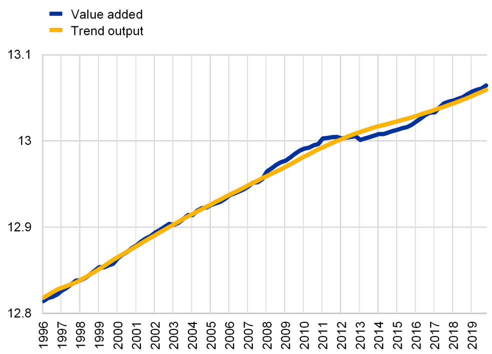


Figure 4.41: Public services: actual and trend output (log levels)

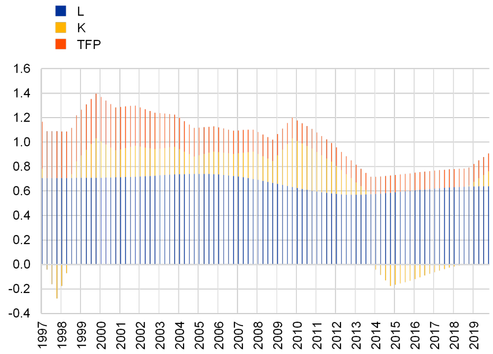


Figure 4.42: Public services: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

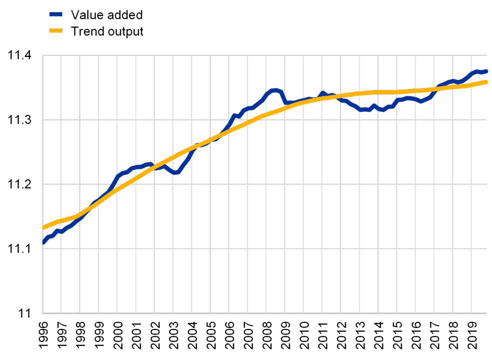


Figure 4.43: Other services: actual and trend output (log levels)

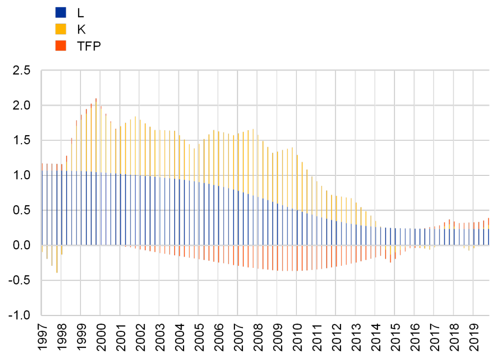


Figure 4.44: Other services: decomposition of trend growth (percentage point contributions)

Source: Eurostat, own calculations

Annex 5: Statistical Issues: Data Availability and Limitations

The sectoral decomposition in 10 sectors presents some shortcomings. For the past, we use the NACE 10 sectoral decomposition available at the quarterly level for gross value added within the euro area ("Gross value added and income A*10 industry breakdowns") and the number of hours worked ("Employment A*10 industry breakdowns"). The weakness of the NACE*10 sectoral decomposition is that it hides intra-sectoral developments that could be important in our case. High-contact subsectors and low contact subsectors can belong to the same sector of the NACE*10 classification. For this reason, a more detailed analysis in NACE*64 might make sense. But for the euro area, these annual data are available with a very long delay. For the euro area, data for 2020 at NACE 64 level should be made available in March 2023.

The capital stock, even over the past, is largely estimated in our study. For the capital stock, we use the sectoral decomposition (NACE 10) by country, extracted from the non-financial balance sheets, available until 2020 (and 2019 in Spain). Beyond this period, the capital stock is estimated (see Annex 1). This decomposition is not available for the euro area as a whole. We aggregate it on the basis of the six largest euro area countries. It refers to the capital stock as a whole, including the housing capital stock. The data is also available with a long delay: the most reliable version of the capital stock for the year 2020, will be released at the end of 2022.

We considered the use of alternative data, for example for robustness checks. This is possible when working on aggregate data, but at a sectoral level, alternative data are lacking. For example, AMECO or the ECB publish slightly different capital stock estimates at the aggregate level, but at the sectoral level, only non-financial balance sheets can be used.

Depending on new updates, the picture will evolve over time. Our analysis is based on the only data available as of 8 March 2022, which includes the quarterly national account data up to the fourth quarter of 2021. In the following quarters and years, final releases should improve our understanding of the current period. In recent quarters, compared to expectations, GDP growth has surprised to the upside to an extent never seen before (see Figure 4.45). Conversely, so far, GDP releases have been relatively unrevised from one release to the next, or at least in similar extents to what was experienced before 2020. However, substantial revisions cannot be ruled out in a few years, as already seen in the past (see Figure 4.46).

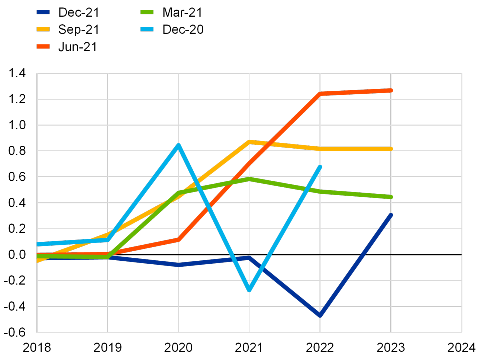


Figure 4.45: Revisions of the projected level of real euro area GDP (percent)

Source: ECB and Eurosystem's projections. Note: this chart shows the revision in the level of GDP for each Eurosystem's projection exercise in comparison with the previous projection

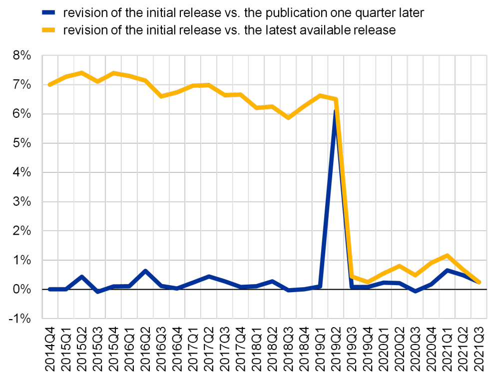


Figure 4.46: Revisions of the released level of real euro area GDP (percent)

Source: Eurostat, own calculations. Note: this chart shows the revision in the level of GDP for each release in comparison with a) the updated release one quarter later (in blue) b) the latest available data (in yellow).

Statistical measurement issues during the pandemic could lead to more substantial revisions in the future. For instance, labour market data is collected mainly through physical interviews. The latter was severely impaired during the pandemic, making estimates more uncertain than usually. Regarding prices, owing to restrictions and lockdown measures, imputed estimates reached high levels. As a matter of illustration, in January 2021, according to Eurostat, the share of imputed prices for the euro area headline HICP was 13% and 18% for HICP excluding energy and food.

Annex 6: BVAR Details and Quarterly Estimates

We use the following standard options and hyperparameters for the BVAR estimates:

- Total number of iterations: 2000
- Number of burn-in iterations: 1000
- Prior AR coefficient: 0.8
- Overall tightness: 0.1
- Cross-variable weighting: 0.5
- Lag decay: 1
- Exogenous variable tightness: 100
- Block exogeneity shrinkage: 0.001
- AR coefficient on residual variance: 0.85
- IG shape on residual variance: 0.001
- IG scale on residual variance: 0.001
- Prior mean on inertia: 0
- Prior variance on inertia: 10000

Quarterly Estimates

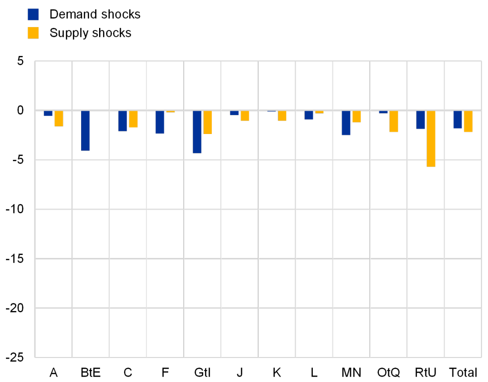


Figure 4.47: Quarterly estimates of demand and supply shocks: 2020Q1

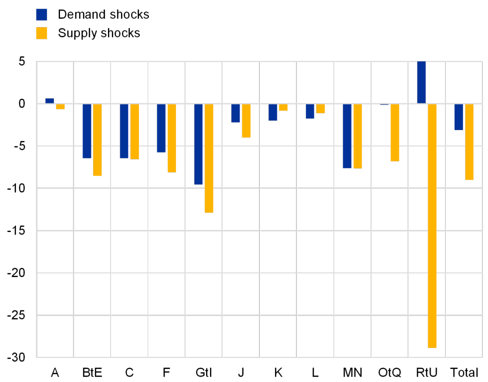


Figure 4.48: Quarterly estimates of demand and supply shocks: 2020Q2

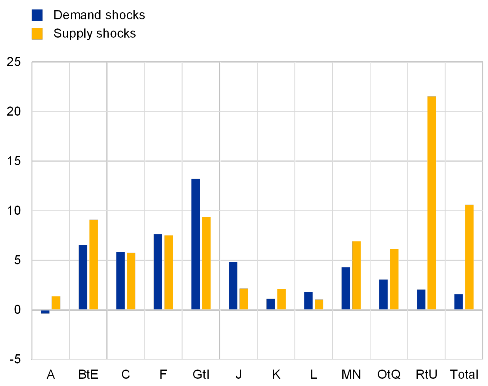


Figure 4.49: Quarterly estimates of demand and supply shocks: 2020Q3

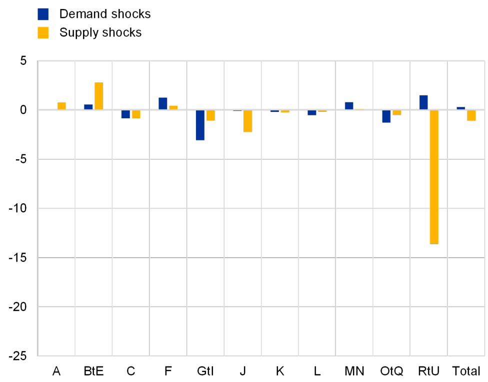


Figure 4.50: Quarterly estimates of demand and supply shocks: 2020Q4

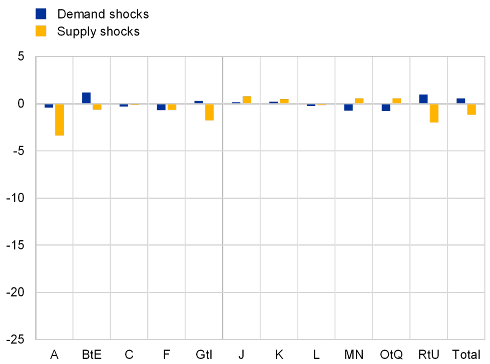


Figure 4.51: Quarterly estimates of demand and supply shocks: 2021Q1

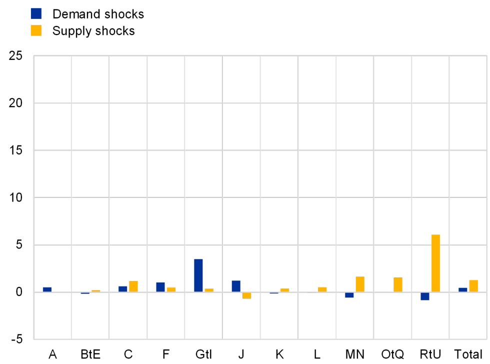


Figure 4.52: Quarterly estimates of demand and supply shocks: 2021Q2

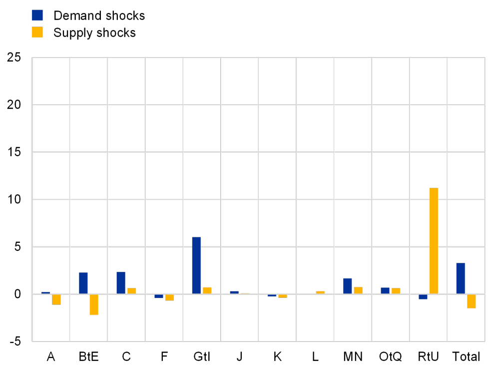


Figure 4.53: Quarterly estimates of demand and supply shocks: 2021Q3

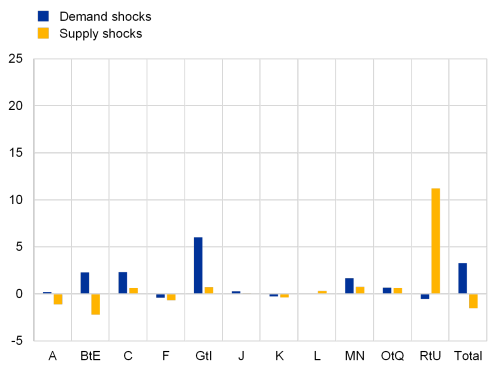


Figure 4.54: Quarterly estimates of demand and supply shocks: 2021Q4

Annex 7: Labour Share by Sector

Table 4.2: Labour share by sector

A	Agriculture, forestry and fishing	25%
BtE	Industry (except construction)	52%
F	Construction	56%
GtI	Wholesale and retail trade, transport, accommodation	56%
J	Information and communication	52%
K	Financial and insurance services	51%
L	Real estate activities	4%
MtN	Professional, scientific and technical activities; administrative and support service activities	59%
OtQ	Public administration, defence, education, human health and social work activities	78%
RtU	Other services	61%
Total	Total	48%

Note: labour share measured as the ratio of compensation of employees over gross value added at current prices, averaged over the period 2015-2019. Source: Eurostat, own calculations.

Chapter Five

Conclusions

The decline in the equilibrium real interest rate observed in recent decades has fundamentally changed the operating environment of central banks in advanced economies. Conducting monetary policy closer to the effective lower bound reduced the room available for policy rate cuts, testing monetary policy's effectiveness in the face of large disinflationary shocks. This "new normal" fuelled a regime change for central banks that since the Global Financial Crisis of 2007-2008 stopped relying uniquely on the constrained policy rate and adopted several non-standard tools. Critically for my dissertation, these unconventional monetary policy (UMP) instruments have been deployed simultaneously — but what are their interactions, synergies and trade-offs?

The new operating environment of central banks is characterised by another feature: following Basel III, UMP is delivered in concert with macro-prudential policies. This dual strategy marked the response to the Covid-19 crisis — when quantitative easing and other UMP tools were complemented by the release of the countercyclical capital buffer — and it begs the question: how does the implementation of macro-prudential policy change the effectiveness of UMP?

My dissertation aimed to answer these questions by studying the synergies between non-standard monetary instruments and their interactions with macro-prudential policy. For this, it employed empirical (SVAR) and mostly theoretical (DSGE) models. The main part of the dissertation built on the unified UMP framework of Sims and Wu (2021), extending it with macro-prudential policy and an additional non-standard monetary tool, the lending facility. The dissertation found new channels for the transmission of monetary policy and new synergies within the central bank's toolbox. The results contribute to the literature — that has typically modelled UMP tools in an "additive way", overlooking the interactions — and inform policymakers, that lack a framework to capture the synergies between the instruments (Pill (2021a) and Rostagno et al. (2019)).

The dissertation began by studying the effectiveness of the People's Bank of China long-term funding programmes when they were used in concert with other policy tools. For this, the first chapter employs a SVAR model previously applied to estimate the impact of ECB balance sheet expansion (Boeckx et al., 2017). The chapter finds that liquidity injections are effective at enhancing the policy rate signal, showing that China's monetary policy is becoming similar to advanced economies'. There is also a high degree of coordination between the liquidity injections and the constellation of other policy tools, necessary to deliver the central bank's multiple objectives. This evidence supports the ECB's "fixed rate full allotment" procedure.

The second chapter assesses whether macro-prudential policy enhances or hinders the efficacy of UMP. This is a theoretical chapter that introduces a countercyclical capital buffer as in Gertler et al. (2012) in the DSGE model of Sims and Wu (2021). Policy simulations show that deploying simultaneously macroprudential policy and UMP strengthens the effectiveness of monetary policy and allows to start earlier unwinding UMP. These results confirm the Bank of England's concerted strategy of delivering monetary and macro-prudential policy simultaneously to fuel the recovery (Carney, 2014).

The third chapter analyses the interactions between central bank lending programmes and quantitative easing, forward guidance and negative interest rate policy. The baseline model is Sims and Wu (2021), extended with lending programmes featuring a collateral policy and a "dual rate system", in the spirit of the ECB strategy during the Covid-19 crisis. The policy experiments reveal that four channels of monetary policy transmission are activated, giving rise to synergies and trade-offs between the UMP tools. The chapter offers policy recommendations on how to increase monetary policy effectiveness capitalising on the interactions between instruments, in this way contributing to the design of modern lending programmes.

The fourth chapter estimates the loss in Euro Area potential output due to the Covid-19 crisis using a sectoral approach. The motivation for this chapter comes from the pandemic's heterogeneous impact across different sectors, leading to different recovery paths and degrees of scarring. Given the lack of a well-established methodology to estimate potential output at the sectoral level, this chapter develops a novel method. It finds that potential output in 2025 might be 0.8% lower relative to a scenario without the Covid-19 crisis. The methodology can be used to assess the effect of the Russia-Ukraine war, highly affecting the energy-intensive manufacturing sector.

To conclude, recent strategy reviews by major central banks made progress in clarifying the mechanics of non-standard monetary policy tools and macro-prudential policy. However, they also highlighted the knowledge gaps regarding the interlinkages amongst these tools, calling for more work on this topic.[1] My dissertation aims to provide some answers to this call, developing a unified framework to analyse the synergies and trade-offs arising from the simultaneous delivery of multiple policy instruments. More research is however needed to reconnect the literature with recent monetary policy decisions and to equip policymakers for future challenges. I highlight four promising research areas to which the framework of my dissertation can be applied. The first is an analysis of UMP channels of transmission and effects on the exchange rate. The second is an evaluation of the transmission mechanism of UMP through non-bank financial institutions, with a focus on the consequences for financial stability and the most efficient central bank's backstop (Pill, 2022). The third is the development of a framework to inform the timing and magnitude of policy decisions during a tightening phase (Quantitative Tightening and policy rate hikes). Finally, the fourth is the design of central bank's policy options when, during a tightening phase, the large central bank's balance sheet generates fiscal consequences. The Global Financial Crisis and Covid-19 pandemic showed that UMP tools are not a panacea: they have limitations, and they exhibit diminishing returns. Therefore, the effectiveness of monetary policy depends critically on researching these unaddressed themes.

[1] See BoE (2022) for the Bank of England and Laeven et al. (2022) for the ECB.

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