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ESSAYS IN MONETARY ECONOMICS

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ABSTRACT

This dissertation consists of three chapters on macroeconomics and monetary economics. In the first chapter, I provide an equilibrium model of the pass-through of direct central bank lending to banks (CBL) into loans and quantitatively analyze the most significant such policy, the ECB's Targeted Long Term Refinancing Operations (TLTRO). The banking sector features bank market power in deposits and lending, and banks borrow funds from the central bank and choose to adjust deposits, liquid asset holdings, and loans. I embed this into a New Keynesian model in which aggregate loan demand and deposit supply are endogenous. I calibrate the model to match the cross-sectional empirical literature on TLTRO, allowing me to translate these micro estimates into an aggregate impact of CBL. I find a 32% pass-through of CBL into bank lending; correspondingly, an increase in central bank lending of 10% of outstanding loans provides stimulus equivalent to a 54 basis point cut to the policy rate. The model also implies that CBL will be more effective when banks hold few liquid assets and lending markets are more competitive.

In the second chapter, I study how conventional and unconventional monetary policies differentially affect lending by banks in the United States. Using bank-level data and high-frequency instruments for standard monetary shocks and quantitative easing, I find that the two policies predominantly affect different types of banks as measured by their balance sheets. Interest rate shocks have a stronger impact on loans for banks that are illiquid, bigger, less capitalized, and less reliant on deposit funding. The opposite is true for quantitative easing shocks, where loans decline more in banks that are liquid, smaller, more capitalized, and more reliant on deposit funding. The amount of heterogeneity is large, with the more affected banks having a two to three times larger response of lending after three years.

The last chapter studies the fact that low-skilled workers tend to display both more cyclical employment and more cyclical earnings compared to high-skilled workers. I develop a model with wage stickiness, differential labor market frictions, and two sectors employing separately high and low-skilled workers. Firms face two cost components when they adjust employment: the wage paid to new employees and hiring costs. Although wages are more flexible in the low-skill sector, the hiring cost is more volatile in the high-skill sector. The implication is that total costs are more volatile for high-skilled workers, thus leading to a lower cyclicality in their employment while also preserving a lower cyclicality in their wages. The result is driven by different matching function elasticities (or equivalently bargaining powers) and Frisch elasticities for high and low-skilled workers.

Contents

1 The Pass-Through of Direct Central Bank Lending to Banks: Evidence from the ECB 1

1.1 Introduction 1

1.2 Institutional Setting and Literature Review 6

1.3 A Banking Model with Central Bank Lending and Liquidity 11

1.3.1 The Banking Sector Setup 11

1.3.2 The Pass-Through to Loans of an Expansion in Direct Central Bank Lending 15

1.3.3 Calibration 21

1.3.4 State-Dependence: CBL Pass-Through and Liquidity 29

1.4 CBL in a General Equilibrium Model 30

1.4.1 Model Setup 32

1.4.2 Agents 33

1.4.3 Calibration of the General Equilibrium Model 41

1.4.4 The Aggregate Impact of Direct Central Bank Lending to Banks . . 43

1.4.5 Alternative Policy Experiments 47

1.5 Conclusions 52

2 The Heterogeneous Impact of Conventional and Unconventional Monetary Policy on Bank Lending 54

2.1 Introduction 54

2.2 Data 58

2.2.1 Banks 58

2.2.2 Exogenous Policy Shocks 58
2.3 Empirical Strategy 59
2.3.1 Impact of monetary shocks 59
2.3.2 Bank Heterogeneity 60
2.4 The overall impact of policy shocks on banks 61
2.5 Bank Heterogeneity 64
2.5.1 Liquidity 64
2.5.2 Capitalization 68
2.5.3 Size 71
2.5.4 Deposit Share of Liabilities 74
2.5.5 Discussion 77
2.6 Robustness 79
2.7 Conclusions 81

3 Reconciling Employment and Wage Cyclicality for High and Low-Skilled Workers: The Role of Labor Market Frictions 83

3.1 Introduction 83
3.2 Literature Review 87
3.3 Empirical Evidence 88
3.3.1 Employment and Wage Volatility in the Data 88
3.3.2 Estimating the Matching Function Elasticity 90
3.4 Model 91
3.4.1 Households 91
3.4.2 Firms 93
3.4.3 Wage Setting 98
3.4.4 Model Closure and Aggregates 101
3.5 Model Dynamics 103

3.5.1 Calibration . . . 103
3.5.2 Model Mechanics . . . 105
3.5.3 Results . . . 107
3.6 TANK Extension . . . 112
3.7 Conclusions . . . 113

A Supplementary Material for Chapter 1 **115**
A.1 Data Sources and Transformations . . . 115
A.2 Parameter Sensitivity to Targets . . . 117
A.3 Robustness of Partial Equilibrium Results . . . 118
A.4 Equilibrium Equations for the General Equilibrium Model . . . 119
A.4.1 Households . . . 119
A.4.2 Retail Firms . . . 120
A.4.3 Intermediate Goods Firms . . . 121
A.4.4 Capital Producers . . . 121
A.4.5 Banks . . . 122
A.4.6 Government and Central Bank . . . 123
A.4.7 Resource Constraints and Shocks . . . 124
A.4.8 Steady State . . . 124
A.5 Other Impulse Responses from the General Equilibrium Model . . . 127
A.6 Quantitative Easing and State-Dependence . . . 129
A.7 Extension with Leverage Costs . . . 130

B Supplementary Material for Chapter 2 **133**
B.1 Additional Robustness Checks . . . 133
B.1.1 Results for the Federal Funds Rate factor . . . 133
B.1.2 Sample starting in 2000 . . . 136

Curriculum Vitae **145**

List of Tables

1.1 Balance Sheet of Bank j 11
1.2 Calibrated Parameters 27
1.3 Targets 28
1.4 Robustness - Pass-through of 1tn€ CBL to Loans 28
1.5 General Equilibrium Parametrization 44

2.1 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Liquidity 65
2.2 Impulse Responses After a QE Shock - 4th vs 1st quartile of Liquidity . . . 67
2.3 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Capitalization 68
2.4 Impulse Responses After a QE Shock - 4th vs 1st quartile of Capitalization 71
2.5 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Size . . 71
2.6 Impulse Responses After a QE Shock - 4th vs 1st quartile of Size 73
2.7 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Deposit Share 75
2.8 Impulse Responses After a QE Shock - 4th vs 1st quartile of Deposit Share 76
2.9 Impulse Responses After a Monetary Shock - Interactions 78
2.10 Impulse Responses After a QE Shock - Interactions 79
2.11 Impulse Responses After a Monetary Shock (Until 2009) - Interactions . . . 80
2.12 Impulse Responses After a FFR Shock (Until 2009) - Interactions 81

3.1 Standard Deviations 108

A.1 Sensitivity of the Calibrated Parameters to the Targets 118
A.2 Impact of 1tn€ CBL and QE Shocks - Robustness 119

B.1 Impulse Responses After a FFR Shock - Interactions 134
B.2 Impulse Responses After a Monetary Shock (From 2000) - Interactions . . 137
B.3 Impulse Responses After a FFR Shock (From 2000) - Interactions 137

List of Figures

1·1 ECB Balance Sheet (Assets) . . . 7

1·2 LTROs and TLTROs as a Share of Eligible Private Loans in the Euro Area . 8

1·3 Loan Supply with CBL Shock . . . 16

1·4 Pass-through of CBL Shock to Loans . . . 17

1·5 Liquid Assets and Loan Supply . . . 20

1·6 Impact of a 1tn€ CBL Shock . . . 29

1·7 Impact of CBL on Loans as a Function of Liquid Assets . . . 30

1·8 Agents in the General Equilibrium Model . . . 33

1·9 IRFs to a CBL Shock of 10% of Outstanding Loans . . . 46

1·10 IRFs to a Capital Efficiency Shock . . . 47

1·11 Impact of 1tn€ CBL and QE Shocks . . . 49

1·12 IRFs to a CBL Shock and a QE Shock - Baseline . . . 49

1·13 IRFs to a CBL Shock and a QE Shock - AR(1) . . . 50

1·14 IRFs to a Liquidity Shock . . . 52

2·1 Impulse Responses After a Monetary Shock . . . 62

2·2 Impulse Responses After a Quantitative Easing Shock . . . 63

2·3 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Liquidity 66

2·4 Impulse Responses After a QE Shock - 4th vs 1st quartile of Liquidity . . . 67

2·5 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Capitalization . . . 69

2·6 Impulse Responses After a QE Shock - 4th vs 1st quartile of Capitalization 70

2·7 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Size . . 72
2·8 Impulse Responses After a QE Shock - 4th vs 1st quartile of Size 73
2·9 Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Deposit Share 75
2·10 Impulse Responses After a QE Shock - 4th vs 1st quartile of Deposit Share 76

3·1 Matching Function Elasticity and Wage Level by Industry 91
3·2 Relative Standard Deviation of Employment as a Function of Heterogeneity 109
3·3 IRFs After Positive Productivity Shock - Flexible Prices Model 110
3·4 IRFs After Positive Productivity Shock - No Heterogeneity 110
3·5 IRFs After Expansionary Monetary Policy Shock - Sticky Prices Model . . 111
3·6 IRFs After Expansionary Monetary Policy Shock - TANK Model 113

A·1 IRFs to a CBL Shock of 10% of Outstanding Loans 127
A·2 IRFs to a Capital Efficiency Shock 128
A·3 IRFs to a CBL Shock and a QE Shock - Baseline 128
A·4 IRFs to a CBL Shock and a QE Shock - AR(1) 129
A·5 Impact of QE on Loans as a Function of Liquid Assets 130
A·6 IRFs to a CBL Shock of 10% of Outstanding Loans - Model with Leverage Costs 131
A·7 IRFs to a CBL Shock of 10% of Outstanding Loans - High Retained Profits 132

B·1 Impulse Responses After a Monetary Policy Shock (FFR Factor) 134
B·2 Impulse Responses After a Monetary Policy Shock (FFR Factor) - until 2009 135

Chapter 1

The Pass-Through of Direct Central Bank Lending to Banks: Evidence from the ECB

1.1 Introduction

Direct lending from central banks to private banks at cheap interest rates has been widely used as a new unconventional monetary policy tool after the Great Recession, with the aim of stimulating lending to the private sector. For example, the European Central Bank's Targeted Long Term Refinancing Operations (TLTROs) is the ECB's second most important unconventional monetary policy program in terms of central bank balance sheet expansion after Quantitative Easing (QE).[1] While QE has been extensively studied both empirically and theoretically, the impact of direct central bank lending (CBL) has been evaluated mainly empirically. The quantitative pass-through of CBL to the real economy depends on how banks substitute other sources of funding such as deposits and debt or allocate these funds to new loans, government bonds, and excess reserves. If the objective of the central bank is to stimulate the supply of new loans, any other use of central bank lending represents a leakage of the policy which is not directed to the real economy. This paper provides a theoretical framework to evaluate to what extent banks use the new funding to expand loan supply, discusses the economics governing the pass-through of CBL to loans, evaluates the determinants of CBL effectiveness, and provides a quantitative evaluation of the general equilibrium effects of the policy.

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1. Also the Bank of England (Term Funding Scheme) and the Bank of Japan have implemented similar policies.

I develop a New Keynesian model with bank market power in deposits and lending in which banks borrow funds with CBL at a cheap interest rate and choose how much of new central bank funding increases the supply of new loans, is stored as excess reserves, is used to purchase government bonds, or substitutes other sources of funding. These central bank loans are convenient, and they are limited by a maximum Euro amount set by the central bank. Banks use part of the central bank loans to buy liquid assets like government bonds and reserves because they provide an insurance benefit against liquidity risk. Moreover, as CBL is cheaper than other types of funding, banks substitute part of their deposit base with the new funds. I calibrate the banking sector to match the cross-sectional empirical literature on TLTRO, which allows me to translate the partial equilibrium estimates of TLTRO pass-through in the literature into an aggregate general equilibrium pass-through. In the general equilibrium model, I account for the expansion in loan supply and deposit demand and the large liquidity benefit determined by the injection of reserves into the banking sector. I find a 32% aggregate pass-through of direct central bank lending into bank lending, compared to a 27% pass-through in partial equilibrium. An increase in CBL by 10% of outstanding loans raises aggregate real loans by 3.2%, GDP by 3.4%, and provides a stimulus equivalent to a 54 basis point cut to the policy rate. The model also implies that CBL will be more effective when banks hold few liquid assets and lending markets are more competitive.

In the model, banks have market power in the loan and deposit markets, access CBL up to a maximum level set by the central bank, hold government bonds and reserves, and pay a cost for insuring against liquidity risk which is decreasing in liquid assets (bonds and reserves). The policy instrument controlled by the central bank is the maximum level of funds (borrowing allowance) that banks can access via direct central bank lending. As these operations represent a cheap source of funding, banks choose to use the entire amount of available funds.[2] When the central bank expands the maximum borrowing allowance,

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[2] In the case of TLTRO, the maximum borrowing allowance has been increased by the ECB various times

banks gain access to new central bank funding, increase their demand for liquid assets in order to reduce liquidity costs, expand loan supply, and diminish other more expensive sources of external funding. Bank market power in the loan and deposit markets determines a downward-sloping demand curve for loans and an upward-sloping supply curve for deposits. The existence of convex liquidity costs implies a downward-sloping demand curve for liquid assets. An expansion in CBL shifts the loan supply curve and the demand curve for liquid assets. In equilibrium, the lending rate, the deposit rate, and the marginal benefit of holding government bonds and reserves decline. As a consequence, loans, government bonds, and reserves increase, while deposits fall. Quantitatively, the relative adjustment in loans, deposits, and liquid assets depends on the loan demand elasticity, the deposit supply elasticity, and the demand elasticity for bonds and reserves. These factors affect the elasticity of loan supply and demand and the pass-through is similar to tax incidence where higher elasticities are associated with larger movements in quantities. Thus, the impact of the policy is stronger when the loan market is competitive, the deposit market is uncompetitive, and the bank demand elasticity for liquid assets is low.

To be consistent with the empirical micro-estimates in the TLTRO literature, I calibrate the banking sector (parameters in the liquidity cost function, loan demand, and deposit supply elasticities) to match estimates on the impact of TLTRO on lending, government bonds, and reserves. In the calibrated partial equilibrium banking model, banks use 27% of CBL to increase lending, 7% to buy government bonds, 25% to hold excess reserves, and 41% to substitute other funding (deposits in the model). The policy impact on loans is consistent, by construction, to empirical estimates reported in Barbiero et al. (2021) and Altavilla et al. (2023). The implied pass-through for 1tn€ of policy shock is larger than the 18.5% and the 13% estimated respectively by Andrade et al. (2019) and Carpinelli and Crosignani (2017) for VLTROs.[3] The model also predicts that the impact of CBL on loans

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to increment the expansionary effect of the policy. For this reason, the maximum borrowing allowance is the policy tool controlled by the central bank in this model.

[3] Various papers (Crosignani et al. (2020), Jasova et al. (2018), Carpinelli and Crosignani (2017)) doc-

is stronger for banks operating in more competitive markets or holding a low share of liquid assets.[4]

The micro-studies on TLTRO use the cross-sectional variation across banks to evaluate the impact of the policy and do not account for the aggregate effect of CBL. In the New Keynesian general equilibrium model, I evaluate the aggregate impact of CBL on bank lending and real activity, accounting for the endogenous variation in loan demand by firms, deposit supply by households, and the injection of reserves into the aggregate banking sector determined by CBL. The pass-through of CBL to bank loans is amplified to 32% of central bank funds. Intuitively, as the economy expands, firms increase their demand for loans, households receive more resources to be allocated to deposits, and the banking sector receives on aggregate an amount of reserves equivalent to the CBL injection which improves its liquidity position. Quantitatively, a CBL shock of 10% of outstanding loans (around 1tn€ in steady state) increases aggregate loans by 3.2%, GDP by 3.4%, and inflation by 2%. As a benchmark, this rise in CBL provides a stimulus equivalent to a 54 basis point cut to the policy rate. Alternatively, the model predicts that the stimulus to loans provided by CBL is three times stronger than a comparable increase in QE. Intuitively, the decline in bond yields caused by QE leads to a substitution from government bonds to loans which is weaker compared to the more direct stimulus provided by CBL. It is important to stress that this model captures only the bank lending channel of QE, and I use it as a yardstick for the impact of CBL on bank lending.[5]

This paper relates to existing work on the study of direct central bank lending to banks, and in particular to the literature on ECB's Long Term Refinancing Operations. Several

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umented that banks used large parts of VLTROs to purchase government bonds, while this channel was way weaker with TLTROs (Benetton and Fantino (2021), Altavilla et al. (2020), Laine (2021), De Haan et al. (2019)). As a consequence, the model calibrated to match the impact of TLTROs implies a stronger pass-through to loans and a weaker pass-through to government bonds compared to the literature on VLTROs.

[4] This property is consistent with García-Posada and Marchetti (2016), Andrade et al. (2019), Benetton and Fantino (2021), Andreeva and García-Posada (2020), Boeckx et al. (2020).

[5] QE leads to a decline in government bond yields and banks find it more profitable to extend loans to firms.

papers estimate the impact of LTRO and TLTRO on bank lending (see for example Altavilla et al. (2023), Barbiero et al. (2021), and Benetton and Fantino (2021)). I use results from these studies which employ bank-level data and identified TLTRO shocks to calibrate the banking sector in partial equilibrium. Other papers have provided general equilibrium models for ECB's direct lending to banks (for example Cahn et al. (2017), Mouabbi and Sahuc (2019), and Van der Kwaak (2017)). I extend this literature in multiple dimensions. First, I model a banking sector where banks have market power and can access direct central bank loans at a cheap interest rate. In this setup, the policy instrument controlled by the central bank is the maximum level of CBL for banks, rather than the interest rate on those loans. Second, I quantify how the cross-sectional estimates in the empirical literature are amplified in a general equilibrium model. Third, to be consistent with empirical findings in the literature, I introduce government bonds, reserves, and benefits from storing liquidity as important determinants of the policy pass-through to loans. Finally, I evaluate state-dependence on the policy impact and compare CBL with other policy instruments. This paper also relates to research on negative interest rates by Ulate (2021), Eggertsson et al. (2019), and Abadi et al. (2022). I propose a similar monopolistically competitive banking setup to study the effects of unconventional monetary policy. In contrast with this literature, I introduce direct central bank loans as a source of bank funding, I account for the active role of liquid assets in the transmission of monetary policy to bank lending, and I quantitatively compare different unconventional monetary policy instruments.

The paper is organized as follows. Section 1.2 discusses the institutional setting of TLTRO and the related literature. Section 1.3 presents the banking sector, its calibration, and the intuition behind the pass-through of CBL to loans. Section 1.4 discusses the dynamic stochastic general equilibrium setting and presents the main results. Section 1.5 concludes.

1.2 Institutional Setting and Literature Review

Institutional setting of TLTRO. In June 2014 the ECB announced a series of Targeted Long Term Refinancing Operations (TLTROs) aimed at improving bank lending to the Euro Area non-financial private sector. European banks were allowed to borrow from the ECB at favorable rates up to a certain share of the total amount of their eligible private loans, defined as loans to the Euro Area non-financial private sector, excluding loans to households for house purchases. Favorable interest rate conditions were subject to the fulfillment by banks of a specific benchmark in terms of lending growth (for this reason these operations were named ”Targeted”). The maturity was set to four years and TLTROs were conducted at quarterly frequency in various rounds. Additional operations with different characteristics in terms of interest rate and borrowing allowance were announced also in March 2016 (TLTRO-II), June 2019 (TLTRO-III), and April 2020 (PELTRO). Before the introduction of TLTROs, banks were allowed to borrow funds from the ECB through LTROs. The main difference between the two programs was related to the shorter maturity of LTROs and the absence of a benchmark in terms of lending growth. In this paper, I abstract from the maturity extension and the targeted nature of TLTROs and focus on their role as a cheap source of funding compared to other liabilities. This assumption allows us to discuss the leakage of the policy through bonds, reserves, and deposits while keeping the model simple.[6] Figure 1·1 shows the evolution of the asset side of the ECB balance sheet. The red area corresponds to securities held for monetary policy purposes (QE) and the blue area relates to liquidity operations such as LTROs and TLTROs. In terms of the quantitative impact on the ECB balance sheet, TLTROs became the second most important unconventional monetary policy tool after QE. Figure 1·2 shows the share of LTROs and TLTROs to eligible outstanding private loans. Blue bars represent the injections of refinancing operations to European banks, while the red line shows the outstanding stock. Between 2014 and 2019,

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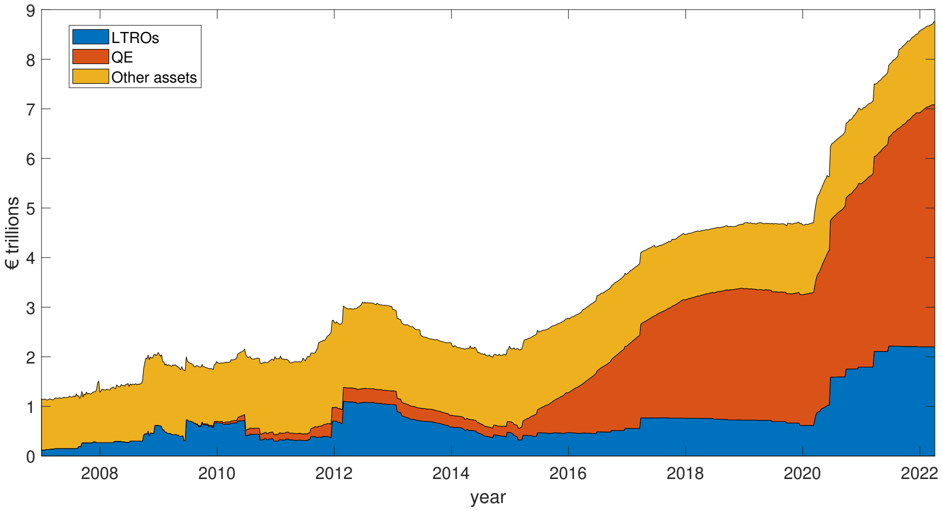
[6] For a presentation of TLTROs as a discount window with extended maturity see Cahn et al. (2017). Da Silva et al. (2021) discuss the targeted nature of TLTROs.

Figure 1·1: ECB Balance Sheet (Assets)

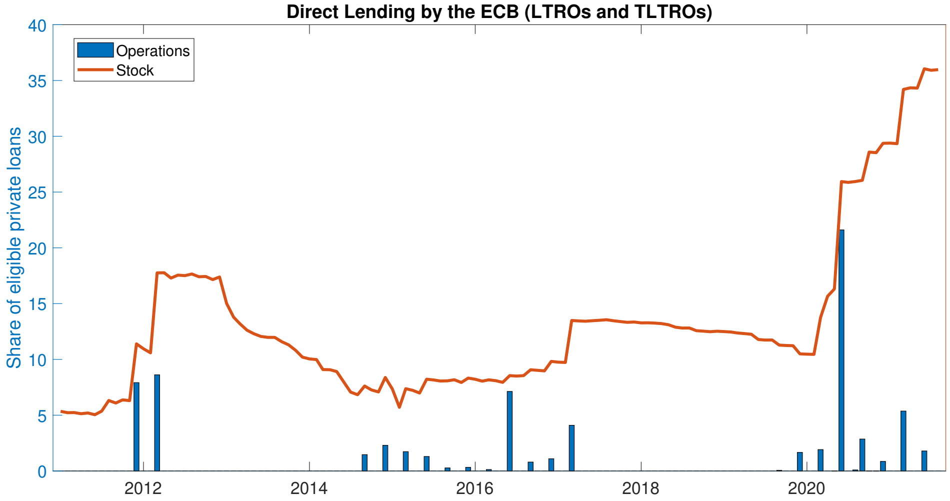


Notes: This Figure reports the asset side of the balance sheet of the European Central Bank in millions of Euros. The red area refers to QE, while the blue area refers to LTROs and TLTROs. The remaining area corresponds to other items in the balance sheet such as gold, claims to non-Euro Area residents denominated in foreign currency, and other assets.

the stock TLTROs reached a level of almost 15% of outstanding eligible loans in the Euro Area, with a peak of 35% during the pandemic.

Related Literature. There exists a literature that estimates the impact of LTROs and TLTROs on lending growth using aggregate and bank-level data for the Euro Area or for specific countries. The first set of studies is related to the 3-year LTROs implemented in 2011 and 2012 (known also as VLTROs). Darracq-Paries and De Santis (2015), Balfoussia and Gibson (2016), Casiraghi et al. (2016), García-Posada and Marchetti (2016), and Carpinelli and Crosignani (2017) find expansionary impacts of the policy on industrial production (around 5.7%) and loans (between 2 and 2.9 percentage points), especially for banks holding a low level of sovereign bonds and in less concentrated markets. Jasova et al. (2018) find that every 100€ of VLTROs translates into 2.5€ of new loans and in an increase in securities, Andrade et al. (2019) estimate an expansion in loans by 18.5€ with a stronger impact for banks having a low level of liquid assets, and Carpinelli and Crosignani (2017) find that banks more exposed to funding dry-up increased credit by 13€ and

Figure 1·2: LTROs and TLTROs as a Share of Eligible Private Loans in the Euro Area



Notes: This Figure reports the amount of LTROs and TLTROs as a percentage share of eligible private loans in the Euro Area. Eligible loans are defined as loans to the Euro Area non-financial private sector, excluding loans to households for house purchases. Blue bars refer to TLTRO injections, while the red line refers to the outstanding stock of TLTROs.

purchased 44€ of government bonds, while banks less exposed to the dry-up purchased 83€ in government bonds. Crosignani et al. (2020) estimate an overall increase of 5.4% in government bond holdings in Portugal.

A related branch of the literature studies the effect of TLTROs. Benetton and Fantino (2018, 2021) estimate an overall impact of TLTRO-I on loan growth of 4% after one year and find that Italian banks participating in TLTROs increased lending by 17% (with a stronger effect in more competitive markets) and reduced the fraction of government bond holdings in their balance sheet compared to non-participating institutions. Andreeva and García-Posada (2020), Bats and Hudepohl (2019), Afonso and Sousa-Leite (2020), Da Silva et al. (2021), and Laine (2021) provide evidence that TLTROs increased lending (between 9 and 16 percentage points), especially in very competitive markets, and did not significantly impact government bond holdings. Altavilla et al. (2023) estimate that the April 2020 recalibration of TLTRO-III increased lending by 1.4 percentage points per year.[7] Boeckx et al. (2020) show that the impact is stronger for banks that are small, illiquid, more reliant on wholesale funding, and less capitalized. De Haan et al. (2019) compare VLTROs and TLTROs and find that VLTROs incentivized carry trade by banks, while TLTROs were associated with an increase in liquid asset share in the balance sheet. Barbiero et al. (2021) provide a meta-analysis of estimated impacts of TLTROs on annual lending growth where the median is around 0.95% for 1tn€ policy shock. They also show that the share of TLTRO funds stored by banks in their own Eurosystem accounts ranges between 20% and 50% 20 days after the TLTRO settlement. Overall, estimates in the literature suggest that VLTROs and TLTROs had a positive effect on lending growth, especially in more competitive markets and for illiquid banks. The impact tends to be weaker for VLTROs as a large part of the funds was used to purchase government bonds, whereas TLTROs have been more successful in stimulating loan supply as the diversion of funds to liquid assets was smaller.

Da Silva et al. (2021) develop a partial equilibrium banking model to study TLTROs, taking into account the existence of eligible and ineligible loans, and how the interest rate on TLTROs is determined depending on how banks increase lending relative to the benchmark. Cahn et al. (2017) model LTROs as a discount window with longer maturity in a DSGE model with a frictional banking sector and find that without LTROs output would have been 2.5% lower over 2009. Mouabbi and Sahuc (2019) quantify the impact of TLTROs and other unconventional monetary policies in a general equilibrium model where the policies are modeled as a change in the shadow interest rate.[8] Van der Kwaak (2017) analyzes LTROs in a DSGE model with balance-sheet-constrained banks facing a portfolio choice between loans and government bonds and find that the effect of the policy is

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[7] In a previous version of the paper (Altavilla et al. (2020)) they show that the impact on the growth rate of government bond holdings is higher than the effect on loans after one year, and becomes insignificant after two years.

[8] They find that in the absence of unconventional measures, Euro Area GDP growth would have been on average 1.09% below its actual level over the period 2014-2017.

neutral.[9] In this paper, I instead abstract from the maturity structure and the existence of eligible and ineligible loans and focus on the allocation of central bank funds in a banking model where banks have market power and own liquid assets to decrease liquidity risk. In addition, I calibrate the banking sector to match the cross-sectional empirical literature on TLTRO, and I evaluate the aggregate impact of direct central bank lending in a New Keynesian model.

This paper is also related to research on how negative rates are transmitted to the economy through banks. In particular, Ulate (2021) presents a banking model where banks intermediate the transmission of monetary policy, have some monopoly power in the loan and deposit markets, and are subject to a lower bound on deposit rates. He shows how negative rates can at the same time stimulate loan supply and depress bank profitability thereby muting their expansionary effect. In this paper, rather than focusing on the lower bound on deposit rates, I study how banks intermediate the transmission of CBL in a similar monopolistically competitive setting where I add liquidity costs and active management of government bond holdings and reserves. Additionally, I incorporate the banking sector into a general equilibrium model in a similar way. Abadi et al. (2022) develop a frictional banking model to discuss the determinants of the reversal interest rate, which is the rate at which accommodative monetary policy becomes contractionary for lending. Similarly, Eggertsson et al. (2019) construct a banking model where negative policy rates become progressively less efficient or even contractionary. With this literature, I share the study of unconventional monetary policy in a monopolistically competitive banking setup which is embedded in a general equilibrium New Keynesian model (Gertler and Karadi (2011)).

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[9] The reason is that banks use government bonds as collateral to obtain central bank funding and therefore they initially substitute loans with government bonds.

Table 1.1: Balance Sheet of Bank j

Assets	**Liabilities**
Loans: L_j (i_j^L)	Deposits: D_j (i_j^D)
Bonds: A_j (i)	Central Bank Funding: O_j (i^o)
Reserves: R_j (i^R)	Equity: F_j

Notes: This Table reports the balance sheet of bank j. For each balance sheet item, the corresponding rate of return is reported in round brackets.

1.3 A Banking Model with Central Bank Lending and Liquidity

In this section, I develop the monopolistically competitive banking model and discuss the intuition behind the transmission mechanism of direct central bank lending to bank loans. The setup is static and in partial equilibrium. The model is then calibrated using European data and is integrated into a dynamic general equilibrium model in Section 1.4.

1.3.1 The Banking Sector Setup

There exist a continuum of $j = [0, 1]$ banks endowed with a given amount of equity F_j which is exogenous. The liabilities side of the bank balance sheet includes equity F_j, deposits D_j, and CBL funding O_j. On the asset side, banks issue loans L_j, hold central bank reserves R_j, and purchase government bonds A_j. Banks have some monopoly power both in the loan market and in the deposit market. Market power could be attributed to switching costs, menu costs, or asymmetric information. It follows that banks face a downward-sloping loan demand curve and an upward-sloping deposit supply curve.

Banks choose the interest rate on loans i_j^L, the quantity of loans L_j, the deposit rate i_j^D, the amount of deposits D_j, the amount of CBL funding O_j, and the quantity of government bonds A_j and reserves R_j. Banks take as given the interest rate on reserves i^R, the interest rate on government bonds i, and the interest rate on CBL i^o. Table 1.1 provides an overview of the balance sheet of bank j.

Note that the central bank directly controls three variables: the maximum amount of central bank funding to banks $\bar{O}$, the interest rate on central bank funding i^o, and the policy rate i^R. Therefore, as in the ECB's institutional setup of TLTROs, private banks can borrow funds from the central bank at a given interest rate i^o, up to a maximum borrowing allowance $\bar{O}$. This way of modeling CBL captures the fact that this policy is essentially a constrained source of cheap funding for banks, and allows a discussion of the quantitative pass-through rather than the interest rate pass-through of the policy.

Banks pay a cost for liquidity risk that is decreasing and convex in government bonds and reserves, which are assumed to be liquid assets. Intuitively, private banks need enough liquid assets for precautionary and regulatory reasons to cover possible outflows of funds. Microfoundations for liquidity costs are provided by Freixas and Rochet (2008): with some probability banks face an outflow of funds which, if big enough, leads banks to pay a penalty for the liquidity shortage. Liquidity costs are a decreasing and convex function of liquid assets. For simplicity and tractability, in this paper I assume a reduced form convex liquidity cost function (similar to Eggertsson et al. (2019)). Government bonds and reserves contribute to the reduction in liquidity costs. For this reason, holding liquid assets provides an additional benefit on top of the rate of return on those assets. The liquidity cost function $\mathcal{C}(A_j, R_j, F_j)$ is assumed to be convex and decreasing in the shares of government bonds and reserves to equity, such that $\mathcal{C}_A < 0$, $\mathcal{C}_R < 0$, $\mathcal{C}_{AA} > 0$, $\mathcal{C}_{RR} > 0$.[10]

The bank maximizes profits subject to the balance sheet constraint, the demand for

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[10] In principle, the intuition would be preserved by assuming the existence of a single liquid asset as what matters is the existence of a liquidity cost function. The distinction between bonds and reserves is introduced because a CBL injection determines a corresponding increase in reserves for the aggregate banking sector, a feature that becomes relevant in the general equilibrium model. The assumption that bonds and reserves might not be perfect substitutes is also because the two assets provide different liquidity benefits as they have different maturities, and government bonds can be used by banks as collateral in repos. This is consistent with their different response to central bank lending estimated in empirical studies.

loans, the supply of deposits, and the central bank funding constraint:

$$\max_{i_j^L, L_j, i_j^D, D_j, O_j, A_j, R_j} \underbrace{(1+i_j^L)L_j}_{\text{Loan Revenues}} + \underbrace{(1+i)A_j}_{\text{Bond Revenues}} + \underbrace{(1+i^R)R_j}_{\text{Reserve Revenues}} - \underbrace{(1+i_j^D)D_j}_{\text{Deposit Funding}} - \underbrace{(1+i^o)O_j}_{\text{Central Bank Funding}} - \underbrace{\mathcal{C}(A_j, R_j, F_j)}_{\text{Liquidity Cost}}$$

s.t.

$$\text{Balance Sheet Constraint} : L_j + A_j + R_j = D_j + O_j + F_j$$

$$\text{Loan Demand} : L_j = \left(\frac{1+i_j^L}{1+i^L}\right)^{-\varepsilon^L} L, \quad \varepsilon^L > 1$$

$$\text{Deposit Supply} : D_j = \left(\frac{1+i_j^D}{1+i^D}\right)^{-\varepsilon^D} D, \quad \varepsilon^D < -1$$

$$\text{Central Bank Funding Constraint} : O_j \leq \bar{O}.$$

Note that banks take as given aggregate loans L, aggregate deposits D, the aggregate lending and deposit rates i^L and i^D, their own equity F_j, the policy rate i^R, the government bond yield i and the CBL interest rate i^o.

First order conditions yield the following equilibrium equations:

$$1 + i_j^L = \mu^L \left(1 + i^R - \mathcal{C}_R\right) \tag{1.1}$$

$$1 + i_j^D = \mu^D \left(1 + i^R - \mathcal{C}_R\right) \tag{1.2}$$

$$1 + i^R - \mathcal{C}_R = 1 + i - \mathcal{C}_A \tag{1.3}$$

$$1 + i^R - \mathcal{C}_R = 1 + i^o + \delta^o \tag{1.4}$$

$$\delta^o \left(O_j - \bar{O}\right) = 0 \, , \; \delta^o \geq 0 \tag{1.5}$$

where δ^o is the Lagrange multiplier on the central bank funding constraint, and μ^L and μ^D

are respectively the markup and markdown on the marginal cost to set the lending rate and the deposit rate.

Equations (1.1) and (1.2) show that the bank optimally sets the lending rate and the deposit rate respectively as a markup and a markdown over the marginal cost. The marginal cost is given by the gross interest rate on reserves net of the marginal liquidity benefit of holding reserves. In a model without liquidity costs, the marginal cost would be only equal to the interest rate on reserves. In this model, the marginal cost of issuing loans takes into account the fact that holding reserves provides a liquidity benefit, with an implied optimal lending rate that is higher than in a model without liquidity costs (as $\mathcal{C}_R < 0$).

Equation (1.3) imposes that the bank should be indifferent between holding reserves and government bonds. As the policy rate i^R is historically smaller than the government bond yield i, liquidity costs guarantee the existence of an interior solution that depends on $\mathcal{C}_R$ and $\mathcal{C}_A$ as long as they are functions of reserves and government bonds. As an example, holding the policy rate fixed, a decline in the government bond yield implies a decrease in $\mathcal{C}_A$ and/or an increase in $\mathcal{C}_R$. By assumption, $\mathcal{C}_{AA} > 0$ and $\mathcal{C}_{RR} > 0$ thus implying a decrease in government bond holdings and an increase in demand for reserves.

Equation (1.4), results from the first order condition with respect to CBL funding O_j. The intuition is that if the cost of borrowing funds via CBL is low enough ($i^o \leq i^R - \mathcal{C}_R$), banks are going to use CBL funding up to the borrowing limit $\bar{O}$. The shadow price of the central bank funding constraint is captured by the Lagrange multiplier $\delta^o \geq 0$. If, instead, the borrowing cost of CBL is too high ($i^o > i^R - \mathcal{C}_R$), banks use other sources of funding and do not use CBL. In Europe, since the introduction of TLTROs in 2014[11], i^o has always been equal to or lower than the interest rate on reserves i^R. Given that by assumption $\mathcal{C}_R < 0$, it follows that the condition $i^o < i^R - \mathcal{C}_R$ represents the relevant case. For this reason, this paper focuses on the case where participating banks decide to use

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[11] Before the introduction of TLTROs, banks had access to LTROs which were characterized by shorter maturities and an absence of a benchmark in terms of lending growth.

all CBL funding made available from the central bank (making the central bank funding constraint binding). An additional reason supporting this assumption is that the central bank has control both over the interest rate on CBL i^o and the maximum borrowing constraint $\bar{O}$. In principle, then, the central bank could always choose $\bar{O}$ and set the CBL interest rate low enough to convince banks to borrow the entire amount of CBL funds available. Moreover, most of the bidding banks especially from stressed European countries have been borrowing a very large share of their maximum borrowing allowance (around 95% in some auctions).[12]

The equilibrium conditions can be combined into equations (1.6).

$$\underbrace{\frac{1+i_j^L}{\mu^L}}_{\text{MB of Lending}} = \underbrace{(1+i)-\mathcal{C}_A}_{\text{MB of Bonds}} = \underbrace{(1+i^R)-\mathcal{C}_R}_{\text{MB of Reserves}} = \underbrace{\frac{1+i_j^D}{\mu^D}}_{\text{MC of Deposits}} = \underbrace{(1+i^o)+\delta^o}_{\text{MC of CBL}} \tag{1.6}$$

The marginal benefit of lending must be equal to the marginal benefit of holding government bonds, the marginal benefit of holding reserves, the marginal cost of issuing deposits, and the marginal cost of CBL funding. Then, any variation in the policy rate i^R, the government bond yield i or the CBL borrowing allowance $\bar{O}$ (which affects δ^o) impacts the endogenous variables in the model.

1.3.2 The Pass-Through to Loans of an Expansion in Direct Central Bank Lending

To understand how an increase in CBL funds results in new loans, let's first focus on loan supply when banks have access to CBL as depicted in the first panel of Figure 1·3. For the time being, assume the absence of liquidity costs and liquid assets and focus on the deposit funding channel. Given that CBL is the cheapest source of funding, banks fund the first part of their loans using central bank funding. The first portion of the loan supply schedule is flat because the interest rate on CBL (marginal cost for the bank) is constant.

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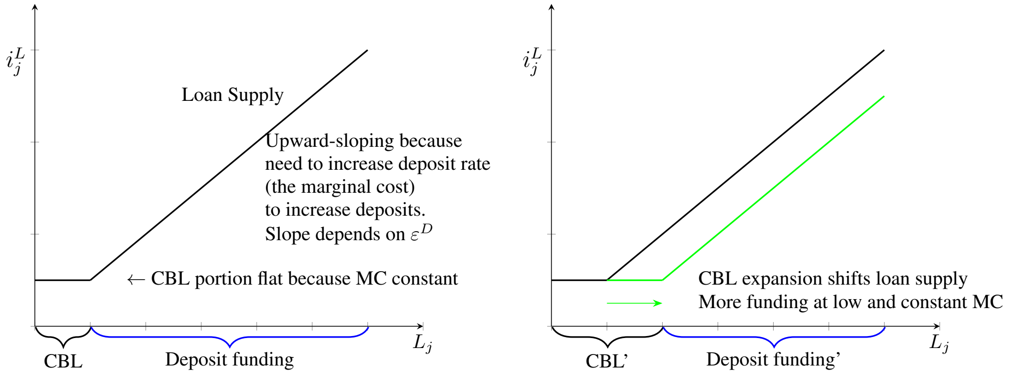
[12] For example, Andreeva and García-Posada (2020) show that 80% of the bidding banks in the initial TLTRO reported an uptake above 90% of their borrowing allowance.

After reaching the maximum CBL borrowing limit, banks fund the remaining part of their loans using deposits. This portion of the loan supply schedule is upward-sloping because banks face an upward-sloping deposit supply curve. The slope depends on the degree of competition in the deposit market which is captured by the elasticity ε^D. In other words, to gain more deposits, banks need to offer higher deposit rates.

The second panel of Figure 1·3 shows the impact of an increase in the CBL borrowing allowance $\bar{O}$ on bank loan supply. The green line represents loan supply after the CBL shock. A larger share of loans can now be funded using CBL at a constant marginal cost which is equal to i^o, and the loan supply schedule shifts to the right. Thus, an increase in direct central bank lending represents a loan supply shock, precisely because it provides a larger amount of funding at a low marginal cost.

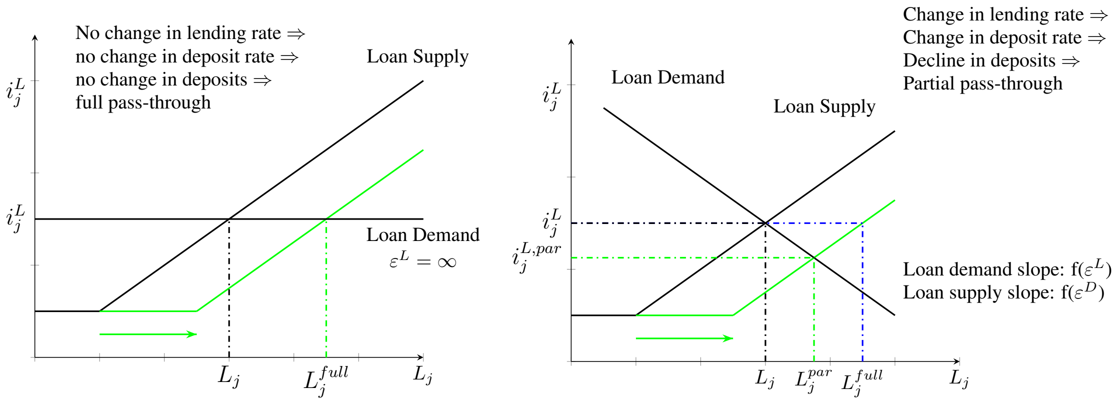
The impact of a CBL shock on loans in equilibrium depends both on loan demand and loan supply. The slope of the loan supply schedule is a function of the degree of competition in the lending market which is captured by the elasticity ε^L. If the loan market is perfectly competitive, the elasticity is infinite and the loan supply curve is flat. This is the case where

Figure 1·3: Loan Supply with CBL Shock



Notes: This Figure reports the loan supply schedule for bank j. The curve is related to the marginal cost of issuing loans which depends on the cost of each source of funding. The first portion is horizontal because CBL can be accessed at a constant interest rate (assumed to be lower than any other source of funding), while the second part is upward-sloping because the deposit supply curve is increasing in the deposit rate offered by the bank. The second panel shows what happens when the amount of CBL increases: the curve shifts horizontally, as a larger portion of loans can be funded by CBL at a constant interest rate.

Figure 1·4: Pass-through of CBL Shock to Loans



Notes: This Figure shows the impact of a CBL shock on equilibrium loans. The left panel presents the case of a perfectly competitive market for loans where the demand elasticity is infinite. In this case, the pass-through of the policy is full because there is no need to change the lending rate and the deposit rate to expand lending. The right panel presents the case of partial pass-through where the loan demand schedule is downward-sloping. The expansion of lending is associated with a decline in the lending rate and in the deposit rate. In this case, there is leakage due to an outflow of deposits determined by the decline in the deposit rate. The amount of funding available to the bank is then partially reduced as banks substitute part of their deposit funding with CBL.

the entire amount of new CBL funds gets channeled into new loans. The left panel of Figure 1·4 shows this case where the quantitative pass-through of CBL to loans is full. I define full pass-through when 1€ of new CBL funds increases lending by 1€. The reason is that with a flat loan demand curve, banks can increase lending without changing the lending rate. In the absence of a change in the marginal benefit of lending, the other equilibrium conditions are unaffected and there is no change in deposit funding or other assets. This is a limiting case that suggests that stronger competition in the lending market increases the pass-through to loans of CBL. This property of the model is also consistent with empirical findings in Andreeva and García-Posada (2020) and Benetton and Fantino (2021) who find that the policy is stronger in areas where the banking sector is more competitive.

Deposit channel. The right panel of Figure 1·4 presents the relevant case, where banks face a downward-sloping loan demand curve due to monopolistic competition in the lending market and $\varepsilon^L < \infty$. After an increase in CBL funds, banks expand their loan supply, but in equilibrium the increase in loans can only be sustained by a decrease in the lending rate. The decline in the marginal benefit of lending has to be matched by a decrease in the marginal cost of deposits via a reduction in the deposit rate. Due to the upward-sloping shape of the deposit supply curve, the result is a decrease in deposit funding. Overall, the increase in loans after the 1€ CBL shock is going to amount to a value lower than 1€ because banks use part of the new funds to substitute for deposit funding. In this sense, there is leakage from the policy objective of expanding loan supply. The intuition is analogous to tax/transfer incidence because the impact of new funds is going to be relatively stronger on the more elastic items of the bank balance sheet. If loan demand is very elastic relative to deposit supply, the adjustment in loans is going to be stronger and deposit substitution is going to be smaller, thus implying less leakage. Graphically, loan demand elasticity pins down the slope of the loan demand curve, whereas deposit supply elasticity affects the slope of the loan supply curve. The implication is a strong pass-through of the policy to the quantity of new loans when loan demand is very elastic. In fact, in equilibrium, the lending rate and the deposit rate are changing by the same amount and the resulting variation in quantities depends on the relative elasticities of loans and deposits. To sum up, compared to the case of full pass-through of CBL to bank loans, now there is some leakage in the policy because part of the funds are used to substitute deposit funding (deposit channel) and only a share of new CBL funds are going to generate new loans.[13]

Liquidity channel. So far, we have abstracted from liquid assets (reserves and government bonds) and liquidity costs to focus on the deposit channel. The left panel of Figure 1·5 shows how the existence of a liquidity channel affects the loan supply curve. The first implication is that the flat portion of the supply curve is smaller because part of CBL funds are used to buy liquid assets, thereby leaving less funds to supply loans. The second implication is that the upward-sloping portion of the supply curve is flatter because, as the

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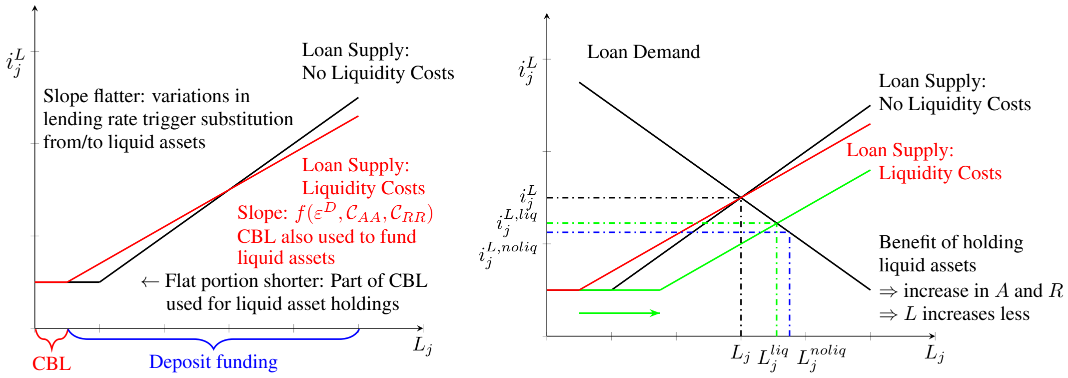
[13] This model abstracts from other sources of external funding such as bank debt. Altavilla et al. (2020) find that TLTROs tend to reduce banks' debt suggesting an important source of funding substitution. Adding debt on the liability side of banks would be a natural extension to the model, but the same intuition would be preserved.

lending rate varies, funds can be reallocated between liquid assets and loans. Now the slope depends also on the second derivatives of the liquidity cost function $\mathcal{C}_{AA}$ and $\mathcal{C}_{RR}$ which pin down bank demand elasticity for government bonds and reserves.

The right panel of Figure 1·5 presents the impact of a CBL shock on loans in the model with liquidity costs and compares it with the model that abstracts from liquidity. Now the horizontal shift in the loan supply curve is smaller because part of the funds are used to purchase government bonds or held as excess reserves. The resulting equilibrium increase in loans is then smaller compared to the previous case, leading to a bigger leakage in the policy. Equation (1.6) helps in understanding the mechanism. An increase in CBL funding reduces the shadow cost of the central bank funding constraint δ^o and the marginal cost of funding. Banks cut the lending rate in order to increase loans, but at the same time, the marginal benefit of holding government bonds and reserves has to fall in equilibrium. Holding the policy rate i^R and the government bond yield i fixed, the marginal benefit of holding liquid assets declines as the bank expands its holdings of government bonds and reserves. Intuitively, banks optimally use part of the new CBL funds to cover liquidity costs. The quantitative response depends on bank demand elasticity for government bonds and reserves which is a function of the shape of the liquidity cost function. Again, the intuition is similar to tax/transfer incidence: if demand for government bonds and reserves is very elastic, a larger part of CBL funds is going to be used to purchase liquid assets and a smaller share ends up in new loans. Overall, when the central bank provides 1€ of new CBL, a part of that € is going to substitute deposit funding (deposit channel), a part is going to be used to increase holdings of bonds and reserves (liquidity channel), and the remaining part ends up in new loans. The deposit channel and the liquidity channel determine a leakage in the policy and the pass-through of CBL to loans is partial.

Total pass-through. The pass-through of CBL to loans can be also evaluated analytically as $\frac{\partial L_j}{\partial O}$. Differentiating the balance sheet constraint together with the first order

Figure 1·5: Liquid Assets and Loan Supply



Notes: The left panel shows how the introduction of liquid assets and liquidity costs changes the shape of the loan supply schedule. The flat portion is shorter because part of CBL funds are used to purchase liquid assets, while the slope of the second portion becomes flatter as variations in the lending rate induce reallocation from/to liquid assets. The right panel shows how a CBL shock is subject to a bigger leakage because part of the funds are now used to purchase liquid assets and the horizontal shift in the curve is smaller.

conditions gives the following result:

$$\frac{\partial L_j}{\partial \bar{O}} = \left[1 + \frac{-\varepsilon^D}{\varepsilon^L} \frac{D_j}{L_j} + \frac{1}{\varepsilon^L L_j} \frac{(1 + i^R - \mathcal{C}_R)}{\frac{\mathcal{C}_{AA}\mathcal{C}_{RR} - \mathcal{C}_{AR}^2}{(\mathcal{C}_{AA} + \mathcal{C}_{RR} - 2\mathcal{C}_{AR})}} \right]^{-1} \tag{1.7}$$

The blue term is related to the deposit channel and the red term is related to the liquidity channel. In absence of those two terms (e.g. when $\varepsilon^L = \infty$) the pass-through is full as $\frac{\partial L_j}{\partial \bar{O}} = 1$. In this case, each € of additional CBL ends up in new loans, as shown graphically in Figure 1·4.

In general, the deposit channel (blue term) is always positive as $\varepsilon^D < -1$. The sign of the liquidity channel (red term) is positive if $\mathcal{C}_{AA} > \mathcal{C}_{AR}$ and $\mathcal{C}_{RR} > \mathcal{C}_{AR}$, a condition which is going to be satisfied in the calibration presented in this paper.[14] The fact that both terms are positive implies a partial pass-through as $\frac{\partial L_j}{\partial \bar{O}} < 1$. This is the case presented in Figure 1·5. The blue term captures the fact that banks substitute part of the deposit funding with CBL depending on elasticities ε^L and ε^D. Higher competition in the lending market

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[14] The opposite is implausible because it would imply bonds and reserves moving in opposite directions after a CBL shock, which is not what is observed in the data.

(high ε^L) determines lower deposit substitution and a stronger increase in loans. Similarly, stronger competition in the deposit market (high $|\varepsilon^D|$) implies stronger deposit substitution and weaker increase in loans.

The liquidity channel arises because banks allocate part of new resources into government bonds and reserves to reduce liquidity costs. When demand elasticity for bonds and reserves is low, a smaller share of new funds is diverted to liquid assets and the increase in loans is stronger (red term is smaller). The reason is that demand elasticity for bonds and reserves is inversely related to $(\mathcal{C}_{AA} - \mathcal{C}_{AR})$ and $(\mathcal{C}_{RR} - \mathcal{C}_{AR})$.

1.3.3 Calibration

Parametrized Liquidity Cost Function

The reason for holding liquid assets comes from the fact that banks pay a cost for liquidity risk $\mathcal{C}(A_j, R_j, F_j)$ (see Eggertsson et al. (2019), Freixas and Rochet (2008)). Intuitively, private banks need enough liquid assets to cover possible outflows of short-term funding for precautionary and regulatory reasons. Therefore, holding government securities and reserves provides two benefits to the bank: the return on the asset and the decline in liquidity costs. For simplicity, I assume a reduced form liquidity cost function. Freixas and Rochet (2008) provide micro-foundations for a liquidity cost function which is decreasing in liquid assets and convex.

Equation (1.8) presents the functional form of the liquidity cost function in this model:

$$\mathcal{C}(A_j, R_j, F_j) = \kappa \left(\frac{\left[\alpha A_j^{\rho} + (1-\alpha) R_j^{\rho}\right]^{1/\rho}}{F_j} \right)^{-\gamma} F_j \tag{1.8}$$

As long as $\kappa > 0$, $\gamma > 0$, $\rho < 1$, and $0 < \alpha < 1$, liquidity costs are decreasing and convex in the share of liquid assets to equity.

There are two important assumptions underlying this functional form. The first is that liquidity costs are a function of the share of liquid assets to equity. This assumption preserves the property that liquidity costs are decreasing in bonds and reserves and can be microfounded by assuming that banks face the risk of an outflow of funds which is equal to a constant share of their equity (as a proxy of their balance sheet).[15] The second important assumption in Equation (1.8) is that government bonds and reserves (liquid assets) are combined via a CES aggregator. In principle, the economic intuition presented so far does not require the existence of two separate liquid assets, and the liquidity channel could be driven only by substitution towards government bond holdings. However, introducing central bank reserves is important in this setup as the central bank settles CBL by crediting a corresponding amount of reserves in private banks' accounts. Then, single banks can always redistribute reserves to other banks, but the aggregate amount of reserves is exogenously set by the central bank. Therefore, the existence of reserves becomes important in the general equilibrium model. Another key assumption is the type of aggregation of liquid assets in the liquidity cost function. In principle, the aggregation could be linear as in Eggertsson et al. (2019). However, government bonds and reserves are different in terms of liquidity, maturity, riskiness, and ability to provide collateral in operations with the central bank and other banks. Moreover, perfect substitutability would imply that the elasticity of banks' demand functions for government bonds and reserves would be the same and their response after a CBL shock would be equal. This result would be in conflict with empirical estimates of the response of government bond holdings and reserves after a CBL shock. The constant returns to scale CES aggregator ensures enough flexibility to calibrate different responses of government bonds and reserves after a shock, nests the case of perfect substitutability, and preserves properties in terms of shares that are useful in the calibration

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15. Eggertsson et al. (2019) do not provide an explicit form for their liquidity cost function, but assume that it is an increasing function of external funds. Abadi et al. (2022) assume that a bank's liquid assets must exceed a constant fraction of deposit issuance. My choice of using the ratio of liquid assets to equity makes sure that liquidity costs depend on the ratio of liquid assets in the bank's balance sheet (which is proxied by equity), rather than their absolute level. Moreover, the fact that equity is exogenous in the model ensures that the calibration of the cost function depends only on movements in assets. Additionally, the choice of using shares has the benefit of making the general equilibrium model more tractable.

of the general equilibrium model.

Overall, the liquidity cost function presented in Equation (1.8) is decreasing in liquid assets ($\mathcal{C}_A < 0, \mathcal{C}_R < 0$) and convex ($\mathcal{C}_{AA} > 0, \mathcal{C}_{RR} > 0$).

Introducing Quantitative Easing

The reason for introducing Quantitative Easing in the model is twofold. First, I use empirical estimates on the impact of QE on government bond holdings by banks and interest rates to calibrate the bank demand elasticity for government bonds. Moreover, the existence of government securities allows a discussion of the direct effects on loans of Quantitative Easing policy via the banking sector. Although QE was introduced to affect the economy more broadly and via different channels (households, firms, financial markets), this model allows an evaluation of the impact of QE via the substitution of government securities with loans.

Assume that the central bank buys A^{QE} assets and these purchases affect the interest rate on government bonds i. In this model, QE determines a change in the interest rate i engineered by the central bank $\frac{\partial i}{\partial A^{QE}}$. This specification makes it possible to compare the two policies in quantitative terms, where CBL appears as a change in $\bar{O}$ and QE as a change in A^{QE}. Therefore, the impact of QE on government bond holdings by banks can be derived as:

$$\frac{\partial A_j}{\partial A^{QE}} = \underbrace{\frac{\partial A_j}{\partial i}}_{\text{endogenous}} * \underbrace{\frac{\partial i}{\partial A^{QE}}}_{\text{exogenous}}$$

The derivative of government bond holdings with respect to the interest rate i is endogenous and can be derived analytically from the model whereas the second term on the right-hand side of the equation is assumed to be exogenous and corresponds to the yield impact of QE. The yield impact of QE in Europe has been estimated in the literature for various maturities and horizons (see Eser et al. (2019) and Altavilla et al. (2021)) and is assumed to be equal to the constant parameter $\gamma^a \equiv \frac{\partial i}{\partial A^{QE}}$.

Additional Modifications to the Quantitative Model

Two modifications are added to the model to ensure that the calibration is consistent with observed data on banks and interest rates. First, the asset side of banks' balance sheet includes other net assets S_j which are exogenous. They are constructed as $S_j = F_j + D_j + O_j - L_j - A_j - R_j$. This feature does not alter the dynamics of the model and is introduced to equate assets and liabilities for banks and at the same time use observed data for loans, bonds, reserves, deposits, CBL, and capital.

The second modification is the introduction of an exogenous benefit of issuing deposits θ^D (as in Ulate (2021) and Abadi et al. (2022)), and an exogenous cost of holding government bonds θ^{ip}. The benefit of issuing deposits can be seen as an additional fee charged to depositors or alternatively a benefit to the bank of having a large and stable deposit base. This modification allows a decoupling of the policy rate i^R, the marginal liquidity cost $\mathcal{C}_R$ and deposit supply elasticity ε^D in the calibration. The cost of holding government bonds captures the different riskiness of this type of asset compared to reserves and makes sure that the spread in the rate of return of the two assets is not only explained by their distinct contribution to the liquidity cost function. These additional features do not alter the model dynamics.

Given these two modifications, the balance sheet constraint becomes:

$$L_j + A_j + R_j + S_j = D_j + O_j + F_j \tag{1.9}$$

and equilibrium conditions for the deposit rate and for government bond holdings become:

$$1 + i_j^D = \mu^D \left(1 + i^R - \mathcal{C}_R + \theta^D\right) \tag{1.10}$$

$$1 + i^R - \mathcal{C}_R = 1 + i - \mathcal{C}_A - \theta^{ip} \tag{1.11}$$

Calibration Strategy

The model is calibrated using monthly Euro Area data for the aggregate banking sector from 2014 to 2019 obtained from the ECB SDW database.[16] There are nine parameters to be calibrated: loan demand elasticity ε^L, deposit supply elasticity ε^D, the parameters of the liquidity cost function κ, α, γ, ρ, the exogenous cost/benefits of issuing deposits and holding bonds θ^D and θ^{ip}, and the yield impact of QE γ^a. Deposit supply elasticity is calibrated as $\varepsilon^D = -275$ at the quarterly frequency as in Abadi et al. (2022) (which is also very close to Ulate (2021) who sets the parameter equal to -268). Both papers calibrate this parameter to target historical averages of the deposit rate spread. The reason for calibrating deposit supply elasticity from the literature is twofold: first, the sample covers a period where deposit rates have been very sticky compared to other interest rates as they got very close to the zero lower bound; second, it would be difficult to decouple loan demand elasticity and the benefit of issuing deposits θ^D in Equation (1.10) using available data as both parameters are pinned down by the historical spread between the deposit rate and the policy rate. The yield impact of QE for 1tn€ central bank purchases is calibrated using empirical results from Altavilla et al. (2021). They estimate an impact on the 10-year European yields of -36 basis points for a 1tn€ envelope, such that $\gamma^a = -0.36\%$ annualized.

The remaining seven parameters are calibrated to match historical averages for the lending rate $\bar{i}^L$, the deposit rate $\bar{i}^D$, the spread between the policy rate and the government bond yield $\bar{i}^R - \bar{i}$, the impact of QE on government bond holdings by banks, and target elasticities obtained from cross-sectional estimates in the empirical literature on TLTRO. The first empirical target is the response of loan growth after a CBL shock of 10% of outstanding loans. Altavilla et al. (2023) estimate that the 1.3tn€ June uptake of TLTRO-III had an aggregate impact on loan growth of 1.4 percentage points over a year. Rescaling the impact to 1tn€

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[16] Data sources and transformations are reported in Appendix A.1.

and assuming that it lasts for three years returns an overall impact of 3.2 percentage points in loan growth. Barbiero et al. (2021) present a meta-analysis of the estimated impact of TLTRO on loan growth after one year where the median is around 0.95 percentage points after a 1tn€ TLTRO injection. Again, assuming that the impact lasts for three years, the overall impact is 2.8 percentage points. Given that the average level of loans in my sample corresponds to 9.82tn€, I target a 2.8% increase in loans after a CBL shock of 10% of outstanding loans. [17]

The second target is the share of CBL funds stored in banks' own reserve accounts with the central bank. This is estimated by Barbiero et al. (2021) to be around 30%[18] after 20 days from the settlement of the operations. Therefore, I target $\frac{\partial R}{\partial O}$ to be equal to 0.30.

The third target is the growth rate of government bond holdings after a CBL shock of 10% of outstanding loans. Various papers such as Altavilla et al. (2020), Carpinelli and Crosignani (2017), Crosignani et al. (2020), Jasova et al. (2018) find that banks using TLTRO funding increase substantially their holdings of government bonds. Altavilla et al. (2020) estimate that the response in the growth rate of bonds after one year is larger than the response in loans by a factor of around 1.33. For this reason, I target the growth rate of government bond holdings to be equal to 1.33 times the growth rate of loans, which returns 3.7 percentage points overall.

The last target is related to the share of bonds that the central bank purchases from private banks with Quantitative Easing. This target pins down the demand elasticity of bank government bond holdings. Koijen et al. (2021) estimate a demand system for government bonds and show how the portfolio of various investor sectors has rebalanced from 2015 to 2017 when the ECB started its program of asset purchases. The ECB bought a total of

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[17] Altavilla et al. (2020) estimate the response of loans to TLTRO up to two years and show that the response in loans is monotonically increasing over the horizon. However, the maturity horizon of TLTRO was four years, suggesting that it might be possible for loans to keep growing for a longer period of time. In the calibration, to calculate the overall impact of a TLTRO shock, I conservatively assume that loans keep growing at the same rate for three years.

[18] Confidence intervals range between 50% and 20%.

Table 1.2: Calibrated Parameters

Param.	Value	Definition	Source
κ	0.015	Liquidity cost function param.	Calibration
γ	0.17	Liquidity cost function param.	Calibration
α	0.86	Liquidity cost function param.	Calibration
ρ	-0.02	Liquidity cost function param.	Calibration
ε^L	169	Loan demand elasticity (quarterly)	Calibration
ε^D	-275	Deposit supply elasticity (quarterly)	Abadi et al. (2022)
θ^D	0.007	Benefit of issuing deposits (quarterly)	Calibration
θ^{ip}	0.007	Cost of holding government bonds (quarterly)	Calibration
γ^a	-0.36	Yield impact of 1tn QE (ann. %)	Altavilla et al. (2021)

Notes: This Table reports the parametrization of the banking sector.

1.33tn€ of government bonds (net of new issuances by governments) between 2015 and 2017 where 0.47tn€ were purchased from private banks. This implies that banks sold 35% of overall government bonds purchased by the central bank. Thus, in the calibration, I target $\partial A/\partial A^{QE} = -0.35$.

Calibrated parameters appear in most of the targeted equations and enter non-linearly. For this reason, I choose parameters by numerically minimizing the squared deviation of model equations from targets.

The parameters that minimize the objective function are presented in Table 1.2. Table 1.3 shows how the various targeted equations are matched by the calibration. The average lending rate is very close to the historical average, while the average deposit rate and average spread between the policy rate and government bond yield are almost perfectly matched. The growth rate of loans and bonds after a CBL shock and the change in government bonds after a 1tn€ QE shock are the same as the target. The share of CBL that is kept by banks as reserves is 25%, which is lower than the target, but still within the confidence bands reported in Barbiero et al. (2021). Appendix A.2 shows how the calibration changes with alternative target elasticities.

Figure 1·6 presents the response of the bank's balance sheet variables to 1tn€ positive CBL shock implied by the calibration. Loans increase by 0.27tn€, banks buy 0.07tn€ of government bonds, increase reserves by 0.25tn€ and substitute other funding (in this case

Table 1.3: Targets

Target	Data	Model	Source
Average lending rate	2.44	2.36	Historical Average 14-19
Average deposit rate	1.47	1.46	Historical Average 14-19
Avg. spread btw. policy rate and bond yield	-1.57	-1.56	Historical Average 14-19
Loan growth after CBL shock	2.8	2.8	Barbiero et al. (2021)
Change in reserves after CBL shock	0.30	0.25	Barbiero et al. (2021)
Bond growth after CBL shock	3.7	3.7	Altavilla et al. (2020)
Share of QE purchased from banks	-0.35	-0.35	Koijen et al. (2021)

Notes: This Table reports the targeted historical averages and elasticities in the partial equilibrium model with their respective sources. Growth rates and interest rates are expressed in percentage points. The CBL shock is assumed to be equal to 10% of outstanding loans.

Table 1.4: Robustness - Pass-through of 1tn€ CBL to Loans

	Calib.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Min.	Max.
CBL	0.27	0.25	0.38	0.28	0.25	0.28	0.27	0.38	0.28	0.27	0.27	0.25	0.38

Notes: This Table reports the impact of 1tn€ CBL on loans for various alternative combinations of the parameters outlined in Appendix A.2 in Table A.1. All the changes are expressed in tn€.

deposits) by 0.41tn€.[19] Overall, the pass-through of CBL to loans is reduced by 0.41tn€ due to the deposit channel and by 0.32tn€ due to the liquidity channel. The implication is that a large part of the funds is used either to substitute other sources of external funding or to increase holdings of liquid assets. These properties of the model are a direct outcome of the calibration which targets the growth rates of loans, government bonds, and the share of reserves held by banks after a CBL shock. To compute the change in € rather than the growth rate, the model is shocked assuming that all bank balance sheet items are at their historical average between 2014 and 2019. The quantitative impact presented depends on the relative elasticities of loan demand, deposit supply, and liquid assets demand.

Table 1.4 presents the pass-through of CBL for different calibrations of the model. The pass-through of CBL to loans ranges between 0.25tn€ and 0.38tn€.[20]

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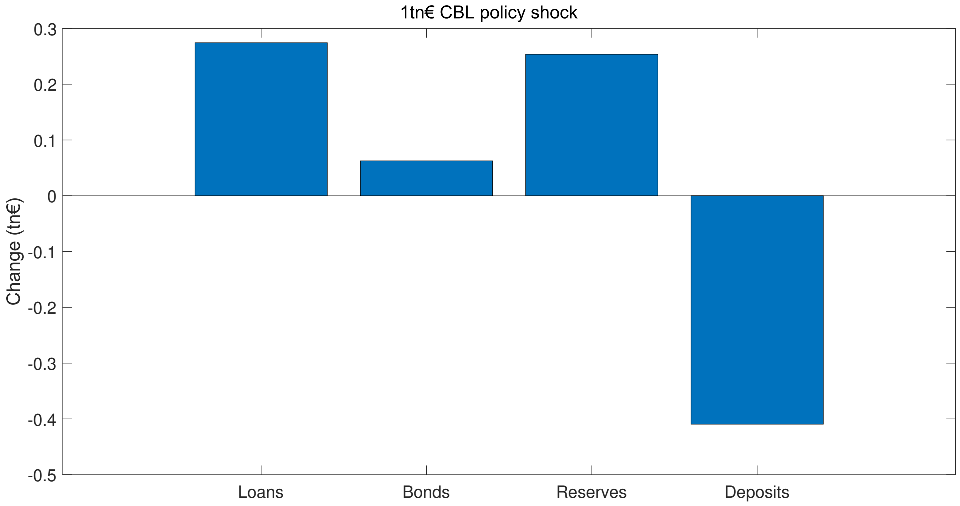
[19] 19. The targets from the literature imply that an increase in CBL equivalent to 10% of outstanding loans (around 1tn€) determines a 2.8% growth in loans and 3.7% growth in bonds. The initial level of loans is 9.82tn€. This means that the shock increases loans by 0.27tn€ (=9.82tn€*0.028), thus 27% of the 1tn€ shock is transmitted to loans. The initial level of bonds is 1.8tn€. This means that the shock increases bonds by 0.07tn€ (=1.8tn€*0.037), thus 7% of the 1tn€ shock is transmitted to bonds.

[20] 20. More details on the different calibrations and on other variables are presented in Appendix A.3.

Figure 1·6: Impact of a 1tn€ CBL Shock

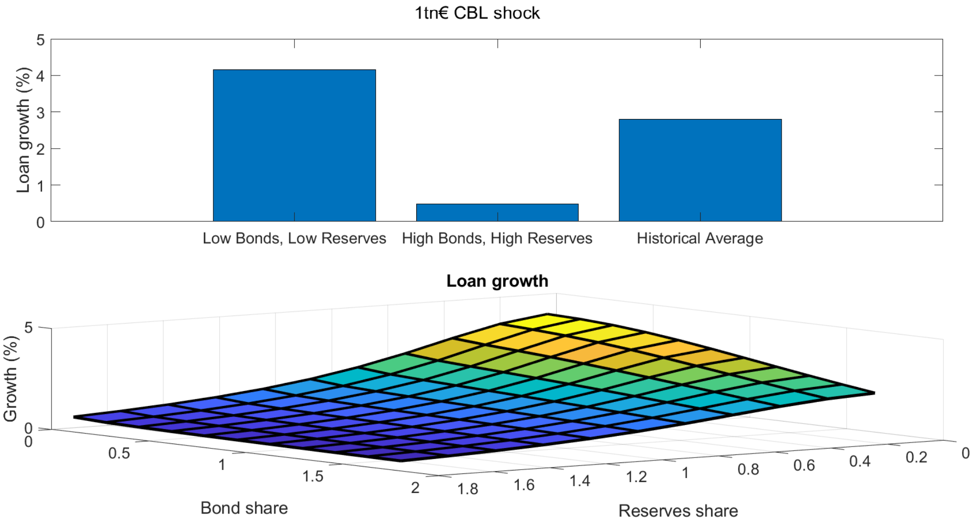


Notes: This Figure reports the change in loans, government bonds, reserves, and deposits after a 1tn€ increase in CBL. All variables are reported in tn€.

1.3.4 State-Dependence: CBL Pass-Through and Liquidity

An interesting implication of the model is that the pass-through of CBL to loans is stronger when banks hold few liquid assets. Figure 1·7 presents this result. The upper panel in Figure 1·7 shows how loan growth can vary between 0.5% and 4% depending on the initial holdings of liquid assets, where the baseline growth using historical averages is 2.8%. This result follows from the convexity of the demand functions for bonds and reserves, implying that low initial liquidity is associated with lower elasticities in the demand for liquid assets and a smaller increase in their quantity. As a consequence, a larger share of CBL funds is directed to new loans. This implication of the model is consistent with empirical results presented in Andrade et al. (2019), García-Posada and Marchetti (2016), and Boeckx et al. (2020). The lower panel shows how loan growth after 1tn€ CBL shock varies substantially depending on the initial holdings of liquid assets (measured as a share of equity). When banks hold very few government bonds or reserves, the change in the marginal benefit of additional liquidity is bigger. In other words, when liquidity is scarce,

Figure 1·7: Impact of CBL on Loans as a Function of Liquid Assets



Notes: The upper panel reports the growth rate of loans after 1tn€ CBL shock in three cases: when banks have low levels of initial liquidity, when banks have high levels of initial liquidity, and when initial levels of liquidity are at the historical average. The lower panel reports the growth rate of loans after 1tn€ CBL shock (vertical axis) as a function of initial holdings of government bonds and reserves (horizontal axes). Loan growth is reported in percentage terms, while government bonds and reserves are reported as a share of bank equity.

receiving CBL funds can improve liquidity costs with a smaller adjustment in liquid assets, thereby leaving more resources to expand lending. From a policy perspective, to maximize the impact on bank lending, CBL should be implemented in periods or regions where banks hold a low share of liquid assets in their balance sheet. This is true in particular for excess reserves, which present a more elastic demand curve compared to government bonds. For example, the model predicts that a CBL shock in 2014 would have determined an overall 3.8% increase in loans compared to a 2% increase in 2019.

1.4 CBL in a General Equilibrium Model

The banking model outlined in Section 1.3 provides useful intuitions on the mechanism governing the pass-through of CBL to loans and other banks' balance sheet items. However, due to its partial equilibrium nature, it is not sufficient to assess the aggregate impact of unconventional monetary policies on loans, output, and inflation. In this Section, I embed the banking sector in a general equilibrium setting where loans demanded by firms and deposits supplied by households are now endogenous, and the aggregate amount of reserves is exogenously determined by the central bank. This allows me to translate the micro estimates from the literature into an aggregate impact of CBL.

Given that loan demand and deposit supply are now endogenous, a CBL shock that expands loan supply and increases economic activity may have positive feedback effects on the behavior of firms and households. In addition, although reserves represent a choice variable from the perspective of a single bank, aggregate reserves are exogenously set by the central bank. The general equilibrium model then features an exogenous increase in reserves which is equivalent to the expansion in CBL funding from banks.[21]

Additionally, bank equity is now endogenous and evolves over time because a share of profits is retained by banks to build up capital. The implication is that as banks get bigger and increase their capital, they need to raise more liquid assets in order to cover liquidity costs. Moreover, the introduction of dynamics makes policy shocks persistent (rather than permanent) and forward-looking banks take into account the expected persistence of the shock when making their optimal choices.

Overall, the model presented in this Section can shed light on the aggregate impact of CBL on loans, GDP, and inflation taking into account the evolution of bank capital, exogenous central bank reserves, and feedback from loan demand and deposit supply. Moreover, this model allows for a discussion of the central bank policy reaction to negative shocks with conventional and unconventional monetary policy instruments when the policy rate is at the zero lower bound. Finally, the model can be used to study how CBL compares with QE and constitutes a useful policy tool when banks are hit by adverse liquidity shocks.

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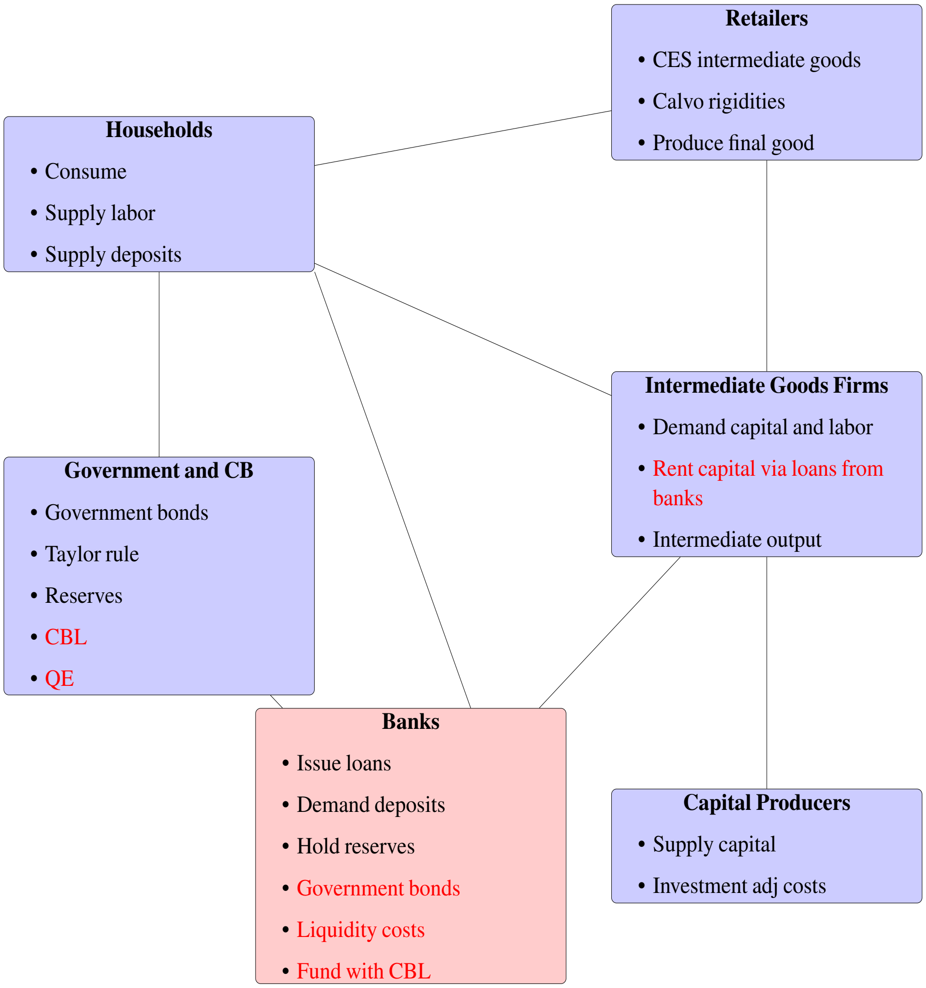
[21] The same is true for QE shocks, where the amount of government bonds sold by banks has to be matched by a corresponding increase in central bank reserves.

1.4.1 Model Setup

The model builds on Gertler and Karadi (2011) and Ulate (2021) where the banking sector is an extension of the model presented in the partial equilibrium Section of this paper. Gertler and Karadi (2011) develop a DSGE model with financial intermediaries facing balance sheet constraints and study the effect of unconventional monetary policy. Ulate (2021) builds on their model and modifies the banking sector to study the effect of negative interest rates on bank lending behavior in a setup where financial intermediaries have market power in the loan and deposit markets, and are subject to a lower bound on the deposit rate. In this paper, what's different from previous models are the banking sector and the policy tools available to the central bank. Banks issue loans, demand deposits, hold government bonds and reserves, are subject to liquidity costs, and have the option to fund with direct central bank loans. The central bank controls reserves, the policy rate via a Taylor Rule, and can decide to engage in CBL or Quantitative Easing. The government consumes goods, sets lump-sum taxes, and issues government bonds. The rest of the general equilibrium model shares a common setup with Gertler and Karadi (2011) and Ulate (2021). There are five agents: households, intermediate goods producers, capital producers, retailers, and banks. Figure 1·8 presents an overview of all the agents in the model and their main characteristics. Retailers are subject to Calvo price rigidities and aggregate the intermediate output demanded from firms. Intermediate goods firms demand capital and labor. They rent capital from capital producers using loans obtained from private banks, and labor from households. Capital producers are subject to investment adjustment costs and supply capital at a price that is not fixed at one. Households consume the retail good, supply labor to intermediate firms, and supply deposits to private banks.

Figure 1·8: Agents in the General Equilibrium Model



Notes: This Figure presents all the agents in the general equilibrium model and their main characteristics. The red terms highlight the main modifications introduced in this paper.

1.4.2 Agents

Households

The economy is populated by a continuum of households of measure 1 who consume, save by supplying deposits to banks and holding money, and supply labor to intermediate goods firms.[22] Households maximize expected discounted lifetime utility as:

$$E_0 \sum_{t=0}^{\infty} \beta^t \varphi_t \left(\frac{(C_t - hC_{t-1})^{1-\sigma} - 1}{1-\sigma} - \chi \frac{N_t^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right) \tag{1.12}$$

where β is the discount factor, φ_t is a shock to the discount factor, h governs habit persistence[23], σ is the inverse of the intertemporal elasticity of substitution, χ is the scale parameter associated to labor disutility, and η is the Frisch elasticity of labor supply. Common assumptions are $0 < \beta < 1$, $0 < h < 1$, and σ, χ, $\eta > 0$. Households can save either by supplying deposits D_t at the gross interest rate $1 + i_t^D$ or by holding money M_t. They supply labor N_t and receive the nominal wage W_t. They consume the final good C_t at the price P_t, receive nominal profits Π_t from the ownership of all firms, and pay lump sum taxes T_t to the government. The budget constraint is then given by:

$$P_t C_t + D_t + M_t = W_t N_t - T_t + (1 + i_{t-1}^D) D_{t-1} + \Pi_t + M_{t-1} \tag{1.13}$$

Optimality conditions are:[24]

$$\chi N_t^{\frac{1}{\eta}} = \phi_t W_t \tag{1.14}$$

$$\phi_t = (C_t - hC_{t-1})^{-\sigma} - \beta h E_t \frac{\varphi_{t+1}}{\varphi_t} (C_{t+1} - hC_t)^{-\sigma} \tag{1.15}$$

$$1 = \beta E_t \left[\frac{\phi_{t+1}}{\phi_t} \frac{\varphi_{t+1}}{\varphi_t} (1 + i_t^D) \frac{1}{1 + \pi_{t+1}} \right] \tag{1.16}$$

where $\pi_t = \frac{P_t}{P_{t-1}} - 1$ is the net inflation rate.

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[22] A natural extension of the model would be to allow households to hold government bonds. This assumption would introduce an additional channel which would make QE even more stimulative, as households would sell government bonds to the central bank after a QE shock. However, the extension would not significantly affect the impact of CBL and for this reason it is not presented.

[23] The main qualitative results of the model are preserved even in the absence of habit persistence. However, this assumption is introduced to gain a better empirical fit of the model and to be consistent with the literature in the field.

[24] The first order condition with respect to money is omitted for brevity.

Retail Firms

Retail firms use intermediate inputs demanded from intermediate goods firms to produce differentiated varieties of a retail good $Y_t(s)$. Varieties are then aggregated into a final good via a CES aggregator.

$$Y_t = \left(\int_0^1 Y_t(s)^{\frac{\varepsilon-1}{\varepsilon}} ds \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{1.17}$$

Demand for retail goods and the price index are:

$$Y_t(s) = \left(\frac{P_t(s)}{P_t} \right)^{-\varepsilon} Y_t \tag{1.18}$$

$$P_t = \left[\int_0^\infty P_t(s)^{1-\varepsilon} ds \right]^{\frac{1}{1-\varepsilon}} \tag{1.19}$$

where ε is the elasticity of demand across differentiated retail goods.

Retail firms are subject to price frictions, as they can reset their price with probability $1-\gamma^p$ (Calvo (1983)). They solve:

$$\max_{P_t^*(s)} E_t \sum_{\tau=0}^{\infty} \beta^\tau (\gamma^p)^\tau \Lambda_{t,t+\tau} \frac{P_t}{P_{t+\tau}} Y_{t+\tau}(s) \left[P_t^*(s) - P_{t+\tau}^m \right] \tag{1.20}$$

subject to demand for $Y_t(s)$. $\Lambda_{t,t+\tau}$ is the stochastic discount factor and P_t^m is the price of the intermediate good. Optimality conditions are standard and they are reported in Appendix A.4.

Intermediate Goods Firms

Intermediate goods firms produce intermediate inputs using labor and capital. To obtain capital K_t, they need to borrow from banks. The timing is as follows: at the end of $t-1$ firms borrow K_t from the bank and use the capital stock to produce goods in period t. After production takes place, firms return the capital stock to the bank. The production function for intermediate goods is then:

$$Y_t^m = Z_t \left(\xi_t K_t\right)^{\alpha^k} N_t^{1-\alpha^k} \tag{1.21}$$

where Z_t is total factor productivity, ξ_t is a capital efficiency shock, and $0 < \alpha^k < 1$ is the capital share parameter in the Cobb-Douglas production function. Firms then choose labor and capital as follows:

$$\max_{N_t, K_t} P_t^m Y_t^m - W_t N_t - Z_t^K K_t \tag{1.22}$$

where P_t^m is the price of the intermediate good, and Z_t^K is the dividend paid by banks for each unit of capital. Optimality conditions are:

$$(1-\alpha^k) P_t^m \frac{Y_t^m}{N_t} = W_t \tag{1.23}$$

$$\alpha^k P_t^m \frac{Y_t^m}{K_t} = Z_t^K \tag{1.24}$$

Note that the two conditions imply that intermediate firms make zero profits. As in Ulate (2021), banks are residual claimants of intermediate goods firms, as banks receive all residual stochastic returns to banks. Therefore, the return for banks of lending a unit of capital is:

$$1 + i_{t+1}^L = \frac{Q_{t+1}\xi_{t+1}(1-\delta) + P_{t+1}^m \alpha^k \frac{Y_{t+1}^m}{K_{t+1}}}{Q_t} \tag{1.25}$$

where Q_t is the nominal price of capital, and δ is the capital depreciation rate.

Capital Producers

Capital producers generate new capital subject to investment adjustment costs. The law of motion of capital is:

$$K_{t+1} = (1-\delta)\xi_t K_t + I_t \tag{1.26}$$

where I_t is investment. The nominal price of capital is Q_t. Capital producers choose the real price of capital $\frac{Q_t}{P_t}$ by maximizing the following:

$$\max E_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \Lambda_{t,\tau} \left[\left(\frac{Q_\tau}{P_\tau} - 1 \right) I_\tau - f\left(\frac{I_\tau}{I_{\tau-1}} \right) I_\tau \right] \tag{1.27}$$

Investment adjustment costs satisfy $f(1) = f'(1) = 0$ and $f''(1) > 0$ as in Christiano et al. (2005), Gertler and Karadi (2011), Ulate (2021).[25] The optimality condition which pins down the price of capital is standard and is reported in Appendix A.4.

Banks

The setup for the banking sector is similar to the one presented in Section 1.3, with three main modifications that are introduced to add dynamics and make the model more realistic.

First, as in Ulate (2021), bank capital is now endogenous as banks can now retain part of their profits to build up equity. Each period, banks retain a constant fraction of profits ω and return the rest as dividends to the owner. Moreover, banks pay each period a constant fraction ς of their net worth as managerial cost. These assumptions make bank equity an endogenous variable that varies over time as in Equation (1.28), and is potentially affected by policy shocks.

Second, banks receive a stochastic return from firms, rather than a deterministic interest rate. The return on loans is stochastic because banks charge firms a fraction of their total return on capital.[26] The implication is that the lending rate is determined in $t+1$ and contains expectations, as the return on capital can be affected by unexpected shocks occurring between t and $t+1$. This assumption is helpful to make shocks to capital efficiency (recessions) relevant to banks and bank equity.

Finally, in the general equilibrium setting aggregate reserves are exogenous. Single

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[25] Eberly et al. (2012) show that this specification of investment adjustment costs is consistent with firm-level data.

[26] Given that all banks are symmetric, the fraction of the total return on capital charged by banks will be equal to one.

banks can always choose the amount of reserves they hold by exchanging them with other banks, but the aggregate amount of reserves in the economy is set by the central bank. This is relevant in the analysis of unconventional monetary policy as policy interventions such as CBL and Quantitative Easing determine an exogenous increase in central bank reserves. Therefore, each € supplied via CBL or purchased in government bonds by the central bank is associated with an equivalent increase in reserves.[27]

As in Ulate (2021) total profits, net of managerial costs and adjusted for inflation are defined as $X_{j,t+1}$:

$$\begin{aligned} X_{j,t+1} =& i_t^R F_{j,t} + (i_{j,t+1}^L - i_t^R) L_{j,t} + (i_{j,t} - \theta_t^{ip} - i_t^R) A_{j,t} - i_t^R S_{j,t} \\ & - (i_{j,t}^D - \theta_t^D - i_t^R) D_{j,t} - (i_t^o - i_t^R) O_{j,t} - \mathcal{C}(A_{j,t}, R_{j,t}, F_{j,t}) - (1-\varsigma) F_{j,t} \pi_{t+1} \end{aligned}$$

The assumption is that banks pay a fraction ω of $X_{j,t+1}$ as dividends and keep the remaining share:

$$DIV_{j,t+1} = (1-\omega) X_{j,t+1}$$

As a consequence, real bank equity evolves as follows:

$$\frac{F_{j,t+1}}{P_{t+1}} = \frac{F_{j,t}}{P_t}(1-\varsigma) + \omega \frac{X_{j,t+1}}{P_{t+1}} \tag{1.28}$$

Banks maximize the present discounted value of dividends:

$$\max E_t \sum_{s=0}^{\infty} \beta^{s+1} \Lambda_{t,t+s+1} DIV_{j,t+s+1}$$

The first order conditions for all the variables except for the lending rate are Equations (1.10), (1.11), (1.4) and (1.5). The return on loans is instead now stochastic and, assuming

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[27] Ulate (2021) and Abadi et al. (2022) introduce an additional friction in their models, where banks pay a cost for deviating from a target leverage ratio. In Appendix A.7 I present an extension that accounts for the existence of leverage costs.

that all banks are symmetric, has the following equilibrium condition:

$$E_t(1+i_{t+1}^L) = \mu^L \left(1 + i_t^R - \mathcal{C}_R(A_t, R_t, F_t)\right) \tag{1.29}$$

Government and Central Bank

The central bank has three monetary policy instruments to stabilize the economy: the policy rate i_t^R, the maximum amount of direct central bank loans to banks $\bar{O}_t$, and Quantitative easing A_t^{QE}.[28] The policy rate is determined by a Taylor Rule subject to a lower bound which is equal to the steady state level of the policy rate:[29]

$$i_t^R = \max\left((1-\rho_i)\left(\bar{i}^R + \psi_\pi \pi_t + \psi_y \frac{Y_t - \bar{Y}}{\bar{Y}}\right) + \rho_i i_{t-1}^R + \varepsilon_t^m, \bar{i}^R\right) \tag{1.30}$$

where $\rho_i \in (0,1)$ is the smoothing parameter of the Taylor Rule, $\bar{i}^R$ and $\bar{Y}$ are steady state policy rate and output, ψ_π and ψ_y are both positive and govern the importance of inflation and output gap in the reaction function of the central bank, and ε_t^m is the exogenous monetary policy shock.

CBL and QE both follow autoregressive processes. The government bond yield i_t is determined by three components: the policy rate i_t^R, an exogenous premium associated with government bonds θ_t^i (which captures the spread with the risk-free rate), and the QE component.

$$i_t = i_t^R + \theta_t^i + \gamma^a A_t^{QE} \tag{1.31}$$

where $\gamma^a < 0$ is the yield impact of QE. Notice that in the absence of QE, the government bond yield is given by the sum of the policy rate and an exogenous spread. When the central bank purchases government bonds, the government bond yield falls and the magnitude depends on γ^a which is calibrated using estimates from Altavilla et al. (2021).

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[28] By assumption, banks use all the available central bank funding, thus implying $O_t = \bar{O}_t$.

[29] The lower bound is not set to zero because the steady state level of the policy rate is already negative. As the model is solved linearly, setting the lower bound below the steady state level of the policy rate would not affect the results presented in this paper.

The central bank controls also aggregate reserves. Whenever the monetary authority increases the amount of CBL available to banks, reserves increase by the same amount. Similarly, government bonds purchased by the central bank from private banks determine an increase in aggregate reserves. Thus, the equation governing the amount of reserves in the economy is the following:

$$R_t = \bar{R} + (O_t - \bar{O}) + \mathcal{I}_{QE} * (\bar{A} - A_t) \tag{1.32}$$

where $\mathcal{I}_{QE}$ is an indicator function that is equal to 1 in case of a QE shock and 0 otherwise. Notice that in this model the only agents holding government bonds are banks. Therefore, to close the model, the change in reserves has to be equal to the amount of government bonds sold by private banks to the central bank, which is an endogenous choice and depends on the impact of QE on government bond yields.

Finally, the government budget constraint and the central bank balance sheet are aggregated as follows:

$$A_t + R_t - O_t = (1 + i_{t-1})A_{t-1} + (1 + i^R_{t-1})R_{t-1} - (1 + i^o_{t-1})O_{t-1} + G_t - T_t \tag{1.33}$$

where G_t is government spending and follows an AR(1) process, and T_t are lump sum taxes.

Resource Constraints and Shocks

Assuming a symmetric equilibrium across all banks, we can drop the j subscript for all the variables and work with aggregate variables. The resource constraint is given by

$$\begin{aligned} Y_t =& C_t + I_t + G_t + f\left(\frac{I_t}{I_{t-1}}\right) I_t + \theta^{ip}_t \frac{A_{t-1}}{P_t} - \theta^D_t \frac{D_{t-1}}{P_t} \\ &+ \varsigma \frac{F_{t-1}}{P_t} + \frac{\mathcal{C}(A_{t-1}, R_{t-1}, F_{t-1})}{P_t} \end{aligned} \tag{1.34}$$

Aggregate loans issued by banks need to be equal to the value of capital:

$$L_t = Q_t K_{t+1} \tag{1.35}$$

All the shocks in the model follow autoregressive processes except for the monetary shock.

1.4.3 Calibration of the General Equilibrium Model

The calibration of the general equilibrium model follows three principles: (i) calibrate the banking sector with parameters obtained in the partial equilibrium model, (ii) match ratios and interest rates in steady state using historical averages, and (iii) use standard parameters from the literature for the remaining blocks. The model is calibrated at the quarterly frequency.

Parameters for the banking sector are the same as in Section 1.3. The reason for calibrating the liquidity cost function and the loan demand and deposit supply elasticities as in the static setup is that those parameters do not involve intertemporal relations and they should not be affected by the dynamic setup of the general equilibrium model. Loan demand and deposit supply elasticities pin down the markup and markdown over the marginal cost in the equations for the lending rate and the deposit rate, while the liquidity cost function determines the bank demand elasticity for liquid assets. Therefore, loan demand elasticity ε^L is equal to 169 at the quarterly frequency, and deposit demand elasticity ε^D is set equal to -275. This parametrization implies a markup μ^L for the lending rate of 1.006 and a markdown μ^D for the deposit rate of 0.996.[30] The liquidity cost function is the same as in the partial equilibrium model: the scale parameter κ is set to 0.015, the elasticity parameter γ is 0.17, the share of government bonds in the CES aggregator α is 0.86 and the substitution parameter ρ is -0.02. The exogenous benefit of issuing deposits and the cost of holding government bonds θ^D and θ^{ip} are both equal to 0.007. The fraction of profits staying in banks ω is equal to 12% as in Ulate (2021) and the share of equity paid as managerial costs

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[30] The markup and the markdown are related to the gross lending rate and deposit rate.

ς is pinned down using steady state relations and is equal to 0.22%.

The impact of 1tn€ QE on 10-year government bond yields is taken from Altavilla et al. (2021) and is set to -36 basis points annualized. The discount rate β is 0.9945 as a result of the steady state deposit rate and household Euler Equation.

The share to equity of various banking balance sheet variables is calibrated in steady state using historical averages between 2014 and 2019. The loan-to-equity share is equal to 3.95, the share of government bonds is 0.68, the share of deposits is 3.65, the share of reserves is 0.50, and the share of CBL is 0.24. Historical averages are also used to calibrate interest rates in steady state: the lending rate is 2.44% annualized, the deposit rate is 1.47%, the policy rate is -0.32%, and the 10-year government bond yield is 1.25%. The steady state amount of government bonds purchased via Quantitative Easing is set to 1.17tn€ and pins down the government bond premium θ^i in steady state which is equal to 0.005.

CBL follows an AR(1) process where ρ_o is the autoregressive coefficient, and ε_t^o is a CBL shock. An AR(2) process is assumed for Quantitative Easing, where $\rho_{qe,1}$ and $\rho_{qe,2}$ are the autoregressive coefficients, and ε_t^{qe} is an exogenous QE shock. The rationale for assuming an AR(2) process for QE is that this kind of policy is implemented over time after the announcement rather than being conducted only in one period. Expressing the two equations in logs, we have:

$$o_t = (1 - \rho_{o,1})\bar{o} + \rho_o o_{t-1} + \varepsilon_t^o \tag{1.36}$$

$$a_t^{qe} = (1 - \rho_{qe,1} - \rho_{qe,2})\bar{a}^{qe} + \rho_{qe,1} a_{t-1}^{qe} + \rho_{qe,2} a_{t-2}^{qe} + \varepsilon_t^{qe} \tag{1.37}$$

The autoregressive coefficient for a CBL shock ρ_o is estimated using an AR(1) regression for the sample 1999-2022 and is equal to 0.97. Similarly, the autoregressive coefficients for the QE shock $\rho_{qe,1}$ and $\rho_{qe,2}$ are estimated with an AR(2) regression in the sample 2015-2022 and are respectively equal to 1.84 and -0.86.

The remaining parameters are taken from the literature and are reported in Table 1.5

with their corresponding sources.

1.4.4 The Aggregate Impact of Direct Central Bank Lending to Banks

The impact of a CBL shock can be now evaluated through the lens of this rich dynamic model. Given that the shock is expansionary, solving the model with traditional perturbation methods would trigger the contractionary response from the Taylor Rule, which is not the ideal setting to evaluate the impact of a policy usually implemented when the policy rate is fixed. For this reason, in order to hold the policy rate constant after the shock, the model is solved by bounding above the policy rate to its steady state level with occasionally binding constraints (Guerrieri and Iacoviello (2015)).

Figure 1·9 shows the impulse response of some selected variables to a CBL shock equivalent to 10% of outstanding loans in steady state. As in the partial equilibrium model, banks use the new resources to cut the lending rate and increase lending. Part of CBL funding is also used to purchase government bonds which grow substantially. The expansion in reserves is mechanical in the general equilibrium model and is not reported. The increment in the supply of loans is associated with an increase in the capital stock used by intermediate goods firms in their production which is reflected in a rise in investment. As a consequence of the increase in the production of intermediate goods, aggregate output, consumption, and inflation are impacted positively by the shock. Quantitatively, the peak response of loans is 3.2% growth, output raises by 3.4% after 3 quarters and inflation increases by 2% in annualized terms. For each € of CBL, banks increase lending by 0.32€, government bond holdings by 0.27€, and capital by 0.04€. As already mentioned, reserves in the banking sector increase by the same amount as the CBL injection. The first difference compared to the partial equilibrium model is the growth in deposits which is equivalent to 0.55€. The reason is that the increase in lending triggers an expansion in production. As households get richer, they save part of the additional resources into deposits. Moreover, the general equilibrium model accounts for the expansion in loan demand by firms due to the increase

Table 1.5: General Equilibrium Parametrization

Parameter	**Value**	**Description**	**Target or source**
Banks			
κ	0.015	Liquidity cost scale param	Calibration
γ	0.17	Liquidity cost exp param	Calibration
α	0.86	Liquidity cost share param	Calibration
ρ	-0.02	Liquidity cost ela sub	Calibration
θ^D	0.007	Benefit of issuing deposits	Calibration
θ^{ip}	0.007	Cost of holding bonds	Calibration
ε^D	-275	Deposit elasticity of subs	Calibration
ε^L	169	Loan elasticity of subs	Calibration
ω	12%	Fraction of profits staying in banks	Ulate (2021)
ς	0.22%	Bank managerial cost	Steady State
ν^A	0.68	Bond share of bank capital	Historical average
ν^L	3.95	Loan share of bank capital	Historical average
ν^o	0.24	CBL share of bank capital	Historical average
ν^R	0.50	Reserves share of bank capital	Historical average
ν^D	3.65	Deposit share of bank capital	Historical average
ν^S	-0.23	Net other asset share of bank capital	Historical average
$\bar{i}^D$	1.47	Steady state deposit rate (ann)	Historical average
$\bar{i}^L$	2.44	Steady state loan rate (ann)	Historical average
$\bar{i}^R$	-0.32	Steady state reserves rate (ann)	Historical average
$\bar{i}^o$	-0.32	Steady state CBL rate (ann)	Same as reserve rate
$\bar{i}$	1.25	Steady state bond rate (ann)	Historical average
$\overline{A^{QE}}$	1.17	Steady state QE (gov. bonds)	Historical average
Household			
β	0.9945	Discount rate	Steady state deposit rate
h	0.56	Habit	Christoffel et al. (2008)
χ	3.409	Leisure parameter	Gertler and Karadi (2011)
η	1	Frisch Elasticity	Chetty et al. (2011)
σ	1	Inverse of IES	Ulate (2021)
Firms			
α^k	0.33	Capital share	Gertler and Karadi (2011)
δ	0.025	Depreciation rate	Gertler and Karadi (2011)
ζ	1.728	Elasticity of Q to investment	Gertler and Karadi (2011)
ε	6	Elasticity of sub among goods	Ulate (2021)
γ^p	0.9	Calvo price param	Christoffel et al. (2008)
Government			
ψ_π	3.5	Inflation coeff. Taylor Rule	Ulate (2021)
ψ_y	0.125	Output coeff. Taylor Rule	Suggestive
ρ_i	0.8	Smoothing param. Taylor Rule	Ulate (2021)
γ^a	-0.36	Yield impact of 1tn QE (ann. %)	Altavilla et al. (2021)
g	0.2	Steady state government share	Gertler and Karadi (2011)
θ^i	0.005	Steady state bond rate shock	Steady State
ρ_1^o	0.97	AR(1) coeff. CBL shock	AR(1) estimation 99-22
ρ_1^a	1.84	AR(1) coeff. QE shock	AR(2) estimation 15-22
ρ_2^a	-0.86	AR(2) coeff. QE shock	AR(2) estimation 15-22

Notes: This Table presents the calibration of the general equilibrium model.

in production determined by the policy. The third general equilibrium channel is related to the large injection of reserves into the aggregate banking sector: as reserves increase, the marginal cost of lending declines because banks reduce their liquidity costs. It follows that in equilibrium the marginal benefit of lending should decline correspondingly, thereby reducing the lending rate by 0.25% in annualized terms.[31] All these three channels determine an amplification in the impact of the policy on bank loans to 32% of CBL funds compared to 27% in the partial equilibrium framework. Impulse responses for other variables are presented in Appendix A.5.

One of the effects of the policy is to increase bank capitalization. In the current setup, bank capital does not play a significant role. In Appendix A.7, I extend the model to include leverage costs for banks. As banks pay a quadratic cost if they deviate from a target loan-to-equity ratio, an increase in bank capital improves banks' ability to extend loans. An increase in the share of profits that are retained by banks (and not rebated to households) increases bank capital and determines a stronger response in bank lending.

Another interesting result of the model is the response of the economy to a capital efficiency shock. This kind of shock has been used by Gertler and Karadi (2011) and Ulate (2021) to model the Great Recession. I study three cases to evaluate the ability of the central bank to provide accommodation with conventional and unconventional policy tools after negative shocks to the economy. First, I do not constrain the policy rate (”No ZLB”) and solve the model with traditional perturbation methods. This is a standard setup where the policy rate can respond to negative shocks via the Taylor Rule. Then, I constrain the interest rate on reserves to be bounded downwards by its steady state level (”ZLB”). In this case, the monetary authority cannot stimulate the economy in a recession. Finally, I allow the central bank to respond to the shock by expanding the availability of CBL even if the policy rate is still bounded below (”ZLB+CBL”). These last two cases are

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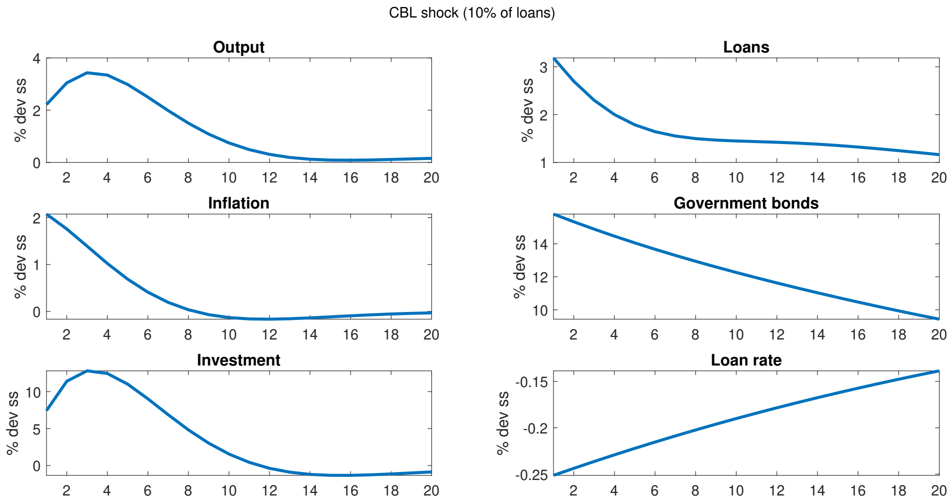
[31] 31. Also the impact on government bonds is amplified. As reserves and government bonds display some degree of complementarity in the liquidity cost function, the large injection of aggregate reserves determines an increase in government bond holdings.

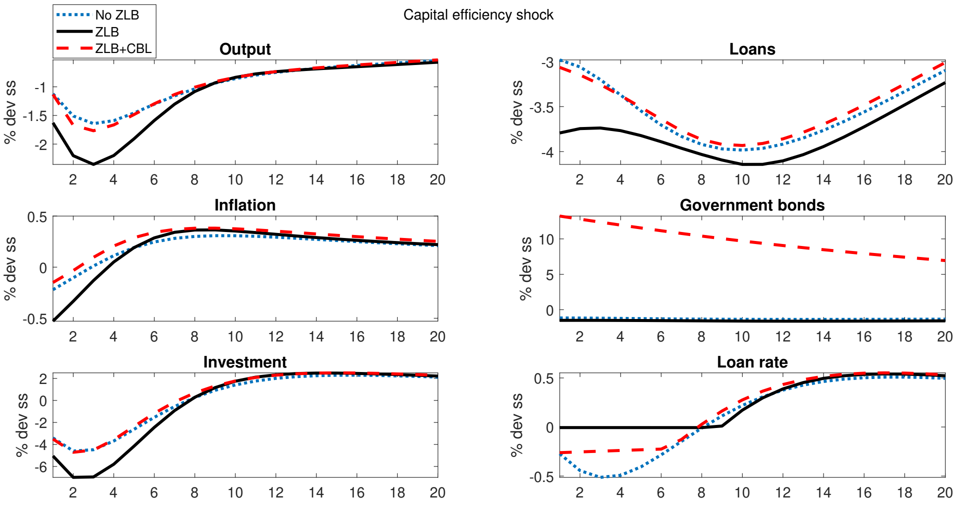
Figure 1·9: IRFs to a CBL Shock of 10% of Outstanding Loans



Notes: This Figure shows the impulse responses after a positive CBL shock of 10% of outstanding loans when the policy rate is fixed at steady state. All variables are in percentage deviations from the steady state, except for inflation and the loan rate which are reported in annualized percentage deviations from the steady state.

solved using occasionally binding constraints where the policy rate is bounded below by its steady state level. Figure 1·10 presents results for this exercise. Capital efficiency falls by 1%, with a persistence parameter of $\rho_\xi = 0.8$. In the absence of any policy response (black line), output falls by around 2.4% and loans decline by 3.8%. Similarly, inflation, consumption, and investment decline substantially. When the policy rate is unconstrained (blue dotted line), monetary policy mutes the peak drop in output to 1.7% and in loans to 3% on impact. The red dashed line presents the case where the policy rate is constrained, but the monetary authority implements CBL to stimulate the economy with a shock equal to 10% of outstanding loans. Notably, the accommodation provided by CBL is very close to the "No ZLB" case, suggesting that this type of unconventional monetary policy instrument is strong enough to replace standard interest rate policies when the policy rate is at the lower bound. The model predicts that a CBL shock equivalent to 10% of outstanding loans in steady state has an impact on output as effective as a 54 basis points drop in the policy rate.

Figure 1·10: IRFs to a Capital Efficiency Shock



Notes: This Figure shows the impulse responses after 1% decrease in capital efficiency ξ_t. The black line reports the response when the policy rate is fixed at the lower bound, the blue dotted line reports the response when the policy rate is unconstrained, and the red dashed line reports the response when the policy rate is constrained, but the central bank increases CBL by 10% of outstanding loans. All variables are in percentage deviations from the steady state, except for inflation and the loan rate which are reported in annualized percentage deviations from the steady state.

1.4.5 Alternative Policy Experiments

Central Bank Lending and Quantitative Easing

A key feature of the model is the ability to compare the impact of a CBL shock and a QE shock of the same initial magnitude. These two unconventional monetary policies are both quantitative, in the sense that they involve expansions of the central bank balance sheet which can be measured in trillions of €.

Figure 1·11 shows how private banks react to an increase in CBL funding and an increase in central bank asset purchases of the same size in the partial equilibrium banking sector. 1tn€ expansion in CBL increases lending by 0.27tn€, while 1tn€ QE purchases determine an increase in loans by 0.09tn€. It is important to stress that the two policies affect banks' balance sheets in different ways: while the entire amount of CBL represents new funding to banks, Quantitative Easing induces substitution between government bonds and loans. The implication is that the increase in lending from QE depends on the amount of government bonds sold by private banks due to the compression in bond yields engineered by central bank purchases. In this model, the impact depends on the bank demand elasticity for government bonds. An increase in QE by 1tn€ reduces government bond yields by 36bp (annualized) which is associated with a drop in government bond holdings by 0.35tn€. Part of this 0.35tn€ is then used to expand lending by 0.09tn€ and increase reserves by 0.12tn€. The drop in interest rates determines also a reduction in the deposit rate which compresses deposits by 0.14tn€. Overall, the differential impact on lending of CBL and QE comes from the fact that banks respond to 1tn€ QE by cutting their holding of government bonds by 0.35tn€, whereas 1tn€ CBL shock is entirely absorbed by banks as new funding. Interestingly, CBL and QE differ in their state-dependence on liquid asset holdings. QE is more effective when banks hold a low level of reserves and a high level of government bonds, whereas CBL is stronger when banks hold a low level of both types of liquid assets.[32] Notice that the results on QE presented here are only related to the direct effect of the policy through the banking sector and do not take into account how QE affects the real economy more broadly through different channels and agents.

Figure 1·12 presents the impulse response of various variables to both shocks of comparable size in the general equilibrium model. Consistent with results from the partial equilibrium model, CBL provides a larger stimulus to the economy. The intuition is similar to the one presented in partial equilibrium: the entire amount of CBL is injected into the banking sector, whereas only a part of central bank purchases of government bonds is sold by private banks. For this reason, the amount of stimulus to the economy through the banking sector is bigger with CBL. The peak impacts on GDP and loans are respectively 3.4% and 3.2% for CBL, and 2.4% and 2.2% for QE. Government bond holdings by banks move in opposite directions as expected: CBL induces banks to purchase government bonds to use part of the new funding to cut liquidity costs, whereas QE determines a decline in

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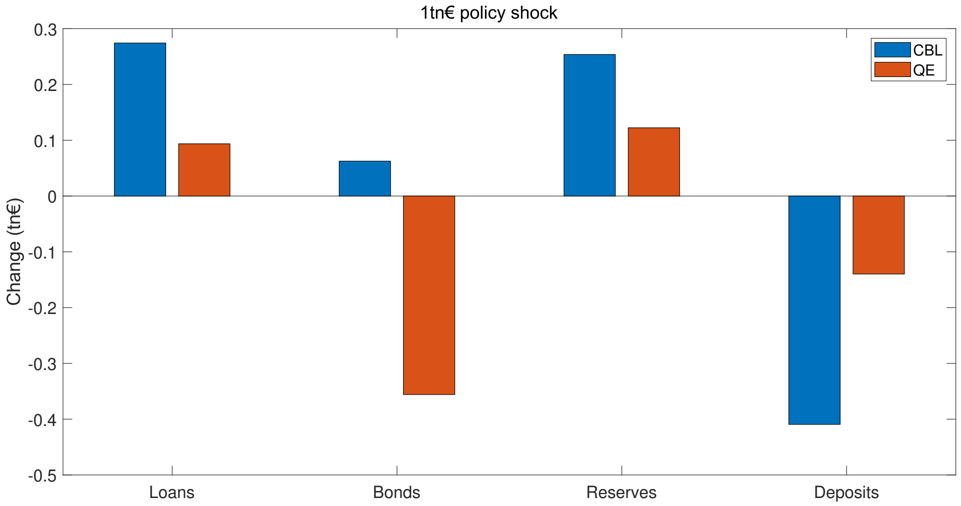
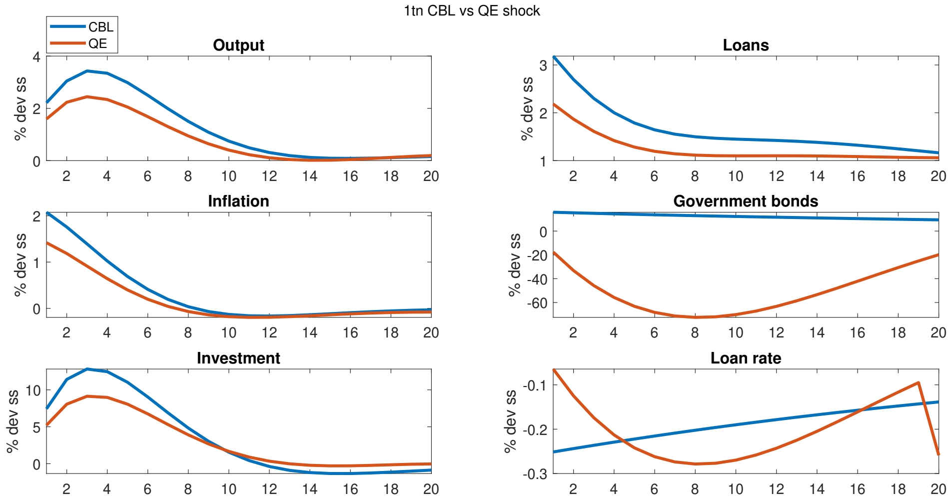
[32] A discussion on the state-dependence of QE is presented in Appendix A.6.

Figure 1·11: Impact of 1tn€ CBL and QE Shocks



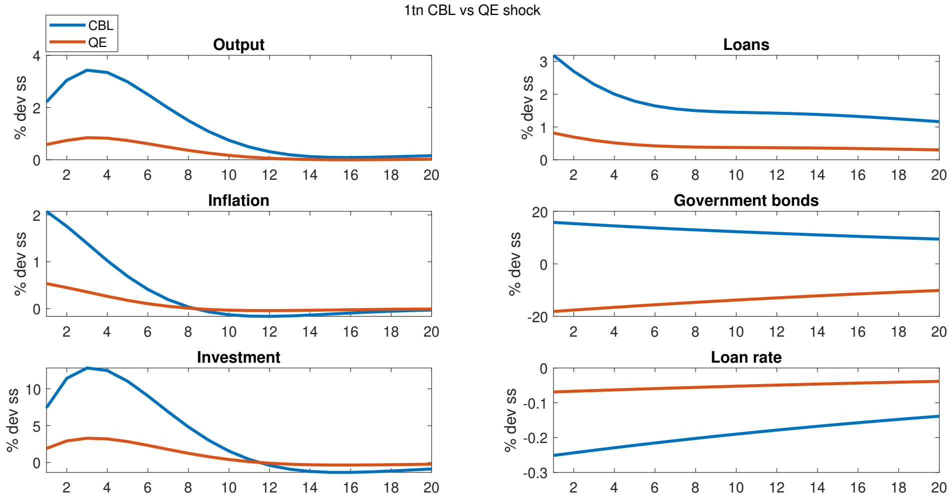
Notes: This Figure reports the change in loans, government bonds, reserves, and deposits after a 1tn€ increase in CBL (blue bars), and QE (red bars). All variables are reported in tn€.

Figure 1·12: IRFs to a CBL Shock and a QE Shock - Baseline



Notes: This Figure shows the impulse responses after a CBL shock of 10% of outstanding loans (1tn€ in steady state) (blue line), and a QE shock of 1tn€ (red line) when the policy rate is fixed at steady state. The CBL shock follows an AR(1) specification. The QE shock is 1tn€ in the first period and peaks at 3.97tn€ after 8 quarters due to the AR(2) specification. All variables are in percentage deviations from the steady state, except for inflation and the loan rate which are reported in annualized percentage deviations from the steady state.

Figure 1·13: IRFs to a CBL Shock and a QE Shock - AR(1)



Notes: This Figure shows the impulse responses after a CBL shock of 10% of outstanding loans (1tn€ in steady state) (blue line), and a QE shock of 1tn€ (red line) when the policy rate is fixed at steady state. Both shocks follow an AR(1) specification with a 0.97 autoregressive coefficient. All variables are in percentage deviations from the steady state, except for inflation and the loan rate which are reported in annualized percentage deviations from the steady state.

government bond holdings as their yield is compressed by the central bank intervention. Compared to the partial equilibrium results, the gap between the impact of CBL and QE on loans is smaller. This outcome comes mainly from the different persistence of the two shocks. CBL is modeled as a very persistent AR(1) process, whereas QE is modeled as an AR(2) process with the first autoregressive coefficient larger than 1 and the second coefficient negative. The implication is that after an initial QE shock of 1tn€, agents expect an expansion in asset purchases by the central bank in the future, which peaks at 3.97tn€. This feature of QE, where central banks purchase gradually government bonds over time rather than in a single period, is consistent with the historical experience. Alternatively, an initial QE shock of 0.25tn€ peaks to 1tn€ after eight quarters and returns an impact on output and loans equal to 0.61% and 0.55%.

For a better quantitative comparison, Figure 1·13 presents the impulse responses after a CBL shock and a QE shock of the same size where both shocks follow the same AR(1) process. In this case, QE increases GDP by 0.85% and loans by 0.82%, thus preserving the wide gap between the effectiveness of the two policies already discussed for the partial equilibrium model.

A Shock to Liquidity Costs for Banks

This model is also well suited to study the impact of adverse liquidity shocks on banks and how CBL can be used as a policy tool to counteract their negative effects on the banking sector. I model liquidity shocks by adding an exogenous shifter ξ_t^{liq} to the liquidity cost function:

$$\mathcal{C}(A_t, R_t, F_t) = \xi_t^{liq} \kappa \left(\frac{[\alpha A_t^\rho + (1-\alpha) R_t^\rho]^{1/\rho}}{F_t} \right)^{-\gamma} F_t$$

An exogenous increase in ξ_t^{liq} raises liquidity costs all else equal. In order to keep liquidity costs constant, then, banks would need to increase their holdings of liquid assets and reduce lending. Intuitively, an increase in ξ_t^{liq} can be seen as a higher probability of an outflow of funds from the bank. The blue dotted line in Figure 1·14 shows the impact of a 10% increase in liquidity costs with a persistence of 0.95. Loans fall by 0.2% and investment declines by 1.2%. The negative impact on the economy leads to an outflow of deposits of 0.2% and a decline in bank capital. Banks respond to the shock also by increasing their holdings of government bonds to counteract the liquidity shock. Suppose now that the central bank does not want to react by reducing the policy rate.[33] In this situation, the central bank can always provide funds to banks with CBL without changing the path of the policy rate. The red dashed line displays the response to a liquidity shock when the central bank increases CBL funding available to banks. Banks use the central bank funding to purchase government bonds to adjust liquidity costs. The outcome is that the decline in loans, investment, and bank capital is reverted. Moreover, also the outflow of deposits is avoided, as the contractionary effects on the economy are muted. Overall, this exercise

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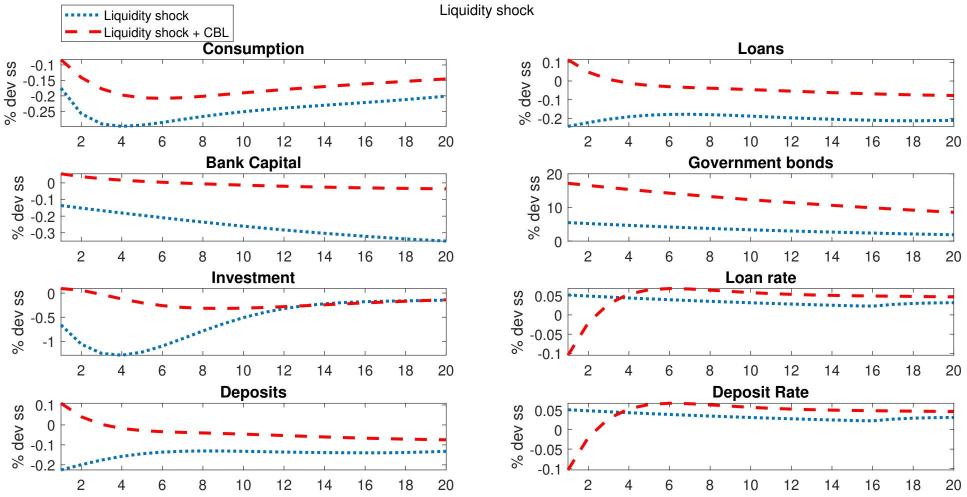
33. This can be true for example when the central bank is tightening the monetary policy stance and does not want to signal an easing of monetary conditions.

shows how CBL can be used as an effective policy tool to counteract liquidity shock to banks.

Figure 1·14: IRFs to a Liquidity Shock



Notes: This Figure shows the impulse responses after a 10% positive shock to the liquidity cost shifter ξ_t^{liq} when the policy rate is constrained. The blue dotted line shows the response after the shock without CBL. The red dashed line shows the response after the shock when the central bank expands CBL by 10% of outstanding private loans.

1.5 Conclusions

The impact of direct and cheap central bank lending on economic activity crucially depends on how private banks decide to use the new funds received from the central bank. This kind of unconventional monetary policy, known as TLTRO in the Eurozone, has been widely employed in the aftermath of the Great Recession. Empirical research using cross-sectional variation across banks in their exposure to TLTRO in Europe has established that direct central bank lending to banks had expansionary effects on private loans, but also that banks used those funds to purchase government bonds, store excess reserves, and substitute other sources of funding.

In this paper, I develop a theoretical framework to study how this form of unconventional monetary policy is transmitted to the real economy, taking into account the different uses that private banks make when receiving central bank loans. I calibrate the banking sector in partial equilibrium to be consistent with the empirical research on TLTRO, which makes use of bank-level data to assess the impact of central bank lending on private banks. I embed this banking model into a New Keynesian model in which aggregate loan demand and deposit supply are endogenous and translate the micro estimates from the literature into an aggregate impact of CBL. I find a 32% aggregate pass-through of direct central bank lending into bank lending, compared to a 27% pass-through in partial equilibrium. The amplification is determined by the expansion in loan supply and deposit demand, and by the large liquidity benefit provided by the injection of reserves into the banking sector.

Quantitatively, an increase in CBL by 10% of outstanding loans raises aggregate real loans by 3.2%, GDP by 3.4%, and provides a stimulus equivalent to a 54 basis point cut to the policy rate. Finally, the model predicts that this policy is state-dependent: direct central bank loans are more effective when banks hold few liquid assets and lending markets are more competitive.

Chapter 2

The Heterogeneous Impact of Conventional and Unconventional Monetary Policy on Bank Lending

2.1 Introduction

Understanding how banks respond to different types of monetary policy instruments is crucial in the study of the transmission mechanism of monetary policy to the real economy. After the Great Recession, central banks expanded their monetary policy toolkit with unconventional policies, including an active use of their balance sheet through large-scale asset purchases (Quantitative Easing). However, conventional adjustments to the policy rate and unconventional interventions in the market for long-term securities might operate differentially through the banking sector. In particular, given the different operational features of the two policies, the balance sheet composition of private banks might play a role in determining the policy impact on bank lending. This paper empirically investigates to what extent standard monetary policy and Quantitative Easing differentially affect lending by banks in the United States, accounting for the different composition of banks' balance sheets.

Using bank-level data and high-frequency instruments for standard monetary shocks and QE, I find that the two policies predominantly affect different types of banks as measured by their balance sheets. Standard interest rate shocks have a stronger impact on loans for banks that are illiquid, bigger, less capitalized, and less reliant on deposit funding. The opposite is true for QE shocks, where the adjustment in lending is more pronounced for banks that are liquid, smaller, more capitalized, and more reliant on deposit funding. Liquidity is the quantitatively most important determinant, followed by capitalization and the deposit share of liabilities, while the contribution of bank size is not statistically significant in the baseline specification. The amount of heterogeneity is large, with the more affected banks displaying a two to three times larger response of lending after three years.

The empirical specification makes use of quarterly bank-level data obtained from Call reports covering the balance sheets of all the commercial banks in the United States from 1988 until 2019. I estimate a panel local projection model to assess the impact of monetary policy on bank lending. To ensure exogeneity in the monetary and QE shocks, I use high-frequency changes in interest rates around FOMC announcements obtained from Bauer and Swanson (2023) and the LSAP factor from Swanson (2021). Some studies have questioned the exogeneity of these monetary shocks, as they tend to be correlated with macroeconomic and financial data which are publicly available before FOMC announcements. To address this issue, I orthogonalize the LSAP factor with respect to macroeconomic data which predate the announcement as in Bauer and Swanson (2023).

First, within each quarter I divide banks into quartiles along four dimensions: liquidity, size, capitalization, and reliance on deposit funding. I estimate the panel local projection model accounting for these bank characteristics and I find that interest rate shocks have a stronger impact on loans for banks that are illiquid, bigger, less capitalized, and less reliant on deposit funding. Quantitative Easing shocks are instead more effective on banks that are liquid, smaller, more capitalized, and more reliant on deposit funding. The degree of heterogeneity is substantial: for example, banks in the 1st quartile of the liquidity distribution reduce lending by 1.43% compared with a 0.63% reduction for banks in the 4th quartile after a one standard deviation monetary policy shock. Similarly, a one standard deviation QE shock determines a decrease in loans by 1.12% for liquid banks and 0.37% for illiquid banks.

I then estimate the same local projection specification and interact the balance sheet characteristics with the policy shocks to assess the relative importance of liquidity, size, capitalization, and funding composition. I find that liquidity owned by banks is the main determinant in affecting the policy impact: a one standard deviation increase in liquidity is associated with a 0.36% reduction in the impact of standard monetary policy shocks on lending, and with a 0.29% increase in the effect of Quantitative Easing shocks. The estimated coefficients for capitalization and deposit share are both 0.24% for standard monetary shocks, and 0.17% and 0.16% respectively for QE shocks. Notably, bank size does not play a statistically significant role.

This paper also provides results on bank deposits and securities holdings. On average, deposits decline by 0.15% after contractionary standard monetary shocks and by 0.18% after QE shocks. In the case of standard monetary shocks, the decline in deposits is weaker for banks with higher liquidity, capitalization, deposit share, and size, while the opposite is true for QE shocks (with an exception for the coefficient related to bank size which is not significant). Liquidity still plays the quantitatively most important role. The response in the share of securities over assets is positive after QE shocks and is stronger for banks with higher liquidity, capitalization, and size. With respect to standard monetary policy shocks, the adjustment in securities is ambiguous and depends on the instrument used to capture interest rate shocks, the sample, and the horizon.

Related Literature. This paper is mainly related to the literature studying the bank-lending channel of monetary policy. Kashyap and Stein (2000) use Call reports data between 1976 and 1993 and find that monetary policy has stronger effects on banks with less liquid balance sheets, thereby providing evidence for a bank-lending channel of monetary policy. In a similar exercise, Carpenter and Demiralp (2012) use Call reports data, a panel VAR specification, but they start their analysis in 1994. They find that the response in loans for banks with different size, liquidity, and capitalization might have opposite signs. Drechsler et al. (2017) show that increases in the Federal Funds Rate lead to outflows of deposits (deposit channel of monetary policy). In this paper, I extend the previous literature along four dimensions: I use a longer sample covering bank-level data from 1988 until 2019, I estimate the impact of monetary policy with panel local projection methods (Jordà (2005)), I use identified high-frequency monetary policy shocks (Bauer and Swanson (2023)), and I add to the analysis the study of unconventional monetary policy (Swanson (2021)).

Another related strand of the literature discusses asymmetries in the impact of monetary policy depending on the state of the economy (Santoro et al. (2014), Tenreyro and Thwaites (2016), Alpanda et al. (2021), Jordà et al. (2020)), and the sign of the shock (Tenreyro and Thwaites (2016), Angrist et al. (2018), Gambacorta and Iannotti (2007)). I contribute to this literature by studying two additional sources driving the asymmetric impact of monetary policy: the composition of banks' balance sheets, and the type of monetary policy instrument.

Finally, this paper is related to the literature studying the impact of conventional and unconventional monetary policy using high-frequency monetary policy surprises. Gürkaynak et al. (2005), Gertler and Karadi (2015), Ramey (2016), Stock and Watson (2018), and Jarociński and Karadi (2020) estimate the impact of monetary policy on asset prices or real variables using high-frequency monetary surprises. Swanson and Jayawickrema (2021) and Swanson (2021) provide instruments for Quantitative Easing shocks and Federal Funds Rate shocks obtained from high-frequency changes in asset prices around FOMC announcements.[1] To address the potential predictability of the policy instrument, Bauer and Swanson (2023) orthogonalize the monetary policy surprises with respect to macroeconomic and financial data that were publicly available before FOMC announcements, and Swanson (2023) estimates the effects of those different monetary policy instruments using aggregate data. In this paper, I employ the same set of orthogonalized high-frequency monetary pol-

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[1] Altavilla et al. (2019) construct similar measures for the Euro Area.

icy surprises to assess the impact of different monetary policy instruments on bank lending using bank-level rather than aggregate data.

This paper is organized as follows. Section 2.2 presents the data sources, transformations, and instruments for the monetary policy shocks. Section 2.3 discusses the empirical specifications used in the paper. Section 2.4 presents empirical results on the impact of monetary policy shocks on banks and Section 2.5 discusses the interaction with banks' balance sheets. Section 2.6 provides robustness checks and Section 2.7 concludes.

2.2 Data

2.2.1 Banks

Bank-level data are available at the quarterly frequency from Call reports, which are filed by financial institutions in the US. This dataset includes information on Balance Sheet and Income Statement for all banks active in the United States. The data are processed as in Drechsler et al. (2017) in order to form a consistent time-series for US bank balance sheets. The relevant banking variables used in the empirical analysis are Commercial and Industrial loans, securities (including also trading assets), bank capital, total bank assets and liabilities, and total domestic deposits. As in Kashyap and Stein (2000), I drop observations for banks displaying a share of commercial and industrial loans over total loans which is below 5%. Finally, to exclude outliers, I drop observations above the 98.5 percentile and below the 1.5 percentile for loan growth, securities growth, and deposit growth. All nominal variables are transformed into real terms by using the US GDP deflator obtained from FRED.

2.2.2 Exogenous Policy Shocks

In this paper, I use instruments for monetary policy and QE shocks identified via high-frequency variation in financial assets around FOMC announcements. Bauer and Swanson

(2023) provide a measure for monetary policy shocks that is orthogonal to macroeconomic and financial data which are publicly available before the respective FOMC announcements. This instrument is used in the empirical analysis presented in the paper to capture standard monetary policy shocks.

Swanson (2021) constructs measures of monetary policy shocks that separate surprise changes in the federal funds rate, forward guidance, and large-scale asset purchases (QE). To ensure the complete exogeneity of these instruments, I orthogonalize the federal funds rate instrument and the QE instrument with respect to information available before the announcements as in Bauer and Swanson (2023).[2] I then use the orthogonalized QE instrument as my main measure of QE shocks, and the FFR instrument as an alternative measure of conventional monetary policy shocks to assess the robustness of the main results of the paper.

2.3 Empirical Strategy

In this Section, I explain the empirical strategy that I use to assess the impact of monetary policy shocks on banks. I first discuss the methodology employed to estimate the impact of monetary shocks on all banks, irrespective of the composition of their balance sheets. I then explain how I evaluate the differential impact of monetary policy across different banks depending on their characteristics.

2.3.1 Impact of monetary shocks

I employ panel local projection methods to estimate the impact of monetary shocks over time as in Jordà (2005). $y_{i,t+h}$ denotes the logarithm of the dependent variable for bank i, h periods ahead. The dependent variables are commercial & industrial loans, securities held

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[2] In particular, I regress the FFR and QE instruments on a set of predictors (nonfarm payrolls surprise, employment growth, 3-month growth in the S&P500, change in the slope of the yield curve, growth rate of commodity prices, skewness of the ten-year Treasury yield), and obtain the regression residuals that are orthogonal to the predictors included in the estimation.

by banks, deposits, and the share of securities over total assets. The monetary policy shock is ϵ_t^k, where the shock could be either a standard policy shock or a Quantitative Easing shock, such that $k \in (MP, QE)$. By using monetary and QE shocks obtained from high-frequency identification and orthogonalized with respect to available information at the time of the announcement, I ensure the exogeneity in the policy instruments. In addition, I add to the regression a set of control variables X_t^i which include a time trend and the lags of loan growth, securities growth, deposits growth, share of loans over assets, share of securities over assets, share of deposits over liabilities, capital share, aggregate GDP growth, and aggregate inflation.[3] Bank fixed-effects are included in each regression, and I assume two lags ($J = 2$) in the baseline specifications. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation.

Equation (2.1) presents the econometric model:

$$y_{i,t+h} - y_{i,t-1} = \alpha_0^h + \alpha^{h,i} + \sum_{j=0}^{J} \beta_j^h \epsilon_{t-j}^k + \sum_{j=1}^{J} \gamma_j^h X_{t-j}^i + \varepsilon_t^{h,i} \tag{2.1}$$

The coefficient of interest is β_0^h, which captures the impact of the policy shock on banks h-periods ahead.

2.3.2 Bank Heterogeneity

The main objective of this paper is to evaluate the potential heterogeneity in the transmission of monetary policy shocks to the banking sector depending on the type of monetary instrument and banks' characteristics. In particular, I assess the importance of liquidity, size, capitalization, and funding composition in determining the effects of monetary policy on bank behavior. For each quarter, I divide banks into quartiles by their share of securities over assets (liquidity), total assets (size), capital share of assets (capitalization), and deposit share of liabilities (funding composition). Quartiles are indexed by $q = [1, 2, 3, 4]$.

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[3] Real GDP and CPI inflation are obtained from FRED.

The econometric model becomes:

$$
\begin{aligned}
y_{i,q,t+h} - y_{i,q,t-1} = &\alpha_0^h + \alpha^{h,i} + \delta^{h,q} + \sum_{j=0}^{J} \beta_j^h \epsilon_{t-j}^k \\
&+ \sum_{s=2}^{4} \beta^{h,s} \epsilon_t^k * 1(s=q) + \sum_{j=1}^{J} \gamma_j^h X_{t-j}^i + \varepsilon_t^{h,q,i}
\end{aligned}
\tag{2.2}
$$

The interpretation of the coefficient β_0^h is now different: it measures the impact of monetary shocks on the dependent variable for banks belonging to the first quartile of the distribution. Coefficients $\beta^{h,q}$ for $q \in (2,3,4)$ capture the differential responses to policy shocks between the first and the q-th quartiles. If $\beta^{h,q}$ is statistically significant, it means that the response of banks in quartile q is different compared to the response for banks in the first quartile.

2.4 The overall impact of policy shocks on banks

In this Section, I present the results on the impact of standard monetary policy and Quantitative Easing shocks using the model outlined in Equation (2.1). This model does not account for the possible heterogeneity in the response after a shock for banks with different balance sheet compositions, which is discussed in Section 2.5.

Figure 2·1 displays the impulse responses for loans, securities, deposits, and the share of securities over assets after a one standard deviation contractionary monetary policy shock. As expected, the contractionary shock leads to a decline in loans and deposits. The response for securities is negative for the first eight quarters after the shock, and positive afterward. The decline in deposits is consistent with the deposit channel of monetary policy discussed by Drechsler et al. (2017). Notably, the peak in the response for loans appears after three years, suggesting that monetary policy shocks take time to be fully transmitted to the real economy.[4]

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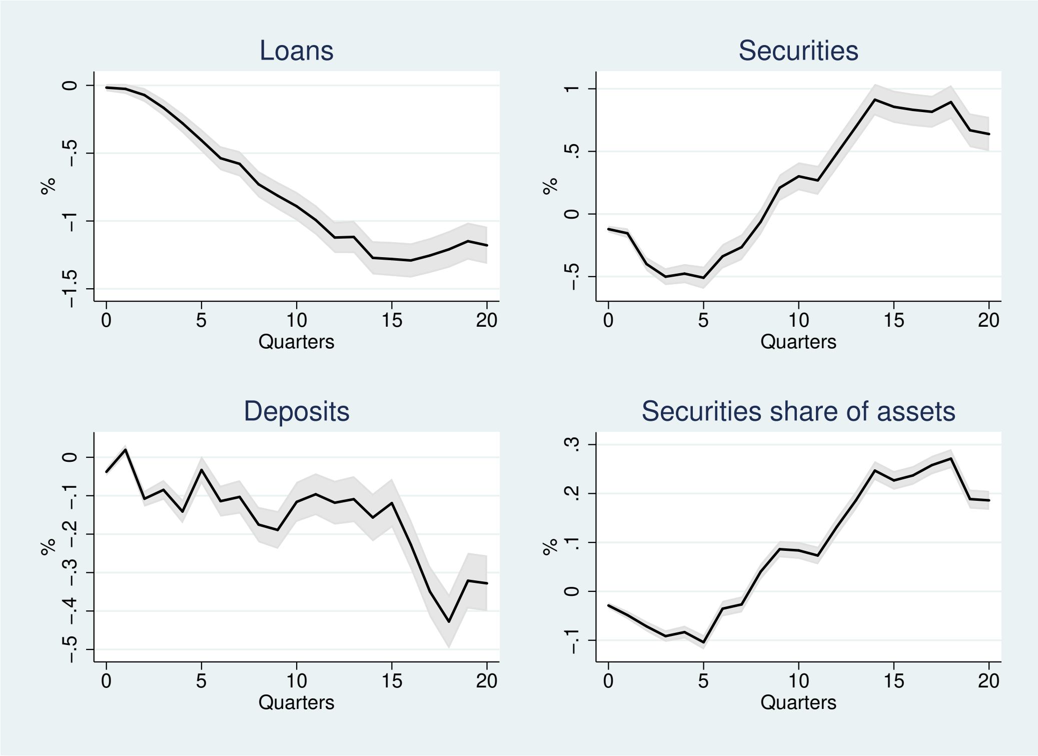
[4] Appendix B.1 shows that the results using the FFR factor as a proxy for the monetary policy shocks are qualitatively the same.

Figure 2·1: Impulse Responses After a Monetary Shock

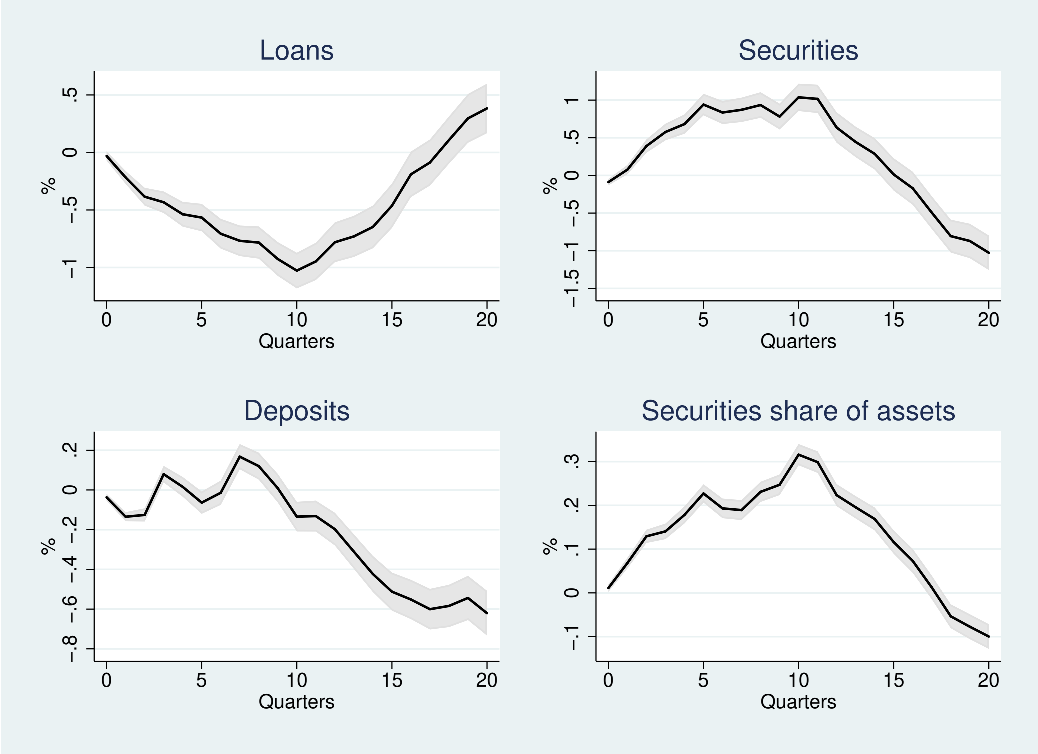


Notes: This Figure reports the impulse responses for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary monetary shock. The model specification is presented in Equation (2.1). 95% confidence intervals are displayed. Sample: 1989Q1-2019Q4.

Figure 2·2 presents the impulse responses after a contractionary Quantitative Easing shock. Similarly to the case of a standard monetary shock, loans and deposits decline. The response in loans reaches its trough after 10 quarters and then reverts, suggesting that standard policy shocks have longer-lasting effects on lending. As expected, the response in securities is positive: when the central bank reduces (increases) its asset purchases, banks increase (reduce) the quantity and share of securities in their balance sheets. Overall, the two policies produce the same qualitative effect on loans and deposits, while the impact on securities is the opposite for the first two years. The reduction in lending is more front-loaded for Quantitative Easing shocks, whereas standard monetary policy shocks produce more persistent effects.

The scale of the two shocks is one standard deviation. The monetary shock is constructed by Bauer and Swanson (2023) such that a unitary change in the policy shocks leads to a 100bp increase in short-term interest rates.[5] Given that the standard deviation on the monetary shock is around 8 basis points, the impact of a 25bp monetary surprise can be computed by multiplying the impulse responses by a factor of 3. It follows that a 25bp monetary surprise leads to a decline in loans by around 3.75% after 14 quarters. For Quantitative Easing, Swanson (2021) reports that a one standard deviation change in the Quantitative Easing factor corresponds to a 215$ billion surprise QE announcement. Thus, impulse responses to the QE shock should be quantitatively interpreted as a response to an unexpected announcement of this magnitude.

Figure 2·2: Impulse Responses After a Quantitative Easing Shock



Notes: This Figure reports the impulse responses for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary Quantitative Easing shock. The model specification is presented in Equation (2.1). 95% confidence intervals are displayed. Sample: 2000Q1-2019Q2.

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[5] In particular, the short-term rate is the Eurodollar futures contract four quarters ahead.

2.5 Bank Heterogeneity

In this Section, I study the possible heterogeneity in banks' response to monetary and Quantitative Easing shocks depending on the composition of their balance sheet. For each quarter, I divide banks into quartiles in terms of liquidity, size, capitalization, and funding composition. To capture bank liquidity, I compute the share of securities held by banks over total assets. Size is measured by total assets in banks' balance sheets, while capitalization is constructed as the share of capital over assets. Finally, I measure banks' funding composition as the share of deposits over total liabilities. I then estimate Equation (2.2) separately for each type of shock and for each source of heterogeneity. To assess the heterogeneity between different quartiles, I focus on the difference between the response of banks in the 4th quartile and banks in the 1st quartile.

2.5.1 Liquidity

Figure 2·3 displays the differential impulse responses between banks in the 4th quartile of liquidity and banks in the 1st quartile of liquidity. A positive response implies that being in the 4th quartile results in a more positive impact compared to the response for banks in the 1st quartile.[6] In particular, the Figure reports coefficients $\beta^{h,4}$ presented in Equation (2.2). Notice that these coefficients do not capture the total impact of the policy shocks on banks in the 4th quartile, but they rather capture the differential impact compared to banks in the 1st quartile. The total impact for banks in quartile q can be computed as $\beta^h + \beta^{h,q}$.

It is clear from Figure 2·3 that loans and deposits in banks with a higher share of liquid assets are less affected by standard monetary policy shocks, and this difference is statistically significant. The response in securities is instead more ambiguous, although it suggests that the most liquid banks reduce the share of securities compared to the least liquid banks. Table 2.1 reports the results for the local projections 4-quarters ahead and

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[6] This does not necessarily mean that the sign of the response is different across quartiles.

12-quarters ahead. A monetary policy shock of one standard deviation leads to a decline in loans by 1.43% for banks in the 1st quartile of liquidity. The interaction term between the policy shock and the 4th quartile dummy is positive and statistically significant, suggesting that banks in the 4th quartile reduce lending by 0.80% less compared to banks in the 1st quartile. In other words, the most liquid banks reduce lending by 0.63% after 12-quarters compared to a reduction of 1.43% for the most illiquid banks. Interestingly, the sign of the response in deposits is different between liquid and illiquid banks. While illiquid banks reduce their deposit funding by 0.44% 12-quarters ahead, liquid banks increase deposits by 0.35%.[7]

Table 2.1: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Liquidity

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
Policy shock	-0.50***	-1.43***	-0.55***	0.91***	-0.19***	-0.44***	-0.04***	0.15***
	(-7.45)	(-12.13)	(-4.87)	(5.24)	(-5.41)	(-6.66)	(-3.45)	(9.05)
2nd quartile × Policy shock	0.12	0.03	-0.08	-0.59***	-0.02	0.07	-0.05***	0.01
	(1.37)	(0.18)	(-0.62)	(-3.03)	(-0.45)	(0.83)	(-3.12)	(0.66)
3rd quartile × Policy shock	0.36***	0.44***	0.06	-0.61***	0.06	0.36***	-0.06***	-0.02
	(4.18)	(2.98)	(0.50)	(-3.26)	(1.33)	(4.54)	(-3.97)	(-0.76)
4th quartile × Policy shock	0.38***	0.80***	0.34***	-0.29	0.15***	0.79***	-0.05***	-0.06**
	(4.28)	(5.35)	(2.88)	(-1.58)	(3.65)	(10.27)	(-3.06)	(-2.44)
R-squared	0.040	0.081	0.098	0.171	0.083	0.074	0.201	0.343
N. Observations	610,283	523,370	610,283	523,370	610,283	523,370	610,283	523,370

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of liquidity. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2019Q4.

I now turn to the study of Quantitative Easing shocks. Figure 2·4 displays the differential response to contractionary QE shocks between liquid and illiquid banks. The differential impulse responses look the opposite compared to the standard monetary shock: after a QE shock, loans and deposits in the most liquid banks are more affected. Table 2.2 helps in understanding the magnitudes and signs in the responses. Illiquid banks reduce lending by 0.37% after 12 quarters, while liquid banks cut lending by 1.12% (which is computed as -0.37% -0.75%=-1.12%). Interestingly, the impact on securities after 12

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[7] Results are not affected by estimating the regression until 2009, the beginning of the ZLB period.

Figure 2·3: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Liquidity

Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of liquidity and banks in the 1st quartile of liquidity for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary monetary shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 1989Q1-2019Q4.

quarters is not significant for illiquid banks and becomes positive and significant for banks in the upper quartiles. It follows that after contractionary QE shocks, banks increase the share of securities over assets, with a stronger impact on liquid banks.[8]

Overall, the analysis outlined in this Section suggests that banks with a large share of liquid assets in their balance sheet are less affected by standard monetary shocks and more affected by QE shocks compared to banks with a low share of liquidity.

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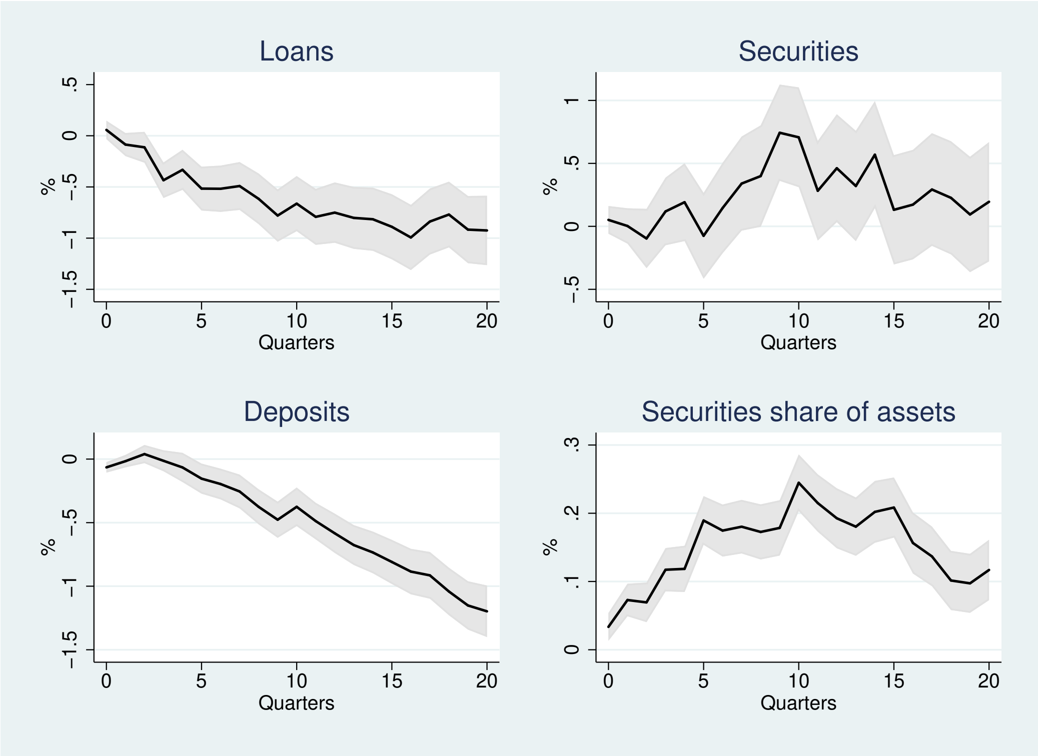
[8] The implication is that after an expansionary QE shock, the most liquid banks increase lending more and sell a larger amount of securities as a share of their balance sheet.

Figure 2·4: Impulse Responses After a QE Shock - 4th vs 1st quartile of Liquidity



Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of liquidity and banks in the 1st quartile of liquidity for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary QE shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 2000Q1-2019Q2.

Table 2.2: Impulse Responses After a QE Shock - 4th vs 1st quartile of Liquidity

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
QE (neg.)	-0.36***	-0.37***	0.48***	0.25	0.07	0.13*	0.11***	0.13***
	(-4.05)	(-2.72)	(3.03)	(1.07)	(1.34)	(1.70)	(8.54)	(7.70)
2nd quartile × QE (neg.)	-0.10	-0.32**	0.25	0.41*	-0.05	-0.18**	0.05***	0.04*
	(-0.99)	(-2.00)	(1.46)	(1.73)	(-0.76)	(-1.98)	(3.08)	(1.68)
3rd quartile × QE (neg.)	-0.27***	-0.51***	0.27	0.53**	-0.11*	-0.45***	0.09***	0.11***
	(-2.73)	(-3.39)	(1.62)	(2.36)	(-1.84)	(-5.52)	(5.60)	(5.26)
4th quartile × QE (neg.)	-0.33***	-0.75***	0.19	0.46**	-0.07	-0.58***	0.12***	0.19***
	(-3.33)	(-4.99)	(1.22)	(2.11)	(-1.12)	(-7.41)	(6.87)	(8.60)
R-squared	0.035	0.080	0.100	0.202	0.104	0.084	0.205	0.390
N. Observations	314,654	261,220	314,654	261,220	314,654	261,220	314,654	261,220

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of liquidity. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 2000Q1-2019Q2.

2.5.2 Capitalization

Does bank capital matter for the transmission of monetary policy through the banking sector? Figure 2·5 displays the differential impulse responses between banks in the 4th quartile of capitalization and banks in the 1st quartile of capitalization for a standard contractionary monetary policy shock. The positive differential impulse responses for loans and deposits imply that banks with a larger capital share are less affected by these shocks compared to banks with a low capital share. The differential response for securities is positive, while the differential response for the share of securities over assets is negative. Table 2.3 helps in quantifying these effects. After 12 quarters, loans decline by 1.41% for less capitalized banks, and by 0.58% for more capitalized banks. Deposits decrease in banks with a low capital share and increase in banks with a high capital share. The adjustment in securities is not significant for less capitalized banks and positive for banks with higher capitalization.[9] However, the share of securities over assets increases for banks with low capital and decreases for banks with high capital, thus suggesting a decline in total assets for the first group and an increase for the latter group.

Table 2.3: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Capitalization

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
Policy shock	-0.24***	-1.41***	-0.55***	0.14	-0.14***	-0.38***	-0.08***	0.12***
	(-3.69)	(-12.71)	(-7.14)	(1.18)	(-4.40)	(-6.19)	(-6.41)	(6.80)
2nd quartile × Policy shock	-0.12	0.04	0.15	0.49***	0.02	0.19**	0.04**	0.07***
	(-1.41)	(0.26)	(1.47)	(3.15)	(0.42)	(2.37)	(2.58)	(3.08)
3rd quartile × Policy shock	-0.10	0.30**	0.07	0.45***	-0.05	0.25***	-0.01	0.02
	(-1.13)	(2.08)	(0.73)	(2.97)	(-1.14)	(3.31)	(-0.83)	(0.99)
4th quartile × Policy shock	0.09	0.83***	0.03	0.36**	0.04	0.59***	-0.05***	-0.07***
	(1.02)	(5.77)	(0.34)	(2.40)	(0.91)	(7.86)	(-2.71)	(-2.85)
R-squared	0.040	0.080	0.091	0.158	0.083	0.074	0.199	0.342
N. Observations	610,283	523,370	610,283	523,370	610,283	523,370	610,283	523,370

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of capitalization. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2019Q4.

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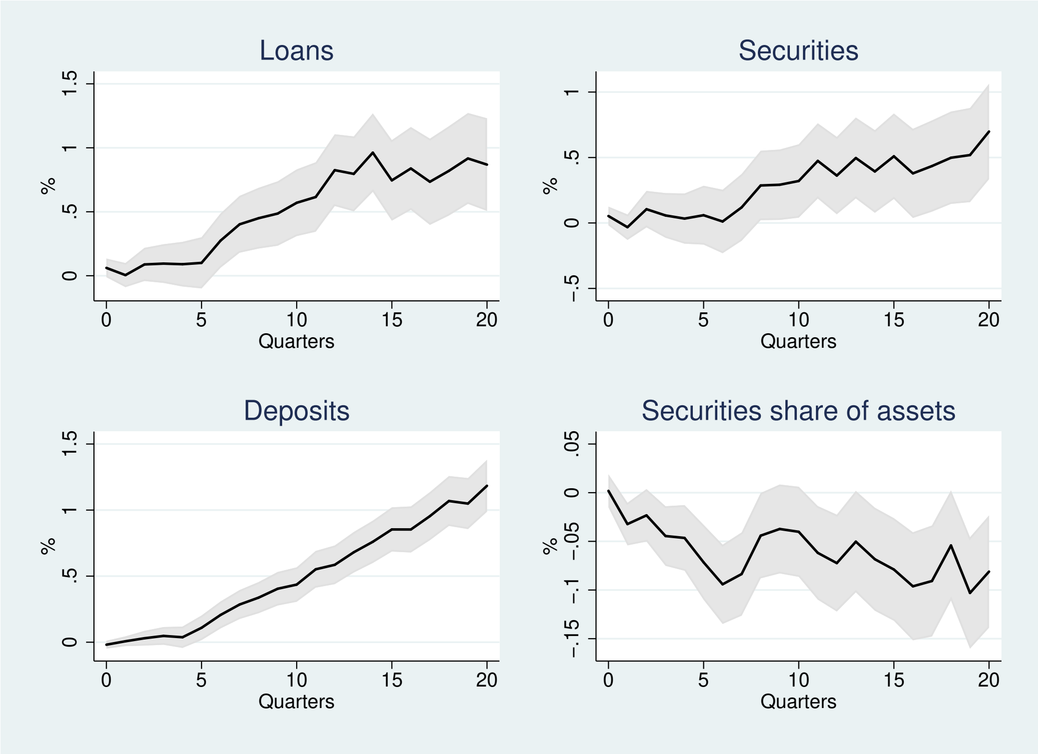
[9] After 4 quarters, the picture is different. All banks similarly reduce their securities holdings irrespective of their capitalization.

Figure 2·5: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Capitalization

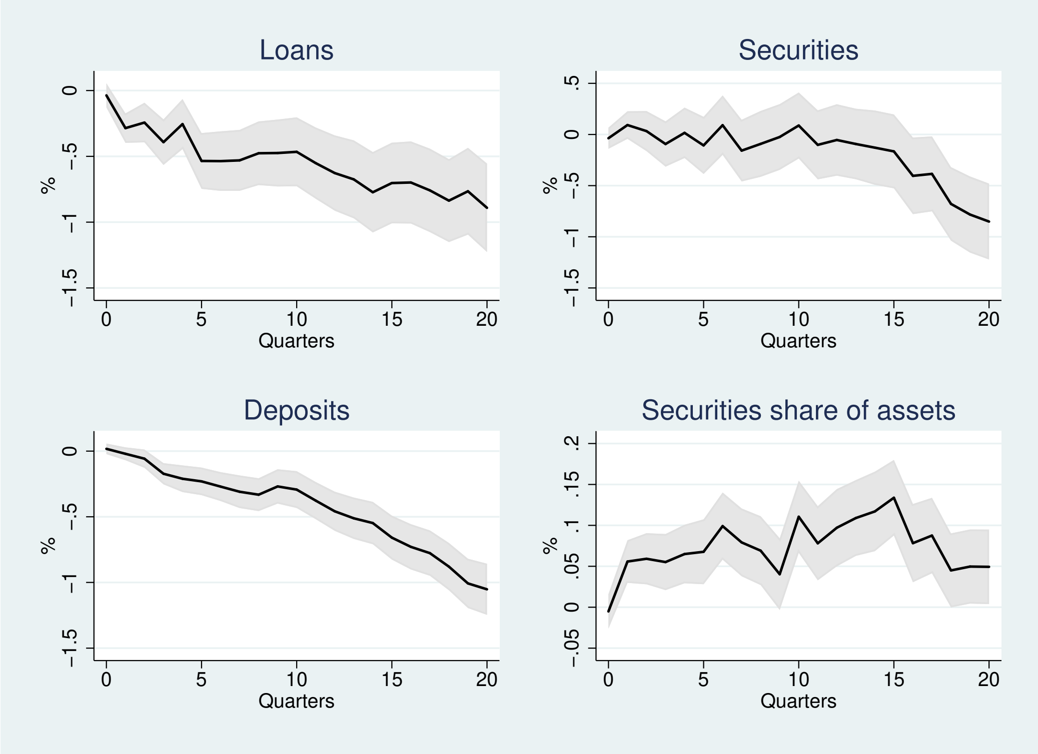


Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of capitalization and banks in the 1st quartile of capitalization for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary monetary shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 1989Q1-2019Q4.

The differential response after Quantitative Easing shocks is the opposite compared to monetary shocks. An increase in central bank purchases determines a stronger impact on loans and deposits for banks with a high level of capitalization. This result is presented in Figure 2·6, where the differential response is negative. The impulse response for securities is not statistically different for the first four years, while the share of securities over assets increases more for the most capitalized banks. Table 2.4 presents the quantitative results. Banks with a low capital share decrease lending by 0.52% after three years, while lending for banks with a high capital share drops by 1.15%. Although the response in securities is the same for all quartiles of the capital distribution, the share of securities increases more for banks with high capitalization, thereby suggesting a differential adjustment in total assets for the two groups of banks.

To summarize, standard monetary shocks affect banks with a low capital share much more compared to banks with a high capital share. The opposite is true for QE shocks, which have a stronger impact on the most capitalized banks.

Figure 2·6: Impulse Responses After a QE Shock - 4th vs 1st quartile of Capitalization



Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of capitalization and banks in the 1st quartile of capitalization for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary QE shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 2000Q1-2019Q2.

Table 2.4: Impulse Responses After a QE Shock - 4th vs 1st quartile of Capitalization

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
QE (neg.)	-0.48***	-0.52***	0.65***	0.58***	0.10***	-0.00	0.16***	0.19***
	(-5.98)	(-4.18)	(6.16)	(3.78)	(2.65)	(-0.05)	(10.64)	(10.24)
2nd quartile × QE (neg.)	0.02	-0.10	0.16	0.33*	-0.02	-0.04	0.02	0.02
	(0.21)	(-0.63)	(1.19)	(1.74)	(-0.52)	(-0.48)	(1.10)	(0.75)
3rd quartile × QE (neg.)	-0.01	-0.33**	-0.05	-0.07	-0.12***	-0.28***	0.01	0.01
	(-0.14)	(-2.34)	(-0.38)	(-0.39)	(-2.59)	(-3.92)	(0.29)	(0.26)
4th quartile × QE (neg.)	-0.25***	-0.63***	0.02	-0.05	-0.21***	-0.46***	0.06***	0.10***
	(-2.63)	(-4.30)	(0.13)	(-0.30)	(-4.07)	(-6.03)	(3.56)	(4.03)
R-squared	0.035	0.079	0.092	0.187	0.104	0.084	0.205	0.390
N. Observations	314,654	261,220	314,654	261,220	314,654	261,220	314,654	261,220

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of capitalization. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 2000Q1-2019Q2.

2.5.3 Size

Figure 2·7 plots the differential impulse responses between banks in the 4th quartile of size (measured by total assets) and banks in the 1st quartile of size. Bigger banks report a stronger decline in loans and deposits after a contractionary monetary policy shock. Table 2.5 quantifies this differential: loans decline by 0.61% for small banks, and by 1.64% for big banks. Interestingly, the share of securities over total assets increases more for bigger banks, suggesting a stronger reallocation of their assets.

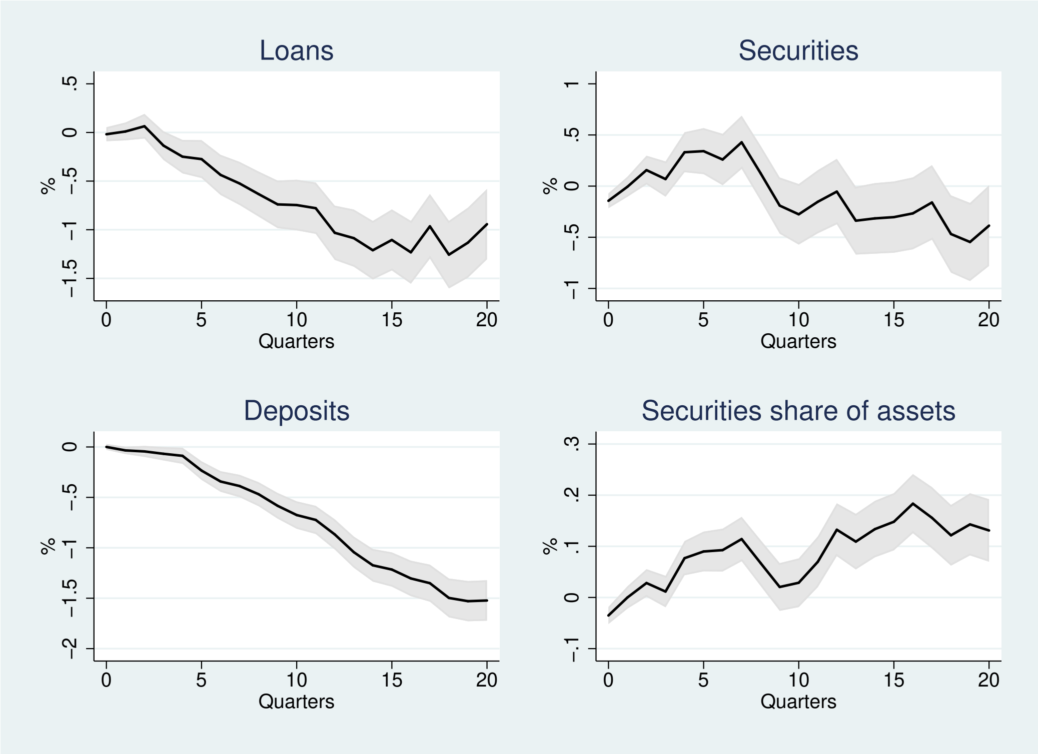
Table 2.5: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Size

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
Policy shock	-0.19***	-0.61***	-0.67***	0.33***	-0.10***	0.28***	-0.12***	0.05**
	(-2.61)	(-5.35)	(-8.84)	(2.62)	(-3.51)	(5.34)	(-9.09)	(2.42)
2nd quartile × Policy shock	-0.11	-0.66***	0.23**	0.29*	-0.07*	-0.39***	0.04**	0.10***
	(-1.18)	(-4.53)	(2.29)	(1.86)	(-1.82)	(-5.96)	(2.43)	(3.95)
3rd quartile × Policy shock	-0.06	-0.54***	0.17*	0.21	-0.09**	-0.51***	0.04**	0.10***
	(-0.65)	(-3.79)	(1.71)	(1.34)	(-2.54)	(-7.78)	(2.54)	(3.77)
4th quartile × Policy shock	-0.25***	-1.03***	0.33***	-0.05	-0.09**	-0.87***	0.08***	0.13***
	(-2.84)	(-7.25)	(3.33)	(-0.33)	(-2.16)	(-11.35)	(4.51)	(5.03)
R-squared	0.044	0.094	0.092	0.164	0.104	0.132	0.200	0.343
N. Observations	610,283	523,370	610,283	523,370	610,283	523,370	610,283	523,370

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of size. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2019Q4.

Figure 2·7: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Size

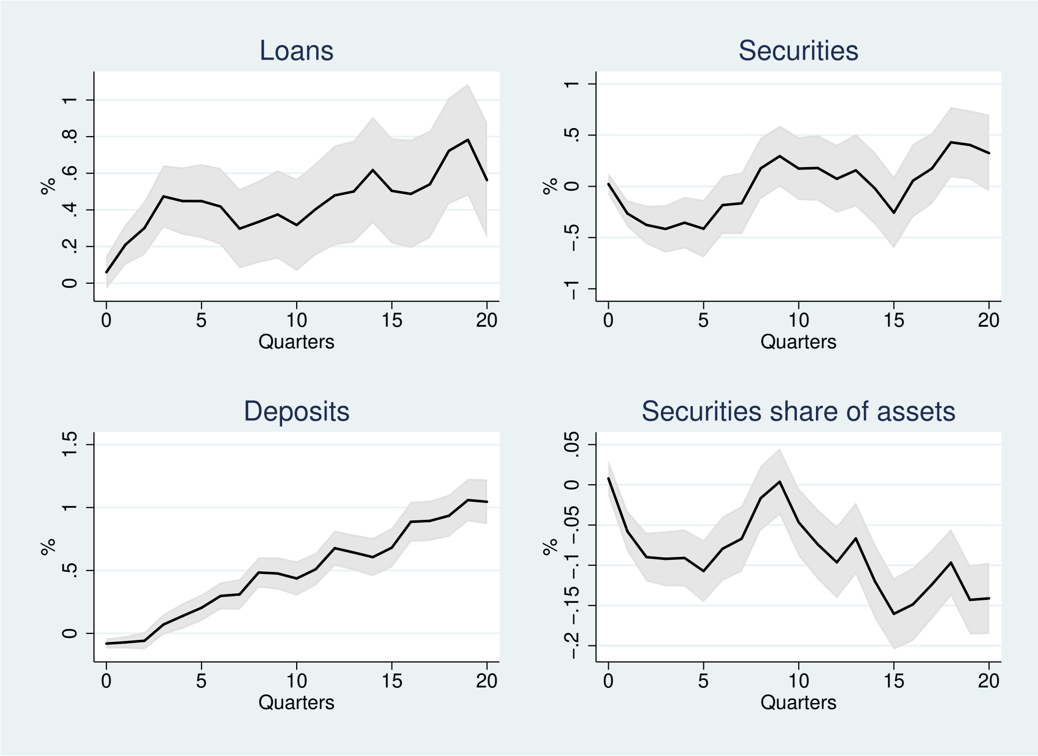


Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of size and banks in the 1st quartile of size for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary monetary shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 1989Q1-2019Q4.

The differential impulse responses after QE shocks are again opposite compared to standard monetary shocks. Figure 2·8 highlights a positive differential response for bigger banks on loans and deposits, thus implying a weaker impact of QE shocks on these banks. Quantitatively, after 12 quarters, smaller banks reduce lending by 1.03% while bigger banks cut loans by 0.55%. Bigger banks also display a smaller increase in the share of securities in their balance sheet.

Overall, the differential impact of monetary and QE shocks is preserved when banks are divided by size quartiles. Bigger banks decrease lending much more after standard monetary shocks, while the same is true for smaller banks affected by QE shocks.

Figure 2·8: Impulse Responses After a QE Shock - 4th vs 1st quartile of Size



Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of size and banks in the 1st quartile of size for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary QE shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 2000Q1-2019Q2.

Table 2.6: Impulse Responses After a QE Shock - 4th vs 1st quartile of Size

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
QE (neg.)	-0.77***	-1.03***	1.00***	0.73***	-0.02	-0.45***	0.24***	0.29***
	(-8.72)	(-7.55)	(8.94)	(4.60)	(-0.50)	(-7.39)	(14.69)	(13.39)
2nd quartile × QE (neg.)	0.27***	0.42***	-0.35***	-0.01	0.04	0.30***	-0.07***	-0.06**
	(2.67)	(2.83)	(-2.64)	(-0.06)	(0.79)	(4.59)	(-3.52)	(-2.57)
3rd quartile × QE (neg.)	0.27***	0.41***	-0.45***	-0.14	0.08*	0.40***	-0.10***	-0.09***
	(2.83)	(2.91)	(-3.45)	(-0.82)	(1.89)	(5.98)	(-5.66)	(-3.93)
4th quartile × QE (neg.)	0.45***	0.48***	-0.35***	0.07	0.14***	0.68***	-0.09***	-0.10***
	(4.81)	(3.46)	(-2.76)	(0.44)	(2.69)	(9.58)	(-5.04)	(-4.24)
R-squared	0.039	0.096	0.093	0.195	0.130	0.162	0.205	0.390
N. Observations	314,654	261,220	314,654	261,220	314,654	261,220	314,654	261,220

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of size. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 2000Q1-2019Q2.

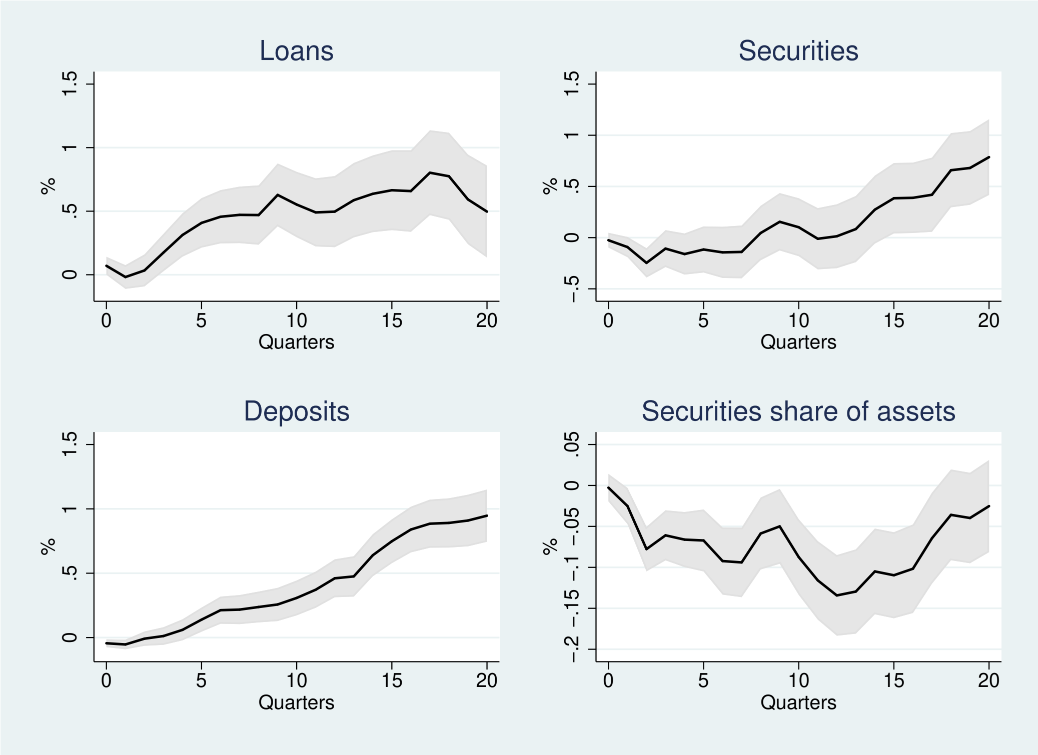
2.5.4 Deposit Share of Liabilities

Finally, I estimate the differential responses to monetary shocks for banks with different compositions in their liabilities, measured by the share of deposits over total liabilities. Standard monetary shocks determine weaker effects on lending and deposits for banks that heavily rely on deposit funding (see Figure 2·9). A bank with a low deposit share cuts lending by 1.48% compared to a drop of 0.98% for banks with a high deposit share (see Table 2.7). The response in deposits changes sign depending on the type of bank: low-deposits banks reduce deposits by 0.35%, while high-deposits banks display an increase by 0.11%. The positive adjustment in the share of securities over assets is stronger for low-deposits banks.

Figure 2·10 and Table 2.8 present impulse responses and regression coefficients for QE shocks. High-deposits banks decrease lending and deposits much more compared to low-deposits banks, while the differential adjustment in the share of securities is more ambiguous. Loans drop by 0.61% in low-deposits banks and by 1.05% in high-deposits banks. Low-deposits banks do not adjust deposits after QE shocks, while high-deposits banks decrease their deposit funding by 0.38%.

Overall, the results presented in this Section suggest that standard monetary shocks determine stronger effects on banks with a low deposit base, while the opposite is true for QE shocks.

Figure 2·9: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Deposit Share



Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of deposit share of liabilities and banks in the 1st quartile of deposit share of liabilities for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary monetary shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 1989Q1-2019Q4.

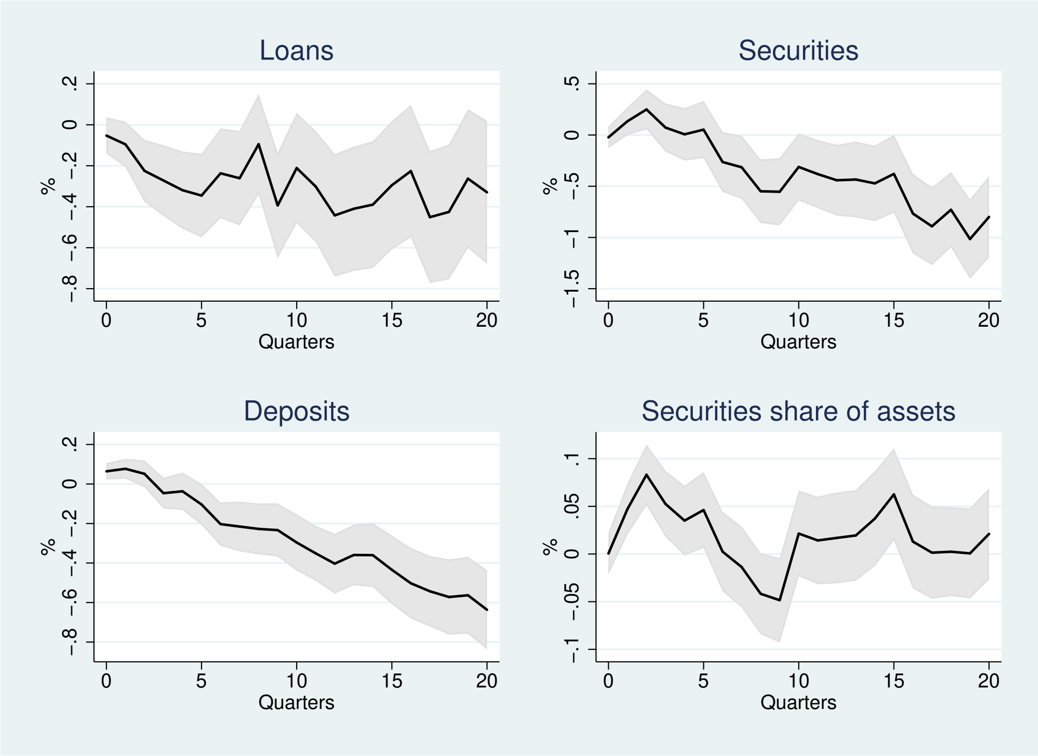
Table 2.7: Impulse Responses After a Monetary Shock - 4th vs 1st quartile of Deposit Share

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
Policy shock	-0.49***	-1.48***	-0.47***	0.20*	-0.17***	-0.35***	-0.06***	0.18***
	(-7.80)	(-14.45)	(-6.27)	(1.86)	(-4.98)	(-5.83)	(-4.71)	(10.73)
2nd quartile × Policy shock	0.12	0.27*	0.08	0.46***	-0.03	0.01	0.00	-0.00
	(1.43)	(1.94)	(0.78)	(3.07)	(-0.67)	(0.17)	(0.31)	(-0.06)
3rd quartile × Policy shock	0.36***	0.65***	0.03	0.58***	0.06	0.39***	-0.05***	-0.05**
	(4.26)	(4.73)	(0.29)	(3.93)	(1.47)	(5.18)	(-2.75)	(-2.08)
4th quartile × Policy shock	0.31***	0.50***	-0.16	0.01	0.06	0.46***	-0.07***	-0.13***
	(3.60)	(3.48)	(-1.57)	(0.09)	(1.45)	(6.14)	(-3.85)	(-5.35)
R-squared	0.040	0.080	0.091	0.158	0.083	0.074	0.199	0.342
N. Observations	610,283	523,370	610,283	523,370	610,283	523,370	610,283	523,370

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of deposit share of liabilities. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2019Q4.

Figure 2·10: Impulse Responses After a QE Shock - 4th vs 1st quartile of Deposit Share



Notes: This Figure reports the differential impulse responses between banks in the 4th quartile of deposit share of liabilities and banks in the 1st quartile of deposit share of liabilities for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary QE shock. The model specification is presented in Equation (2.2). The Figure plots coefficients $\beta^{h,4}$, where h refers to the horizon. 95% confidence intervals are displayed. Sample: 2000Q1-2019Q2.

Table 2.8: Impulse Responses After a QE Shock - 4th vs 1st quartile of Deposit Share

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
QE (neg.)	-0.36***	-0.61***	0.82***	1.09***	0.07	0.02	0.17***	0.24***
	(-4.52)	(-4.90)	(8.22)	(7.40)	(1.62)	(0.34)	(12.31)	(13.02)
2nd quartile × QE (neg.)	-0.09	0.06	-0.31**	-0.39**	-0.05	-0.05	-0.03	-0.05**
	(-0.90)	(0.39)	(-2.42)	(-2.09)	(-0.95)	(-0.58)	(-1.57)	(-2.05)
3rd quartile × QE (neg.)	-0.32***	-0.47***	-0.11	-0.62***	-0.09	-0.32***	0.02	0.00
	(-3.31)	(-3.18)	(-0.89)	(-3.64)	(-1.62)	(-4.09)	(0.95)	(0.18)
4th quartile × QE (neg.)	-0.32***	-0.44***	0.01	-0.44**	-0.04	-0.40***	0.04*	0.02
R-squared	0.035	0.079	0.092	0.187	0.104	0.085	0.204	0.390
N. Observations	314,654	261,220	314,654	261,220	314,654	261,220	314,654	261,220

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.2) where banks are divided into quartiles of deposit share of liabilities. Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 2000Q1-2019Q2.

2.5.5 Discussion

In this Section, I assess the relative importance of liquidity, size, capitalization, and the deposit share of liabilities in affecting the differential impact of monetary policy on banks. Rather than dividing banks into separate quartiles, I interact banks' balance sheet characteristics with the policy shock within a single regression specification. The econometric model is presented in Equation (2.3). The matrix $\tilde{W}^i_{t-1}$ includes four continuous lagged measures of banks' characteristics. The vector β^w contains the four interaction coefficients that quantify how different balance sheet attributes affect the transmission of policy shocks. For an easier interpretation of the coefficients, I standardize the regressors in the matrix $\tilde{W}^i_{t-1}$ with their cross-sectional mean and standard deviation within each quarter.[10]

The regressors included in the matrix $\tilde{W}^i_{t-1}$ are the share of securities over assets (liquidity), the capital share (capitalization), total assets (size), and the deposit share of liabilities (funding composition). Equation (2.3) is estimated with panel local projection methods. For standard monetary shocks, the sample starts in 1989Q1 and ends in 2019Q4.[11] For QE shocks, the sample starts in 2000Q1 and ends in 2019Q2.

$$y_{i,t+h} - y_{i,t-1} = \alpha^h_0 + \alpha^{h,i} + \sum_{j=0}^{J} \beta^h_j \epsilon^k_{t-j} + \beta^w \epsilon^k_t * \tilde{W}^i_{t-1} + \sum_{j=1}^{J} \gamma^h_j X^i_{t-j} + \varepsilon^{h,i}_t \tag{2.3}$$

Table 2.9 reports the estimated regression coefficients for standard monetary policy shocks. On average, loans decline by 1.16% after 12 quarters, securities grow by 0.48%, and deposits drop by 0.15%. The share of securities over total assets increases by 0.13%. The interaction terms in the equation for lending growth are all significant and positive except for the interaction with size. The implication is that banks with higher liquidity, stronger

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[10] Formally, given a generic regressor w^i_t, I construct $\tilde{w}^i_t = \frac{w^i_t - \bar{w}_t}{\sigma^w_t}$, where $\bar{w}_t$ is the cross-sectional mean, and σ^w_t is the cross-sectional standard deviation.

[11] In the Appendix I report results for an alternative estimation running until 2009Q4, thereby excluding the zero lower bound period.

Table 2.9: Impulse Responses After a Monetary Shock - Interactions

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
Policy shock	-0.29***	-1.16***	-0.49***	0.48***	-0.15***	-0.15***	-0.08***	0.13***
	(-8.00)	(-19.94)	(-12.17)	(7.45)	(-9.04)	(-4.93)	(-12.68)	(14.23)
Policy shock × Std. Securities share of assets t-1	0.12***	0.36***	0.24***	-0.01	0.07***	0.31***	-0.00	-0.03***
	(3.56)	(6.05)	(5.06)	(-0.16)	(4.68)	(10.60)	(-0.69)	(-2.61)
Policy shock × Std. Capital Share t-1	-0.03	0.24***	-0.15**	-0.01	0.00	0.16***	-0.02**	-0.04***
	(-0.69)	(3.38)	(-2.39)	(-0.12)	(0.04)	(4.92)	(-2.50)	(-3.54)
Policy shock × Std. Assets t-1	0.01	0.04	0.02	-0.01	0.02	0.11***	0.00	-0.01
	(0.63)	(0.93)	(0.77)	(-0.22)	(1.62)	(3.20)	(0.55)	(-1.51)
Policy shock × Std. Deposit Share t-1	0.14***	0.24***	-0.01	0.16**	0.00	0.11***	-0.02**	-0.03**
	(4.01)	(4.06)	(-0.14)	(2.25)	(0.08)	(2.61)	(-2.30)	(-2.49)
R-squared	0.040	0.080	0.091	0.158	0.083	0.074	0.199	0.341
N. Observations	610,283	523,370	610,283	523,370	610,283	523,370	610,283	523,370

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.3). Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2019Q4.

capitalization, and a larger deposit share of liabilities are less affected by standard monetary policy shocks. Quantitatively, the share of liquid assets has a bigger effect on lending growth: a one standard deviation increase in liquidity is associated with a 0.36% lower impact of the policy shock, compared to 0.24% for capitalization and deposit share. Interaction coefficients in the regression predicting deposit growth are all positive and significant (including size), and the biggest coefficient is the one related to the share of liquidity. For securities growth, the only significant interaction term is the one associated with the deposit share of liabilities. On the other hand, the share of securities over assets increases less for banks that are liquid, more capitalized, and more reliant on deposit funding.

Table 2.10 reports the estimated coefficients for Quantitative Easing shocks. On average, banks reduce lending by 0.76%, deposits by 0.18%, and increase securities and the share of securities respectively by 0.63% and 0.22%. The interaction coefficients in the equation for lending growth are all negative and significant except for the interaction with size, which is not significant. Liquidity, capitalization, and deposit share are now associated with a stronger decline in lending, which is the opposite compared to a standard monetary policy shock. Quantitatively, liquidity still plays the biggest role in determining the impact of QE shocks in affecting lending growth. Results for deposit growth are similar: all the interaction coefficients are negative except for the one associated with size which is not sig-

Table 2.10: Impulse Responses After a QE Shock - Interactions

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1) 4-quarters Coef./t-stat	(2) 12-quarters Coef./t-stat	(3) 4-quarters Coef./t-stat	(4) 12-quarters Coef./t-stat	(5) 4-quarters Coef./t-stat	(6) 12-quarters Coef./t-stat	(7) 4-quarters Coef./t-stat	(8) 12-quarters Coef./t-stat
QE (neg.)	-0.53***	-0.76***	0.68***	0.63***	0.01	-0.18***	0.18***	0.22***
	(-9.67)	(-8.60)	(10.17)	(5.90)	(0.57)	(-4.33)	(17.99)	(17.01)
QE (neg.) × Std. Securities share of assets t-1	-0.12***	-0.29***	0.02	0.12	-0.01	-0.20***	0.04***	0.08***
	(-3.24)	(-5.17)	(0.41)	(1.60)	(-0.51)	(-7.24)	(5.76)	(9.18)
QE (neg.) × Std. Capital Share t-1	-0.06	-0.17**	-0.00	-0.08	-0.06	-0.15***	0.02**	0.02*
	(-1.53)	(-2.37)	(-0.08)	(-0.88)	(-1.50)	(-3.87)	(2.35)	(1.90)
QE (neg.) × Std. Assets t-1	-0.02	-0.03	-0.01	0.04	0.00	-0.01	0.00	0.01**
	(-0.74)	(-0.44)	(-0.22)	(1.08)	(0.34)	(-0.61)	(0.41)	(2.11)
QE (neg.) × Std. Deposit Share t-1	-0.13***	-0.16***	-0.06	-0.19***	-0.04	-0.10***	0.00	-0.00
	(-3.84)	(-3.14)	(-1.20)	(-2.93)	(-1.43)	(-3.04)	(0.48)	(-0.28)
R-squared	0.035	0.079	0.091	0.187	0.104	0.084	0.204	0.390
N. Observations	314,654	261,220	314,654	261,220	314,654	261,220	314,654	261,220

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.3). Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 2000Q1-2019Q2.

nificant. The increase in the share of securities over assets is positively related to liquidity, capitalization, and size.

To summarize, this Section highlights three important results related to the impact of monetary policy on bank lending. First, standard monetary policy shocks and QE shocks have opposite effects on different types of banks as measured by their balance sheets. Second, the determinants of the differential response are liquidity, capitalization, and deposit share of liabilities, whereas size does not have a significant impact. Third, liquidity plays the most prominent quantitative role in determining the impact of monetary policy on bank lending.

2.6 Robustness

In this Section, I evaluate the robustness of the results presented in Section 2.5.5 along two dimensions: the estimation sample, and the proxy for standard monetary policy shocks. Additional robustness checks are reported in Appendix B.1.

First, I estimate Equation (2.3) for standard monetary policy shocks ending the sample in 2009Q4 in order to exclude the period in which the Federal Funds rate reached the zero lower bound. Table 2.11 shows that results are very close to the baseline estimation. The average impacts on loans, deposits, and securities are slightly stronger, whereas the

Table 2.11: Impulse Responses After a Monetary Shock (Until 2009) - Interactions

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
Policy shock	-0.47***	-1.37***	-0.40***	0.50***	-0.16***	-0.24***	-0.05***	0.19***
	(-12.28)	(-23.64)	(-9.55)	(8.09)	(-9.51)	(-8.07)	(-6.90)	(20.24)
Policy shock × Std. Securities share of assets t-1	0.11***	0.36***	0.15***	-0.00	0.07***	0.28***	-0.02**	-0.04***
	(3.13)	(5.96)	(3.28)	(-0.07)	(4.40)	(9.64)	(-2.40)	(-3.85)
Policy shock × Std. Capital Share t-1	-0.03	0.19***	-0.10*	0.03	-0.02	0.10***	-0.01	-0.03**
	(-0.69)	(2.76)	(-1.68)	(0.49)	(-0.85)	(3.13)	(-1.37)	(-2.34)
Policy shock × Std. Assets t-1	0.02	0.04	0.02	-0.00	0.05***	0.11***	0.00	-0.01
	(0.86)	(0.76)	(0.84)	(-0.05)	(2.98)	(3.14)	(0.00)	(-1.06)
Policy shock × Std. Deposit Share t-1	0.14***	0.24***	-0.02	0.12*	0.04	0.13***	-0.02**	-0.04***
	(3.80)	(3.80)	(-0.47)	(1.70)	(1.25)	(2.87)	(-2.44)	(-3.05)
R-squared	0.046	0.097	0.110	0.177	0.070	0.061	0.232	0.387
N. Observations	474,734	424,972	474,734	424,972	474,734	424,972	474,734	424,972

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.3). Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2009Q4.

interaction coefficients are similar.

Second, I estimate the same equation using the Federal Funds Rate Factor from Swanson (2021) as a proxy for standard monetary policy shocks in the sample running until 2009Q4, and report results in Table 2.12. This instrument captures the dimension of surprise monetary policy announcements related to changes in the Federal Funds Rate. Magnitudes in Tables 2.11 and 2.12 are not comparable, as the two instruments are constructed with different normalizations. Nevertheless, the signs and relative magnitudes of the interaction coefficients provide interesting information. The coefficients in the equation for lending growth have the same sign as in the baseline specification. The relative importance of balance sheet items is now different: liquidity plays a smaller role compared to capitalization and deposit share in determining the impact of the shock on loans. The coefficients for deposit growth are all in line with the baseline specification, although the interactions with capital, size, and deposit share are significant at the 90% level. The most important differences appear in the equations for securities growth and the share of securities over assets. Now banks on average decrease their securities holdings also after 12 quarters (the sign was positive in Table 2.11). They also reduce their share of securities over assets irrespective of their balance sheet composition.

Table 2.12: Impulse Responses After a FFR Shock (Until 2009) - Interactions

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
FFR shock	0.05	-0.24***	-0.17***	-0.53***	-0.29***	-0.32***	-0.01	-0.08***
	(1.25)	(-3.98)	(-4.05)	(-8.19)	(-15.82)	(-10.15)	(-1.34)	(-9.09)
FFR shock × Std. Securities share of assets t-1	0.02	0.20***	0.05	-0.07	0.06***	0.17***	0.02**	-0.00
	(0.48)	(2.92)	(0.86)	(-0.92)	(3.14)	(4.86)	(2.26)	(-0.06)
FFR shock × Std. Capital Share t-1	0.09*	0.29***	-0.06	0.15**	-0.05*	0.06*	-0.00	-0.00
	(1.83)	(3.61)	(-1.10)	(2.19)	(-1.91)	(1.75)	(-0.32)	(-0.19)
FFR shock × Std. Assets t-1	-0.03	0.05	-0.01	0.03	0.00	0.08*	-0.00	-0.00
	(-1.52)	(0.95)	(-0.28)	(0.59)	(0.08)	(1.82)	(-0.26)	(-0.14)
FFR shock × Std. Deposit Share t-1	0.06	0.27***	0.02	0.11	0.06	0.09*	0.00	-0.01
	(1.54)	(3.72)	(0.53)	(1.44)	(1.53)	(1.87)	(0.21)	(-0.45)
R-squared	0.045	0.111	0.102	0.164	0.073	0.061	0.227	0.381
N. Observations	398,291	355,627	398,291	355,627	398,291	355,627	398,291	355,627

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.3). Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2009Q4.

Overall, the results presented in this Section have two implications: first, the baseline specification for loan growth and deposit growth is robust to differences in the sample and in the instrument for policy shocks; second, the instrument used to capture monetary policy shocks might contain information on central bank's asset purchases of forward guidance, thereby affecting the estimated response in securities.

2.7 Conclusions

In this paper, I show that the composition of banks' balance sheets matters for the transmission of different monetary policy instruments to the real economy. Using bank-level data for the United States and high-frequency instruments for standard monetary policy shocks and Quantitative Easing, I estimate a panel local projections model to assess the differential impact of the two policies on banks with different liquidity, capitalization, size, and funding composition. I find that conventional interest rate shocks determine a stronger impact on bank lending for banks that are illiquid, bigger, less capitalized, and less reliant on deposit funding. In contrast, QE shocks are more effective in stimulating bank lending for banks that are liquid, smaller, more capitalized, and more reliant on deposit funding. The most important quantitative determinant is liquidity, while capitalization and funding composition contribute to a lesser extent to the heterogeneity in the impact of policy shocks across banks, and the contribution of bank size is not statistically significant in the baseline specification.

The results presented in this paper highlight two policy implications. First, the fact that different policy instruments affect different parts of the banking sector suggests that a combination of conventional interest rate adjustments and asset purchases might be more effective than the implementation of a single monetary policy measure. Second, central banks shall take into account the state of banks' balance sheets when evaluating the quantitative impact of their monetary policy interventions.

Finally, this paper suggests that a promising avenue for future research is the development of structural banking models that account for the different transmission channels of the various monetary policy instruments and their interaction with the balance sheet composition of banks.

Chapter 3

Reconciling Employment and Wage Cyclicality for High and Low-Skilled Workers: The Role of Labor Market Frictions

3.1 Introduction

There are two stylized facts that at first sight seem to be inconsistent with each other: low-skilled workers tend to display both more cyclical employment and more cyclical earnings compared to high-skilled workers. In standard models, instead, quantities adjust less when prices are more flexible and vice-versa. Developing a mechanism that can make these facts consistent is important first of all to make models with heterogeneous workers more realistic, especially in the context of a growing literature in this field. Moreover, a model in which low-wage agents present more cyclical employment generates a composition effect in the wage equation which helps to shed light on the low volatility in aggregate wages; this effect has been already discussed in the empirical literature by Solon et al. (1994) but it was never explicitly incorporated into standard macro models where it can be used for policy simulations. Finally, the main result of this paper is relevant to the literature on wage inequality and how it varies over the business cycle and after aggregate shocks.

In this paper, I show how heterogeneous labor market frictions make these facts compatible. The intuition is that hiring costs for high-skilled workers are much more volatile, thus more than compensating for the lower volatility of their wages. This leads to a stronger response in low-skilled employment with only a small modification of standard macro models. More specifically, in the case of a frictional labor market, when choosing the level of employment, firms face two costs: the wage to be paid to new workers and the cost of hiring. Assuming low-skilled wages are more flexible than high-skilled ones we would expect low-skilled employment to be less volatile than high-skilled employment. In the case of the model presented in this paper, instead, the hiring cost component is more volatile for high-skilled workers due to a lower matching function elasticity. This makes the total cost more volatile too and implies both more flexible wages and more volatile employment for low-skilled workers.

Hiring costs are tightly related to the matching function and its parameterization. If the elasticity parameter associated with vacancies is lower for high-skilled workers, variations in market tightness have stronger effects on the hiring cost of firms, thereby making it more volatile. It is worth stressing that this result does not rely on price rigidities or the specific shock causing the fluctuations, but it only depends on wage rigidities and the different cyclicality of hiring costs. In this paper, I present how the above result holds after a productivity shock in a flexible price environment. To show that this remains true after a monetary policy shock, I also present a sticky price version of the model. The literature related to the matching function and its elasticity has a strong focus on the aggregate matching function and on tests to verify the constant returns to scale property.[1] Little interest has been devoted to sectorial or skill differences in matching function parameters, probably due to the lack of consistent data to perform the estimation. Low-skilled workers indeed tend to have lower bargaining power (see Cahuc et al. (2006)) and in an efficient search model the matching function elasticity can be calibrated accordingly with a higher elasticity on vacancies for low-skilled workers. In Section 3.3, I provide empirical evidence on matching function parameters across industries: I estimate elasticities using industry data on vacancies, unemployment, and hires and then proxy the skill level of the sector using the wage level. I find a slight negative relation between the elasticities and wage levels,

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[1] See Petrongolo and Pissarides (2001) for a comprehensive review on the topic.

thus supporting the choice of the calibration used in this paper.

Another crucial choice in the calibration is related to the Frisch elasticity, which affects the marginal rate of substitution which is related to hiring costs and unemployment via its effect on the labor force participation choice. Intuitively, a higher Frisch elasticity implies a stronger response of labor force participation to changes in job-finding probability, wages, or consumption (wealth effect). The labor force participation is directly related to unemployment (holding employment fixed), and a larger pool of unemployed makes it easier for firms to hire workers for a given number of vacancies. Thus, the hiring cost of an additional worker is negatively related to unemployment and therefore to labor force participation. Low-skilled workers, with a higher Frisch elasticity, tend to adjust much more their labor force participation and this implies that during expansions they will increase participation, affecting the number of unemployed and thus decreasing market tightness relative to the high-skilled. This leads to a lower increase in hiring costs for firms seeking low-skilled workers and helps mitigate the fluctuation in their total cost. Moreover, the effect of Frisch elasticity on the marginal rate of substitution has implications also on the wage bargained: higher Frisch elasticity implies a flatter labor supply curve, leading to a smaller increase in wages for a given change in employment. Overall, the higher Frisch elasticity associated with low-skilled workers contributes to the reduction in the cyclicality of their wages even though they can be reset more often than high-skilled wages. The literature on Frisch elasticity and how it differs across groups is broader compared to the literature on the matching function elasticity (see for example Chetty et al. (2011, 2013)). Attanasio et al. (2018) study the importance of heterogeneity in labor supply elasticities and find that Frisch elasticities are largest for the young and people with the least wealth. In particular, their estimate for the bottom quartile of the wealth distribution is more than four times larger than their estimate for the top quartile. Consistently, in this paper high-skilled workers (presumably with an overall higher wealth) have a lower elasticity than low-skilled workers.

The baseline model is a flexible price, two-sector extension of Galí (2010) where I maintain sticky wages and labor market frictions. I split the production side into two intermediate goods sectors, one employing only high-skilled labor and the other only low-skilled labor. The final goods firm combines the two intermediate goods via CES technology. Moreover, there are two separate frictional labor markets for the two skill groups and there are no transitions between sectors and groups. First, I show how the standard deviations of employment and wages are larger for low-skilled workers in the model with heterogeneity, whereas this is not true in a model without heterogeneity. Then, I show how employment, wages, and the unemployment rate are more volatile for low-skilled workers after a productivity shock. These results also induce the composition bias in aggregate wages studied by Solon et al. (1994).[2]

Finally, I provide two extensions to the baseline model. First, I develop a model with price rigidities and show that the main results are preserved after a productivity shock.[3] Moreover, in case of an expansionary monetary policy shock, the results are still consistent with larger fluctuations in the variables associated with low-skilled workers, and with the composition effect operating in the expected direction and muting the response in aggregate wages. Second, I further extend the model into a TANK version with low-skilled workers being hand-to-mouth. In this alternative version, low-skilled consumption fluctuates much more giving an important role to wealth effects in the low-skilled agent intratemporal equation. This leads, for example, to a relative decline in labor force participation during expansions which causes an increase in hiring costs in the low-skill sector. Nevertheless, I show how it is possible to preserve the main results of the paper with a reasonable calibration.

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2. Solon et al. (1994) show that due to a composition effect, the aggregate Wage Phillips Curve becomes flatter. This is precisely what happens in the model presented in this paper due to the higher cyclicality of low-skilled employment which is also associated with a lower wage. This result can help to reconcile the fact that micro estimates of wage rigidities are usually smaller than macro estimates.

3. With the caveat that in this case the response in employment changes sign, a common feature of classic New Keynesian models.

The paper is organized as follows: in Section 3.2 I briefly review the literature; in Section 3.3 I present some facts and discuss the empirical exercise related to matching elasticities; in Section 3.4 I present the structure of the model; in Section 3.5 calibration, model mechanics and impulse responses both for the flexible price and the sticky price versions are presented; in Section 3.6 the TANK extension is discussed; Section 3.7 concludes.

3.2 Literature Review

In this paper, I combine in a novel way two important branches of the business cycle literature in macroeconomics: nominal wage rigidities and frictional labor markets. The basic framework is a two-sector model with two kinds of agents (high-skilled and low-skilled) working in different sectors with different frictional labor markets. The distinction between these sectors/agents relies on the calibration. A two-sector search model with high and low-skilled agents has been already presented by Acemoglu and Autor (2011). However, they focus on steady state relationships and introduce labor market frictions differently, whereas in this paper I focus on business cycle variation and introduce labor market frictions in terms of hiring costs as in Galí (2010). Similarly, Brückner and Pappa (2012) and Dolado et al. (2021) use New Keynesian models with high and low-skilled workers and frictional labor markets to study fiscal expansions and monetary policy. With this paper, they share a focus on how differences in labor market frictions affect workers heterogeneously. However, they introduce frictions differently, they focus on matching efficiency parameters, and they don't investigate how the model interacts with heterogeneous wage rigidities. Moreover, their results are in contrast with the implications that my setup has on wage inequality.

More in general, the branch of the literature in macroeconomics that has studied models of unemployment and frictional labor markets is based on the work of Diamond (1982a, 1982b), Mortensen (1982a, 1982b), Pissarides (1985, 2000) and Mortensen and Pissarides (1994). Hall (2005) and Shimer (2005) pointed out that in these models the volatility of unemployment is too small compared to the empirical estimate. Subsequently, the New Keynesian framework and the DMP framework have been combined by some authors both assuming flexible and sticky wages: important contributions came from Walsh (2003, 2005) and Trigari (2006, 2009). A different approach to introducing unemployment in general equilibrium models can be found in Blanchard and Galí (2010) and Galí (2010, 2011). This approach models labor market frictions in the form of a cost per hire and can be easily related to the matching function which is common in the search literature. With this literature, I share how unemployment, labor market frictions, and staggered wage bargaining are introduced.

The TANK extension of the paper is related to the literature on Two Agents New Keynesian Models (TANK) in the spirit of Galí et al. (2007), Bilbiie (2008) and Debortoli and Galí (2017) where there are two agents: one Ricardian and the other hand to mouth. However, to the best of my knowledge, this literature never implemented a TANK model version with labor market frictions.

On the empirical side, this paper rationalizes in a simple model some empirical evidence on wage stickiness. In particular, Solon et al. (1994) established that the composition bias in aggregate wages is quite substantial due to the higher cyclicality of low-skill employment. Other papers such as Ziliak et al. (2022) show that earnings volatility for low-educated workers is much higher. This model reconciles the two findings by having at the same time more flexible wages and more volatile employment for low-skilled agents, allowing for the composition bias to work in the empirically consistent direction.

3.3 Empirical Evidence

3.3.1 Employment and Wage Volatility in the Data

The motivation for this paper comes from two empirical facts that seem to be inconsistent: low-skilled workers display both more cyclical wages and more cyclical employment compared to high-skilled workers. These facts have been already documented in the literature (see for example Solon et al. (1994) and Ziliak et al. (2022)), and in this Section I provide some additional supporting evidence.

First of all, I base the distinction between high and low-skilled workers on educational attainment. I collect seasonally adjusted monthly data from CPS on employment rates and unemployment rates by educational attainment from 1992 until 2019. The low-skilled group is composed of people with less than a High School diploma and High School graduates without college. The high-skilled group is made of individuals with some college or associate degree and those with a Bachelor's degree and higher. I then HP-filter the series to work with the cyclical component and compute the standard deviations to measure the variability of the series. The employment rate for high-skilled workers has a standard deviation of 0.35 whereas for low-skilled workers the figure is 0.38. If, instead, I focus only on the two extremes of the educational attainment levels, I find that workers with less than a High School diploma have a standard deviation of 0.63 while the figure for workers with at least a Bachelor's degree is 0.35. The difference in the standard deviation of unemployment rates is larger: 0.27 for high-skilled and 0.46 for low-skilled. This confirms that low-skilled workers tend to have more volatile employment and unemployment.

Regarding wage volatility, I use quarterly data on median usual weekly earnings by educational attainment from CPS. The sample spans from 2000Q1 until 2019Q4. To create the two wage groups I sum the wages of the sub-groups weighted by the number of employed in each period. I seasonally adjust the data using Census X-13 and compute the growth rates as suggested in the literature on earnings volatility (see Ziliak et al. (2022)). Then, I HP-filter the series to obtain the cyclical component and drop 2007 from the sample to avoid some big outliers. Wages for low-skilled workers display a standard deviation of 1.04, while the figure for high-skilled workers is 0.88. Again, the fact already established in the literature is confirmed by this brief analysis of the data.[4]

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[4] A point that has been made in the literature is that what matters in hiring decisions is the present value

3.3.2 Estimating the Matching Function Elasticity

In this Section, I provide some empirical evidence supporting the choice of assigning lower matching elasticity to the high-skill sector. Recall that a constant returns to scale matching function can be written as $H = V^{\zeta}U^{1-\zeta}$, where H is the number of hires, V is the number of vacancies, U is the number of unemployed (having normalized matching efficiency to 1 for simplicity). Taking logs we are left with $h = \zeta v + (1-\zeta)u$, where lowercase letters denote logs. The strategy is to collect data on hires, vacancies, and unemployment by sector and estimate the above sectoral elasticity.

Seasonally adjusted monthly data for hires and vacancies can be obtained by JOLTS, spanning from 2000 to 2020, while unemployment data by sector come from the CPS. I seasonally adjust unemployment data and then HP-filter the log of the above series to obtain the cyclical component. Finally, I run the following regression for each sector:

$$\hat{h}_t = \zeta \hat{v}_t + (1-\zeta)\hat{u}_t + \varepsilon_t$$

Then, I proxy the sectoral skill intensity by using average hourly earnings of production and nonsupervisory employees by industry sector from July 2020 provided by BLS. Thereafter, I compare the elasticities in a scatter plot to see whether any trend can be spotted.[5]

Figure 3·1 plots elasticities and wage levels for each sector. There are two main takeaways: first, there is a lot of heterogeneity in elasticities across sectors, supporting a calibration that stresses these differences (some sectors have elasticities two or three times larger than other sectors); second, there seems to be a very slight negative relation between skill level and elasticities. However, the slope is almost zero and depends on which sectors are included in the analysis.

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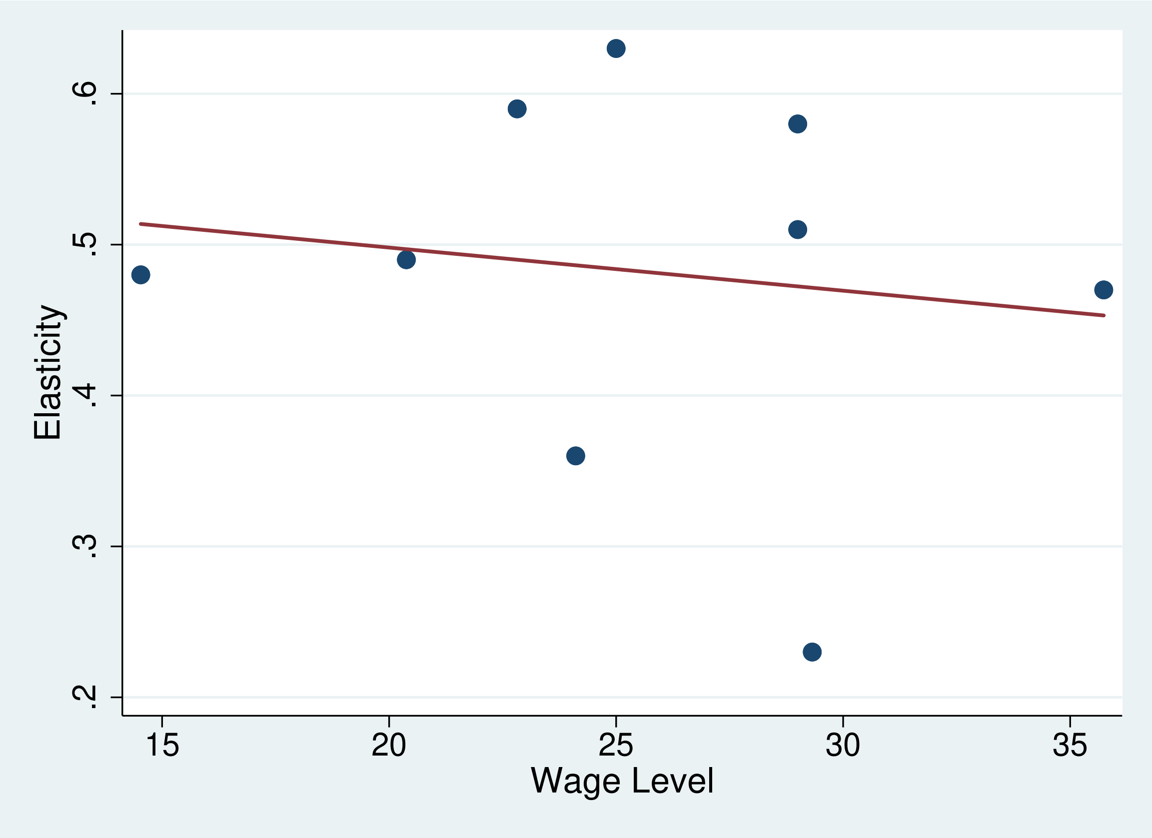
of wages. This means that even though wage contracts are sticky, the present value can be volatile if starting wages are volatile. For the sake of tractability, these concepts are not present in this paper because in the model presented in Section 3.4 new hires are paid the average wage. Thus, when I talk about wage stickiness, I refer to aggregate wages combining together new hires and continuing employees.

[5] Note that this exercise does not take into account possible endogeneity issues related to the estimation.

Figure 3·1: Matching Function Elasticity and Wage Level by Industry



Notes: This Figure presents the relation between the estimated matching function elasticities and wage levels across sectors. Each dot corresponds to a specific sector. Wage levels are measured by the average hourly earnings of production and nonsupervisory employees in July 2020.

This means that calibrating the model with different elasticities finds some support in the data and it makes sense to use lower elasticities for high-skill sectors.

3.4 Model

3.4.1 Households

The model is a two-sector extension of Galí (2010) where I keep nominal wage rigidities but not nominal price rigidities. There is a representative household made up of a continuum of members of two types: high-skilled (superscript H) and low-skilled (superscript L). There is full consumption risk sharing within the household.

The household maximizes

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, L_t^H, L_t^L)$$

where

$$L_t^i = N_t^i + \Psi_i U_t^i, \; i = H, L$$

N_t^i and U_t^i $(i = H, L)$ denote the fraction of i-type members employed and unemployed. Parameter $\Psi_i \in [0,1]$ represents the marginal disutility generated by an i-type unemployed member relative to an employed one. Staying out of the labor force, instead, does not generate disutility. Note also that labor force participation is given by $F_t^i = N_t^i + U_t^i$ and in general $N_t^H + N_t^L = N_t$, $U_t^H + U_t^L = U_t$, $F_t^H + F_t^L = F_t$.

I assume the following utility function:

$$U(C_t, L_t^H, L_t^L) \equiv \log C_t - \frac{\chi_H}{1+\varphi_H}\left(L_t^H\right)^{1+\varphi_H} - \frac{\chi_L}{1+\varphi_L}\left(L_t^L\right)^{1+\varphi_L}$$

The law of motion for employment is

$$N_t^i = (1-\delta_i)N_{t-1}^i + x_t^i U_t^{0,i}$$

where δ^i is the separation rate, x_t^i is the job-finding rate and $U_t^{0,i}$ is the fraction of household members who are of type i and unemployed at the beginning of period t. Something to note is that hires become productive in the same period, making employment a non-predetermined variable. This assumption ensures consistency with most of the business cycle literature, although it contrasts with a large part of the search and matching literature.

The budget constraint is

$$\int_0^1 P_t(z)C_t(z)dz + Q_t B_t \leq B_{t-1} + \int_0^1 W_t^H(j)N_t^H(j)dj + \int_0^1 W_t^L(j)N_t^L(j)dj + \Pi_t$$

where $P_t(z)$ is the price of good z, $W_t^i(j)$ is the nominal wage paid by firm j to i-type worker, B_t are bonds and Π_t are profits.

The standard Euler equation can also be derived:

$$Q_t = \beta E_t \left[\frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \right]$$

3.4.2 Firms

There are two types of perfectly competitive intermediate goods firms producing two different goods which are combined by monopolistically competitive final goods firms with CES production.

Final Goods

There is a continuum of monopolistically competitive final goods firms indexed by z producing differentiated goods. Their production function is given by

$$Y_t(z) = \left[\nu_L^{\frac{1}{\sigma}} \left(X_t^L(z) \right)^{\frac{\sigma-1}{\sigma}} + \nu_H^{\frac{1}{\sigma}} \left(X_t^H(z) \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{3.1}$$

where $Y_t(z)$ is the quantity of final good produced by firm z and $X_t^i(z)$ is the quantity of intermediate good from i-sector used by firm z.

Flexible price setting implies that the price is a markup over the marginal cost. The real marginal cost from the CES production function can be derived as

$$MC_t = \left[\nu_L \left(\frac{P_t^L}{P_t} \right)^{1-\sigma} + \nu_H \left(\frac{P_t^H}{P_t} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

where P_t^i is the price of intermediate good from sector i. Log-linearizing gives

$$\hat{mc}_t = \frac{\Gamma^L}{\Gamma^H + \Gamma^L}(\hat{p}_t^L - \hat{p}_t) + \frac{\Gamma^H}{\Gamma^H + \Gamma^L}(\hat{p}_t^H - \hat{p}_t) \tag{3.2}$$

with $\Gamma^i = \nu_i \left(\frac{P^i}{P_t}\right)^{1-\sigma}$.

The optimal choice of the two inputs is given by the following relation:

$$\frac{P_t^H}{P_t^L} = \left(\frac{\nu_H}{\nu_L}\right)^{\frac{1}{\sigma}} \left(\frac{X_t^H}{X_t^L}\right)^{-\frac{1}{\sigma}} \tag{3.3}$$

Log-linearizing and using the intermediate goods production function returns

$$\hat{p}_t^H - \hat{p}_t^L = -\frac{1}{\sigma}\left(\hat{a}_t^H + (1-\alpha_H)\hat{n}_t^H - \hat{a}_t^L - (1-\alpha_L)\hat{n}_t^L\right) \tag{3.4}$$

Sticky Price Extension In the paper, I also present a version of the model with sticky price setting a la Calvo (1983) to show that the main result does not depend on price-setting decisions and that it holds also after a monetary policy shock. In this case, the model returns the usual New Keynesian Phillips Curve. Flexible price-setting can be seen as a special case of sticky price setting with the parameter associated with rigidities set to zero.

Each firm can adjust its price each period with $1 - \theta_p$ probability. The derivations are the same as in a textbook New Keynesian model and a New Keynesian Phillips Curve can be obtained.

$$\pi_t = \beta E_t \pi_{t+1} + \lambda_p \hat{mc}_t$$

where lower case variables are logs, hats denote (log) deviations from steady state, π denotes inflation, mc denotes the marginal cost and $\lambda_p \equiv \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$.

Intermediate Goods

There are two sub-sectors in the intermediate goods sector: one producing good X^H and employing only high-skilled workers, and the other producing X^L and employing only low-skilled workers. These two sectors are not in competition and also their labor markets are separate. Thus, we can show the derivations for a generic sector i and they will be valid for both.

The intermediate good i is produced by a continuum of identical and perfectly competitive firms indexed by j. The production technology is Cobb-Douglas with only labor as input

$$X_t^i(j) = A_t^i \left(N_t^i(j)\right)^{1-\alpha_i}, i = H, L$$

where A_t^i denotes productivity. Employment moves as

$$N_t^i(j) = (1-\delta_i) N_{t-1}^i(j) + H_t^i(j)$$

where $H_t^i(j)$ is the number of hires of type i at firm j. Employment is a non-predetermined variable, implying that hires will adjust each period to ensure that the optimal choice for employment is reached.

Labor market frictions are introduced as a cost per hire that I denote G_t as in Galí (2010). This cost is taken as given by firms, but it depends on the aggregate situation of the labor market and in particular on the job-finding rate. The assumption is that

$$G_t^i = \Gamma_i \left(x_t^i\right)^{\gamma_i}$$

where Γ_i is a constant parameter. The advantage of this formulation is that it can be related to the matching function approach common to the search and matching literature. To ease the notation I drop index i, but what follows must be true for both sectors.

Assuming a matching function of the form $H_t = V_t^{\zeta} U_t^{0,1-\zeta}$, the implied job-finding

probability is $x_t \equiv \frac{H_t}{U_t^0} = \left(\frac{V_t}{U_t^0}\right)^{\zeta}$.
The cost per hire G_t is given by the cost of one vacancy multiplied by the number of vacancies divided by the number of hires.

$$G_t = \Gamma \frac{V_t}{H_t} = \Gamma x_t^{\frac{1-\zeta}{\zeta}}$$

The above relation also implies that there is a mapping between the parameter γ and the elasticity of the matching function ζ: $\gamma \equiv \frac{1-\zeta}{\zeta}$.

Let's now derive the optimal choice of employment by firms. In general, it must be true in equilibrium that the marginal product of labor must be equal to the cost of a marginal worker. The real marginal product of labor is given by

$$MRPN_t^i(j) = \frac{P_t^i}{P_t}(1-\alpha_i)A_t^i \left(N_t^i(j)\right)^{-\alpha_i}$$

The cost of a marginal worker is given by two components: the real wage $\frac{W_t^i(j)}{P_t}$ that has to be paid to the worker and the net hiring cost $B_t^i = G_t^i - (1-\delta_i)E_t\Lambda_{t,t+1}G_{t+1}^i$ which is composed by the cost of hiring the worker today and the future discounted saving of not having to hire the same worker tomorrow if separation does not occur.
The optimal employment equation therefore becomes

$$\frac{P_t^i}{P_t}(1-\alpha_i)A_t^i \left(N_t^i(j)\right)^{-\alpha_i} = \frac{W_t^i(j)}{P_t} + B_t^i \tag{3.5}$$

which in log deviations from the steady state is

$$(\hat{p}_t^i - \hat{p}_t) + \hat{a}_t^i - \alpha_i \hat{n}_t^i(j) = (1-\Phi_i)\hat{\omega}_t^i(j) + \Phi_i \hat{b}_t^i$$

where $\hat{\omega}_t^i$ is the log linearized real wage and $\Phi_i = \frac{B^i}{\frac{W^i}{P}+B^i}$ is the weight of non-wage costs over total costs in steady state.

The above equation can be rewritten in terms of average employment and wages as

$$(\hat{p}_t^i - \hat{p}_t) + \hat{a}_t^i - \alpha_i \hat{n}_t^i = (1 - \Phi_i)\hat{\omega}_t^i + \Phi_i \hat{b}_t^i$$

and combining both equations, the relative demand for employment by any firm can be derived.

$$\alpha_i(\hat{n}_t^i(j) - \hat{n}_t^i) = -(1 - \Phi_i)(\hat{\omega}_t^i(j) - \hat{\omega}_t^i) \tag{3.6}$$

For completeness, I also report a log-linearized version of the net hiring cost component

$$\hat{b}_t^i = \frac{1}{1 - \beta(1 - \delta_i)}\hat{g}_t^i - \frac{\beta(1 - \delta_i)}{1 - \beta(1 - \delta_i)}\left[E_t \hat{g}_{t+1}^i - \hat{r}_t\right]$$

and hiring cost

$$\hat{g}_t^i = \gamma_i \hat{x}_t^i$$

It is immediately clear that the choice of how much labor to use in production depends on two cost components: the wage and a non-wage component related to labor market frictions. By calibrating $\zeta_H \neq \zeta_L$ (matching function elasticity) I obtain $\gamma_H \neq \gamma_L$ and this results in different cyclical employment dynamics between high and low-skilled workers. It is worth stressing that this point does not depend at all on wage or price rigidities and it is just a byproduct of heterogeneous labor market frictions. In the calibration that I present, γ is higher for high-skilled workers, implying a stronger response of the non-wage cost component to a change in labor market tightness (or job-finding probability). This mutes the response of high-skilled employment compared to the low-skilled counterpart even if low-skilled workers have more flexible wages. As a final comment, the marginal cost combined with intermediate goods firms' optimal hiring conditions can be rewritten as

$$\begin{aligned}\hat{mc}_t = & \frac{\Gamma^L}{\Gamma^H + \Gamma^L}(\alpha_L \hat{n}_t^L - \hat{a}_t^L + (1 - \Phi_L)\hat{\omega}_t^L + \Phi_L \hat{b}_t^L) \\ & + \frac{\Gamma^H}{\Gamma^H + \Gamma^L}(\alpha_H \hat{n}_t^H - \hat{a}_t^H + (1 - \Phi_H)\hat{\omega}_t^H + \Phi_H \hat{b}_t^H)\end{aligned}$$

3.4.3 Wage Setting

In this Section, I discuss only the sticky wage case. The reason is that the main point of the paper relies on the fact that high and low-skilled workers have different degrees of wage flexibility and therefore some degree of wage stickiness is needed. For a complete treatment of both the flexible and the sticky wage cases see Galí (2011).

First of all, the wage is the outcome of a Nash bargaining process between firms and workers where the relative bargaining powers are fixed parameters. The sticky wages assumption implies that only a fraction of firms $1-\theta_w^i$ can reset the nominal wage in each period.

$\mathcal{V}_{t+k|t}^{N,i}$ is the value for the household in period $t+k$ from being employed in a firm that last reset its wage at time t and it is equal to

$$\begin{aligned}\mathcal{V}_{t+k|t}^{N,i} =& \frac{W_t^{*,i}}{P_{t+k}} - MRS_{t+k}^i \\ &+ E_{t+k}\left[\Lambda_{t+k,t+k+1}\left[(1-\delta_i)\left(\theta_w^i\mathcal{V}_{t+k+1|t}^{N,i} + (1-\theta_w^i)\mathcal{V}_{t+k+1|t+k+1}^{N,i}\right) + \delta_i\mathcal{V}_{t+k+1}^{U,i}\right]\right]\end{aligned}$$

$W_t^{*,i}$ is the optimal wage set at time t and $\mathcal{V}^{U,i}$ is the value for the household of a type-i member being unemployed which is equal to

$$\mathcal{V}_t^{U,i} = x_t^i\int_0^1 \frac{H_t^i(s)}{H_t^i}\mathcal{V}_t^{N,i}(s)ds + (1-x_t^i)(-\Psi_i MRS_t^i + E_t\left[\Lambda_{t,t+1}\mathcal{V}_{t+1}^{U,i}\right])$$

Since being out of the labor force gives a value of 0, optimal participation requires that $\mathcal{V}_t^{U,i} = 0$ too.

Define $\mathcal{S}_t^{H,i} \equiv \mathcal{V}_t^{N,i} - \mathcal{V}_t^{U,i}$ as the surplus accruing to the household from an established employment relation of type i. It is true then that

$$\begin{aligned}\mathcal{S}_{t+k|t}^{H,i} =& \frac{W_t^{*,i}}{P_{t+k}} - MRS_{t+k}^i \\ &+ (1-\delta_i)E_{t+k}\left[\Lambda_{t+k,t+k+1}\left(\theta_w^i\mathcal{S}_{t+k+1|t}^{H,i} + (1-\theta_w^i)\mathcal{S}_{t+k+1|t+k+1}^{H,i}\right)\right]\end{aligned}$$

and, imposing $\mathcal{V}_t^{U,i} = 0$ we obtain the following equilibrium relation:

$$\Psi_i MRS_t^i = \frac{x_t^i}{1 - x_t^i} \int\limits_0^1 \frac{H_t^i(s)}{H_t^i} \mathcal{S}_t^{H,i}(s) ds \tag{3.7}$$

The wage is bargained only when firms have the opportunity to reset it. Therefore, we need to derive the household surplus from an employment relation at a firm that can reset the wage at time t. This means that we set $k = 0$ and iterate forward to get

$$\begin{aligned} \mathcal{S}_{t|t}^{H,i} =& E_t \left[\sum_{k=0}^{\infty} ((1-\delta_i)\theta_w^i)^k \left(\frac{W_t^{*,i}}{P_{t+k}} - MRS_{t+k}^i \right) \right] \\ &+ (1-\theta_w^i)(1-\delta_i) E_t \left[\sum_{k=0}^{\infty} ((1-\delta_i)\theta_w^i)^k \Lambda_{t,t+k+1} \mathcal{S}_{t+k+1|t+k+1}^{H,i} \right] \end{aligned} \tag{3.8}$$

Regarding firms, the surplus of a match for a firm that last reset the wage in period t is

$$\begin{aligned} \mathcal{S}_{t+k|t}^{F,i} =& MRPN_{t+k|t}^i - \frac{W_t^{*,i}}{P_{t+k}} \\ &+ (1-\delta_i) E_{t+k} \left[\Lambda_{t+k,t+k+1} \left(\theta_w^i \mathcal{S}_{t+k+1|t}^{F,i} + (1-\theta_w^i) \mathcal{S}_{t+k+1|t+k+1}^{F,i} \right) \right] \end{aligned}$$

Combine this equation with the optimal employment Equation (3.5) to get

$$\mathcal{S}_{t+k|t}^{F,i} = G_{t+k}^i \tag{3.9}$$

Iterating forward and setting $k = 0$ gives

$$\begin{aligned} \mathcal{S}_{t|t}^{F,i} =& E_t \left[\sum_{k=0}^{\infty} ((1-\delta_i)\theta_w^i)^k \left(MRPN_{t+k|t}^i - \frac{W_t^{*,i}}{P_{t+k}} \right) \right] \\ &+ (1-\theta_w^i)(1-\delta_i) E_t \left[\sum_{k=0}^{\infty} ((1-\delta_i)\theta_w^i)^k \Lambda_{t,t+k+1} \mathcal{S}_{t+k+1|t+k+1}^{F,i} \right] \end{aligned} \tag{3.10}$$

The wage obtained via Nash bargaining is the solution to

$$\max_{W_t^{*,i}} \left(\mathcal{S}_{t|t}^{H,i} \right)^{1-\xi_i} \left(\mathcal{S}_{t|t}^{F,i} \right)^{\xi_i}$$

subject to equations (3.8) and (3.10), where ξ_i is the bargaining power of the firm. The solution is

$$\xi_i \mathcal{S}^{H,i}_{t|t} = (1-\xi_i)\mathcal{S}^{F,i}_{t|t} \tag{3.11}$$

Now combine the solution above with the two constraints to get

$$E_t\left[\sum_{k=0}^{\infty}((1-\delta_i)\theta^i_w)^k \Lambda_{t,t+k}\left(\frac{W^{*,i}_t}{P_{t+k}} - \Omega^{tar,i}_{t+k|t}\right)\right] \tag{3.12}$$

where

$$\Omega^{tar,i}_{t+k|t} \equiv \xi_i MRS^i_{t+k} + (1-\xi_i)MRPN^i_{t+k|t} \tag{3.13}$$

is the target real wage.

Finally, log-linearize Equation (3.12) around a zero inflation steady state to get

$$\hat{w}^{*,i}_t = (1-\beta(1-\delta_i)\theta^i_w)E_t\sum_{k=0}^{\infty}(\beta(1-\delta_i)\theta^i_w)^k\left[\hat{\omega}^{tar,i}_{t+k|t} + \hat{p}_{t+k}\right] \tag{3.14}$$

Now, log-linearizing the definition of target real wage, we obtain

$$\hat{\omega}^{tar,i}_{t+k|t} = \Upsilon_i(\hat{c}_{t+k} + \varphi_i\hat{l}^i_{t+k}) + (1-\Upsilon_i)(\hat{p}^i_{t+k} - \hat{p}_{t+k} + \hat{a}^i_{t+k} - \alpha_i\hat{n}^i_{t+k}) \tag{3.15}$$

where $\Upsilon_i = \frac{\xi_i MRS^i}{W^i/P}$.

Define the average target wage as the current target wage for a firm whose employment is equal to average employment:

$$\hat{\omega}^{tar,i}_t \equiv \Upsilon_i(\hat{c}_t + \varphi_i\hat{l}^i_t) + (1-\Upsilon_i)(\hat{p}^i_t - \hat{p}_t + \hat{a}^i_t - \alpha_i\hat{n}^i_t) \tag{3.16}$$

Combine equations (3.15), (3.16) and (3.6) to obtain

$$\hat{\omega}^{tar,i}_{t+k|t} = \hat{\omega}^{tar,i}_{t+k} + (1-\Upsilon_i)(1-\Phi_i)(\hat{w}^{*,i}_t - \hat{w}^i_{t+k}) \tag{3.17}$$

Plug back Equation (3.17) into (3.14) to get

$$\hat{w}_t^{*,i} = \beta(1-\delta_i)\theta_w^i E_t \hat{w}_{t+1}^{*,i} - \frac{(1-\beta(1-\delta_i)\theta_w^i)}{1-(1-\Upsilon_i)(1-\Phi_i)}(\hat{w}_t^i - \hat{w}_t^{tar,i}) + (1-\beta(1-\delta_i)\theta_w^i)\hat{w}_t^i$$

The law of motion of the average wage is

$$\hat{w}_t^i = \theta_w^i \hat{w}_{t-1}^i + (1-\theta_w^i)\hat{w}_t^{*,i}$$

Combine both equations to obtain the Wage Phillips Curve:

$$\hat{\pi}_t^{w,i} = \beta(1-\delta_i)E_t\hat{\pi}_{t+1}^{w,i} - \lambda_w^i(\hat{\omega}_t^i - \hat{\omega}_t^{tar,i})$$

where $\lambda_w^i \equiv \frac{(1-\beta(1-\delta_i)\theta_w^i)(1-\theta_w^i)}{\theta_w^i(1-(1-\Upsilon_i)(1-\Phi_i))}$.

Whenever the current real wage is above the target real wage, wage inflation is pushed down because agents want to readjust their wages towards the target. In other words, the wage gap, defined as $\hat{\omega}_t^i - \hat{\omega}_t^{tar,i}$, is the main determinant of wage inflation.

Labor force participation is pinned down by Equation (3.7), which log-linearized can be expressed as

$$\hat{c}_t + \varphi_i \hat{l}_t^i = \frac{1}{1-x^i}\hat{x}_t^i + \hat{g}_t^i - \Xi_i \hat{\pi}_t^{w,i}$$

where $\Xi_i \equiv \frac{\xi_i(W^i/P)}{(1-\xi_i)G^i}\frac{\theta_w^i}{(1-\theta_w^i)(1-\beta(1-\delta_i)\theta_w^i)}$.

Note that participation is increasing in job-finding probability and in hiring costs (because workers generate a surplus proportional to hiring costs) and is decreasing in consumption (wealth effect) and wage inflation (because newly hired agents are paid the average wage which is below the target wage in case of positive wage inflation).

3.4.4 Model Closure and Aggregates

The model is closed by the following goods market clearing equation

$$Y_t = C_t + G_t^H H_t^H + G_t^L H_t^L$$

which log-linearized is

$$\hat{y}_t = (1 - \Theta_H - \Theta_L)\hat{c}_t + \Theta_H(\hat{g}_t^H + \hat{h}_t^H) + \Theta_L(\hat{g}_t^L + \hat{h}_t^L)$$

where $\Theta_i \equiv \frac{G^i H^i}{Y}$ is the steady state share of type i hiring costs over GDP.

The aggregate production function can be log-linearized as follows (where dispersions are second order and therefore disappear):

$$\begin{aligned} \hat{y}_t = & \frac{\nu_L^{1/\sigma}\left(A^L\left(N^L\right)^{1-\alpha_L}\right)^{\frac{\sigma-1}{\sigma}}}{Y}((1-\alpha_L)\hat{n}_t^L + \hat{a}_t^L) \\ & + \frac{\nu_H^{1/\sigma}\left(A^H\left(N^H\right)^{1-\alpha_H}\right)^{\frac{\sigma-1}{\sigma}}}{Y}((1-\alpha_H)\hat{n}_t^H + \hat{a}_t^H) \end{aligned}$$

Aggregate wage is given by

$$W_t = S_t^H W_t^H + S_t^L W_t^L$$

where S_t^H is the share of h-type workers over total employment. Log-linearized and transformed into real terms becomes

$$\hat{\omega}_t = \frac{W^H - W^L}{W}\hat{s}_t^H + \frac{S^H W^H}{W}\hat{\omega}_t^H + \frac{(1-S^H)W^L}{W}\hat{\omega}_t^L$$

The first term on the right-hand side is very important because it captures the composition effect discussed by Solon et al. (1994). Assuming that in steady state wages for high-skilled workers are larger than wages for low-skilled workers, the coefficient in front of the first term will be positive. Now suppose that when real wages increase, the share of low-skilled employment increases too (something true in this model due to the higher cyclicality of low-skilled employment). The first term is negative, thus muting the variation in aggregate wages and weakening the relation between wages and real variables.

3.5 Model Dynamics

3.5.1 Calibration

The calibration of the model plays a central role. There are some parameters and steady states that are calibrated independently, while others are obtained via steady state relationships.

I set steady state employment equal to 0.7 and steady state share of high-skilled employment equal to 0.7. Steady state unemployment is 0.03 and the share of high-skilled unemployment is 0.5. Other parameters calibrated independently are steady state job-finding probabilities for both high and low-skilled workers equal to 0.7 (consistent with Galí (2010)), $\alpha_H = 1/3$ and $\alpha_L = 1/2$ (to take into account a lower labor share in low-skill sector), $\sigma = 1.6$ as standard in the literature and $\nu_H = 0.7$, $\nu_L = 0.3$. To diversify steady state productivities between high and low-skilled workers I set $A^H = 1.5$ and $A^L = 0.5$. Note that the above parametrization does not drive the main qualitative results of the paper but just makes a quantitative difference.

The most important parameters are φ_i, θ_p, θ_w^i, γ_i and ξ_i. I pick two widely used, but very different, calibrations for the inverse of Frisch elasticity: $\varphi_H = 5$ and $\varphi_L = 1$. The first one implies an elasticity of 0.2 and is very close to the elasticity reported by Chetty et al. (2013). The second one delivers an elasticity of 1 and has been often used in the business cycle literature. This calibration ensures that low-skilled workers have a Frisch elasticity more than four times larger than high-skilled workers as discussed by Attanasio et al. (2018). Regarding the degree of price stickiness, in the flexible price version of the model, I set $\theta_p = 0.01$, while in the sticky price version, I set $\theta_p = 0.75$ as common in the New Keynesian literature to ensure that firms reset prices on average every four quarters. The degree of nominal wage stickiness is set to $\theta_w^H = 0.75$ and $\theta_w^L = 0.50$, consistent with the fact that low-skilled workers have more flexible wages.

As discussed in Section 3.3, the parameter γ_i is related to the matching function elasticity. A higher elasticity implies a lower γ_i. In this paper, I assume that low-skilled workers have higher matching function elasticities and therefore lower γ_i. Although my estimates presented in Section 3.3 are larger, I use numbers within the range of plausible parametrization discussed in Petrongolo and Pissarides (2001) and calibrate $\gamma_H = 4$ and $\gamma_L = 1$ (implying elasticities of 0.2 and 0.5 respectively). The results are robust to an alternative parametrization closer to my estimates where $\gamma_H = 2.33$ and $\gamma_L = 0.66$ (with elasticities of 0.3 and 0.6 respectively).

Finally, the last relevant parameters are firm bargaining powers. By the Hosios condition, I set them equal to the respective matching function elasticities and obtain $\xi_H = 0.2$ and $\xi_L = 0.5$. This is also consistent with Cahuc et al. (2006) showing that low-skilled workers have lower bargaining power. Note that in the alternative parametrization mentioned above, I adjust also bargaining power parameters accordingly.

Given the choices above, the rest of the parameters and steady states can be derived as follows. The separation rate is $\delta_i = \frac{x^i}{1-x^i}\frac{U^i}{N^i}$ which gives $\delta_H = 0.07$ and $\delta_L = 0.17$. The parameters and steady states $\Psi_H, \Psi_L, \chi_H, \chi_L, G^H, G^L, C, \frac{P^H}{P}, \frac{P^H}{P}$ are obtained by solving the following system of equations:

- From market clearing and the fact that in steady state $H^i = \delta_i N^i$

$$Y = C + \delta_H N^H G^H + \delta_L N^L G^L \tag{3.18}$$

- Combining Equation (3.5) with (3.13) in steady state and the definitions of B, MRS and $MRPN$

$$(1-\beta(1-\delta_i))G^i = \xi_i \left[(1-\alpha_i)\frac{P^i}{P}A^i\left(N^i\right)^{-\alpha_i} - \chi_i C\left(N^i + \Psi_i U^i\right)^{\varphi_i}\right] \tag{3.19}$$

- Setting (3.7) in steady state, substituting (3.9), (3.11) and the definition of MRS gives

$$(1-x^i)\xi_i\Psi_i\chi_i C\left(N^i + \Psi_i U^i\right)^{\varphi_i} = (1-\xi_i)G^i x^i \tag{3.20}$$

- Imposing that the share of hiring costs over the wage paid to workers is equal to 0.045 for both types, using $G^i = 0.045 * \frac{W^i}{P}$ and the definition of real wage in the steady state gives

$$\frac{G^i}{0.045} = \xi_i \chi_i C \left(N^i + \Psi_i U^i\right)^{\varphi_i} + (1-\xi_i)\left((1-\alpha_i)\frac{P^i}{P} A^i \left(N^i\right)^{-\alpha_i}\right) \tag{3.21}$$

- Using Equation (3.3) in steady state and intermediate goods production functions:

$$\frac{P^H}{P} = \frac{P^L}{P}\left(\frac{\nu_H}{\nu_L}\right)^{\frac{1}{\sigma}} \left(\frac{A^H \left(N^H\right)^{1-\alpha_H}}{A^L \left(N^L\right)^{1-\alpha_L}}\right)^{-\frac{1}{\sigma}} \tag{3.22}$$

- Imposing that the sum of the labor share of incomes over output of the two types is equal to the average labor share coming from the intermediate goods production function parametrization weighted by steady state shares of employment:

$$\frac{N^H G^H}{0.045 Y} + \frac{N^L G^L}{0.045 Y} = (1-\alpha_H)\frac{N^H}{N} + (1-\alpha_L)\frac{N^L}{N} \tag{3.23}$$

After solving this system, the results are used to compute $\Gamma^i = \frac{G^i}{(x^i)^{\gamma_i}}$, $B^i = (1 - \beta(1-\delta_i))G^i$, $MPRN^i = \frac{P^i}{P} A^i (1-\alpha_i)\left(N^i\right)^{-\alpha_i}$, $L^i = N^i + \Psi_i U^i$, $MRS^i = \chi_i C (L^i)^{\varphi_i}$, $\frac{W^i}{P} = \xi_i MRS^i + (1-\xi_i) MRPN^i$, $\frac{W}{P} = \frac{N^H}{N}\frac{W^H}{P} + \frac{N^L}{N}\frac{W^L}{P}$, and Υ_i, Φ_i, Ξ_i, Θ_i, λ_p, λ_w^i as previously defined in the paper.

Finally, the parametrization of the Taylor rule is consistent with Galí (2010): $\phi_\pi = 1.5$ and $\phi_y = 0.5/4$.

3.5.2 Model Mechanics

The main intuition behind this model is that whenever firms need to change the level of employment, they take into account both the real wage they have to pay to employees and the hiring costs that come from frictional labor markets. Firms in the low-skill sector face less volatile hiring costs compared to their counterparts in the high-skill sector and this more than compensates the fact that wages for low-skilled workers are more volatile.

To show how the model works, let's suppose there is a generic shock that drives production higher. Intermediate goods firms in both sectors expand production by increasing employment via an increase in hiring. This leads to an increase in job-finding probability (due to the increase in vacancies). Hiring costs $\hat{g}$ increase because the labor market is tighter and it is harder for firms to fill vacancies. The effect on labor force participation is ambiguous because job-finding probability and hiring costs tend to drive upwards this variable, but wage inflation and consumption tend to drive it downwards. The relative strength of these two effects depends on the calibration. Both the marginal product of labor and the marginal rate of substitution increase, driving up the target real wage and wage inflation. In the case of sticky prices, price inflation is driven up by the increase in the marginal cost for the final goods firm determined by the increase in real wages and hiring costs.

So far, I have not mentioned any heterogeneity because the mechanism is the same for both sectors and the only difference comes from differential calibrations. There are two equations that is useful to report in order to explain why even though wages for low-skilled workers are more flexible, also low-skilled employment is more volatile.

Hiring costs for firms rewritten to explicitly show unemployment in the equation:

$$\hat{g}_t^i = \gamma_i(1 - x^i)(\hat{h}_t^i - \hat{u}_t^i)$$

and labor force participation choice by the household rewritten to explicitly show how unemployment is affected:

$$\hat{u}_t^i = -\frac{N^i}{\Psi_i U^i}\hat{n}_t^i + \frac{1}{\varphi_i}\frac{L^i}{\Psi_i U_i}\left[\left(\frac{1}{1 - x^i} + \gamma_i\right)\hat{x}_t^i - \Xi_i \hat{\pi}_t^{w,i} - \hat{c}_t\right]$$

The first equation is crucial because it determines hiring costs that, for the main mechanism of the paper to work, must be less volatile for low-skilled workers. Calibrating $\gamma_L < \gamma_H$ reduces the volatility of the variable for a given change in hiring and unemployment. This is one of the two main drivers of the result.

The other driver comes from the calibration of the inverse Frisch elasticity, where $\varphi_H > \varphi_L$ increases the volatility of labor force participation and, as a consequence, of unemployment for low-skilled workers, thus contributing to the reduction in the volatility of their hiring costs.

As a final point, it is important to mention that higher Frisch elasticity for low-skilled workers leads to a smaller increase in their marginal rate of substitution and therefore a smaller increase in their target wage and wage inflation. This effect partly counteracts their higher wage flexibility.

3.5.3 Results

Flexible Prices Model

Table 3.1 presents the standard deviations of employment and wage inflation and compares them with their empirical counterparts computed in Section 3.3. The first line shows how the model presented in this paper matches the volatility of high-skilled and low-skilled employment ensuring that their relative volatility is very close to the data. Regarding wage inflation, the volatility for low-skilled agents is the same as in the data, but the figure for high-skilled agents is a bit higher, leading to a higher relative volatility. Still, the moments generated by the model and the data are very close. The most important point is that the model is successful at generating higher volatility both in wages and employment for low-skilled workers as the relative volatilities are below 1.

The second line shows the standard deviations from a model without heterogeneity in Frisch elasticities, matching function elasticities, and bargaining powers. I calibrate $\varphi_H = \varphi_L = 2.3$, $\xi_H = \xi_L = 0.3$ and $\gamma_H = \gamma_L = 2.3$. [6] The model without heterogeneity cannot have at the same time both relative volatilities below 1. Although it does a good

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[6] The parameters are computed as a weighted average of the calibration for high-skilled and low-skilled workers in the baseline model where the weights are respectively 0.7 and 0.3. Note that I compute the weighted average of the Frisch elasticity and not of its inverse.

Table 3.1: Standard Deviations

	$\sigma\left(\hat{n}^H\right)$	$\sigma\left(\hat{n}^L\right)$	$\frac{\sigma\left(\hat{n}^H\right)}{\sigma\left(\hat{n}^L\right)}$	$\sigma\left(\hat{\pi}^{w,H}\right)$	$\sigma\left(\hat{\pi}^{w,L}\right)$	$\frac{\sigma\left(\hat{\pi}^{w,H}\right)}{\sigma\left(\hat{\pi}^{w,L}\right)}$
Model	0.35	0.37	**0.94**	0.94	1.03	**0.91**
Model - No Het.	0.52	0.24	**2.12**	0.90	1.11	**0.82**
Data	0.35	0.38	**0.92**	0.88	1.04	**0.85**

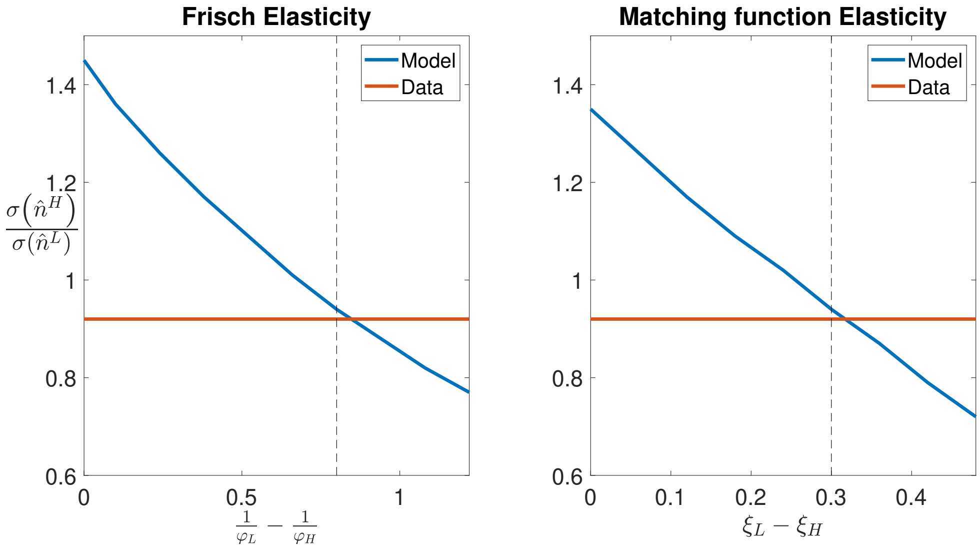
Notes: This Table reports the standard deviations of employment and wages for high-skilled and low-skilled workers implied by the baseline model, the model without heterogeneity, and compares them with their empirical counterparts.

job of matching the relative volatility in wage inflation, it performs poorly in terms of employment. High-skilled employment has a standard deviation which is more than twice the low-skilled counterpart, which is not consistent with the data.

In Figure 3·2, I show how important is heterogeneity in Frisch elasticity and matching function elasticity to push the volatility of high-skilled employment below the volatility of low-skilled employment. To plot the first graph, I take the baseline calibration of the model and I change for both agents only the parameters associated with Frisch elasticity (φ_H and φ_L). The second graph is constructed in the same way, but in this case, I change only parameters associated with matching function elasticity (ξ_H, ξ_L, γ_H and γ_L). On the horizontal axis, I report the gap in the elasticities between the two agents: a zero gap means that both agents have the same elasticity. On the vertical axis, I report the relative standard deviation of employment. The vertical line corresponds to the gap used in the baseline calibration of the model. In both cases, the larger the heterogeneity, the lower the relative standard deviation. When the calibration is the same for both types, the model is far away from matching the data because high-skilled employment is too volatile compared to low-skilled employment. As heterogeneity gets larger, the relative volatility falls because the mechanism presented in Section 3.5.2 mutes fluctuations in high-skilled employment and increases the variability of low-skilled employment.

In Figure 3·3, I present impulse response functions after a common productivity shock. The discontinuous blue line is the response for high-skilled workers, while the green line is for low-skilled workers and the red line is for aggregates. I also report the response

Figure 3·2: Relative Standard Deviation of Employment as a Function of Heterogeneity

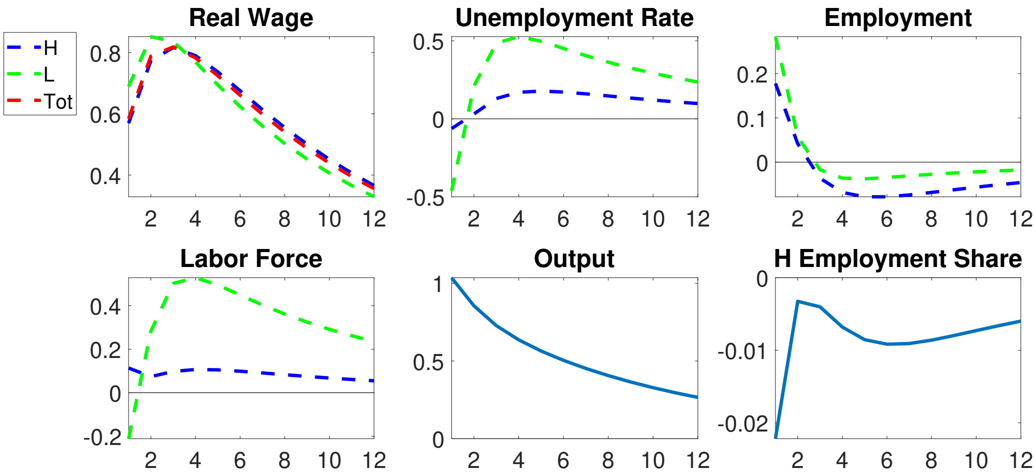


Notes: This Figure reports the relative standard deviations between high-skilled and low-skilled workers (vertical axes) as a function of the gap between Frisch elasticities (left panel) and matching function elasticities (right panel). The horizontal red line refers to the relative standard deviation in the data.

of aggregate output and the share of high-skilled employment as continuous blue lines. Employment, unemployment rate, and labor force participation are more volatile for low-skilled individuals. The real wage is slightly more volatile for low-skilled individuals too. Output increases and the share of high-skilled employment over total employment is countercyclical as suggested by the data. This also drives the composition effect which mutes the response of aggregate wages (red line) making it very close to the response of high-skilled wages.

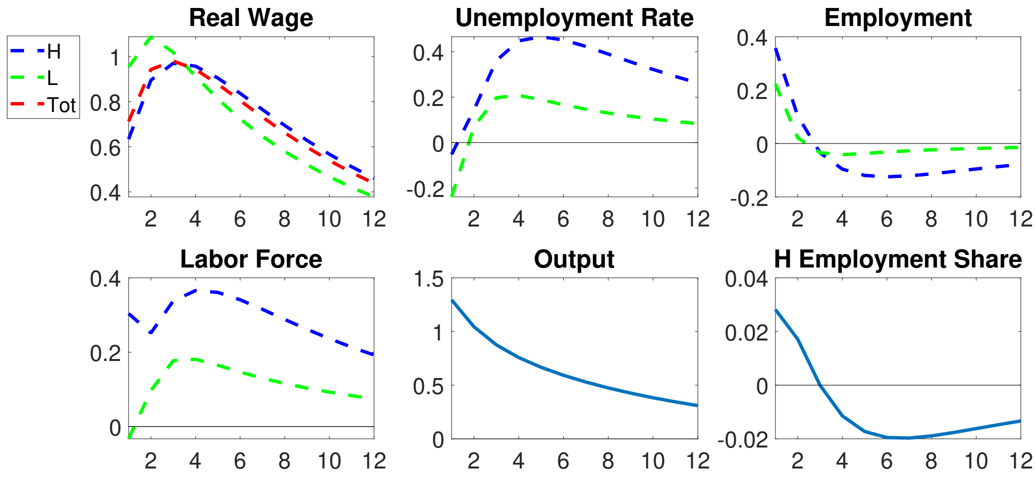
Figure 3·4 presents impulse responses for the model without heterogeneity in Frisch and matching function elasticities. Wages are still more volatile for low-skilled workers, but the volatility of their employment becomes smaller compared to high-skilled workers. As a consequence, the composition effect on employment changes direction.

Figure 3·3: IRFs After Positive Productivity Shock - Flexible Prices Model



Notes: This Figure presents impulse response functions after a positive productivity shock in the flexible prices model. All variables are reported in percentage deviations from steady state. The dashed red line refers to total wages. The dashed blue (green) lines refer to high-skilled (low-skilled) workers.

Figure 3·4: IRFs After Positive Productivity Shock - No Heterogeneity

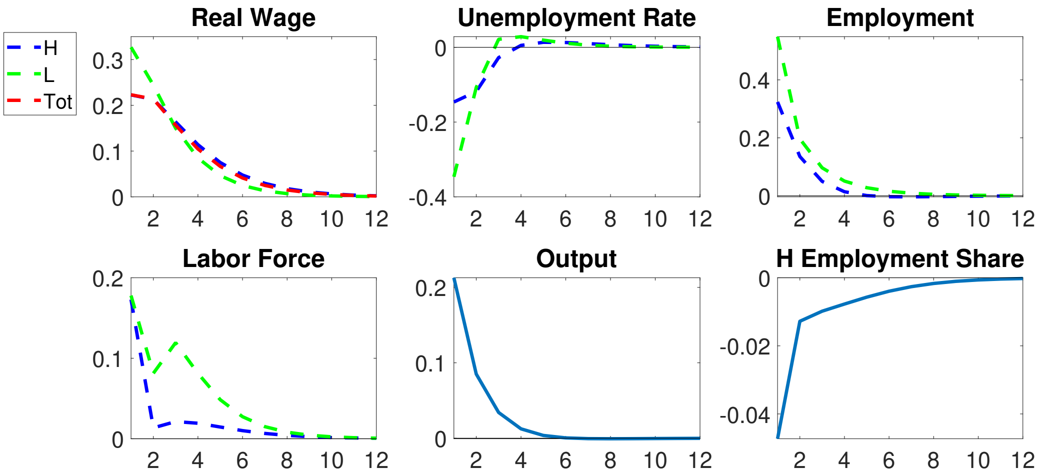


Notes: This Figure presents impulse response functions after a positive productivity shock in the flexible prices model without heterogeneity in the parametrization. All variables are reported in percentage deviations from steady state. The dashed red line refers to total wages. The dashed blue (green) lines refer to high-skilled (low-skilled) workers.

Sticky Prices Model

In the model presented so far, final goods firms have the opportunity to adjust their prices in each period without any constraint. The main mechanism underlying the results of this

Figure 3·5: IRFs After Expansionary Monetary Policy Shock - Sticky Prices Model



Notes: This Figure presents impulse response functions after a monetary policy shock in the sticky prices model. All variables are reported in percentage deviations from steady state. The dashed red line refers to total wages. The dashed blue (green) lines refer to high-skilled (low-skilled) workers.

paper works through labor market frictions and does not rely on the assumption of flexible prices. To confirm that this is true and to show the implications that monetary policy has on inequality, I present an extension with sticky prices. The only differences with the previous model are that now the price stickiness parameter is $\theta_p = 0.75$ and $\theta_w^L = 0.4$ (this is needed for better quantitative performance, but the sign of the results would not change also with the baseline calibration).

In Figure 3·5, I present impulse response functions after an expansionary monetary policy shock in the model with sticky prices. The variability of low-skilled wages, employment, unemployment rate, and labor force are still larger. The share of high-skilled employment declines generating the composition effect. This effect can be seen also from the fact that the aggregate wage response (red line) overlaps with the high-skilled wage response (blue line) whereas in principle in the absence of the composition effect, it should lie between the blue and the green lines.

An additional result is that expansionary monetary policy has stronger beneficial effects for low-skilled workers, whose employment and wages react much more, leading to a decline in wage inequality.

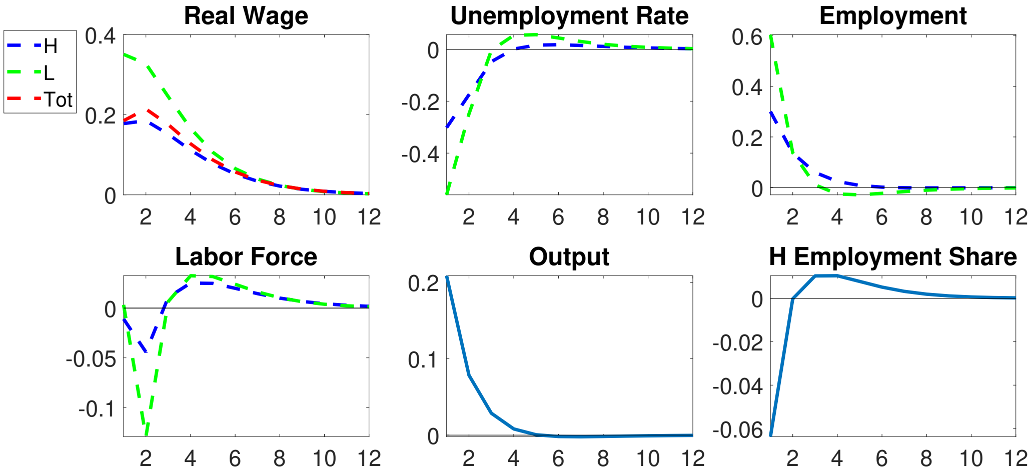
3.6 TANK Extension

The model presented in this paper can also be further extended into a two-agent version where the low-skilled agent is hand-to-mouth. The most important difference compared to the previous model is the fact that now resources are not pooled and consumption for the low-skilled agent is equal to its labor income. This inability to smooth consumption over time makes it much more volatile, strengthening the wealth effect in the labor force participation choice. In principle, this variation would work against the mechanism outlined in Section 3.5.2 because now low-skilled workers are less likely to adjust labor force participation procyclically. Nevertheless, with a reasonable calibration, the main results of the paper are preserved also in this extension. The only difference from the sticky prices model that is necessary to obtain the same results for employment and wages is calibrating $\theta_w^L = 0.6$ (low-skill sector can reset wages on average every 7.5 months instead of 5 months) and dropping the Hosios condition by setting the bargaining power of firms in both sectors equal to $\xi_H = \xi_L = 0.3$ (a value often used in the literature).

Figure 3·6 reports impulse response functions after an expansionary monetary policy shock. Employment and real wages behave very similarly to the single agent case presented above. The main difference comes from labor force participation, where now the stronger wealth effect drives a change of sign. The share of high-skilled employment falls on impact and returns above steady state after two quarters.

Overall, the important result that low-skilled agents present larger volatility in wages and employment is preserved also in this extension and the implications that monetary policy has on wage inequality are the same as in the single-agent New Keynesian model.

Figure 3·6: IRFs After Expansionary Monetary Policy Shock - TANK Model



Notes: This Figure presents impulse response functions after a monetary policy shock in the TANK model. All variables are reported in percentage deviations from steady state. The dashed red line refers to total wages. The dashed blue (green) lines refer to high-skilled (low-skilled) workers.

3.7 Conclusions

In this paper, I develop a model that reconciles two empirical facts that seem to be inconsistent with each other: low-skilled workers present more cyclicality both in employment and earnings compared to high-skilled workers. This fact contrasts with models where quantities adjust more when prices adjust less and viceversa.

I show that a reasonable calibration of a simple extension of a standard model can deliver results consistent with the data. I construct a model with wage stickiness, heterogeneous labor market frictions and two sectors employing separately high and low-skilled workers where wages are more flexible in the low-skill sector. Firms face two cost components when they adjust employment: the wage paid to new employees and hiring costs. Although wages are more flexible in the low-skill sector, the hiring cost is more volatile in the high-skill sector. This makes total costs more volatile for high-skill workers, leading to a lower cyclicality in their employment.

Two parameters explain this result: the matching function elasticity, which is related to firm bargaining power, and the Frisch elasticity which are both higher for low-skilled workers. Larger matching function and Frisch elasticities reduce the volatility of hiring costs while larger Frisch elasticity has the additional effect of decreasing the volatility of wages.

I present both model standard deviations and impulse response functions after productivity shocks in a model with flexible prices. Low-skilled workers present more cyclical employment and wages than high-skilled workers, consistent with the data. This is not true in a model without heterogeneity, where high-skilled employment is more volatile than low-skilled employment.

I also present impulse responses after a monetary policy shock in a model with sticky prices. The main result is preserved, suggesting that it does not depend on price flexibility or a specific shock. Moreover, this result implies that the share of high-skilled employment is countercyclical, determining a composition effect on wages that flattens the Wage Phillips Curve.

Finally, I extend the model to a two-agents New Keynesian version and show that under a reasonable calibration, the main results are still preserved.

Appendix A

Supplementary Material for Chapter 1

A.1 Data Sources and Transformations

List of data sources used in the paper.

LTROs and TLTROs (Stock): *Longer-term refinancing operations - Eurosystem*. Source: ECB SDW. Key: ILM.W.U2.C.A050200.U2.EUR.

LTROs and TLTROs (operations): *Longer-term refinancing operations*. Source: ECB website.[1]

QE: *Securities held for monetary policy purposes*.

Source: ECB SDW. Key: ILM.W.U2.C.A070100.U2.EUR.

Total Assets ECB: *Total assets/liabilities*.

Source: ECB SDW. Key: ILM.W.U2.C.T000000.Z5.Z01.

Loans to households: *Loans vis-a-vis euro area households reported by MFIs excl. ESCB in the euro area (stocks)*.

Source: ECB SDW. Key: BSI.M.U2.N.A.A20.A.1.U2.2250.Z01.E .

Loans to nonfinancial corporations: *Loans vis-a-vis euro area NFCs reported by MFIs excl. ESCB in the euro area (stocks)*.

Source: ECB SDW. Key: BSI.M.U2.N.A.A20.A.1.U2.2240.Z01.E .

Loans for house purchases: *Lending for house purchase vis-a-vis euro area households reported by MFIs excl. ESCB in the euro area (stocks)*.

Source: ECB SDW. Key: BSI.M.U2.N.A.A22.A.1.U2.2250.Z01.E.

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[1] https://www.ecb.europa.eu/mopo/implement/omo/html/top_history.en.html

Eligible private loans: Loans to households - Loans for house purchases + Loans to nonfinancial corporations.

Loans: Loans to households + Loans to nonfinancial corporations.

Government Bonds: *Holdings of Debt securities issued by euro area General Government reported by MFIs excl. ESCB in the euro area (stocks).*

Source: ECB SDW. Key: BSI.M.U2.N.A.A30.A.1.U2.2100.Z01.E.

Reserves: *Loans vis-a-vis the Eurosystem reported by MFIs excl. ESCB in the euro area (stocks).* Source: ECB SDW. Key: BSI.M.U2.N.A.A20.A.1.U2.1100.Z01.E.

Deposits from households: *Deposit liabilities vis-a-vis euro area households reported by MFIs excl. ESCB in the euro area (stocks).*

Source: ECB SDW. Key: BSI.M.U2.N.A.L20.A.1.U2.2250.Z01.E.

Deposits from nonfinancial corporations: *Deposit liabilities vis-a-vis euro area NFCs reported by MFIs excl. ESCB in the euro area (stocks).*

Source: ECB SDW. Key: BSI.M.U2.N.A.L20.A.1.U2.2240.Z01.E.

Deposits: Deposits from households + Deposits from nonfinancial corporations.

Capital: *Capital and reserves reported by MFIs excl. ESCB in the euro area (stocks).* Source: ECB SDW. Key: BSI.M.U2.N.A.L60.X.1.Z5.0000.Z01.E.

Lending Rate: *Bank interest rates - loans to corporations (outstanding amounts) - euro area.* Source: ECB SDW. Key: MIR.M.U2.B.A20.A.R.A.2240.EUR.O.

Deposit rate: *Bank interest rates - deposits from households with an agreed maturity (on outstanding amounts) - euro area.*

Source: ECB SDW. Key: MIR.M.U2.B.L22.A.R.A.2250.EUR.O.

Policy Rate: *Deposit Facility Rate.* Source: ECB website.[2]

Government Bond Yield: *Euro area 10-year Government Benchmark bond yield - Yield.* Source: ECB SDW. Key: FM.M.U2.EUR.4F.BB.U2_10Y.YLD.

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[2] https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html

A.2 Parameter Sensitivity to Targets

Table A.1 presents calibration results using alternative targets (in bold). Loan growth after a CBL shock of 1tn€ is assumed to be between 2.5% and 3.9% as estimated in Altavilla et al. (2020) where the baseline is 2.8%. The growth rate of government bonds is between 1.3% and 5.2%, thereby covering the wide uncertainty related to this elasticity.[3] The share of CBL funds stored in banks' own reserves accounts was estimated by Barbiero et al. (2021) to be between 20% and 50%. Finally, in this exercise the share of bonds that the central bank purchases from other banks ranges between 20% and 50%.

The share parameter α in the CES aggregator of the cost function tends to be quite stable, ranging between 0.70 and 0.95. The lowest levels are associated with a strong impact of CBL or QE on bond growth, or a weak impact of CBL on reserves. Loan demand elasticity ε^L takes values between 151 and 205 and mainly depends on the targeted loan growth after a CBL shock. The benefit of issuing deposits θ^D and the cost of holding bonds θ^{ip} all range between 0.004 and 0.008. The elasticity parameter in the cost function γ ranges between 0.11 and 3.82, where the highest values are associated with very negative values of ρ (which is the parameter governing the elasticity of substitution between bonds and reserves in the CES aggregator and ranges between -3.75 and 0.45). These parameters tend to get bigger in absolute value when the target change in reserves after CBL and the target change in bonds after QE become very different. Finally, the scale parameter κ adjusts according to the magnitude of the other parameters.

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[3] 1.3% is obtained by halving the lower estimate of loan growth (2.5%), while 5.2% is calculated by multiplying the upper estimate for loan growth (5.2%) by 1.33 which is the coefficient used in the baseline exercise.

Table A.1: Sensitivity of the Calibrated Parameters to the Targets

Targets	***Baseline***	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\frac{\partial L/\partial O}{\bar{L}}$	*2.8*	**2.5**	**3.9**	2.8	**2.5**	2.8	2.8	**3.9**	2.8	2.8	2.8
$\partial R/\partial O$	*0.30*	0.30	0.30	0.30	0.30	**0.20**	**0.50**	**0.20**	0.30	0.30	0.30
$\frac{\partial A/\partial O}{\bar{A}}$	*3.7*	**3.3**	**5.2**	**1.4**	**1.3**	3.7	3.7	**2.0**	3.7	3.7	**1.4**
$\partial A/\partial A^{QE}$	*-0.35*	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	**-0.20**	**-0.50**	**-0.50**
Model											
$\frac{\partial L/\partial O}{\bar{L}}$	*2.8*	2.5	3.9	2.8	2.5	2.8	2.8	3.9	2.8	2.8	2.8
$\partial R/\partial O$	*0.25*	0.28	0.06	0.32	0.36	0.18	0.29	0.09	0.21	0.26	0.34
$\frac{\partial A/\partial O}{\bar{A}}$	*3.7*	3.3	5.2	1.4	1.3	3.7	3.7	1.9	3.7	3.7	1.4
$\partial A/\partial A^{QE}$	*-0.35*	-0.35	-0.33	-0.34	-0.30	-0.37	-0.36	-0.32	-0.28	-0.50	-0.34
Parameters											
κ	*0.015*	0.002	0.0009	0.03	0.009	0.00004	0.00009	0.0007	0.00005	0.014	0.004
γ	*0.17*	0.74	1.20	0.11	0.30	3.82	2.76	1.66	3.68	0.15	0.49
α	*0.86*	0.89	0.70	0.85	0.88	0.90	0.94	0.71	0.95	0.79	0.87
ρ	*-0.02*	-0.42	-2.01	0.45	0.33	-2.73	-2.51	-0.08	-3.75	0.29	0.24
ε^L	*169*	156	205	185	168	151	181	197	153	173	194
θ^D	*0.007*	0.008	0.006	0.007	0.007	0.008	0.008	0.007	0.008	0.007	0.008
θ^{ip}	*0.007*	0.006	0.004	0.008	0.008	0.004	0.005	0.005	0.005	0.006	0.007

Notes: This Table reports the results of the calibration exercise with different assumptions on the targets. Targets are reported in bold when different from the baseline. Each column represents a different calibration exercise. Parameter ε^D is always assumed to be equal to -275 and γ^a to be equal to -0.36%. $\frac{\partial L/\partial O}{\bar{L}}$ and $\frac{\partial A/\partial O}{\bar{A}}$ are expressed in percentage points.

A.3 Robustness of Partial Equilibrium Results

Table A.2 presents the impact of 1tn€ CBL and QE shocks in the model calibrated with different combinations of the parameters that have been presented in Table A.1. The pass-through of CBL to loans ranges between 0.25tn€ and 0.38tn€, while leakage from government bonds ranges between 0.03tn€ and 0.09tn€. The change in reserves takes values between 0.06tn€ and 0.36tn€ while most of the calibrations return values above 0.18tn€. Leakage from deposits varies between -0.36tn€ and -0.49tn€. Regarding QE, the impact on loans is between 0.03tn€ and 0.16tn€ with an associated change in government bond holdings ranging from -0.28tn€ and -0.53tn€. The maximum decline in deposits is -0.20tn€ while some calibrations return a figure of -0.06tn€.

Table A.2: Impact of 1tn€ CBL and QE Shocks - Robustness

	Loans		Bonds		Reserves		Deposits	
	CBL	QE	CBL	QE	CBL	QE	CBL	QE
Baseline	*0.27*	*0.09*	*0.07*	*-0.35*	*0.25*	*0.12*	*-0.41*	*-0.14*
(1)	0.25	0.07	0.05	-0.32	0.28	0.13	-0.41	-0.12
(2)	0.38	0.16	0.09	-0.33	0.06	-0.02	-0.47	-0.20
(3)	0.28	0.04	0.03	-0.35	0.32	0.25	-0.38	-0.06
(4)	0.25	0.03	0.02	-0.31	0.36	0.23	-0.37	-0.05
(5)	0.28	0.08	0.06	-0.33	0.18	0.11	-0.48	-0.14
(6)	0.27	0.10	0.06	-0.37	0.29	0.13	-0.38	-0.14
(7)	0.38	0.05	0.03	-0.30	0.09	0.18	-0.49	-0.07
(8)	0.28	0.08	0.06	-0.28	0.21	0.06	-0.46	-0.14
(9)	0.27	0.10	0.07	-0.53	0.26	0.28	-0.40	-0.15
(10)	0.27	0.04	0.03	-0.36	0.34	0.26	-0.36	-0.06

Notes: This Table reports the impact of 1tn€ CBL and QE shocks on loans, government bonds, reserves, and deposits for various alternative combinations of the parameters outlined in Table A.1. All the changes are expressed in tn€.

A.4 Equilibrium Equations for the General Equilibrium Model

A.4.1 Households

Households maximize the present discounted value of their utility subject to the balance sheet constraint.

$$E_0 \sum_{t=0}^{\infty} \beta^t \varphi_t \left(\frac{(C_t - hC_{t-1})^{1-\sigma} - 1}{1-\sigma} - \chi \frac{N_t^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right) \tag{A.1}$$

$$P_t C_t + D_t + M_t = W_t N_t - T_t + (1 + i_{t-1}^D) D_{t-1} + \Pi_t + M_{t-1} \tag{A.2}$$

Optimality conditions are:

$$\chi N_t^{\frac{1}{\eta}} = \phi_t W_t \tag{A.3}$$

$$\phi_t = (C_t - hC_{t-1})^{-\sigma} - \beta h E_t \frac{\varphi_{t+1}}{\varphi_t} (C_{t+1} - hC_t)^{-\sigma} \tag{A.4}$$

$$1 = \beta E_t \left[\frac{\phi_{t+1}}{\phi_t} \frac{\varphi_{t+1}}{\varphi_t} (1 + i_t^D) \frac{1}{1 + \pi_{t+1}} \right] \tag{A.5}$$

And $\Lambda_{t,t+1} = \frac{\phi_{t+1}}{\phi_t} \frac{\varphi_{t+1}}{\varphi_t}$.

A.4.2 Retail Firms

Retail firms use intermediate inputs demanded from intermediate goods firms to produce the final retail good.

$$Y_t = \left(\int_0^1 Y_t(s)^{\frac{\varepsilon-1}{\varepsilon}} ds \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{A.6}$$

Demand for retail goods and the price index are:

$$Y_t(s) = \left(\frac{P_t(s)}{P_t} \right)^{-\varepsilon} Y_t \tag{A.7}$$

$$P_t = \left[\int_0^\infty P_t(s)^{1-\varepsilon} ds \right]^{\frac{1}{1-\varepsilon}} \tag{A.8}$$

Retail firms solve:

$$\max_{P_t^*(s)} E_t \sum_{\tau=0}^{\infty} \beta^\tau (\gamma^p)^\tau \Lambda_{t,t+\tau} \frac{P_t}{P_{t+\tau}} Y_{t+\tau}(s) \left[P_t^*(s) - P_{t+\tau}^m \right] \tag{A.9}$$

subject to demand for $Y_t(s)$. Their optimality conditions are:

$$1 = (1-\gamma^p) \left(\frac{P_t^*}{P_t} \right)^{1-\varepsilon} + \gamma^p \left(\frac{P_{t-1}}{P_t} \right)^{1-\varepsilon} \tag{A.10}$$

$$\varepsilon \Gamma_t^1 = (\varepsilon - 1) \Gamma_t^2 \tag{A.11}$$

$$\Gamma_t^1 = \varphi_t \phi_t \frac{P_t^m}{P_t} Y_t + \gamma^p \beta E_t \left(\frac{P_{t+1}}{P_t} \right)^\varepsilon \Gamma_{t+1}^1 \tag{A.12}$$

$$\Gamma_t^2 = \varphi_t \phi_t \frac{P_t^*}{P_t} Y_t + \gamma^p \beta E_t \left(\frac{P_t^*}{P_{t+1}^*} \right) \left(\frac{P_{t+1}}{P_t} \right)^\varepsilon \Gamma_{t+1}^2 \tag{A.13}$$

$$Y_t^m = Y_t v_t^p \tag{A.14}$$

$$v_t^p = \gamma^p \left(\frac{P_t}{P_{t-1}}\right)^{\varepsilon} v_{t-1}^p + (1-\gamma^p)\left(\frac{P_t^*}{P_t}\right)^{-\varepsilon} \tag{A.15}$$

A.4.3 Intermediate Goods Firms

Intermediate goods firms produce intermediate inputs using labor and capital. The production function for intermediate goods is:

$$Y_t^m = Z_t \left(\xi_t K_t\right)^{\alpha^k} N_t^{1-\alpha^k} \tag{A.16}$$

The objective function is:

$$\max_{N_t, K_t} P_t^m Y_t^m - W_t N_t - Z_t^K K_t \tag{A.17}$$

Optimality conditions are:

$$(1-\alpha^k) P_t^m \frac{Y_t^m}{N_t} = W_t \tag{A.18}$$

$$\alpha^k P_t^m \frac{Y_t^m}{K_t} = Z_t^K \tag{A.19}$$

The return on capital is:

$$1 + i_{t+1}^L = \frac{Q_{t+1}\xi_{t+1}(1-\delta) + P_{t+1}^m \alpha^k \frac{Y_{t+1}^m}{K_{t+1}}}{Q_t} \tag{A.20}$$

A.4.4 Capital Producers

Capital producers are subject to investment adjustment costs. The law of motion of capital is:

$$K_{t+1} = (1-\delta)\xi_t K_t + I_t \tag{A.21}$$

Capital producers choose the real price of capital $\frac{Q_t}{P_t}$ by maximizing the following:

$$\max E_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \Lambda_{t,\tau} \left[\left(\frac{Q_\tau}{P_\tau} - 1\right) I_\tau - f\left(\frac{I_\tau}{I_{\tau-1}}\right) I_\tau\right] \tag{A.22}$$

The optimality condition is:

$$\frac{Q_t}{P_t} = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + f'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}} - E_t\beta\frac{\phi_{t+1}}{\phi_t}\frac{\varphi_{t+1}}{\varphi_t}f'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{A.23}$$

A.4.5 Banks

Assuming a symmetric equilibrium across banks, they maximize the present discounted value of dividends:

$$\max E_t \sum_{s=0}^{\infty} \beta^{s+1}\Lambda_{t,t+s+1} DIV_{t+s+1} \tag{A.24}$$

where dividends are defined as:

$$DIV_{t+1} = (1-\omega)X_{t+1} \tag{A.25}$$

and X_{t+1} is defined as:

$$X_{t+1} = i_t^R F_t + (i_{t+1}^L - i_t^R)L_t + (i_t - \theta_t^{ip} - i_t^R)A_t - i_t^R S_t - \tag{A.26}$$

$$(i_t^D - \theta_t^D - i_t^R)D_t - (i_t^o - i_t^R)O_t - \mathcal{C}(A_t, R_t, F_t) - (1-\varsigma)F_t\pi_{t+1} \tag{A.27}$$

Their choice for CBL O_t is constrained to be less or equal to $\bar{O}_t$. Real bank equity evolves as follows:

$$\frac{F_{t+1}}{P_{t+1}} = \frac{F_t}{P_t}(1-\varsigma) + \omega\frac{X_{t+1}}{P_{t+1}} \tag{A.28}$$

Optimality conditions are:

$$1 + i_t^D = \mu^D\left(1 + i_t^R - \mathcal{C}_R(A_t, R_t, F_t) + \theta^D\right) \tag{A.29}$$

$$1 + i_t^R - \mathcal{C}_R(A_t, R_t, F_t) = 1 + i_t - \mathcal{C}_A(A_t, R_t, F_t) - \theta^{ip} \tag{A.30}$$

$$1 + i_t^R - \mathcal{C}_R(A_t, R_t, F_t) = 1 + i_t^o + \delta_t^o \tag{A.31}$$

$$\delta_t^o\left(O_t - \bar{O}_t\right) = 0 \;,\; \delta_t^o \geq 0 \tag{A.32}$$

$$E_t(1+i^L_{t+1}) = \mu^L \left(1 + i^R_t - \mathcal{C}_R(A_t, R_t, F_t)\right) \tag{A.33}$$

where δ^o is the Lagrange multiplier on the central bank funding constraint.

The balance sheet constraint is:

$$L_t + A_t + R_t + S_t = D_t + O_t + F_t \tag{A.34}$$

A.4.6 Government and Central Bank

The policy rate follows a Taylor rule which is subject to a lower bound.

$$i^R_t = \max\left((1-\rho_i)\left(\bar{i}^R + \psi_\pi \pi_t + \psi_y \frac{Y_t - \bar{Y}}{\bar{Y}}\right) + \rho_i i^R_{t-1} + \varepsilon^m_t, \bar{i}^R\right) \tag{A.35}$$

The interest rate on government bonds is linked to the policy rate and is affected by QE.

$$i_t = i^R_t + \theta^i_t + \gamma^a A^{QE}_t \tag{A.36}$$

The aggregate amount of reserves varies with CBL and QE.

$$R_t = \bar{R} + (O_t - \bar{O}) + \mathcal{I}_{QE} * (\bar{A} - A_t) \tag{A.37}$$

The consolidated budget constraint for the government and the central bank is:

$$A_t + R_t - O_t = (1+i_{t-1})A_{t-1} + (1+i^R_{t-1})R_{t-1} - (1+i^o_{t-1})O_{t-1} + G_t - T_t \tag{A.38}$$

CBL and QE follow autoregressive processes (in log-linear terms):

$$o_t = (1-\rho_{o,1})\bar{o} + \rho_o o_{t-1} + \varepsilon^o_t \tag{A.39}$$

$$a^{qe}_t = (1-\rho_{qe,1}-\rho_{qe,2})\bar{a}^{qe} + \rho_{qe,1} a^{qe}_{t-1} + \rho_{qe,2} a^{qe}_{t-2} + \varepsilon^{qe}_t \tag{A.40}$$

A.4.7 Resource Constraints and Shocks

The resource constraint is:

$$\begin{aligned} Y_t = & C_t + I_t + G_t + f\left(\frac{I_t}{I_{t-1}}\right) I_t + \theta_t^{ip} \frac{A_{t-1}}{P_t} - \theta_t^D \frac{D_{t-1}}{P_t} \\ & + \varsigma \frac{F_{t-1}}{P_t} + \frac{\mathcal{C}(A_{t-1}, R_{t-1}, F_{t-1})}{P_t} \end{aligned} \tag{A.41}$$

Aggregate loans are equal to the value of capital:

$$L_t = Q_t K_{t+1} \tag{A.42}$$

All the remaining exogenous variables follow an AR(1) process.

A.4.8 Steady State

The steady state is derived as follows.

First, notice that with no inflation, $\frac{\bar{P}^*}{\bar{P}} = 1$, $\bar{v}^p = 1$, $\bar{Y}^m = \bar{Y}$, and $\frac{\bar{Q}}{\bar{P}} = 1$.

The real price for intermediate goods is:

$$\frac{\bar{P}^m}{\bar{P}} = \frac{\varepsilon - 1}{\varepsilon} \tag{A.43}$$

From the household Euler equation obtain:

$$\beta = (1 + \bar{i}^D)^{-1} \tag{A.44}$$

Combining equilibrium conditions in steady state, get the capital-labor ratio:

$$\frac{\bar{K}}{\bar{N}} = \left(\frac{\alpha^k \bar{Z}(\varepsilon - 1)}{\varepsilon(1 + \bar{i}^L + \delta - 1)}\right)^{\frac{1}{1-\alpha^k}} \tag{A.45}$$

Define:

$$\begin{aligned}\Xi_1 =& \frac{1}{\nu^L}(\nu^R \bar{i}^R + \bar{i}^L \nu^L + (\bar{i} - \theta^{ip})\nu^A - (\bar{i}^D - \theta^D)\nu^D - \bar{i}^o \nu^o \\ & - \kappa((\alpha(\nu^A)^\rho + (1-\alpha)(\nu^R)^\rho)^{1/\rho})^{-\gamma})\end{aligned} \tag{A.46}$$

and

$$\Xi_2 = \delta + \theta^{ip}\frac{\nu^A}{\nu^L} - \theta^D \frac{\nu^D}{\nu^L} + \frac{\kappa}{\nu^L}((\alpha(\nu^A)^\rho + (1-\alpha)(\nu^R)^\rho)^{1/\rho})^{-\gamma} + \omega \Xi_1 \tag{A.47}$$

and

$$\Xi_3 = (1-h)^{-\sigma}(1-h\beta)(1-\alpha^k)\bar{Z}\left(\frac{\bar{K}}{\bar{N}}\right)^{\alpha^k} \frac{\varepsilon - 1}{\varepsilon} \tag{A.48}$$

Steady state labor is then:

$$\bar{N} = \left(\frac{\Xi_3}{\chi\left(\bar{Z}\left(\frac{\bar{K}}{\bar{N}}\right)^{\alpha}(1-g) - \frac{\bar{K}}{\bar{N}}\Xi_2\right)^{\sigma}}\right)^{\frac{1}{\sigma + (1/\eta)}} \tag{A.49}$$

Steady state capital is:

$$\bar{K} = \bar{N}\frac{\bar{K}}{\bar{N}} \tag{A.50}$$

Steady state consumption is:

$$\bar{C} = \bar{N}\left(\frac{\Xi_3}{\chi \bar{N}^{\sigma + (1/\eta)}}\right)^{1/\sigma} \tag{A.51}$$

Steady state output is:

$$\bar{Y} = \bar{Y}^m = \bar{Z}\bar{K}^{\alpha^k}\bar{N}^{1-\alpha^k} \tag{A.52}$$

Steady state investment is:

$$\bar{I} = \delta \bar{K} \tag{A.53}$$

Steady state government spending is:

$$\bar{G} = g\bar{Y} \tag{A.54}$$

Steady states for the banking sector are:

$$\bar{L} = \bar{K} \tag{A.55}$$

$$\bar{F} = \frac{\bar{L}}{\nu^L} \tag{A.56}$$

$$\bar{D} = \nu^D \bar{F} \tag{A.57}$$

$$\bar{R} = \nu^R \bar{F} \tag{A.58}$$

$$\bar{O} = \nu^o \bar{F} \tag{A.59}$$

$$\bar{A} = \nu^A \bar{F} \tag{A.60}$$

$$\bar{S} = \nu^S \bar{F} \tag{A.61}$$

$$\mathcal{C}(\bar{A}, \bar{R}, \bar{F}) = \kappa \left((\alpha(\nu^A)^\rho + (1-\alpha)(\nu^R)^\rho)^{1/\rho} \right)^{-\gamma} \bar{F} \tag{A.62}$$

$$\begin{aligned} \frac{\bar{X}}{\bar{P}} =& \frac{\bar{L}}{\nu^L} \Big(\nu^R \bar{i}^R + \bar{i}^L \nu^L + (\bar{i} - \theta^{ip})\nu^A - (\bar{i}^D - \theta^D)\nu^D - \bar{i}^o \nu^o \\ & - \kappa \left((\alpha(\nu^A)^\rho + (1-\alpha)(\nu^R)^\rho)^{1/\rho} \right)^{-\gamma} \Big) \end{aligned} \tag{A.63}$$

$$\varsigma = \omega \frac{\frac{\bar{X}}{\bar{P}}}{\bar{F}} \tag{A.64}$$

The government budget constraint pins down taxes in steady state:

$$\bar{T} = \bar{i}\bar{A} + \bar{i}^R \bar{R} - \bar{i}^o \bar{O} + \bar{G} \tag{A.65}$$

Wages are:

$$\bar{W} = (1-\alpha) \frac{\varepsilon - 1}{\varepsilon} \frac{\bar{Y}}{\bar{N}} \tag{A.66}$$

and

$$\bar{\phi} = \bar{C}^{-\sigma} (1-h)^{-\sigma} (1 - h\beta) \tag{A.67}$$

And state variables for intermediate firm optimization are:

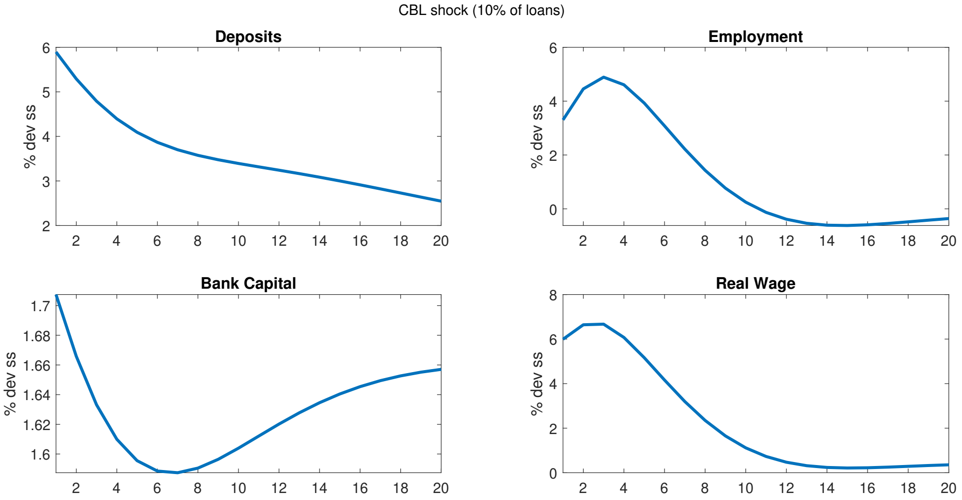
$$\Gamma^1 = \bar{\phi}\frac{\bar{P}^m}{\bar{P}}\frac{\bar{Y}}{1-\gamma^p\beta} \tag{A.68}$$

$$\Gamma^2 = \bar{\phi}\frac{\bar{Y}}{1-\gamma^p\beta} \tag{A.69}$$

A.5 Other Impulse Responses from the General Equilibrium Model

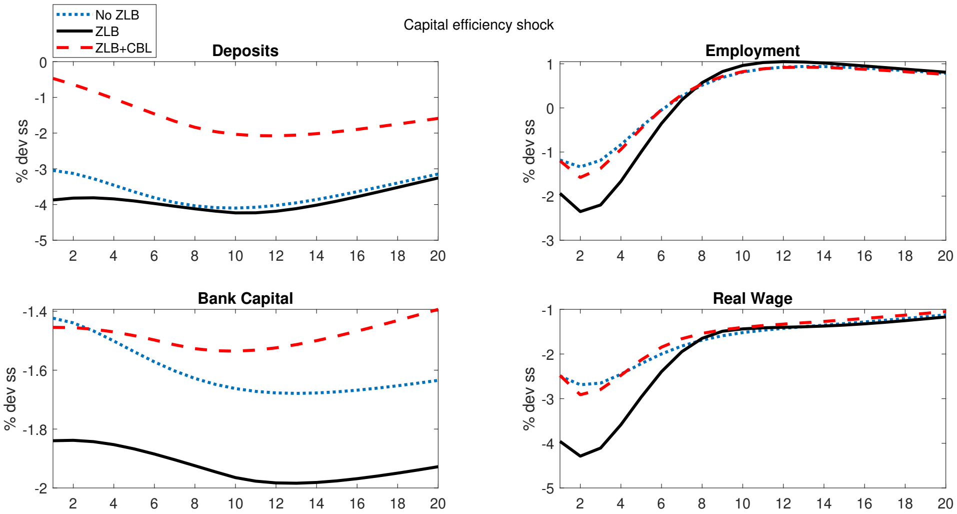
This Section presents the impulse responses for deposits, bank capital, employment, and real wages for the policy experiments outlined in Section 1.4.4 and Section 1.4.5.

Figure A·1: IRFs to a CBL Shock of 10% of Outstanding Loans



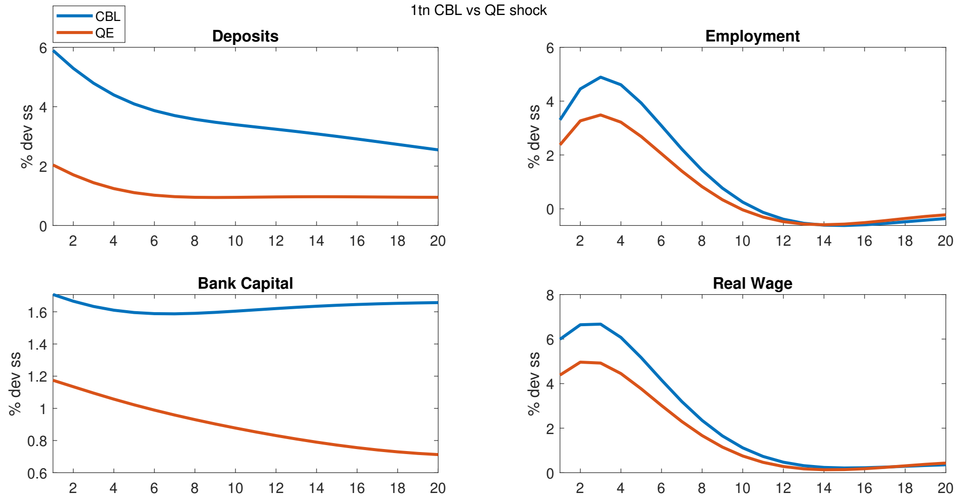
Notes: This Figure shows the impulse responses after a positive CBL shock of 10% of outstanding loans when the policy rate is fixed at steady state. All variables are in percentage deviations from steady state.

Figure A·2: IRFs to a Capital Efficiency Shock



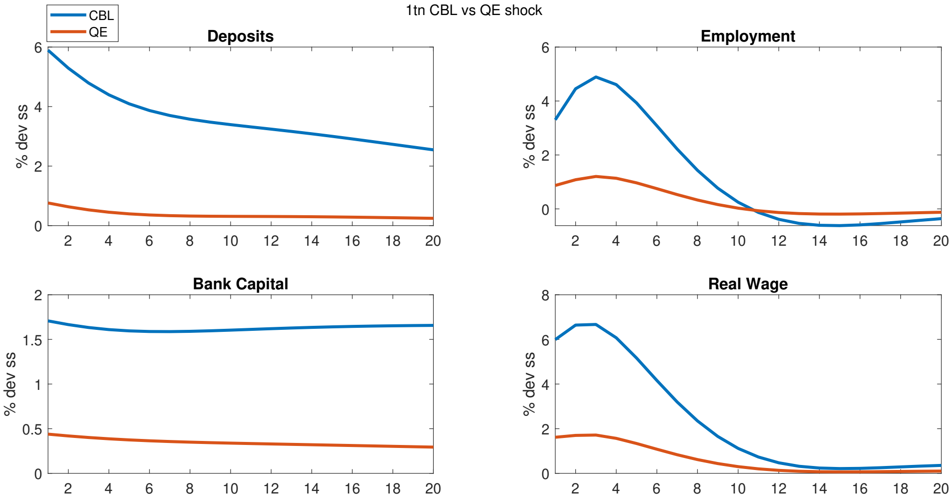
Notes: This Figure shows the impulse responses after 1% decrease in capital efficiency ξ_t. The black line reports the response when the policy rate is fixed at the lower bound, the blue dotted line reports the response when the policy rate is unconstrained, and the red dashed line reports the response when the policy rate is constrained, but the central bank increases CBL by 10% of outstanding loans. All variables are in percentage deviations from steady state.

Figure A·3: IRFs to a CBL Shock and a QE Shock - Baseline



Notes: This Figure shows the impulse responses after a CBL shock of 10% of outstanding loans (1tn€ in steady state) (blue line), and a QE shock of 1tn€ (red line) when the policy rate is fixed at steady state. The CBL shock follows an AR(1) specification. The QE shock is 1tn€ in the first period and peaks at 3.97tn€ after 8 quarters due to the AR(2) specification. All variables are in percentage deviations from steady state.

Figure A·4: IRFs to a CBL Shock and a QE Shock - AR(1)



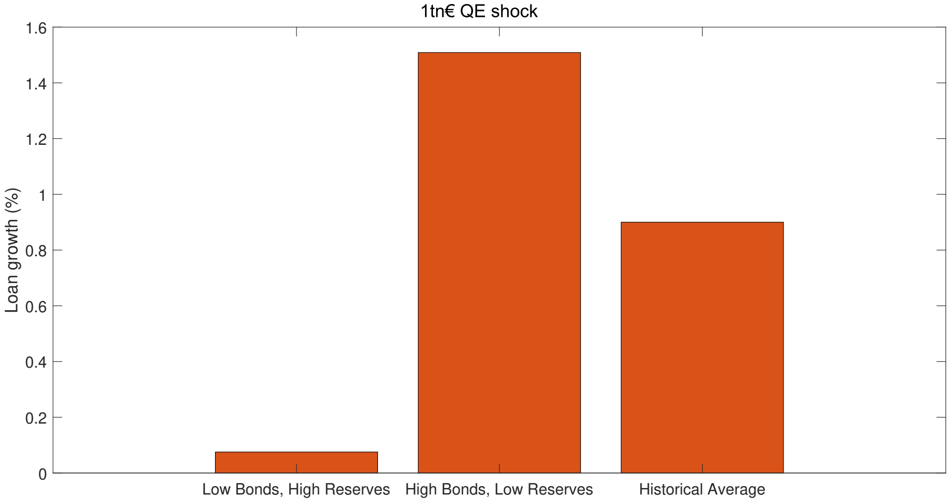
Notes: This Figure shows the impulse responses after a CBL shock of 10% of outstanding loans (1tn€ in steady state) (blue line), and a QE shock of 1tn€ (red line) when the policy rate is fixed at steady state. Both shocks follow an AR(1) specification with a 0.97 autoregressive coefficient. All variables are in percentage deviations from steady state.

A.6 Quantitative Easing and State-Dependence

In this section, I show how the impact of a QE shock depends on the amount of liquid assets that banks hold at the time of the shock. QE is more effective when banks hold a high level of government bonds and a low level of reserves. Intuitively, when banks hold a large amount of government bonds, their demand is more elastic. The implication is that for the same decline in the government bond yield, banks are more willing to substitute a larger share of bonds with loans. On the other hand, as already discussed for CBL, a low level of reserves implies a more inelastic demand for reserves. It follows that the substitution of government bonds towards loans is going to be stronger, as banks adjust less their holdings of reserves.

Therefore, compared with CBL, the state-dependence is different: CBL is more effective when banks hold low levels of bonds and reserves, whereas QE is stronger when banks hold few reserves and a large amount of government bonds. The variation in the impact

Figure A·5: Impact of QE on Loans as a Function of Liquid Assets



Notes: This Figure reports the growth rate of loans after 1tn€ QE shock in three cases: when banks have low levels of government bonds and high levels of reserves, when banks have high levels of government bonds and low levels of reserves, and when initial levels of liquidity are at the historical average. Loan growth is reported in percentage terms.

on loan growth ranges between 0.1% to 1.5% depending on the initial level of liquid assets held by banks. The model predicts that a QE shock in 2015 would have raised loans by around 1.5%, while the same shock in 2018 would have increased lending by 0.5%.

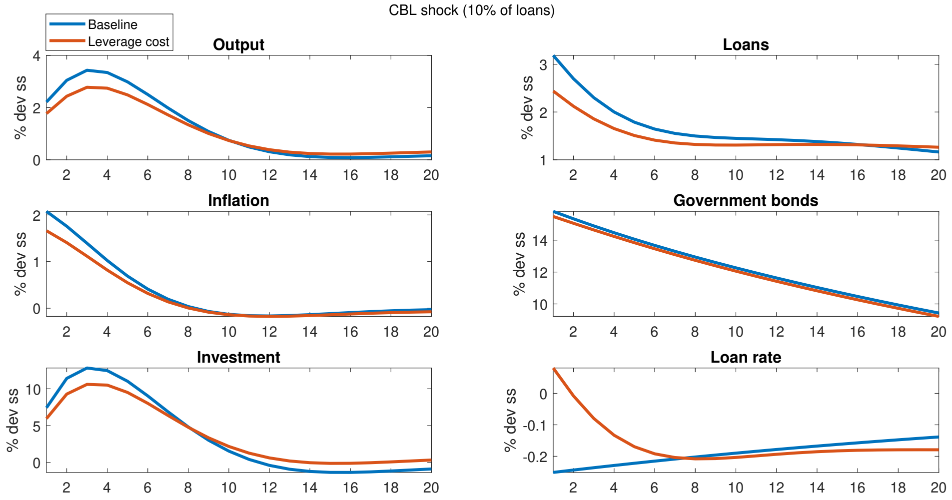
A.7 Extension with Leverage Costs

In this section, I extend the model to account for the existence of leverage costs for banks. Leverage costs arise when banks face capital constraints. Ulate (2021) and Abadi et al. (2022) assume that banks pay an increasing and convex cost for deviating from a target loan-to-equity ratio. I define the leverage cost as:

$$\Psi\left(L_t, F_t\right) = \kappa^L \left(\frac{L_t}{F_t} - \nu^L\right)^2 F_t \tag{A.70}$$

where $\kappa^L > 0$ is a scale parameter, and ν^L is the target loan-to-equity ratio which is assumed to be the ratio in steady state.

Figure A·6: IRFs to a CBL Shock of 10% of Outstanding Loans - Model with Leverage Costs



Notes: This Figure shows the impulse responses after a positive CBL shock of 10% of outstanding loans when the policy rate is fixed at steady state. The blue lines refer to the baseline model, while the red lines refer to the model with leverage costs. All variables are in percentage deviations from the steady state, except for inflation and the loan rate which are reported in annualized percentage deviations from the steady state.

The optimality condition for the lending rate now becomes:

$$E_t(1+i_{t+1}^L) = \mu^L \left(1 + i_t^R - \mathcal{C}_R(A_t, R_t, F_t) + \Psi_L\left(L_t, F_t\right)\right) \tag{A.71}$$

Intuitively, the existence of leverage costs makes loan issuance more costly and mutes the response in lending after an expansionary shock.

I calibrate κ^L to be equal to 0.0093 such that a 1 percentage point increase in banks' target loan-to-equity ratio increases the lending rate by 28 basis points as in Abadi et al. (2022).[4]

Figure A·6 shows impulse responses after a CBL shock of 10% of outstanding loans. As expected, the impact on loans and real variables is lower compared to the model without leverage costs. Loans grow by 2.4% compared to 3.2% in the baseline model.

In this extension of the model, capital plays a significant role. In Figure A·7 I show the

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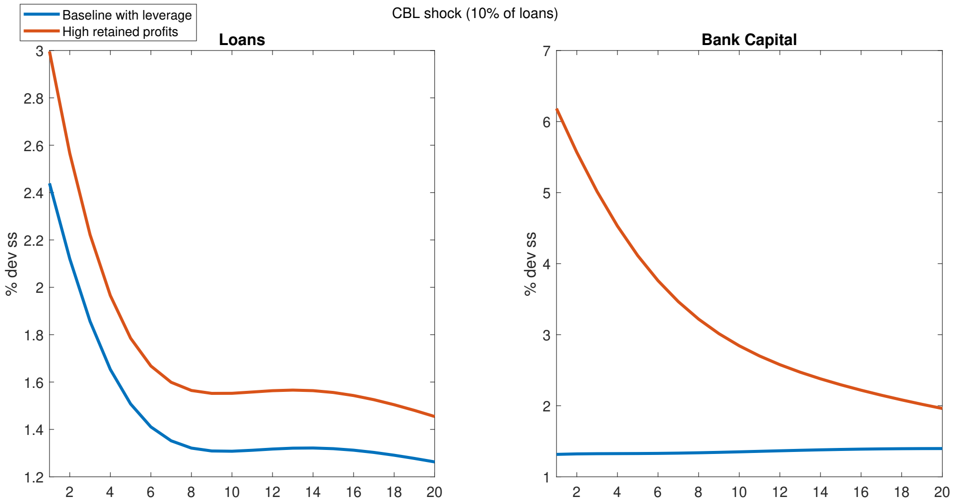
4. In practice, I set $0.0028 = 2\kappa^L \left(\frac{\bar{L}}{\bar{F}} - \frac{\bar{L}}{\bar{N}+0.01\bar{L}}\right)$. It follows that $\kappa^L = \frac{0.0028/2}{\left(\frac{\bar{L}}{\bar{F}} - \frac{\bar{L}}{\bar{N}+0.01\bar{L}}\right)}$.

impulse response of loans and bank capital after a CBL shock in two cases: when banks retain 12% of profits (baseline), and when banks retain 50% of profits. As expected, a larger share of retained profits helps banks to build more bank capital. The ensuing decrease in the leverage ratio leaves more room to expand loan supply. The steeper decline in bank capital in the model with higher retained profits is due to the higher share of bank managerial costs. In fact, in steady state, the calibration of bank managerial costs is positively related to the share of retained earnings. In the second model bank managerial costs amount to 0.92% of bank capital, compared to 0.22% in the baseline calibration.

Figure A·7: IRFs to a CBL Shock of 10% of Outstanding Loans - High Retained Profits



Notes: This Figure shows the impulse responses after a positive CBL shock of 10% of outstanding loans when the policy rate is fixed at steady state. The blue lines refer to the model with leverage costs and a 12% share of retained profits. The red lines refer to the model with leverage costs where banks retain 50% of their profits. All variables are in percentage deviations from the steady state, except for inflation and the loan rate which are reported in annualized percentage deviations from the steady state.

Appendix B

Supplementary Material for Chapter 2

B.1 Additional Robustness Checks

B.1.1 Results for the Federal Funds Rate factor

In this Section, I report the estimation results using the Federal Funds Rate Factor from Swanson (2021) as a proxy for standard monetary policy shocks. Figure B·1 reports the impulse responses after a one standard deviation FFR shock obtained by estimating Equation (2.1) with local projection methods. Results for loans and deposits are qualitatively similar to the baseline specification, although the impact on loans becomes significant only after 10 quarters. Securities and the share of securities over assets initially decline and become positive only after 18 quarters, while the response was turning positive after 8 quarters in the baseline specification.

Figure B·2 presents the same impulse responses with the estimation sample ending in 2009 to exclude the zero lower bound period. The estimated IRFs are very similar.

Table B.1 reports estimated coefficients for Equation (2.3) with the Federal Funds Rate factor used as policy shock. The main difference compared to the baseline estimation is the negative response in securities, as discussed in Section 2.5.5.

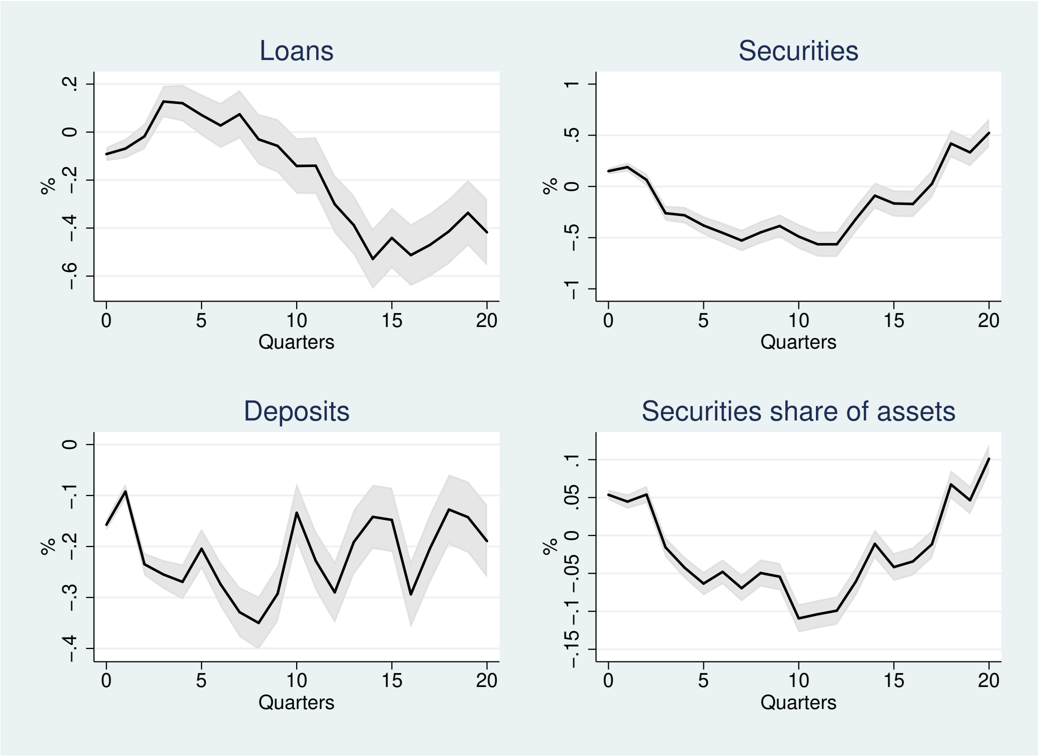
Table B.1: Impulse Responses After a FFR Shock - Interactions

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters Coef./t-stat	12-quarters Coef./t-stat	4-quarters Coef./t-stat	12-quarters Coef./t-stat	4-quarters Coef./t-stat	12-quarters Coef./t-stat	4-quarters Coef./t-stat	12-quarters Coef./t-stat
FFR shock	0.12***	-0.32***	-0.29***	-0.56***	-0.27***	-0.30***	-0.04***	-0.10***
	(3.09)	(-5.25)	(-6.81)	(-8.55)	(-15.29)	(-9.60)	(-6.16)	(-10.54)
FFR shock × Std. Securities share of assets t-1	0.02	0.20***	0.13**	-0.10	0.07***	0.17***	0.02***	-0.00
	(0.52)	(2.77)	(2.44)	(-1.24)	(3.48)	(4.91)	(3.00)	(-0.15)
FFR shock × Std. Capital Share t-1	0.08	0.31***	-0.09	0.14*	-0.03	0.10***	-0.01	-0.01
	(1.58)	(3.81)	(-1.55)	(1.87)	(-1.42)	(2.58)	(-0.77)	(-0.51)
FFR shock × Std. Assets t-1	-0.04**	0.02	-0.01	0.01	-0.02	0.05	0.00	-0.00
	(-2.33)	(0.39)	(-0.35)	(0.27)	(-1.16)	(1.30)	(0.15)	(-0.25)
FFR shock × Std. Deposit Share t-1	0.05	0.23***	0.03	0.15*	0.03	0.07	0.00	0.00
	(1.26)	(3.15)	(0.69)	(1.86)	(0.76)	(1.32)	(0.06)	(0.19)
R-squared	0.041	0.091	0.083	0.148	0.087	0.079	0.191	0.338
N. Observations	533,840	454,025	533,840	454,025	533,840	454,025	533,840	454,025

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.3). Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 1989Q1-2019Q4.

Figure B·1: Impulse Responses After a Monetary Policy Shock (FFR Factor)



Notes: This Figure reports the impulse responses for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary Quantitative Easing shock. The model specification is presented in Equation (2.1). 95% confidence intervals are displayed. Sample: 1989Q1-2019Q4.

Figure B·2: Impulse Responses After a Monetary Policy Shock (FFR Factor) - until 2009

Notes: This Figure reports the impulse responses for loans, securities, deposits, and the share of securities over assets after a 1 standard deviation contractionary Quantitative Easing shock. The model specification is presented in Equation (2.1). 95% confidence intervals are displayed. Sample: 1989Q1-2009Q4.

B.1.2 Sample starting in 2000

In this Section, I present the estimated coefficients for Equation (2.3) using standard monetary policy shocks (Table B.2) and the Federal Funds Rate factor (Table B.3) where the sample starts in 2000 as for the baseline estimation of QE shocks. The main results presented in Table B.2 are preserved compared with the baseline specification for standard policy shocks. There are three differences: the interaction coefficient with bank size in the equation for lending growth is now positive and significant; in the equation for securities growth, the interaction coefficient with liquidity is now significant (and negative), and the coefficient related to deposit share has opposite sign; the average impact on deposits is now not significant, although all the interactions preserve their magnitude and significance. Results in Table B.3 look similar to the baseline specification except for a few differences: size is now significant and the deposit share is not significant in determining the impact on lending; the interaction with liquidity is negative and significant in the equations for securities and securities share of assets; all the interaction terms in the equation for deposits are not significant.

Notice that all the interaction terms, when significant, still have opposite signs compared to the interaction terms estimated with QE shocks, thus preserving the main result of the paper on the differential impact of different policy shocks on banks.

Table B.2: Impulse Responses After a Monetary Shock (From 2000) - Interactions

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
Policy shock	-0.07	-1.23***	-0.67***	1.12***	0.07***	0.05	-0.16***	0.22***
	(-1.40)	(-14.80)	(-10.15)	(10.89)	(2.78)	(1.16)	(-16.96)	(16.97)
Policy shock × Std. Securities share of assets t-1	0.17***	0.45***	-0.02	-0.38***	0.02	0.35***	-0.04***	-0.07***
	(3.92)	(6.30)	(-0.35)	(-4.09)	(0.96)	(10.06)	(-5.15)	(-5.68)
Policy shock × Std. Capital Share t-1	-0.03	0.16*	-0.09	-0.04	0.08**	0.16***	-0.01	-0.03***
	(-0.46)	(1.66)	(-1.00)	(-0.38)	(2.54)	(3.51)	(-1.40)	(-2.60)
Policy shock × Std. Assets t-1	-0.01	0.11***	0.04	-0.01	0.01	0.05***	0.01	-0.01*
	(-0.47)	(2.79)	(1.17)	(-0.16)	(0.53)	(2.60)	(0.89)	(-1.74)
Policy shock × Std. Deposit Share t-1	0.21***	0.29***	0.07	0.20**	-0.00	0.16***	0.00	-0.02
	(4.37)	(3.98)	(1.17)	(2.33)	(-0.14)	(3.59)	(0.13)	(-1.64)
R-squared	0.037	0.079	0.089	0.184	0.103	0.085	0.205	0.385
N. Observations	325,334	271,199	325,334	271,199	325,334	271,199	325,334	271,199

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.3). Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 2000Q1-2019Q4.

Table B.3: Impulse Responses After a FFR Shock (From 2000) - Interactions

	Loan growth		Securities growth		Deposits growth		Securities asset share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters	4-quarters	12-quarters
	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat	Coef./t-stat
FFR shock	0.09*	-0.68***	-0.45***	-0.32***	-0.06***	-0.17***	-0.11***	-0.07***
	(1.75)	(-9.09)	(-7.17)	(-3.52)	(-2.61)	(-4.23)	(-11.10)	(-5.96)
FFR shock × Std. Securities share of assets t-1	0.05	0.27***	-0.02	-0.49***	0.00	0.04	-0.04***	-0.10***
	(1.00)	(3.49)	(-0.36)	(-4.83)	(0.01)	(1.05)	(-4.15)	(-7.70)
FFR shock × Std. Capital Share t-1	-0.01	0.21**	-0.07	0.10	-0.04	0.03	-0.00	0.01
	(-0.15)	(2.28)	(-1.08)	(1.04)	(-1.11)	(0.67)	(-0.15)	(0.75)
FFR shock × Std. Assets t-1	-0.03	0.11***	0.01	-0.00	0.00	0.00	0.00	-0.00
	(-1.18)	(2.58)	(0.15)	(-0.14)	(0.10)	(0.09)	(0.57)	(-0.48)
FFR shock × Std. Deposit Share t-1	0.06	0.11	0.05	0.09	0.04	0.00	0.01	0.01
	(1.22)	(1.49)	(0.87)	(1.00)	(0.68)	(0.07)	(0.78)	(0.79)
R-squared	0.037	0.079	0.089	0.183	0.103	0.085	0.204	0.384
N. Observations	325,334	271,199	325,334	271,199	325,334	271,199	325,334	271,199

* p¡0.10, ** p¡0.05, *** p¡0.01

Notes: This Table reports results from the panel estimation of Equation (2.3). Results for local projections 4-quarters ahead and 12-quarters ahead are reported. Results for control variables are omitted for brevity. Bank fixed-effects are included. Standard errors are clustered at the bank level and are robust to heteroskedasticity and autocorrelation. Sample: 2000Q1-2019Q4.

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