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Essays on Mortgage Supply in a Low Rate Environment and Gender Effects of Covid-19

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Abstract

As policy rate fell below zero, some countries experienced an increase in house prices and an expansion of mortgages. Only a few bank categories contributed to this mortgage expansion, leading to a change in their mortgage market share. Such change in exposure to real estate may pose a risk to financial stability. My dissertation research studies the role played by specific bank features, such as reliance on deposits and covered bonds or capital surplus relative to the required level, in explaining these developments in the mortgage market.

The first chapter, in collaboration with Prof. Luisa Lambertini, studies the dynamics in the Swiss mortgage market under low interest rates. The Swiss National Bank (SNB) cut its policy rate to near zero in 2008 and further into negative territory in 2015 to stem pressure on the Swiss Franc to appreciate, which has led to strong growth in mortgage loans. Interestingly, small banks (cantonal banks and Raiffeisen) have mostly contributed to this mortgage expansion at the expenses of two big global systemic banks (UBS and Credit Suisse). We set up a model featuring big and small banks that compete in the deposit and mortgage market and face different capital requirements, and calibrate it to the Swiss banking sector. In this model, a falling policy rate drives up borrowing demand and leads to an expansion in mortgage lending; however, an asymmetric tightening of capital requirement gives small banks a competitive advantage and causes a shift in market share towards small banks. Quantitatively, our model is able to replicate these developments in the Swiss mortgage market.

In the second chapter, with Prof. Luisa Lambertini, we use Swedish bank-level data and employ a triple diff strategy to investigate whether funding side differences play a role in explaining banks' different lending responses to negative rate policy. First, we find that high-deposit banks expand their mortgage supply less relative to low-deposit banks during negative rate periods, confirming the well-documented deposit channel effect. However, this pattern works only for weakly-capitalized banks, which have a low capital buffer, i.e., capital in excess of requirement. Second, we show that banks more reliant on covered bonds to finance mortgages lend out more under negative rates, as they can shift into cheap deposits to reduce their funding costs. We extend our model in the first chapter to be consistent with these empirical findings, by introducing banks with different deposit and covered bond ratios. Then we use this framework to study the implications of the Covid-19 pandemic for the mortgage market.

The third chapter analyzes the transmission of housing price dynamics to the economy in the context of China. Over the last decade, the rapid growth in house and land prices have coincided with local governments' land supply control. These governments transform agricultural land into constructible land, which is then sold to raise revenues. Housing firms purchasing constructible land can use it as collateral to finance their production. First, I analyze the empirical relationship between these variables. Then, I build a real business cycle model which embeds governments' revenues from land sales and housing firms' collateral constraints. The simulated results show that land-use conversion and land finance amplify the crowding out effects of housing price fluctuations on the non-housing sector. Imposing a lower bound on the stock of arable land helps mitigate this effect.

The year 2020 was marked by the outbreak of the Covid-19 pandemic, which adversely affected the labor market. The fourth chapter is an additional line of work, with Dr. Corinne Dubois and Prof. Luisa Lambertini, exploring the gendered consequences in the Swiss labor market during the crisis. We take the Swiss labor force survey data and document gender gap in labor market outcomes, such as employment and nonactive status, reliance on short-time working scheme, hours worked and labor income. Our estimation results suggest that, all else equal, women have been more likely to exit the labor market altogether or to use short-term working schemes than their male counterparts. Contrary to expectations, increased family-care responsibility is not the driver. Occupational teleworkability explains some of the differential impact of Covid-19 on men and women.

Key Words: Capital Requirement; Bank Heterogeneity; Deposit; Covered Bonds; Market Power; Mortgage Supply; Financial Intermediation; DSGE model; Housing; Land Finance; Covid-19 Pandemic; Gender Inequality.

Résumé

Lorsque le taux directeur est tombé en dessous de zéro, certains pays ont connu une augmentation des prix des logements et une expansion des prêts hypothécaires. Seules quelques catégories de banques ont contribué à cette expansion hypothécaire, entraînant une modification de leur part de marché hypothécaire. Un tel changement dans l'exposition au risque immobilier peut présenter un risque pour la stabilité financière. Ma recherche de thèse étudie le rôle joué par les spécificités bancaires, telles que le recours aux dépôts et aux obligations sécurisées ou l'excédent de capital par rapport au niveau requis, pour expliquer ces évolutions du marché hypothécaire.

Dans le deuxième chapitre, avec le professeur Luisa Lambertini, nous utilisons des données au niveau des banques suédoises et employons une stratégie triple diff pour déterminer si les différences de financement jouent un rôle dans l'explication des différentes réponses des banques à la politique de taux négatifs. Premièrement, nous constatons que les banques à dépôts élevés augmentent moins leur offre de prêts hypothécaires par rapport aux banques à faibles dépôts pendant les périodes de taux négatifs, ce qui confirme l'effet de canal de dépôt bien documenté. Cependant, ce modèle ne fonctionne que pour les banques faiblement capitalisées, qui ont un coussin de capital faible, c'est-à-dire un capital supérieur aux besoins. Deuxièmement, nous montrons que les banques plus dépendantes des obligations sécurisées pour financer les prêts hypothécaires prêtent davantage à des taux négatifs, car elles peuvent se tourner vers des dépôts bon marché pour réduire leurs coûts de financement. Nous étendons notre modèle dans le premier chapitre pour être cohérent avec ces résultats empiriques, en introduisant des banques avec différents ratios de dépôts et d'obligations sécurisées. Ensuite, nous utilisons ce cadre pour étudier les implications de la pandémie de Covid-19 pour le marché hypothécaire.

Le troisième chapitre analyse la transmission de la dynamique des prix du logement à l'économie dans le contexte de la Chine. Au cours de la dernière décennie, la croissance rapide des prix des logements et des terrains a coïncidé avec le contrôle de l'offre foncière par les gouvernements locaux. Ces gouvernements transforment les terres agricoles en terres constructibles, qui sont ensuite vendues pour augmenter les revenus. Les sociétés de logement qui achètent des terrains constructibles peuvent l'utiliser comme garantie pour financer leur production. Dans un premier temps, j'analyse la relation empirique entre ces variables. Ensuite, je construis un modèle de cycle économique réel qui intègre les revenus des gouvernements

provenant des ventes de terrains et les contraintes collatérales des entreprises de logement. Les résultats simulés montrent que la conversion de l'utilisation des terres et le financement des terres amplifient les effets d'éviction des fluctuations des prix du logement sur le secteur non-logement. Imposer une limite inférieure au stock de terres arables permet d'atténuer cet effet.

Le troisième chapitre analyse la transmission de la dynamique des prix du logement à l'économie dans le contexte de la Chine. Au cours de la dernière décennie, la croissance rapide des prix des logements et des terrains a coïncidé avec le contrôle de l'offre foncière par les gouvernements locaux. Ces gouvernements transforment les terres agricoles en terres constructibles, qui sont ensuite vendues pour augmenter les revenus. Les sociétés de logement qui achètent des terrains constructibles peuvent les utiliser comme garantie pour financer leur production. Premièrement, j'analyse la relation empirique entre ces variables ; puis je construis un véritable modèle de cycle économique qui intègre les revenus des gouvernements provenant des ventes de terrains et les contraintes collatérales des entreprises de logement. Cet article montre que la conversion de l'utilisation des terres et le financement des terres amplifient les effets d'éviction des fluctuations des prix du logement sur le secteur non-logement. Une limite moins impotante sur les terres arables peut aider à atténuer cet effet.

Le quatrième chapitre est un axe de travail supplémentaire, avec le Dr Corinne Dubois et le Pr Luisa Lambertini, explorant les différences de genre dans le marché du travail pendant la pandémie de Covid-19. Nous prenons les données de l'enquête suisse sur la main-d'œuvre et documentons l'écart entre les sexes dans les résultats du marché du travail, tels que l'emploi et le statut d'inactif, le recours au régime de chômage partiel, les heures travaillées et les revenus du travail. Les résultats de nos estimations suggèrent que, toutes choses égales par ailleurs, les femmes ont été plus susceptibles de quitter complètement le marché du travail ou d'avoir recours à des programmes de travail à court terme que leurs homologues masculins. Contrairement aux attentes, la responsabilité accrue en matière de soins familiaux n'est pas le facteur. La disponibilité du télétravail explique cependant une partie de l'impact différentiel de Covid-19 sur les hommes et les femmes.

Mots clefs : Capital requis ; Hétérogénéité de la banque ; Verser ; Obligations sécurisées ; Pouvoir du marché ; offre de prêts hypothécaires ; Intermédiation financière ; modèle DSGE ; Logement ; Financement foncier ; Pandémie de covid19 ; Inégalité des genres.

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Introduction

After the financial crisis, policy rates in the major advanced economies have moved downwards to near/below zero. Some countries have experienced an increase in house prices and an expansion of mortgages, like Switzerland and Sweden. Also, there have been considerable changes in the mortgage market share, with only a few bank categories contributing to this mortgage expansion. The recent Covid-19 pandemic has reinforced these developments. Such change in exposure to real estate may create a potential risk to financial stability. My dissertation research attempts to assess the impact of this low rate environment on the banking sector and identify bank-specific characteristics and policies that are related to banks' different mortgage lending behavior.

The declining policy rate moved in parallel with a tightening of capital regulation. Following the financial crisis, policymakers strengthened capital requirements under the Basel III standards to promote a more resilient banking sector. Capital requirements are regulatory standards mandating banks to maintain a certain percentage of capital, concerning their overall holdings. Tighter requirements increase banks' funding costs and thus hamper their ability to provide credit to customers. Additionally, the Basel III as well as Swiss specific regulation standards incorporate bank-specific aspects, like total assets. In particular, systematically important banks are associated with tighter capital regulation. For example, in Switzerland, the required risk-weighted capital ratio for UBS and Credit Suisse was around 26% in 2020, which is much larger than the average ratio of 12% for the country's smaller banks. Such regulatory development fosters the heterogeneity of capitalization and buffer levels across banks and constrains their lending capacities to varying extents.

Several balance sheet characteristics affect bank lending behavior. First, banks competing in the credit market are of different sizes, which implies that banks have varied levels of market power in setting lending rates. Second, banks can finance themselves via deposit collection and/or wholesale funding, such as covered bonds issued with mortgages as collateral; big banks have strongly increased the issuance of bonds since the financial crisis. In the low rate environment, reliance on deposit funding becomes critical for banks' lending decisions. Since negative rates are not passed through to deposits, high-deposit banks' net interest margins decline markedly and thus are expected to increase the lending rate and cut loan supply. This is referred to as the "deposit funding channel" in the previous literature (Heider et al. (2019),Eggertsson et al. (2019)). The goal of chapters 1 and 2 of my thesis is to understand the role of these bank-specific features, such as capitalization level and funding structure, and the interactions between them in explaining banks' heterogeneous mortgage supply in this low rate environment.

Persistently increasing house prices and rapid expansion of mortgages may pose a risk to financial stability, as the financial crisis revealed. Analyzing the macroeconomic consequences of house price fluctuations has crucial policy implications and will be the subject of chapter 3. The Chinese housing market provides an excellent laboratory for this study. China went through a decade-long housing boom featuring a rapid growth in house and land prices of 4 and 15 percent, respectively. Understanding its propagation to other economic activities is thus important.

The first chapter, in collaboration with Prof. Luisa Lambertini, studies the dynamics in the Swiss mortgage market under low interest rates. The Swiss National Bank (SNB) cut its policy rate to near zero in 2008 and further into negative territory in 2015 to stem pressure on the Swiss Franc to appreciate, which has led to strong growth in mortgage loans. Interestingly, small domestic banks (cantonal banks and Raiffeisen) have mostly contributed to this mortgage expansion at the expenses of two big global systemic banks (UBS and Credit Suisse). A key feature differentiating the two groups is that small banks are better capitalized relative to the requirement, i.e, small banks have larger capital buffers than the two big banks. We set up a model featuring big and small banks that compete in the deposit and mortgage market and face different capital requirements, and calibrate it to the Swiss banking sector. In this model, a falling policy rate drives up borrowing demand and leads to an expansion in mortgage lending; however, an asymmetric tightening of capital requirement gives small banks a competitive advantage and causes a shift in market share towards small banks. Quantitatively, our model is able to replicate these developments in the Swiss mortgage market.

While the first chapter focuses on bank capitalization, the second chapter also considers the role of funding sources in explaining heterogeneous mortgage supply across banks. In the second chapter, with Prof. Luisa Lambertini, we investigate whether banks differing in reliance on deposits and covered bonds are affected differently by the reduction of the policy rate. We use Swedish bank-level data and employ a triple diff strategy for this study. First, we find that high-deposit banks expand their mortgage supply less relative to low-deposit banks during negative rate periods; however, this pattern works only for weakly-capitalized banks, which have low capital buffer, i.e. capital in excess of requirement. We demonstrate that the well-documented deposit funding channel effect depends on the capitalization level. Second, we show that banks more reliant on covered bonds to finance mortgage lending lend out more under negative rates, as they can lower covered bond yields or switch into deposits, which are cheaper than covers bonds, giving them more room to reduce funding costs. We extend our model laid out in the first chapter to be consistent with these empirical findings, by introducing banks with different deposit and covered bond ratios. In the second part of the chapter, we introduce a negative housing supply shock into this framework to study the implications of the Covid-19 pandemic for the mortgage market. We find that policies used in the pandemic have been more beneficial for weakly-capitalized banks and fueled their mortgage expansion, thereby accelerating house price appreciation.

The third chapter analyzes the transmission of housing price dynamics to the economy in the context of China. The empirical evidence suggests a crowding out effect on the non-housing sector: the house-price growth was accompanied by a positive co-movement with residential investment, and a negative one with nonresidential investment. An important contributing factor is from the supply side. Local governments control land supply, and transform agricultural land into constructible land, which is then sold to raise revenues. Housing firms purchasing constructible land can use it as collateral to finance their production. I first analyze the empirical relationship between these variables under a VAR framework; then I extend the two-sector real business cycle model in Iacoviello and Neri (2010) to include governments' revenues from land sales and housing firms' collateral constraints. The simulated results show that land-use conversion and land finance can strengthen the housing boom induced by a positive demand shock and amplify the crowding out effects of housing price fluctuations on the non-housing sector. Imposing a lower bound on the stock of arable land helps mitigate this effect.

The year 2020 was marked by the outbreak of the Covid-19 crisis. Governments around the globe imposed some form of lockdowns to contain the spread of the virus. As an outcome, the pandemic strongly affected the labor market. Among others, the impact on gender inequality in the labor market may be considerable: women who usually bear most of the family care responsibilities and dominate in the service sector are more vulnerable to the crisis than men. Previous studies (Alon et al. (2020), Collins et al. (2021)) used the term "she-cession" to characterize the gendered impact of the pandemic. Inspired by that, the fourth chapter is an additional line of work, with Dr. Corinne Dubois and Prof. Luisa Lambertini, exploring gender consequences of the Covid-19 pandemic in the Swiss labor market.

In the fourth chapter, we take the quarterly Swiss labor force survey data in 2019 and 2020, and document the gender gap in labor market outcomes, such as employment and nonactive status, reliance on short-time working scheme, hours worked, and labor income. We employ a diff-in-diff approach to test whether the gender gap has changed during Covid-19 relative to normal times. Controlling for the usual labor market confounders, we find that women have been more likely to exit the labor market altogether. Unlike other studies, we find no evidence of a worsening in the gender gap in unemployment during Covid-19. This could be driven by the massive usage of short-time work, a public policy that allows firms facing a fall in demand to keep their employees while transferring the cost to the government. We provide evidence of a large gender gap in short-time work, as women have been more likely to engage in short-time work than men during Covid-19. To better understand the causes of gender effects, we look into the gender gap conditional on a specific characteristics. First, we find that asymmetric family-care responsibility is associated with a reduction of gender gap in labor non-participation, contrary to our expectations. We find evidence of a family insurance mechanism during Covid-19: women with lower occupation rates than their partners during normal times work more during the pandemic, and vice versa for women who work more than their partners during normal times. We speculate this effect to be driven by the incentive to compensate for partners' income loss during the Covid-19 pandemic. Second, we show that telework availability of occupation explains some of the differential impact of Covid-19 on men and women.

The thesis is organized as follows. Chapter 1 presents the first paper *Mortgage Supply and Capital Regulation in a Low Rate Environment*. Chapter 2 relates to the second paper *Bank Heterogeneity and Mortgage Supply under Negative Policy Rates*. Chapter 3 discusses the third paper on *Housing Price, Land Finance, and Investment*. Chapter 4 analyzes *Gender Effects of the Covid-19 Pandemic in the Swiss Labor Market*.

1 Mortgage Supply and Capital Regulation in a Low Interest Rate Environment

Joint work with Prof. Luisa Lambertini (EPFL)

Low-for-long nominal interest rates have resulted in strong growth in mortgage lending and real house prices in Switzerland. Domestically-oriented, small banks have mostly contributed to this expansion in mortgage lending while the two big, global systemic banks (UBS and Credit Suisse) have lost market share. We develop a model with two types of banks and monopolistic competition in the deposit and mortgage market, which we calibrate to the Swiss banking sector. In this model, a contemporaneous expansion in mortgage lending and change in market shares as in the data emerges only if the monetary policy rate is reduced and capital requirements on the big banks are tightened. Any of the two policies in isolation fails to match the empirical evidence.

1.1 Introduction

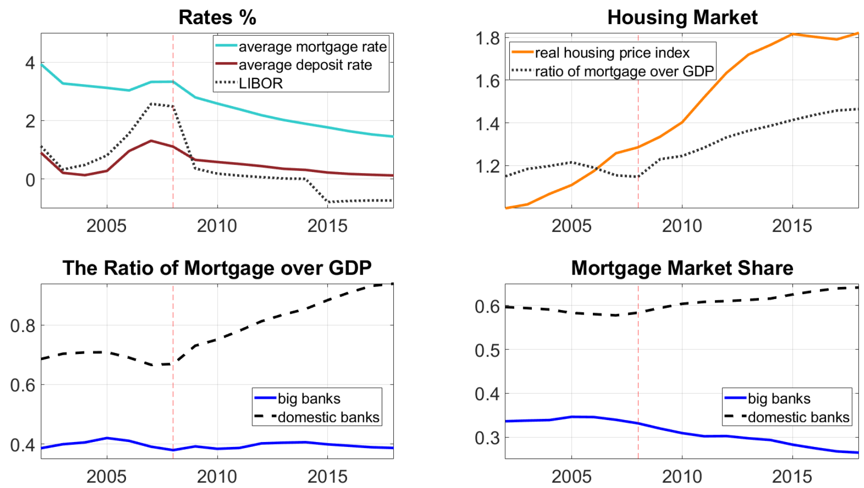
The global financial crisis has led to a reduction in nominal interest rates in many countries around the world. In Europe, the debt crisis of 2010-12 has put further downward pressure on interest rates, which remain at or below zero. Switzerland has been no exception. The Swiss National Bank (SNB) reduced its policy rate to near zero in 2008 and in negative territory in 2015 to stem pressure on the Swiss Franc to appreciate.[1] This low-for-long interest rate environment and the emergence of negative nominal interest rates have brought attention to the bank lending channel. Eggertsson et al. (2019) and Brunnermeier and Koby (2016) argue that the standard transmission mechanism of monetary policy breaks down in such environment so that low interest rates may in fact be associated with a reduction in output due to lower lending. Yet, there is little debate on the effect of low rates on the supply of mortgages and on housing market conditions.

The empirical evidence for Switzerland suggests that low nominal interest rates are fueling an

[1]The SNB exempts most commercial banks sight deposits from the negative rate, which is levied only on deposits in excess of 20 times the minimum reserve requirement.

expansion in the housing market. The upper left panel of Figure 1.1 reports evidence that the reduction in the monetary policy rate has transmitted to lending and deposit rates, although the pass through has been sluggish and partial. The upper right panel of Figure 1.1 displays housing market conditions. Since the monetary policy rate was reduced to almost zero in 2008Q4 until 2018Q4, the ratio of domestic mortgages to GDP has increased by 35 percentage points and the real house price index has increased by 80 percentage points.[2]

Figure 1.1: Dynamics in the Swiss Mortgage Market



Notes: Data are from the Swiss National Bank (SNB). The vertical dashed red line indicates the financial cirsis in 2008.

The Swiss banking system consists of two large, global systemic financial institutions, UBS and Credit Suisse, and several smaller domestically-oriented banks. Henceforth we refer to UBS and Credit Suisse as the two big banks while we label the domestically-oriented financial institutions as small banks. The small banks have been mostly responsible for the expansion in mortgages over the period under consideration. The lower left panel of Figure 1.1 shows that the share of mortgages issued by the big banks as fraction of GDP has remained stable at 40 percent while the share of small banks has increased by almost 40 percentage points, which has led to a shift of market share towards small banks by 10 percent, , as documented the lower right panel of Figure 1.1.

The global financial crisis negatively affected UBS and Credit Suisse because of their global nature. [3] In the aftermath of the financial crisis, bank capital regulation has been significantly tightened in Switzerland. Banks in Switzerland are subject to regulatory capital requirements, which are based on international standards (Basel I at the beginning of the period to Basel III at the end of the period) supplemented by Swiss specificities. Additional capital requirements

[2]On an annualized basis, nominal GDP growth rate was negative in 2009Q1 to 2009Q3 and positive in the rest of the sample period.

[3]UBS and Credit Suisse had experienced significant losses in the global financial crisis. They were therefore shorter of capital and liquidity than they would presumably have been otherwise. This mechanism is discussed in more detail in Basten and Ongena (2020).

by bank category have been gradually imposed since 2008 and have resulted in much higher requirements for the big banks (Category 1) relative to the small ones (Category 2 to 5), as shown in Table 1.1.[4]

In this paper we show that both the reduction in the monetary policy rate and the asymmetric tightening of capital requirements are necessary to generate a mortgage expansion and an increase in house prices as experienced in Switzerland since 2008. We develop a model with two types of banks, big and small, which collect deposits from savers, issue mortgages to borrowers and invest in safe assets. Capital and liquidity requirements aim to limit leverage in the banking sector and maintain a minimum ratio of safe assets to deposits; these requirements constrain the behavior of financial institutions. The banking sector is imperfectly competitive; we assume that the semi-elasticity of mortgage and deposit demand is a function of the market share of the bank so that markups and markdowns also respond to market shares. We calibrate our model to match observed interest rates and regulatory requirements before entering the low interest rate environment. We then reduce the monetary policy rate and tighten capital requirements for the big banks. The reduction in the monetary policy rate generates a housing boom, namely an increase in mortgages and in real house prices. An asymmetric tightening in capital requirements leads to an increase in the mortgage and deposit share of small banks.

It is the combination of the two policies that is consistent with actual developments. A reduction in the monetary policy rate with either unchanged or slack capital constraints results in the two types of bank behaving identically, market shares not changing, an expansion followed by a flattening out of mortgages and deposits. On the other hand, if the monetary policy rate is held constant at a positive level while capital requirements are tightened for the big but not for the small banks, the market share of big and small banks move (as in the data), but aggregate mortgages contract (unlike in the data).

In our model, savers demand liquidity services provided by money and/or deposits and/or bonds. When the policy rate falls into negative territory, bonds are substituted away but deposits are not eliminated because banks keep deposit rates from becoming negative. At this point, banks stop expanding mortgages and deposit if capital constraints are unchanged; if capital constraints are tightened for big banks, mortgages go down for this type of banks and the housing boom is partly reversed. We allow for money and deposits to become perfect substitutes when the policy rate becomes negative and our results are unaffected.

[4]The requirements of the Basel III framework are supplemented by additional capital requirements introduced by the Swiss Financial Market Supervisory Authority (FINMA). Under this regulation, banks are divided into five categories based on their total assets, assets under management, privileged deposits and required own funds. Big banks are associated with tighter capital requirements for the following reasons. First, Category 1 banks (UBS and Credit Suisse) have to fulfill the Too-big-to-fail package's particular requirement in the form of CET1 and Contingent Convertible Bonds (CoCos) as conservation buffer. Second, systemically important banks (in categories 1 and 2) should have enough capital to cover losses from current operating activities (going concern requirements) and funds for restructuring or orderly resolution (gone concern requirements). Going and gone concern requirements make up the total loss absorbing capacity (TLAC) and became effective for UBS and Credit Suisse in 2016. Third, big banks compute their risk weights following the Internal Ratings Based (IRB) approach, while all other banks in the sample had to follow the more conservative and simplified Standardized Approach. Please see Rochet (2014) for detailed discussion.

Table 1.1: 2020 Banking regulation in Switzerland

Bank Category	Criteria (CHF in billions)	Total Risk-weighted Capital Ratio (%)
1	Total assets ≥ 250	26.8
2	Total assets ≥ 100	18.8
3	Total assets ≥ 15	12
4	Total assets ≥ 1	11.2
5	Total assets < 1	10.5

Notes: Banks are divided into five categories depending on their size and complexity. The total risk-weighted capital ratio is based on Swiss SRB Basel III phase-in requirements, which includes Common Equity Tier 1 capital (CET1), Additional Tier 1 capital, Tier 2 capital, additional capital buffer in the form of CET1, and systemic surcharge.

We extend our model to study the effects of sectoral counter-cyclical capital buffer targeted to mortgages and find it helps to avoid excessive credit growth but does not alleviate concentration of market share and default risk in small banks.

We draw several policy implications from our analysis. First, tightening capital requirements as the policy rate is reduced is successful in limiting and/or undoing a boom in the housing market. Second, if requirements are raised only for big banks, small banks become more exposed to the housing market. If an increase in lending is associated with an increase in risk taking, as it is typically the case, then small banks become more risky. This is to say that, asymmetric capital regulation may have the unintended consequence of shifting risk from big to small banks. Third, the sectoral counter-cyclical capital buffer as well as the exemption from negative rates on reserves help in either reducing credit growth or raising bank net worth; quantitatively, however, these effects are small.

The rest of the paper is organized as follows. Section 1.2 reviews the literature. Section 1.3 presents the model and section 1.4 discusses the calibration. Section 1.5 presents our main results and provide intuition. Section 1.6 studies the robustness of our results to alternative modeling assumptions. Section 1.7 analyzes two policy experiments: the counter-cyclical capital buffer and the exemption on reserves. In section 1.8, we conclude.

1.2 Literature

Our work builds on four main strands of literature. First, it relates to a large literature that studies monetary policy transmission through the banking sector (Gertler and Karadi (2015)). How banks adapt their asset and liability structures determines the transmission to real economic activities. Several mechanisms could be at play. Kashyap and Stein (2000) and Jiménez et al. (2012) provide evidence on the bank-lending channel: lower policy rates increase the supply of credit. Drechsler et al. (2017) and Polo (2018) propose a deposit channel, suggesting that the collection of loanable funds to banks increases as rates fall slow due to the slow adjustment of deposit rates. More recently, the implementation of the negative rate policy has attracted a great deal of attention (Brown (2020)). Substantial empirical work (Bech and

Malkhozov (2016), Claessens et al. (2018), Bottero et al. (2019) and Brandao-Marques et al. (2021)) generally find that rate cut in a low rate environment implies a reduced net interest margin and thus hurts banks' profitability and lending capacity. Basten and Mariathasan (2018) study the case of Switzerland and show that banks more affected by negative rates have to reduce costly reserves and raise their fee income to compensate for the loss. From a theoretical perspective, Eggertsson et al. (2019) presents a general equilibrium model in which as rate turns negative, the usual lending channel breaks down because of the zero lower bound on deposit rate. Brunnermeier and Koby (2016) use a New Keynesian banking model and find that, once the policy rate goes below its reversal level, rate cuts become contractionary for those capital-constrained banks. Relative to this literature, our work focuses on heterogeneous effects of rate cuts across banks and exploits bank differences in capital position. We study the interaction between a falling policy rate and an asymmetric tightening of capital regulation and show how this affects bank mortgage lending behavior.

Our paper also fits into the literature that discusses the influence of macroprudential regulation on bank behavior. Kashyap et al. (2010), Baker and Wurgler (2015), and Kisin and Manela (2016) empirically document that an increase in capital ratios leads to a modest increase in banks' cost of capital. Consistent with their findings, Bichsel et al. (2019) use bank- and loan-level data for Switzerland and estimate an increase in corporate lending spreads following an increase in capital requirements. Auer and Ongena (2019) also focus on Swiss banks and find that the introduction of the sectoral countercyclical capital buffer, an additional requirement of capital holdings targeted to mortgages, led them to shift into non-mortgage related lending. Other recent works document unintended consequences caused by the regulatory heterogeneity across different lenders and asset classes, such as potential regulatory arbitrage and reduced competition in the market (Acharya et al. 2013; Greenwood et al. 2017). Among others, Begenau and Landvoigt (2018) propose a model with regulated and unregulated banks and show that tightening the capital requirement leads to riskier shadow banking activity despite a safer banking system. Benetton (2018) develops an empirical model for the UK mortgage market and show that the two-tier regulatory system increases the concentration of mortgage origination. Our paper's analysis contributes to this line of research, as we build up a model to study the effect of heterogeneous capital requirements on banks' lending and competition in the mortgage market, especially when the policy rate falls; our focus is on the low rate environment and on the housing market.

Our work also connects to the line of literature that studies competition in the banking sector. Cuciniello and Signoretti (2014) develop a New Keynesian model with imperfect competition in the banking sector and collateral-constrained borrowers to address how much the banking industry market structure amplifies business cycles. Drechsler et al. (2017) also show that pass-through of the policy rate to deposit rates depends on market power by banks in local deposit markets. Wang et al. (2020) quantify that bank market power explains a significant portion of monetary transmission, which is comparable in magnitude to that of the bank capital channel. Our work contributes to this literature by adopting the modeling framework of Atkeson and Burstein (2008) in a banking model to examine how the interaction between heterogeneous capital regulations and bank competition affect the transmission of monetary policy.

Finally, our paper studies the risk choice of banks. Jiménez et al. (2014) and Dell'Ariccia et al. (2017) provide evidence that banks' loan portfolio tend to be riskier when interest rates are low. Michelangeli and Sette (2016) find that banks' risk choice depends on their capital; higher bank capital is associated with a higher likelihood of application acceptance of riskier borrowers. Nucera et al. (2017) look into the different responses to negative rates across banks in the Euro Area and show that large banks with more diversified income become less systemically risky, while riskiness increases for smaller banks. Ravn (2016) builds a macroeconomic model in which countercyclical lending standards emerge as an equilibrium outcome. Coimbra and Rey (2017) model the difference in risk taking behaviour by incorporating heterogeneous VaR constraints and Ferrante (2018) assumes pooling different loans. Our model delivers different risk exposure of small and big banks as the policy rate falls, as captured by the proportion of substandard borrowers accepted when the policy rate falls.

1.3 The Model

We present a two-period partial equilibrium model that captures the relationships between monetary policy, capital requirement and bank lending. Later we use this model to illustrate how a reduction in the policy rate, even into negative territory, passes through to the rates on mortgages and deposits, and how it interacts with a tightening of capital requirement to influence mortgage supply.

In the model, the growth rate of house prices and the policy rate are exogenous. All other prices and quantities are chosen optimally by the agents in the economy. The model features savers, borrowers and two types of banks. Savers consume final goods and invest on liquid assets namely bonds, deposits and cash. Borrowers consume and finance their house purchases with mortgages. Banks collect deposits from savers and then lend to borrowers, and they operate under imperfect competition in the deposit and mortgage market.

The timing is as follows:

- In period 1, banks set the rates they charge on mortgages and pay for deposits, borrowers choose how much to borrow for their housing and consumption demand, savers also decide the amount of consumption and how much liquid asset to hold.

- In period 2, there is an idiosyncratic shock to house values, which leads some borrowers to default on their mortgages. Banks get payment from repaying borrowers, liquidate houses of defaulting borrowers, and then pay out savers. Then, savers and borrowers consume, and banks net return are determined.

1.3.1 Savers

In the case of Switzerland, big and small banks have branches in each canton which offer differentiated services to savers and borrowers. They compete on interest rates and take different level of risk. Each saver and borrower has an established relationship with a bank and she is reluctant to change bank. This gives banks a degree of market power in rate setting. If we take bank rates as given, the optimal problem of savers/borrowers can be split into two parts: first, deciding the amount of consumption/housing service and savings/debt, and second, choosing whichever bank to save in/borrow from. We will address the first issue at the family level for savers and borrowers in Section 1.3.1 and 1.3.2 respectively, and disclose their individual preferences on banks later in Section 1.3.3. Hereafter variables indexed by s refer to savers, and by b refer to borrowers.

The economy is populated by a saver family which consists of many individual savers. Each of them has his own investment choice on liquid assets. We further assume that a family leader will aggregate returns on all liquid assets and assign the amount of consumption evenly across members.

The goal of this household is to maximize the present discounted value of utility, given by:

$$V_s(C, Liq) = lnC_{s,1} + \frac{j_m}{1-\eta}(Liq_1)^{1-\eta} + \beta_s lnC_{s,2}, \tag{1.1}$$

where β_s is the discount factor, j_m governs the weight of utility from holding liquid assets in period 1 Liq_1 relative to consumption, η is the intertemporal elasticity of substitution. Savers have preferences over consumption in period 1 and period 2 ($C_{s,1}$ and $C_{s,2}$). Besides, our paper relates to debate on the importance of deposit supply by savers in a low rate environment. To this end, we also need to model savers' preference for liquidity, either by imposing a cash-in-advance constraint or by using a money-in-the-utility function specification. Following Drechsler et al. (2017) we assume savers' utility from liquidity services takes form of the second term on the right-hand side of 1.1. Liquidity assets are only held by savers and the amount is determined in period 1; hereafter, we drop the index s and time subscript for convenience.

Liquidity services are produced from bonds B and deposits D, according to a CES aggregator:

$$Liq(B, D) = [\alpha_B B^{1-\frac{1}{\xi_m}} + D^{1-\frac{1}{\xi_m}}]^{\frac{\xi_m}{\xi_m - 1}}, \tag{1.2}$$

where ξ_m is the elasticity of substitution between bonds and deposits, and α_b measures the liquidity of bonds relative to deposits. First, bonds and deposits both provide liquidity and are in come way substitutes. But, as data suggests, there is no significant drop in the propensity to save in deposits even though deposit rate is heading towards zero, which is evidence that bonds and deposit are not perfect substitutes. Hence we assume $\xi_m > 1$. Second, nowadays electronic payments are becoming the norm and deposits can be used for transactions very conveniently, leading the economy into a cashless state, therefore we can assume that savers only have access to deposits and bonds to transfer their resources to period 2. To assess the role of cash, in Section 1.6.3 we will introduce cash into the aggregator for liquidity assets, and assume that cash share the same value in terms of liquidity as deposits. We assume $\alpha_B < 1$, which implies that bonds are less liquid than deposits and cash.

In period 1, savers finance their consumption demand and investment on liquid assets by initial wealth W_s and sales of house endowment h. In period 2, they receive returns on liquid assets, lump-sum transfers and taxes, and all resources are spent on buying consumption goods. Their budget constraints in the two periods are:

$$C_{s,1} + D + B = W_s + q_{h,1} h, \tag{1.3}$$

$$C_{s,2} + T = RB + R^d D + \pi^b. \tag{1.4}$$

The policy interest rate R is the return rate that applies to government bonds, R^d is the average deposit rate offered by banks. T is lump-sum tax paid to the government. Banks' profits π^b are also rebated in a lump–sum fashion to savers.[5]

Maximizing the utility (1.1) subject to their budget constraints (1.3) and (1.4) we derive the first-order conditions relative to $C_{s,1}$, $C_{s,2}$, B and D:[6]

$$\frac{1}{C_{s,1}} = \mu_{s,1}, \tag{1.5}$$

$$\beta_s \frac{1}{C_{s,2}} = \mu_{s,2}, \tag{1.6}$$

$$\mu_{s,1} = j_m (Liq)^{-\eta - \frac{1}{\xi_m}} \alpha_b B^{-\frac{1}{\xi_m}} + \mu_{s,2} R, \tag{1.7}$$

$$\mu_{s,1} = j_m (Liq)^{-\eta - \frac{1}{\xi_m}} D^{-\frac{1}{\xi_m}} + \mu_{s,2} R^d, \tag{1.8}$$

$\mu_{s,i}$ denotes the Lagrangian multiplier on the budget constraint in period i. Equations (1.7) to (1.8) show savers' demand for bonds and deposits. Substituting (1.8) into (1.7) we obtain

$$j_m (Liq)^{-\eta - \frac{1}{\xi_m}} (D^{-\frac{1}{\xi_m}} - B^{-\frac{1}{\xi_m}}) = \mu_{s,2}(R - R^d).$$

These equations show that saver family's asset allocation is based on the relevant rates. When the policy rate is positive and bigger than deposit rate, saver family invests more money in bonds rather than deposits. Then as the policy rate falls accompanied by a decrease or even a reverse in the spread between policy rate and deposit rate, it then likes to cut bond holdings and deposit more money in banks. When we introduce cash, this is initially, namely when R is positive, a comparatively expensive source of liquidity; hence, any substitution out of bonds is almost entirely into deposits. Note, however, as deposit rate goes to zero, cash becomes a

[5] $\pi^b = N_G + N_D$ is interest income earned by big and small banks

[6] More details on how to solve the maximize problem are given in Section 1.A of the Appendix.

less expensive source of liquidity, thus the saver household is more likely to substitute out of bonds into cash, and even substitute deposits into cash. This suggests that deposit supply elasticity increases as rates fall, so that banks cannot pass-through monetary policy rate cuts to deposit rates, to avoid large outflows from deposits into cash.

1.3.2 Borrowers

As for borrowers, we assume that their consumption is fully insured within the family against the idiosyncratic risk in housing investment. The borrower family aggregates the amount of housing and mortgages, and then divides the respective returns and consumption equally among household members.

Borrowers differ from savers in their initial endowment, discount factor, and preferences. Their initial wealth is lower ($W_b < W_s$), and they have no houses, so that they need to borrow in order to finance their housing purchases. This is consistent with the evidence that wealthier households hold less debt, see the discussion in Iacoviello and Neri (2010).[7] The discount factor is smaller ($\beta_b < \beta_s$), which implies that borrowers are less patient than savers and therefore willing to borrow from banks for current consumption demand. Like savers, borrowers gain utility from consumption $C_{b,i}$ in period i, but they also enjoy housing services h, thus borrower family's lifetime utility is:

$$V_b(C,h) = lnC_{b,1} + j_h ln(h) + \beta_b lnC_{b,2}, \tag{1.9}$$

where j_h measures the weight of housing service in the utility function.

In period 1, besides using initial wealth, borrowers take out mortgages L at an average rate R^l to purchase housing at a relative price $q_{h,1}$ and consumption goods. In period 2, an idiosyncratic shock occurs which affects the value of their houses. Following Forlati and Lambertini (2011) we assume that this shock is independently and identically distributed across borrower members within the family and follows the log-normal distribution:

$$ln(\omega) \sim N(-\frac{\sigma_\omega^2}{2}, \sigma_\omega^2) \; .$$

After the shock, borrowers decide whether to default or not by comparing the housing value against mortgage payment. This leads to a threshold of this idiosyncratic shock denoted by:

$$\bar{\omega} = \frac{R^l L}{q_{h,2} h}, \tag{1.10}$$

at which borrowers are indifferent between default and repaying. More specifically, when the idiosyncratic shock ω is smaller than $\bar{\omega}$, the aftershock housing value ($\omega q_{h,2} h$) is below mortgage payment and thus borrower will default. If borrowers default on their mortgages

[7] Iacoviello and Neri (2010) find that credit-constrained agents have a lower labor income share than the unconstrained.

banks will repossess their houses; if not borrowers keep their houses and sell them in order to repay their mortgages and consume. $1-F(\bar{\omega})$ denotes the share of borrowers who repays, where

$$F(\bar{\omega}) = \int_0^{\bar{\omega}} f(\omega)d\omega,$$

and $1-G(\bar{\omega})$ is the fraction of housing stock owned by repaying borrowers, where

$$G(\bar{\omega}) = \int_0^{\bar{\omega}} \omega f(\omega)d\omega.$$

Summarizing, we can aggregate the budget constraints across the borrower family:

$$C_{b,1} + q_{h,1}h = W_b + L, \tag{1.11}$$

$$C_{b,2} = (1-G(\bar{\omega}))q_{h,2}h - (1-F(\bar{\omega}))R^l L. \tag{1.12}$$

Maximizing the utility (1.9) subject to above constraints 1.11 and (1.12), and substituting $\bar{\omega}$ by (1.10), we obtain first-order conditions relative to $C_{b,1}$, $C_{b,2}$, h and L:

$$\frac{1}{C_{b,1}} = \mu_{b,1}, \tag{1.13}$$

$$\beta_b \frac{1}{C_{b,2}} = \mu_{b,2}, \tag{1.14}$$

$$\mu_{b,1}q_{h,1} = \frac{j_h}{h} + \mu_{b,2}[(1-G(\bar{\omega}))q_{h,2} + G^{'}(\bar{\omega})\frac{R^l L}{h} - F^{'}(\bar{\omega})\frac{(R^l L)^2}{q_{h,2}h^2}], \tag{1.15}$$

$$\frac{\mu_{b,1}}{\mu_{b,2}} = (1-F(\bar{\omega}))R^l - F^{'}(\bar{\omega})\frac{(R^l)^2 L_t}{q_{h,2}h} + G^{'}(\bar{\omega})R^l, \tag{1.16}$$

where $\mu_{b,i}$ denotes the Lagrangian multipliers on the budget constraint in period i. Notice that R^l is predetermined for borrower family at the beginning of period 1, therefore there is no incentive compatibility constraint for them to satisfy as in Bernanke et al. (1998) and the threshold value depends on the leverage chosen by the family according to (1.10).

Plugging (1.13) and (1.14) into (1.16) gives the consumption Euler equation of borrowers. It equalizes the marginal rate of substitution between consumption in period 1 and period 2, to the actual cost of an addition unit of mortgage, which involves the repayment rate in case of no default (the first term on the RHS) and marginal impact on $\bar{\omega}$ (the last two terms on the RHS). An increase in mortgage leads to a higher default threshold value $\bar{\omega}$, which translates into a smaller share of borrowers repaying and therefore total mortgage repayment shrinks. Equation (1.15) shows that marginal utility of forgone consumption for buying one additional unit of housing must equal marginal utility gain from housing service in period 1 (the first term on the RHS), plus the utility from consumption in period 2 stemming from the sale of the non-defaulted housing stock. The latter internalizes the impact of an increase in housing on the threshold value as shown by the last two terms on the RHS.

1.3.3 Aggregation of Mortgages and Deposits

We now turn to describe the composition of family demand for mortgage and supply of deposit taking bank rates as given, and the rates setting will be explained in section 1.3.4. Inspired by Allen and Gale (2004), we assume that members in the saver and borrower family are dispersed in a continuum of locations indexed by $i \in [0,1]$. At each location, there are branches of both big and small domestic banks offering differentiated depository and lending services, and we index big banks by G and small domestic banks by D. As in previous work by Gerali et al. (2010), we assume that mortgages taken by borrowers are CES aggregate of big and small banks' loans and similarly for deposits held by savers. Agents' demand for a particular bank's service depends on its rates. Local branches act atomistically, this is to say that when a branch sets its rates., it affects local mortgage granting and deposit collecting but it does not have effect on the aggregate demand and rates.

Mortgage market: Aggregate mortgage is a CES aggregator of loans taken out by members at all locations:

$$L = [\int_0^1 L_i^{1-1/\rho_l} di]^{\rho_l/(\rho_l-1)}, \tag{1.17}$$

where ρ_l is the elasticity of substitution across locations. The aggregate mortgage rate R_t^l is defined as

$$R^l = [\int_0^1 (R_i^l)^{1-\rho_l} di]^{1/(1-\rho_l)}. \tag{1.18}$$

Minimizing total mortgage repayment over all locations $\int_0^1 R_i^l L_i$ subject to (1.18), we obtain the demand for mortgages at location i:

$$L_i = (\frac{R_i^l}{R^l})^{-\rho_l} L. \tag{1.19}$$

At location i, a mortgage is a CES composite of differentiated loans supplied by local big and small banks, according to the following function

$$L_i = [\alpha_{l,G}^{\frac{1}{\xi_l}} L_{i,G}^{1-\frac{1}{\xi_l}} + \alpha_{l,D}^{\frac{1}{\xi_l}} L_{i,D}^{1-\frac{1}{\xi_l}}]^{\frac{\xi_l}{\xi_l-1}}, \tag{1.20}$$

where ξ_l is the elasticity of substitution across banks. $\alpha_{l,j}$ measures the initial share of bank $j = G, D$ in the mortgage market, and we have $\alpha_{l,G} + \alpha_{l,D} = 1$. The average mortgage rate at location i is defined as

$$R_i^l = [\alpha_{l,G}(R_{i,G}^l)^{1-\xi_l} + \alpha_{l,D}(R_{i,D}^l)^{1-\xi_l}]^{\frac{1}{1-\xi_l}}. \tag{1.21}$$

Again, minimizing mortgage repayment to both big and small banks at location i subject to local CES mortgage constraint, yields demand for mortgages granted by bank j at location i as:

$$L_{i,j} = \alpha_{l,j}(\frac{R^l_{i,j}}{R^l_i})^{-\xi_l} L_i, \quad j = G, D. \tag{1.22}$$

Plugging (1.19) in, we can write (1.22) as

$$L_{i,j} = \alpha_{l,j}(\frac{R^l_{i,j}}{R^l_i})^{-\xi_l}(\frac{R^l_i}{R^l})^{-\rho_l} L, \quad j = G, D\,. \tag{1.23}$$

With $\xi_l > 1$, the higher the mortgage rate $R^l_{i,j}$, the lower is mortgage demand $L_{i,j}$.

Deposit market: This nested CES setting is also applicable to the deposit market. Aggregate deposit supply and rate are respectively given by:

$$D = [\int_0^1 D_i^{1-1/\rho_d} di]^{\rho_d/(\rho_d-1)}, \quad R^d = [\int_0^1 (R^d_i)^{1-\rho_d} di]^{1/(1-\rho_d)}\,.$$

Maximizing the revenue of deposits over all locations $\int_0^1 R^d_i D_i$ subject to the above CES supply constraint gives the supply of deposits at location i as:

$$D_i = (\frac{R^d_i}{R^d})^{-\rho_d} D. \tag{1.24}$$

At each location, deposit supply is a composite of deposits supplied to local branches of big and small banks, that takes the form of

$$D_i = [\alpha_{d,G}^{\frac{1}{\xi_d}} D_{i,G}^{1-\frac{1}{\xi_d}} + \alpha_{d,D}^{\frac{1}{\xi_d}} D_{i,D}^{1-\frac{1}{\xi_d}}]^{\frac{\xi_d}{\xi_d-1}}, \tag{1.25}$$

where ξ_d is the elasticity of substitution across banks in the deposit market. $\alpha_{d,j}$ measures the initial share of bank $j = G, D$ in the deposit market, and we have $\alpha_{d,G} + \alpha_{d,D} = 1$. The local deposit rate is denoted by

$$R^d_i = [\alpha_{d,G}(R^d_{i,G})^{1-\xi_d} + \alpha_{d,D}(R^d_{i,D})^{1-\xi_d}]^{\frac{1}{1-\xi_d}}. \tag{1.26}$$

Maximizing returns on deposits from local banks subject to (1.25) generate the deposit supply to bank j, and then by plugging in (1.24) we obtain

$$D_{i,j} = \alpha_{d,j}(\frac{R^d_{i,j}}{R^d_i})^{-\xi_d}(\frac{R^d_i}{R^d})^{-\rho_d} D, \quad j = G, D. \tag{1.27}$$

With $\xi_d < -1$, the higher the deposit rate $R^d_{i,j}$, the larger is deposit supply $D_{i,j}$.

We assume that branches of each type of bank at different locations behave symmetrically: $L_{i,j} = L_j$ and $D_{i,j} = D_j$. We can drop the index i going forward to focus on bank behavior of each type.

1.3.4 Banks

Banks raise deposits from savers, invest in safe assets (government bonds) and grant mortgages to borrowers. As mentioned before, there are two types of banks competing in both deposit and mortgage markets. Savers and borrowers treat their services as imperfectly substituable products, thereby giving banks a degree of market power. Banks can internalize mortgage demand (1.23) and deposit supply (1.27) of agents when choosing rates so as to maximize the discounted value of final net worth. Since banks are owned by savers, they share the same discount factor β_s and transfer their profits to savers in the second period.

The balance sheet identity of bank j is given by:

$$L_j + S_j = D_j + N_{j,0}, \quad j = G, D. \tag{1.28}$$

Bank j has initial net worth $N_{j,0}$ and deposits D_j taken from savers, and uses its resource to make mortgages L_j and invest in safe assets S_j. Its net worth in period 2 N_j is the returns on these investments net of the funding cost

$$N_j = R_j^{l,2} L_j + RS_j - R_j^d D_j, \quad j = G, D. \tag{1.29}$$

where R_j^d is deposit rate chosen by the bank. Safe assets receive a riskless interest rate R, and the gross return on mortgage is given by:

$$R_j^{l,2} L_j \equiv (\frac{L_j}{L}) \int_0^{\bar{\omega}} (1-\mu)\omega q_{h,2} h \, f(\omega) d\omega + \int_{\bar{\omega}}^{\infty} R_j^l L_j f(\omega) d\omega,$$

which comprises repayments from non-defaulting borrowers (the second term on the RHS), plus the proceeds from seizing the housing stock of defaulting borrowers, net of monitoring cost as a proportion μ of the housing value (the first term on the RHS). Since the borrower family holds a composite mortgage, in case of default each bank seizes the fraction $\frac{L_j}{L}$ of the defaulted housing stock.[8] Banks sustain losses when borrowers default. We assume that banks anticipate that a fraction of borrowers will default, and incorporate expectation in their optimal choice of deposit and mortgage rates.

Macroprudential Regulations: Banks are subject to two constraints, capital constraint and

[8]The housing stock seized by each type of bank is dependent on the bank's share in the mortgage market.

liquidity constraint, as follows

$$\varphi_j^c(R)L_j \le N_j, \quad j = G, D, \tag{1.30}$$

$$\varphi^l D_j \le S_j, \quad j = G, D. \tag{1.31}$$

The banks' risk-weighted assets are mortgages weighted by a risk measure φ_j^c plus safe assets weighted by zero, in line with actual regulation,[9] and capital constraint (1.30) requires a proportion of these risk-weighted assets to be covered by banks net worth. Liquidity constraint (1.31) requires that a fraction φ^l of deposits should be invested in safe assets to maintain sufficient liquidity.

After the financial crisis, these requirements have been tightened significantly based on the revised Basel III international standards and the Swiss-specific too big to fail regulation. In particular, the required ratio of total capital to risk-weighted assets has increased from around 9.6 percent in 2008 to 24 percent in 2018 for the two big banks; capital requirements have also increased for small banks, although to a much lesser extent. Since the policy rate fell during this period, for simplicity we model the risk-weighted capital ratio φ_j^c as a decreasing function of the policy rate. Since the policy rate fell throughout this period, the required capital ratio increases. More importantly, we assume that the initial level of risk-weighted capital ratio is lower for small banks, and that capital constraint on small banks is raised less than for big banks when the policy rate falls. That is, $\varphi_D^c < \varphi_G^c$ over the entire period.

Banks choose their rates to maximize discounted value of net worth in period 2 taking mortgage demand and deposit supply as given. Thus their optimization problem can be written as

$$\begin{aligned}\max_{R_j^L, R_j^d} \; & \beta_s\{R_j^{l,2}L_j + RS_j - R_j^d D_j\} + \lambda_j^b\{D_j + N_{j,0} - L_j - S_j\} \\ & + \lambda_j^c\{R_j^{l,2}L_j + RS_j - R_j^d D_j - \varphi_G^c L_j\} + \lambda_j^l\{S_j - \varphi^l D_j\} \\ & + \lambda_j^m\{L_j - \alpha_{l,j}(\frac{R_{i,j}^l}{R_i^l})^{-\xi_l}(\frac{R_i^l}{R^l})^{-\rho_l}L\} + \lambda_j^d\{D_j - \alpha_{l,j}(\frac{R_{i,j}^d}{R_i^d})^{-\xi_d}(\frac{R_i^d}{R^d})^{-\rho_d}D\}, \quad j = G, D.\end{aligned}$$

where λ_j^b, λ_j^c, λ_j^l, λ_j^m and λ_j^d are Lagrangian multipliers on balance sheet constraint, capital constraint, liquidity constraint, mortgage demand and deposit supply functions respectively.

[9] Safe assets, as government bonds, are secured by the government and carry no risk, while residential mortgages without guarantee from the government are weighted anywhere from 35% to 100% depending on the related LTV ratios in Switzerland.

The first-order conditions relative to R_j^L and R_j^d are:

$$R_j^l = \underbrace{\frac{1}{1-\frac{1}{\epsilon_j^l}}}_{\text{markup}} \frac{1}{1-F()}[R-(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + \underbrace{\frac{1}{\beta_s+\lambda_j^c}(\varphi_j^c\lambda_j^c+\lambda_j^l)]}_{\text{regulation cost}}, \quad j=G,D. \tag{1.32}$$

$$R_j^d = \underbrace{\frac{1}{1-\frac{1}{\epsilon_j^d}}}_{\text{markdown}} [R+\underbrace{\frac{1}{\beta_s+\lambda_j^c}(1-\varphi^l)\lambda_j^l]}_{\text{regulation cost}}, \quad j=G,D. \tag{1.33}$$

where ϵ_j^l and ϵ_j^d denotes the semi-elasticity of demand for mortgages and deposits respectively. Following Atkeson and Burstein (2008) these are functions of bank's market share:

$$\epsilon_j^l = \xi_l(1-s_j^l)+\rho_l s_j^l,$$

$$\epsilon_j^d = \xi_d(1-s_j^d)+\rho_d s_j^d,$$

where s_j^l and s_j^d denotes the share of bank j in the mortgage and deposit market, which is the ratio of mortgages/deposits granted by it relative to the total mortgages/deposits granted by all banks. With $\xi_l > \rho_l$ the elasticity ϵ_j^l is a decreasing function of bank's market share and thus markup is an increasing function of that. With $\xi_d < \rho_d$ the elasticity ϵ_j^d is an increasing function of bank's market share and thus markdown is a decreasing function of that. Accordingly, banks with bigger market share have larger market power, and are able to set a relatively higher markup and a lower markdown.

The Kuhn-Tucker conditions are

$$\lambda_j^c[N_j - \varphi_j^c L_j] = 0, \quad j=G,D. \tag{1.34}$$

$$\lambda_j^l[S_j - \varphi^l D_j] = 0, \quad j=G,D. \tag{1.35}$$

$$\lambda_j^c \geq 0, \quad j=G,D. \tag{1.36}$$

$$\lambda_j^l \geq 0, \quad j=G,D. \tag{1.37}$$

All these equations characterize the optimal interest rates chosen by banks under macroprudential regulation. First, because of imperfect competition across banks in the deposit and mortgage market, mortgage rate is a markup on the policy rate while deposit rates is a markdown. Second, when capital constraint binds banks charge a higher margin between the mortgage rate and the policy rate, which reduces loan demand and leverage. When the liquidity constraint binds, banks increase both the deposit rate and the mortgage rate, so as to increase their liquidity ratio. This effect could be so strong as to reverse the markdown relationship between the deposit rate and the policy rate. And when both constraints are slack, the respective Lagrangian multipliers are zero, and there is no effect of regulations on bank rates setting.

A point worth noting is that the optimization problem is similar for big and small banks with only difference being the level of the capital requirement. This is a key aspect driving the shift in market share between the two groups of banks. As the police rate falls, banks increase their mortgage supply by lowering mortgage rates. An expansion in assets makes the capital constraint more likely to bind, and a stricter requirement on big banks means that the capital constraint is more likely to bind first for them. As shown in equation (1.32), lending spreads are affected by binding regulatory requirements, thus big banks would set a relatively higher lending spread than small banks do, which reduces their lending capacity. Taking advantage of big banks' reduction in loan supply, small banks gain share in the mortgage market. Additionally, small banks can derive a competitive advantage from higher market share in increasing markup and lowering markdown, which contributes to raise their net worth.

1.3.5 Markets Clearing

The quantity of houses is fixed at

$$h = 1, \tag{1.38}$$

which implies that borrowers' demand for housing determines entirely its price. There is no mechanism in the model to price housing in the second and final period of the economy. As typical in this class of models, we fix house prices in the final period; more precisely, we fix the rate of growth of house prices from period 1 to 2 to be g_q. In section 1.C.1 of the appendix, we study the robustness of our results to different values of g_q. Hence,

$$q_{h,2} = g_q * q_{h,1}. \tag{1.39}$$

Government supplies bonds to savers and banks. We assume that government keeps proceeds from bond issuance in period 1 thanks to a costless technology. In period 2, government pays interest on bonds with lump-sum tax transfers T.

$$T = (R-1)(B+S). \tag{1.40}$$

Similarly, when we introduce cash into our framework, we assume that cash M is elastically supplied by the government with the costless technology; the demand for cash pins down its supply.

Equilibrium: Given the policy rate exogenously chosen by the central bank, an equilibrium is a set of prices (mortgage rates, deposits rates and house prices) and quantities (consumption, cash, deposits, bonds and mortgages) such that savers, borrowers and banks optimize, and all markets clear.

1.4 Parameterization

All parameter values are specified in Table 1.2. Most parameter values are calibrated to match the average value of relevant variables over the period 2000-2007; during this period, market share of big and small banks remained roughly constant.

Targets: We have four sources of data. The first is nominal interest rates which we then deflate by the CPI inflation. The SNB publishes monthly interest rates for new transactions, but we are limited to use the variable mortgage rate and term deposit rate because other interest rate data starts in 2008. The average real mortgage rate for the period 2000-07 is 2.5% and deposit rate is 0.25%. We use the three-month Swiss Franc Libor as the policy rate, and the average real rate over 2000-07 is 0.7%. Markdown and markup can be derived from dividing the average deposit rate and mortgage rate by this benchmark rate, which are 0.995 and 1.018, respectively.

The second set of data are the monetary aggregates. We take the Swiss banknotes in circulation and the total value of demand, time and saving deposits from the SNB, and then calculate the average money-to-deposit ratio for the period 2000-07, which is 0.05. The average general government debt to GDP ratio for the period 2000-07 as 40% using data from the Federal Statistics office, and we calculate the average bond-to-deposit ratio, which is 0.38.[10]

The next source of data are statistics on banks balance sheet, including mortgages, deposits and reserves, which is published by the SNB. We use these data to calculate the market share of the small banks in deposit and mortgage markets, as shown below in Panel (b) of Figure 1.3.

Finally, we use regulatory data including the Basel I to III capital requirements plus Swiss specific requirements. More precisely, we take the required risk-weighted capital ratios for big and small banks from Bichsel et al. (2019) and express them as a function of the policy rate.[11]

Calibrated parameters: One issue we do not discuss is that all these rates are annual; which means that our model is also annual. Savers' discount factor β_s and initial wealth W_s are calibrated jointly to pin down the average real deposit rate of 0.3% along with a policy rate at

[10]Government Debt accounts for 40% of GDP for the period 2000-2007, and total domestic deposits accounts for 105% of GDP. So we get the bond-to-deposit ratio to be 0.38.

[11]See section 1.E.1 in the Appendix for the data about total required capital ratio. We set $\varphi_j^c = 0.1 + (R <= 1.005) * \alpha_j^c * (1.0075 - R)$ to match the increasing capital ratio when the policy rate falls, where $\alpha_G^c = 6$ and $\alpha_G^c = 3$.

Table 1.2: Model Parameters

Parameter	Value	Description	Targets
β_s	0.99	discount factor for savers	deposit rate 0.3%
β_b	0.95	discount factor for borrowers	mortgage rate 2.5%
j_m	0.006	weight on liquidity in savers' utility	
ξ_m	2.5	elasticity of substitution between deposits and cash	money-to-deposit ratio 0.05
η	1	utility curvature in liquid assets	
α_b	0.4	liquidity quality of bonds	bond-to-deposit ratio 0.38
j_h	0.075	weight on housing in borrowers' utility	
φ_G^c	0.1	capital constraint for big banks	required capital ratio 0.096
φ_D^c	0.08	capital constraint for small banks	
φ^l	0.1	liquidity constraint	
$N_{G,0}, N_{D,0}$	0.4	initial net worth of banks	
W_s, W_b	8,5	initial wealth of savers and borrowers	
ξ_d	-160	elasticity of substitution of deposits across banks	markdown 0.996
ξ_l	140	elasticity of substitution of mortgages across banks	markup 1.018
ρ_d	-10	elasticity of substitution of deposits across locations	
ρ_l	10	elasticity of substitution of mortgages across locations	
g_q	0.0	growth rate of housing price	
μ	0.12	liquidation cost for banks	Bernanke et al. (1998)
σ_ω	0.16	std of idiosyncratic shock	Bernanke et al. (1998)

0.75%. Borrowers' discount factor and initial wealth are calibrated to be $\beta_b = 0.95$ and $W_b = 5$ to obtain an average real mortgage rate of 2.5%. To match initial bond-to-deposit ratio, we set the measurement of bonds' relative liquidity quality α_b to be 0.6, the weight on liquid assets in the Savers' utility function to be $j_m = 0.006$, and Borrower's housing preference to be $j_h = 0.075$. The curvature parameter of Savers' utility with respect to liquid assets η affects the pass-through of changes in the policy rate to deposit rates and we set it equal to 1, which implies log utility from liquidity.

Initial net worth for big and small banks is chosen to be the same and equal to 0.4; before the financial crisis, the joint capital of the two big banks and the domestically-oriented banks was roughly of the same magnitude. In the CES aggregators, the elasticity of substitution of deposits across banks ξ_d is set to -160 to match a markdown for the deposit rate $\frac{R^d}{R}$ which is equal to 0.996, and the elasticity of substitution of mortgages across banks ξ_l is set to 140 to match a markup for the mortgage rate $\frac{R^l}{R}$ equal to 1.018.

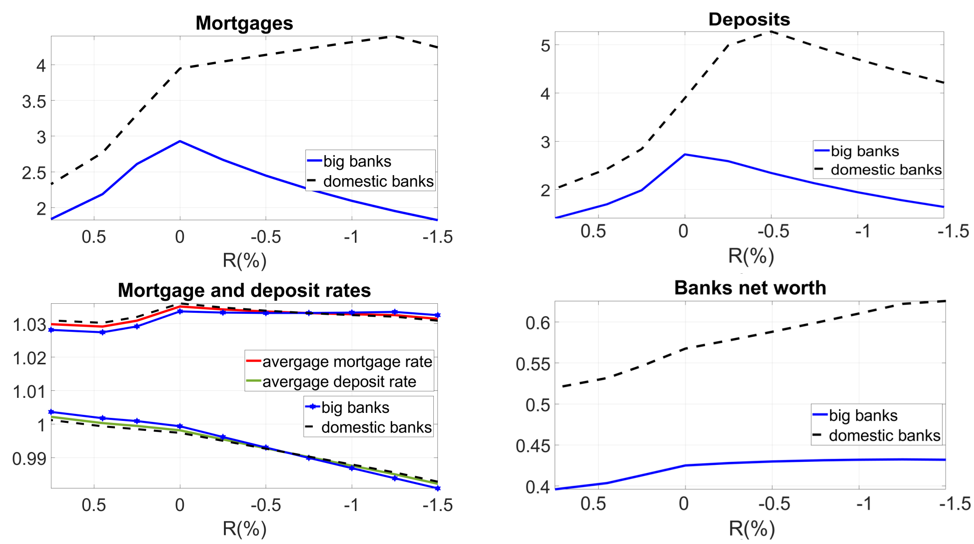
The initial required risk-weighted capital ratios for big banks and small banks are 0.1 and 0.08 respectively, which broadly match required capital ratios before 2008. Since the financial crisis capital requirements have been gradually tightened to reach 0.24 and 0.14 by the end of our sample in 2018. We model risk-weighted capital requirements that increase as the policy rate falls so as to match their actual temporal profile, see Figure 1.19. We set the parameter φ^l of the liquidity requirement equal to 0.1 for both big and small banks. This implies that banks must hold 10 percent of their deposits in the form of liquid assets.

Finally, we set the growth rate of house price to 0.[12] μ is set to 0.12 as in Bernanke et al. (1998), so that the monitoring cost after default is 12 percent of housing value. The standard deviation of idiosyncratic shock σ_ω is at 0.16 to reach an average default rate around 3%.

1.5 Model Evaluation

We solve our model non-linearly for levels of the policy rate R between 0.75% and -1.5%, which match the real interest rate at the beginning and the end of our sample (2008-2018). We present the period-2 equilibrium level of mortgages, deposits, the relevant rates and banks net worth below, see Figure 1.2. We remind the reader that a reduction in the policy rate is accompanied by a tightening of capital constraint for the two sets of banks as shown in subsection 1.E.1.[13]

Figure 1.2: The Impact of a Decreasing Policy Rate and a Tightening of Capital Requirement



For all plots, the horizontal axis measures the level of the policy rate, starting from 0.75% (our baseline calibration) to -1.5% moving from left to right. The lower left panel shows that, from 0.75% the reduction in R is fully transmitted to both deposit and mortgage rates. Cheaper mortgages drive up housing demand, leading to an increase in mortgage lending. Both big and small domestic banks respond in the same way to the initial reduction in the policy rate, collecting more deposits and then issuing more mortgages. This process continues until the policy rate reaches 0%; at this point, the capital constraint becomes binding for big banks.

Further reductions in the policy rate are accompanied by higher capital requirements, which the big banks meet by cutting their supply of mortgages and their demand of deposits. The

[12] We perform a sensitivity analysis in Section 1.C.1 of the Appendix by choosing a positive growth rate of house prices, and find that our qualitative results remain unchanged.

[13] To isolate the effect of a declining policy rate and a tighter capital requirement, we proceed by eliminating one at a time and then repeat our analysis. Section 1.6.1 presents our results.

reduction in mortgages by big banks is achieved by raising the mortgage rate above the level offered by the small domestic banks; similarly, the reduction in deposits is achieved by bringing the rate on deposits below the small domestic banks' counterpart. As a result, a fraction of mortgages and deposits shifts from big to small domestic banks, raising the market share of the latter. Small domestic banks expand their mortgages and deposits as the policy rate falls below 0% because their capital requirement is lower relative to the big banks and not yet binding.[14] In fact, small domestic banks absorb borrowers and depositors that leave the big banks because of their widened interest margins. The lower left panel confirms that big banks widen their interest rate margin by raising R^l and reducing R^d relative to the small domestic banks; the red and green line are the average mortgage and deposit rate.[15]

When the policy rate falls, savers switch out of bonds into deposits because they need liquidity services and deposits are better remunerated than bonds. It is thanks to this mechanism that small domestic banks can expand their deposits and their lending even if R is below one. However, when the policy rate reaches -1.25%, the capital requirement becomes binding also for small domestic banks, which constrains their lending capacity as well. Afterwards small domestic banks follow big banks to reduce their supply of mortgage and demand of deposits. The asymmetric response of banks to further rate reductions ends.

The lower right panel of Figure 1.2 displays bank net worth in period 2. When the policy rate is reduced from its initial level of 0.75%, banks issue more mortgages, which improves bank profits. Once the capital constraint becomes binding, the big banks increase mortgage rate, partly offsetting the negative effect of limited lending capacity on their profits. However, their net worth starts to grow at a lower pace than in small domestic banks. The difference in capital constraint results in differing lending capacity, and thereby net worth disparities between big and small domestic banks.

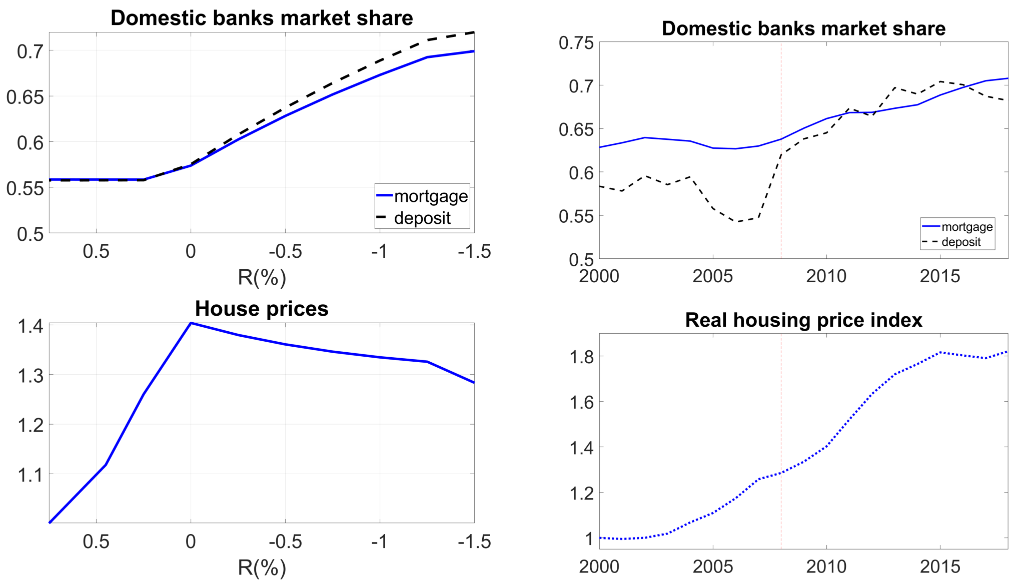
The upper left panel of Figure 1.3 plots the mortgage and deposit market share of small domestic banks implied by the model. The market share of small domestic banks is constant until the capital requirement becomes binding for big banks; at this point, the big banks curtail lending while small domestic banks continue expanding in response to further reduction in the policy rate. As a result, the market share of small domestic banks increases steadily. Once the capital constraint also binds for small domestic banks, the market share of small domestic banks continues to increase albeit at a reduced rate, because small domestic banks still offer better rates than the big banks, as documented in Figure 1.2. We find that our model rationalizes fairly well the actual change in market share that occurred between 2008 and 2018, which is plotted in the right panel of Figure 1.3.

[14] Please see the discussion in Fuster et al. (2021). The SNB Financial Stability Report reports that domestically focused Swiss banks held large capital buffers. Their capital ratios were typically 7.5 - 12.5 percentage points above the requirement.

[15] In the model, liquidity constraints are binding for both big and small domestic banks. Intuitively, as the rate falls close to or below zero, it becomes costly for banks to hold safe assets, leading them to reduce reserves, and thus liquidity constraints are likely to become binding. If liquidity constraints were not binding initially, we would observe a more significant mortgage expansion as banks can transfer excess safe asset holdings into loan supply.

Our model predicts that a decreasing policy rate fuels a growth in housing price, but only up to a point where capital constraint becomes binding for both banks. Our model predicts a 39 percentage point increase in the real house price, which is broadly consistent with the 46 percentage point increase in the real house price index in Switzerland since 2008, when our data sample starts from. However, our result overestimates the decrease in house prices relative to the data once the real policy rate falls below -1.25%. In our model, deposits and therefore mortgages fall because capital constraint becomes binding for both banks; in the data, deposits and mortgages continued to grow after 2015.

Figure 1.3: Model v.s. Data: Market Share and House Prices



(a) Model (b) Data

Notes: The initial level of interest rate at 0.75% in the simulated results is set to match the average value during the period 2000-2008, thus we calculate the increase in small domestic banks' market share and house prices since the period 2000-2008. To make it easy to compare the results, we normalize initial level of house prices to 1 on both sides.

Figure 1.4: Movement of Saver Family's Liquidity Holdings

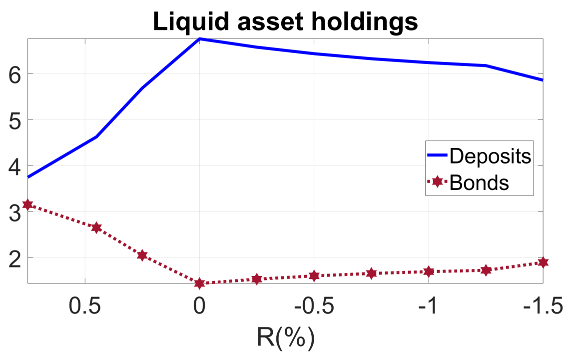


Figure 1.4 plots the evolution of saver bond and deposit holdings, which helps better under-

stand the dynamics of deposits. When the policy rate is positive, savers enjoy positive returns on bonds. As the policy rate falls, savers reduce bond holdings and transfer them into deposits since the deposit rate is not reduced one-to-one with the policy rate. When capital constraints bind, banks need to reduce deposits, savers substitute part of deposits back into bonds since banks lower deposit rate nearly one-for-one along with further rate cuts.

1.6 Understanding the Mechanism

This section analyzes the role played by our modeling assumptions on the results presented in section 1.5. Besides, we augment our benchmark model with substandard mortgages, to capture the fact that an expansion of credit typically goes hand-in-hand with an increase in risk, especially for small domestic banks.

1.6.1 Absent Changes in R

To understand the relative importance of falling policy rate versus tightened capital regulation, we simulate counterfactual experiments in which we subtract each from the model one at a time. In this subsection, we set the policy rate R fixed at 0.75%, and still allow capital constraint on big banks to get tighter. Figure 1.5 shows simulated result against different level of φ_G^c. All the variables stay put initially. When φ_G^c increases to the level 0.21 capital constraint becomes binding for big banks, they start to cut mortgage lending, thus losing market share to small domestic banks. Increased market power leads small domestic banks to raise the markup on mortgage rate, therefore they also decrease mortgage lending from this point, but not as sharply as big banks. On the whole, we find that a binding capital constraint for big banks make them lose market share.

1.6.2 Absent Regulatory Changes in φ^c

Then we simulate our model against different levels of the policy rate without changing the required capital ratios φ_G^c and φ_D^c. In Figure 1.6 we find that as rate falls banks increase mortgage supply. The increasing mortgage lending means a higher default risk, thus banks raise the mortgage rate. Importantly, capital constraints are not binding for big and small domestic banks, both small and big banks behave exactly the same way, and thus there is no shift in market share from one to the other. This suggests that the falling policy rate in our baseline result is essential to generate increased mortgage lending.

1.6.3 With Propensity to Substitute into Cash

In the baseline framework, savers only have access to deposits and bonds to smooth consumption across periods. As the policy rate falls, savers switch out of bonds into deposits because they need liquidity services and deposits are better remunerated than bonds. Even when the

Figure 1.5: Only φ_G^c Increases

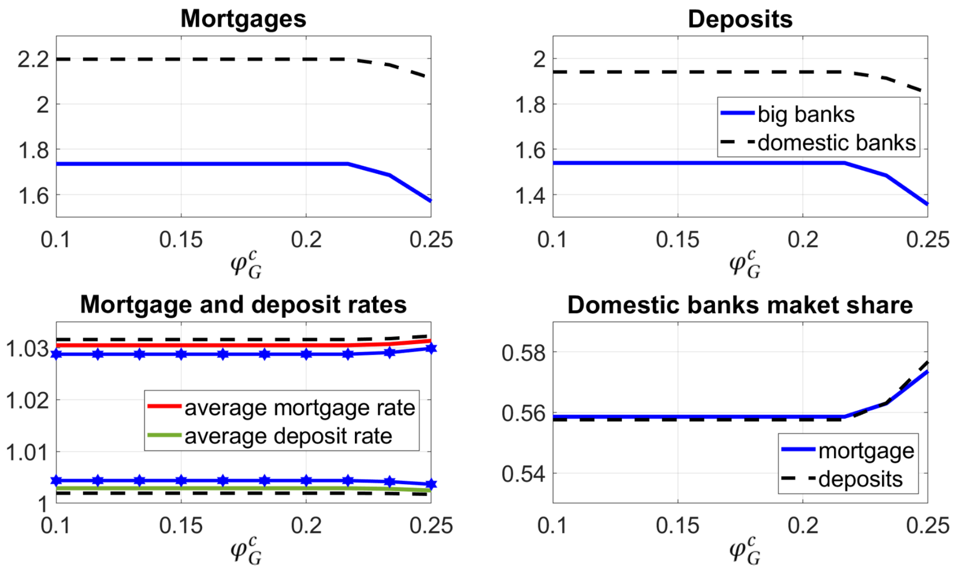
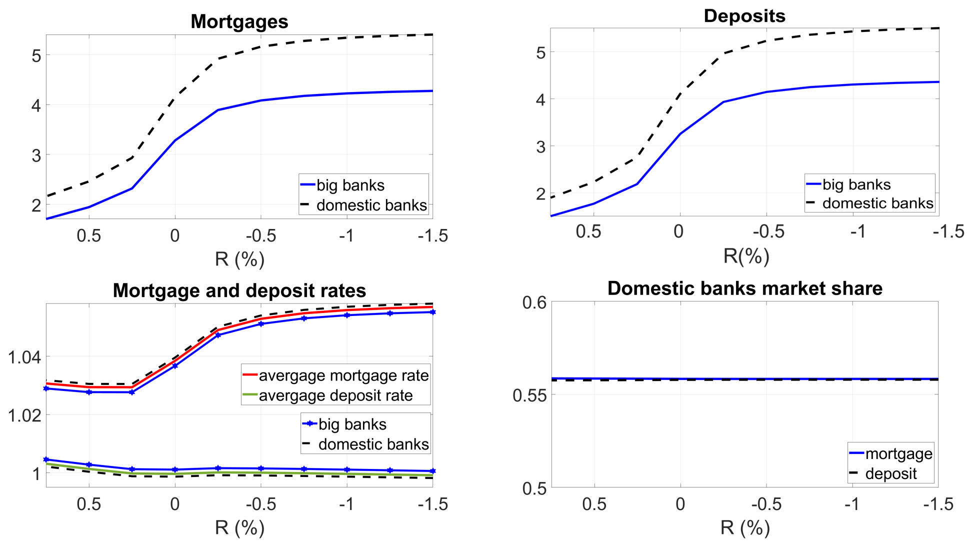


Figure 1.6: Only *R* Falls



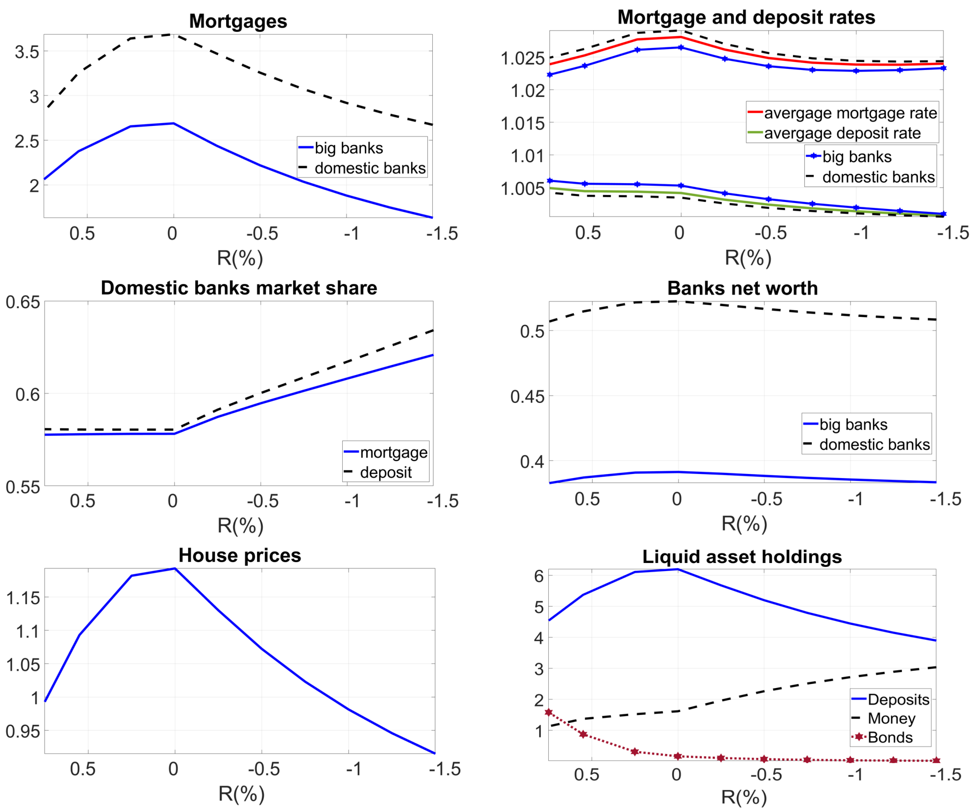
policy rate becomes negative, banks still can expand their deposit funding, and therefore their lending increases.

It is possible that cash provides liquidity services and may dominate liquid assets with negative nominal returns. In this subsection we introduce cash into our model. Savers can transfer resources from period 1 to 2 by holding cash, which pays zero nominal interest rate; cash and deposits provide identical liquidity services and are substitutable, although not perfectly. For capturing this, the aggregator of liquidity assets now becomes

$$Liq(B,D,M) = [\alpha_b B^{1-\frac{1}{\xi_m}} + [(D^{1-\xi_c} + M^{1-\xi_c})^{\frac{1}{1-\xi_c}}]^{1-\frac{1}{\xi_m}}]^{\frac{\xi_m}{\xi_m - 1}}, \tag{1.41}$$

with $0 < \xi_c < 1$. We consider the case of perfect substitutability where ξ_c goes close to zero in the next subsection. The main effect of having cash in our model is that deposits and mortgages start falling for a higher policy rate; qualitative dynamics of the model is otherwise identical, as seen in Figure 1.7.

Figure 1.7: With Cash Holdings



When the real policy rate gets close to negative, savers switch out of deposits into cash so that banks start to lose deposits. This funding squeeze negatively influences their mortgage supply, and consequently total mortgage lending decreases. A related result is that default risk becomes smaller, leading the average mortgage rate to fall. To avoid large outflows from deposits into cash, banks cannot push the deposit rate too much into negative territory; the markdown is first eliminated and then becomes a markup, eventually flipping the sign of conventional markdown. Once the policy rate falls below zero, we find a decaying pass-through of the policy rate cuts onto mortgage and deposit rate across banks.

The second right panel of Figure 1.7 shows that banks net worth falls significantly when the policy rate becomes negative. There are a number of reasons. First, the reduction in the policy rate cannot be passed-through to the deposit rate because savers have the option to hold cash, whose net return is zero. Banks therefore make a loss from holding deposits. Second, banks must hold safe assets due to the liquidity constraint; when the policy rate turns negative, banks make a loss from holding safe assets. Third, decreased deposits make banks cut lending; once lending falls, the net worth of the bank falls.

The differences in capital requirements still make banks respond differently to the rate cuts. Similar to our baseline result, the market share of small domestic banks increases, although at a reduced rate. It is because the funding constraint restrict banks to expand their lending as before.

1.6.4 Constant Market Power

Bank market power plays an important role in banks' responses to the policy rate cuts because they can adjust markups and markdowns, thereby influencing their net worth and the amount of mortgages issued. The benchmark model allows for the market power to increase with the market share of the bank; as a result, differences in size across banks imply different lending and funding decisions. In this subsection, we compare our baseline result to that emerges from the setting where banks have constant market power. In this case, changes in the relative size and market share of banks do not cause a change in markups and markdowns.

We solve our model under the assumption that bank j, when choosing the mortgage and deposit rate in location i, does not internalize the influence on the CES composite rate in the location, R_i. The first-order conditions now become:

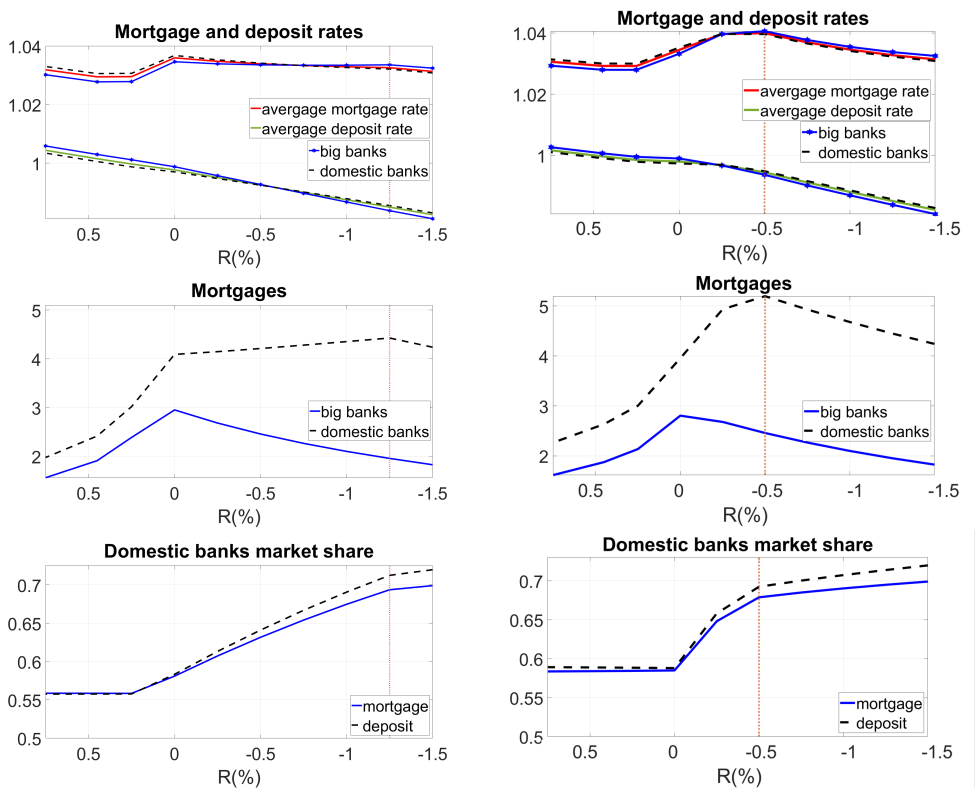
$$R_j^l = \underbrace{\frac{1}{1-\frac{1}{\xi_l}}}_{\text{markup}} \frac{1}{1-F()}[R-(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + \underbrace{\frac{1}{\beta_s+\lambda_j^c}(\varphi_j^c\lambda_j^c+\lambda_j^l)}_{\text{regulation cost}}], \quad j = G, D. \tag{1.42}$$

$$R_j^d = \underbrace{\frac{1}{1-\frac{1}{\xi_d}}}_{\text{markdown}} [R + \underbrace{\frac{1}{\beta^s+\lambda_j^c}(1-\varphi^l)\lambda_j^l}_{\text{regulation cost}}], \quad j = G, D. \tag{1.43}$$

The difference relative to equations (1.32) and (1.33) is that the markup (for mortgages) and markdown (for deposits) are only a function of the elasticity of substitution across banks, ξ, which does not depend on market size.

Figure 1.8 compares the results with variable and constant market power. With constant market power, small domestic banks increase market share in both mortgage and deposit markets as the policy rate falls, but less than in the benchmark model. Intuitively, as small domestic banks gain market share, variable market power enables them to raise markup and lower markdown (top panel), which affects their lending behavior in two ways. On the one hand, since small domestic banks charge a relatively higher mortgage rate and raise their mortgage supply at a slower pace, this helps make capital constraint bind at a lower level of the policy rate (second panel). On the other hand, a higher interest margin raises the net worth of small domestic banks, which also contributes to making the capital requirement bind at a lower policy rate. And when capital constraint becomes binding at the level -1.25% of the policy rate, mortgage supply would be constrained by the net worth; accordingly a larger net worth strengthens small domestic banks' lending capacity and brings in higher market share (bottom panel).

Figure 1.8: Variable and Constant Market Power



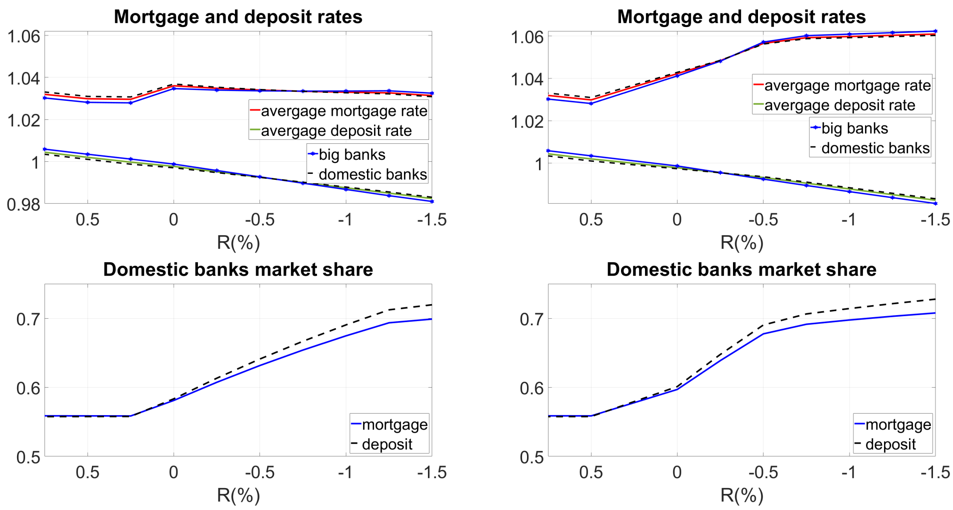
(a) Variable (b) Constant

1.6.5 An Increase in Idiosyncratic Risk

The banking literature (Jiménez et al. 2014; Dell'Ariccia et al. 2017) has found that a decrease in the policy rate comes with a reduction in the lending rate and an increase in the leverage, which is associated with a shift to riskier assets, as a credit expansion is typically achieved by a reduction in lending standards. To study how an increase in mortgage risk affects our analysis, we assume that the standard deviation of idiosyncratic shock is a linear decreasing function of the policy rate. As a result, mortgages become more risky and the rate of default increases as the policy rate falls.

The impact of an increase in idiosyncratic risk is shown in Figure 1.9. Relative to our baseline result, higher default risk leads to higher mortgage rate to compensate for higher expected default losses. Notably, small domestic banks gain more market share relative to the baseline case. This is because a higher lending rate has a disproportionate impact on big banks, whose mortgage rate is already high because the capital constraint is higher and already binding. A proportional increase in mortgage rate driven by larger rate of default further widens the interest differential between big and small domestic banks,so that big banks lose even more borrowers. The bottom panel shows that when the policy rate falls to -1.5%, small domestic banks' market share is about 1 percentage points larger than in the baseline case.

Figure 1.9: An Increase in Idiosyncratic Risk



(a) Baseline

(b) σ_ω increases when R falls

1.6.6 Risk Taking

Do low interest rates encourage banks to reach into riskier group of borrowers? To answer this question, we augment our baseline framework to include subprime borrowers, namely a group of borrowers characterized by higher default risk. Lending to subprime borrowers can be used as a measure of its risk-taking. That is, the larger fraction of mortgages a bank lends to bad borrowers, the higher default risk it is exposed to.

We refer to the borrowers in our baseline model as prime borrowers. There also exists two identical families of subprime borrowers; for simplicity we assume that one family can borrow from big banks while the other from small domestic banks, and we index them by the bank j they borrow from. Like in the prime borrower family, members' consumption is also fully insured against idiosyncratic risk in housing investment. The subprime borrower family uses initial wealth $w_b^{'}$ and mortgages Lb_j taken from banks j at rate R_j^* to purchase houses h_j^* and buy consumption goods. In period 2, there is an idiosyncratic shock across subprime borrowers to the value of their house holding. Following Nuño and Thomas (2017), we assume that this substandard idiosyncratic shock is identically and independently distributed, and follows the log-normal distribution

$$ln(\omega_j^*) \sim N(\frac{-\nu\sigma_\omega^2 - \Phi}{2}, \sqrt{\nu}\sigma_\omega^2),\ j = G, D,$$

for $\Phi > 0$ and $\nu > 1$, which implies that the idiosyncratic shock to subprime borrowers have a higher variance relative to that of prime borrowers. Hence, the budget constraints of subprime borrower family in period 1 and 2 are given by:

$$C_{j,1}^{bb} + q_{h,1}h_j^* = w_b^{'} + Lb_j,\ j = G, D, \tag{1.44}$$

$$C_{j,2}^{bb} = (1 - \tilde{G}(\bar{\omega}_j^*))q_{h,2}h^* - (1 - \tilde{F}(\bar{\omega}_j^*))R_j^* Lb_j,\ j = G, D, \tag{1.45}$$

where $C_{j,i}^{bb}$ denotes consumption demand of subprime borrower family j in period i, and $\bar{\omega}_j^*$ is the default threshold for subprime borrowers.

The total housing supply is equal to

$$h + h_G^* + h_D^* = 1. \tag{1.46}$$

We study the robustness of our results to different levels of housing supply in subsection 1.C.2 of the Appendix.

Aggregate mortgage for a subprime borrower family is a CES aggregator of loans taken out by members at all locations:

$$Lb_j = [\int_0^1 Lb_{i,j}^{1-1/\rho^*} di]^{\rho^*/(\rho^*-1)},\ j = G, D,$$

where ρ^* is the elasticity of substitution across locations.

At each location i, bank j's branch offers lending service to both good and bad borrowers. The balance sheet and net worth in period 2 become

$$L_j + Lb_j + S_j = D_j + N_0,\ j = G, D, \tag{1.47}$$

$$N_j = R_j^{l,2} L_j + [(1-\mu)\tilde{G}(\bar{\omega}_j^*)q_{h,2}h_j^* + (1 - \tilde{F}(\bar{\omega}_j^*))R_j^* Lb_j] + RS_j - R_j^d D_j,\ j = G, D. \tag{1.48}$$

Mortgages granted to subprime borrowers are associated with a higher level of risk weights than those issued to prime borrowers ($\gamma^{lb} > 1$),[16] so that capital constraint is now equal to

$$\varphi_j^c L_j + \gamma^{lb} * \varphi_j^c Lb_j \le N_j,\ j = G, D. \tag{1.49}$$

[16] We assume that risk weights on subprime mortgage is 1.3 times that of good mortgages, it is driven by the fact that mortgages with LTV ratio above/below 0.8 are given a risk weight 100%/75% on average.

Since big and small domestic banks lend to the two groups of subprime borrowers separately, there is no competition across bank types for these subprime mortgages. Thus, markups only depend on the elasticity of substitution across locations. The first-order condition for Lb_j is:

$$R_j^* = \frac{1}{1-\frac{1}{\rho^*}}\left[\frac{\bar{\omega}_j^*}{\bar{\omega}_j^*(1-\tilde{F}(\bar{\omega}_j^*))+(1-\mu)\tilde{G}(\bar{\omega}_j^*)}\right]\left[R+\frac{1}{\beta^s+\lambda_j^c}(\gamma^{lb}\varphi_j^c\lambda_j^c+\lambda_j^l)\right],\ j=G,D. \tag{1.50}$$

The default rate for a bank is denoted by

$$P(\omega)_j = \frac{L_j}{L_j+Lb_j}F(\bar{\omega}_j)+\frac{Lb_j}{L_j+Lb_j}\tilde{F}(\bar{\omega}_j^*),\ j=G,D. \tag{1.51}$$

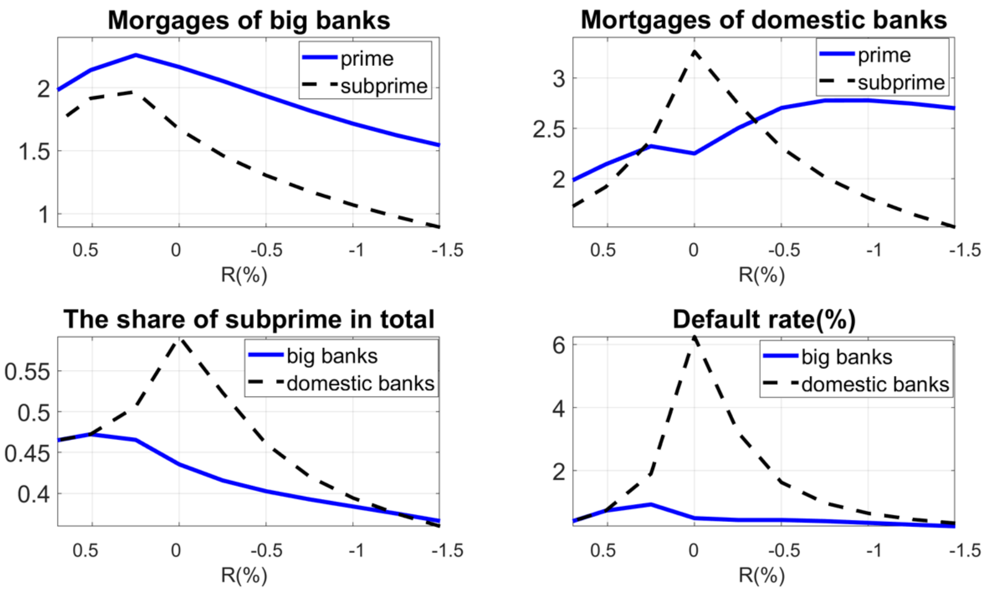
The quantities of mortgages granted to prime and subprime borrowers by two groups of banks and the average default rate are shown in Figure 1.10. Small domestic banks lend more to bad borrowers and thereby are exposed to a higher default rate than big banks.

Less competition on bad borrowers relative to good ones encourages banks to grant more substandard mortgages to bad borrowers and load up on aggregate risk, in particular, before capital constraint binds. When the policy rate falls to 0.25%, capital constraint binds for big banks, since then they have to cut these substandard mortgages which bear a higher risk-based capital ratio. However, less tightened capital regulation has not yet become binding for small domestic banks so that they are still able to increase mortgage lending to bad borrowers. Thus the share of substandard mortgages in total loans for small domestic banks rises up until capital constraint also binds for them at the level 0% of the policy rate. This indicates that small domestic banks hold a larger fraction of riskier mortgages and consequently they are exposed to larger default risk than big banks. As the policy rate keeps falling, small domestic banks also have to cut substandard mortgages sharply. Small domestic banks have a higher percentage of substandard mortgages on their balance sheet than big banks do until the policy rate falls to -1.5%. Overall, the competitive advantage from a less tight capital regulation raises the market share of small banks, as well as their exposure to default risk.

1.7 Policy Analysis

Last we analyze the effects of two policies: sectoral countercyclical capital buffer and negative rate exemption on reserves. Both have been implemented in Switzerland since the financial crisis.

Figure 1.10: Risk-taking by Banks



1.7.1 Sectoral Countercyclical Capital Buffer

Switzerland activated the sectoral Countercyclical capital buffer (SCCyB)[17] requirement targeting mortgage loans at 1% in 2013, and further raised it to 2% in 2015. This measure aims to mitigate housing boom and to protect the banking system from periods of excessive credit growth.

The SCCyB can be easily introduced in our model by modifying the capital requirement to

$$(\varphi_j^c + CC)L_j \leq N_j,\ j = G, D,$$

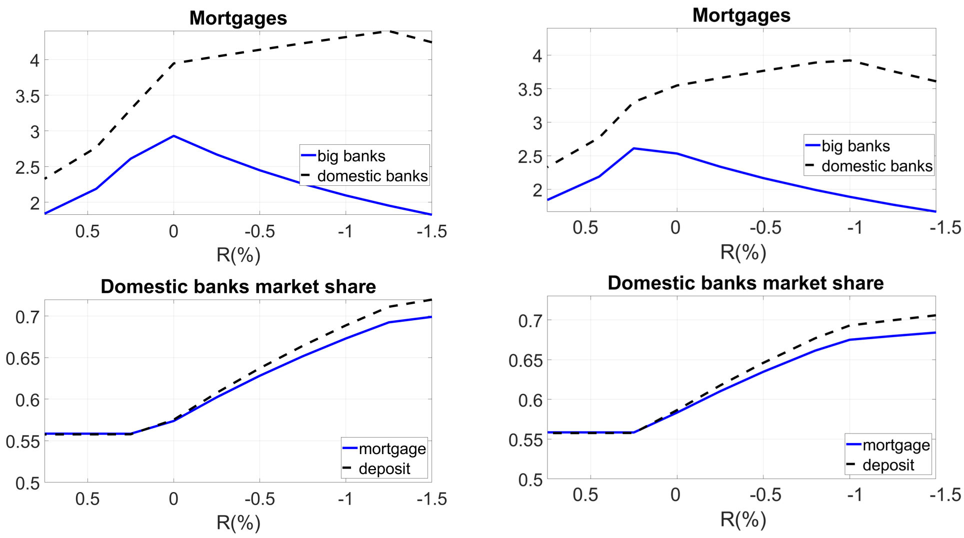
where CC represents the SCCyB requirement and is the same across all banks, so the total required risk-weighted capital ratio is equal to the level $\varphi^c + CC$. To match the fact that the SCCyB has been implemented since 2013, we set CC equal to zero for $R > 0.25\%$ and then to 0.02 for $R < 0.25\%$.

Figure 1.11 shows the effect of the SCCyB on the lending side. Comparing to the baseline case, we notice that mortgage lending and small domestic banks' gain in market share are

[17] The CCyB is an important component of the Basel III framework and has been introduced into Swiss legislation since 2012. Two important characteristics are embedded in the Swiss CCyB framework. First, the buffer is developed in such a way that it can be implemented on a broad basis or target specific segments of the credit market. Second, in line with Basel III, the maximum level of the CCyB is set at 2.5% of an individual bank's total domestic risk-weighted assets. The CCyB applies to Swiss banks and subsidiaries of foreign banks in Switzerland. Given the risks of cyclical imbalances developing in the domestic mortgage and real estate markets, Swiss authorities considered the targeted sectoral CCyB to be the best-suited instrument, increasing the capital requirements associated with residential mortgage loans while leaving those for other exposures unchanged.

smaller with the SCCyB. The SCCyB makes the capital requirement stronger, thus imposing stricter limits on their mortgage lending. For small domestic banks, the capital constraint starts binding at a higher policy rate, which limits their mortgage expansion and their market share increase. The SCCyB helps to reduce credit expansion as the policy rate falls; it also plays a role in containing small domestic banks' market share increase.

Figure 1.11: The Effect of Sectoral Countercyclical Capital Buffer



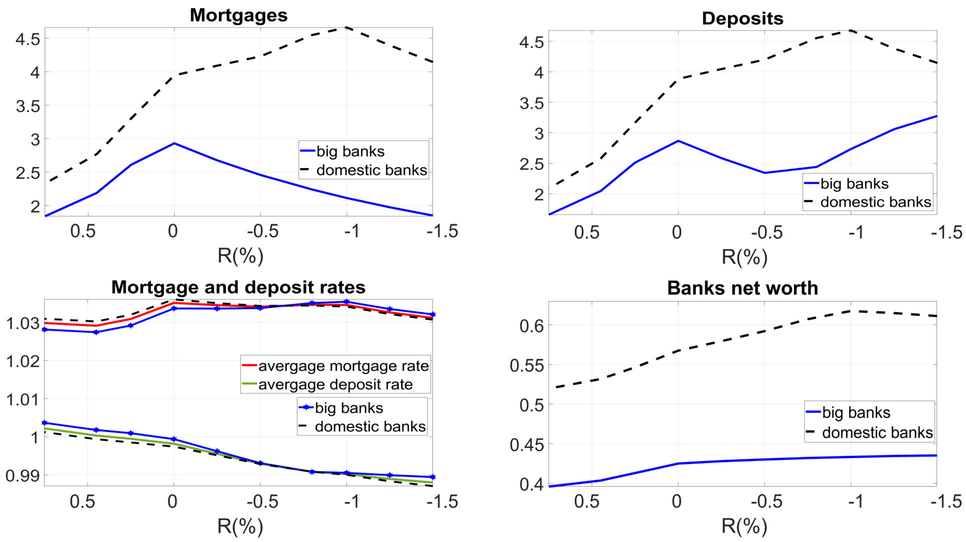
(a) Benchmark (b) With SCCyB implemented

1.7.2 Negative Rate Exemption on Reserves

When the SNB brought its policy rate into negative territory, it contemporaneously set an exemption threshold for sight deposit account balances. By setting the threshold at 20 times the minimum reserves, the SNB de facto relieved practically all balances from negative interest rates. Nevertheless, the exemption threshold could be reduced and therefore become binding for banks. To show the impact of this exemption policy, we assume that when the policy rate falls into negative territory, the net return on the safe assets held by banks remains zero rather than becoming negative. Figure 1.12 plots mortgage lending, deposit taking, relevant rates setting and net worth with the exemption policy implemented. It is effective for $R <= 0\%$. The results show that this policy is more favorable to big banks.

Two major changes from our baseline results in Figure 1.2 show up once the policy rate turns negative. First, the exemption policy raises bank net worth before capital constraint binds for small domestic banks at the rate -1%. Banks take more deposits and fund more mortgages than in baseline case, the peak value of mortgage supply increases by around 3%. Up to this point, the exemption policy improves not only banks' net worth but also their lending capacity. Second, after capital constraint becomes binding for small domestic banks they have to cut their mortgage lending, but they cannot lower deposit rate as much as they do in the

Figure 1.12: Exemption of Reserves from NIRP



baseline case. Thus, the relatively smaller spread between mortgage and deposit rate and the reduced loan supply lead to a declining net worth of small domestic banks. The reason for their reluctance to decrease deposit rate is that big banks now find safe assets profitable and then compete for those deposits. By this, big banks offer a better deposit rate than in baseline case and invest these increased deposit funding into safe assets. In the end, big banks raise their net worth while small domestic banks reduce it. Overall, we find the exemption policy is more beneficial for big banks, and it is effective in curbing mortgage growth only when the policy rate is negative.

1.8 Conclusions

To summarize, we provide a two-period partial equilibrium model consisting of two types of bank to evaluate the effect of the reduction in the monetary policy rate as well as the asymmetric tightening of capital requirements on mortgage lending across banks. The reduction in the monetary policy rate from its initial positive level to zero generates a housing boom, namely an increase in mortgages and in real house prices; A tightening in capital requirements is able to generate a reduction of mortgages and house prices. A combination of them is necessary to generate a mortgage expansion and an increase in house prices as experienced in Switzerland since 2008. Additionally, an asymmetric tightening of capital constraint can rationalize different bank lending behavior. It is the tighter capital constraint on big banks that limits their capacity to lending and thus generate an increase in the mortgage and deposit share of small domestic banks, which is consistent with the data.

However, we are concerned about that market share concentration in small domestic banks implies larger default risk in this sector. To maintain financial stability and mitigate excessive credit growth, an uniformed CCyB requirement was introduced, we find that it can help to constrain mortgage lending, and correct the effect of decreasing policy rate and a tightening of capital regulation on market share concentration by a little. However, default risk still largely builds up in small domestic banks. Making financial system safer is one of the key targets a continuously strengthened capital requirement tries to hit, from this point of view, we may need to reflect on it. A complementary revise on risk weights or a specific restriction on housing purchase may be needed in this situation to cope with the unintended credit boom.

1.A Mathematical Derivations

This section presents how we obtain the equilibrium conditions.

Savers' dynamic programming is given by

$$max \quad lnC_{s,1} + \frac{j_m}{1-\eta}(Liq)^{1-\eta} + \beta_s lnC_{s,2} + \mu_{s,1}(W_s - C_{s,1} - B - D) + \mu_{s,2}(R^d D + RB - C_{s,2} - T + \pi_b) \ .$$

The first-order conditions relative to $C_{s,1}$, $C_{s,2}$, B and D are shown by equations 1.5-1.8.

Borrowers' dynamic programming is then given by

$$max \quad lnC_{b,1} + j_h \ln h + \beta_b lnC_{b,2} + \mu_{b,1}(L + W_b - C_{b,1} - q_{h,1}h) + \mu_{b,2}[(1 - G(\frac{R^l L}{q_{h,2}h}))q_{h,2}h - (1 - F(\frac{R^l L}{q_{h,2}h}))R^l L - C_{b,2}] \ .$$

The first-order conditions relative to $C_{b,1}$, $C_{b,2}$, h and L are given by equations 1.13-1.16.

Banks: First, we solve banks' optimal problem in the baseline setting of variable market power, they choose their rates and implied quantities to maximize their next-period net worth:

$$\begin{aligned} max \ \beta_s\{[(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + (1 - F(\bar{\omega}))R^l_{i,j}]L_{i,j} + RS_j - R^d_{i,j}D_{i,j}\} \\ + \lambda^c_{i,j}\{[(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + (1 - F(\bar{\omega}))R^l_{i,j}]L_{i,j} + RS_{i,j} - R^d_{i,j}D_{i,j} - \varphi^c_{i,j}L_{i,j}\} \\ + \lambda^l_{i,j}\{S_{i,j} - \varphi^l D_{i,j}\} + \lambda^b\{D_j + N_{j,0} - L_j - S_j\} \\ + \lambda^m\{L_{i,j} - 0.5(\frac{R^l_{i,j}}{R^l_i})^{-\xi_l}(\frac{R^l_i}{R^l})^{-\rho}L)\} + \lambda^d\{D_{i,j} - 0.5(\frac{R^d_{i,j}}{R^d_i})^{-\xi_d}(\frac{R^d_i}{R^d})^{-\rho}D)\} \end{aligned}$$

We take first-order conditions with respect to $L_{i,j}$ and $R^l_{i,j}$:

$$(\beta_s + \lambda^c_{i,j})\{[(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + (1 - F(\bar{\omega}))R^l_{i,j}] - R\} - \lambda^c_{i,j}\varphi^c_{i,j} - \lambda^l_{i,j} + \lambda^m_{i,j} = 0 \ ,$$

$$(\beta_s + \lambda^c_{i,j})[(1 - F(\bar{\omega}))]L_{i,j} - \lambda^m_{i,j}\{-\xi_l 0.5(\frac{R^l_{i,j}}{R^l_i})^{-\xi_l - 1}(\frac{R^l_i}{R^l})^{-\rho}L\frac{1}{R^l_i} + (-\rho + \xi_l)0.5(R^l_{i,j})^{-\xi_l}(R^l)^{\rho}L(R^l_i)^{-\rho+\xi_l-1}\frac{\partial R^l_i}{\partial R^l_{i,j}}\} = 0 \ .$$

Plugging the local mortgage demand function 1.23 into the first-order condition to $R^l_{i,j}$ we get

$$(\beta_s + \lambda^c_{i,j})[(1 - F(\bar{\omega}))]L_{i,j} - \lambda^m_{i,j}\{-\xi_l L_{i,j}(R^l_{i,j})^{-1} + (-\rho + \xi_l)L_{i,j}(R^l_{i,j})^{-1}s^l_{i,j}\} = 0 \quad .$$

This implies

$$\lambda^m_{i,j} = \frac{(\beta_s + \lambda^c_{i,j})[(1 - F(\bar{\omega}_{t+1}))]R^l_{i,j}}{\xi_l - (-\rho + \xi_l)s^l_{i,j}} \, .$$

Then substituting this $\lambda^m_{i,j}$ into the first-order condition to $L_{i,j}$ yields the optimal mortgage rate chosen by the bank:

$$R^l_{i,j} = \underbrace{\frac{1}{1 - \frac{1}{\epsilon^l_{i,j}}}}_{\text{markup}} \frac{1}{1 - F()}[R - (1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + \underbrace{\frac{1}{\beta_s + \lambda^c_{i,j}}(\varphi^c_{i,j}\lambda^c_{i,j} + \lambda^l_{i,j})]}_{\text{regulation}} \, ,$$

where

$$\epsilon^l_{i,j} = \xi_l(1 - s^l_{i,j}) + \rho s^l_{i,j} \, .$$

Similarly, by combining first-order conditions with respect to $D_{i,j}$ and $R^d_{i,j}$ we get the optimal deposit rate set by the bank:

$$R^d_{i,j} = \underbrace{\frac{1}{1 - \frac{1}{\epsilon^d_{i,j}}}}_{\text{markdown}} \underbrace{[R + \frac{1}{\beta^s + \lambda^c_{i,j}}(1 - \varphi^l)\lambda^l_{i,j}]}_{\text{regulation}} \, ,$$

where

$$\epsilon^d_{i,j} = \xi_d(1 - s^d_{i,j}) + \rho s^d_{i,j} \, .$$

Second, we repeat this exercise in a setting of constant market power where there will be no influence on the CES composite rate in the location, $\frac{\partial R^l_i}{\partial R^l_{i,j}} = 0$. Now $\epsilon^l_{i,j} = \xi_l$ and $\epsilon^d_{i,j} = \xi_d$, thus the implied first-order conditions become

$$R^l_{i,j} = \underbrace{\frac{1}{1 - \frac{1}{\xi_l}}}_{\text{markup}} \frac{1}{1 - F()}[R - (1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + \underbrace{\frac{1}{\beta_s + \lambda^c_{i,j}}(\varphi^c_{i,j}\lambda^c_{i,j} + \lambda^l_{i,j})]}_{\text{regulation}} \, ,$$

$$R^d_{i,j} = \underbrace{\frac{1}{1 - \frac{1}{\xi_d}}}_{\text{markdown}} \underbrace{[R + \frac{1}{\beta^s + \lambda^c_{i,j}}(1 - \varphi^l)\lambda^l_{i,j}]}_{\text{regulation}} \, .$$

Last, when we include substandard borrowers in our model, the Lagrangian of bank's problem becomes

$$
\begin{aligned}
max\ \beta_s\{[(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + (1-F(\bar{\omega}))R^l_{i,j}]L_{i,j} + [(1-\mu_b)\frac{\tilde{G}(\bar{\omega}^*)}{\bar{\omega}^*} + (1-\tilde{F}(\bar{\omega}^*))]R^*_{i,j}Lb_{i,j} \\
+ RS_{i,j} - R^d_{i,j}D_{i,j}\} + \lambda^c_{i,j}\{[N_{i,j} - \varphi^c_j L_{i,j} - 1.3\varphi^c_j Lb_{i,j}\} \\
+ \lambda^l_{i,j}\{S_{i,j} - \varphi^l D_{i,j}\} + \lambda^b\{D_{i,j} + N^0 - L_{i,j} - Lb_{i,j} - S_{i,j}\} \\
+ \lambda^m\{L_{i,j} - L(R^l_{i,j})\} + \lambda^{mb}\{Lb_{i,j} - (\frac{R^*_{i,j}}{R^*_j})^{-\rho^*}Lb_j\} + \lambda^d\{D_{i,j} - D(R^d_{i,j})\}
\end{aligned}
$$

The optimal rates $R^l_{i,j}$ and $R^d_{i,j}$ chosen by banks stay the same, and we obtain the first-order condition to $R^*_{i,j}$:

$$
(\beta_s+\lambda^c_{i,j})\{[(1-\mu_b)\frac{\tilde{G}(\bar{\omega}^*)}{\bar{\omega}^*}+(1-\tilde{F}(\bar{\omega}^*))](Lb_{i,j}+R^*_{i,j}\frac{\partial Lb_{i,j}}{\partial R^*_{i,j}})-R\frac{\partial Lb_{i,j}}{\partial R^*_{i,j}}\}-\varphi^c_j 1.3\varphi^c_j\frac{\partial Lb_{i,j}}{\partial R^*_{i,j}}-\lambda^l_{i,j}\frac{\partial Lb_{i,j}}{\partial R^*_{i,j}} = 0
$$

where $\frac{\partial Lb_{i,j}}{\partial R^*_{i,j}} = -\rho^*(\frac{R^*_{i,j}}{R^*_j})^{-\rho^*-1}\frac{1}{R^*_j}Lb_j = -\rho^*\frac{Lb_{i,j}}{R^*_{i,j}}$. By rearranging this equation we obtain

$$
R^*_{i,j} = \frac{1}{1-\frac{1}{\rho^*}}[\frac{\bar{\omega}^*}{\bar{\omega}^*(1-\tilde{F}(\bar{\omega}^*)) + (1-\mu_b)\tilde{G}(\bar{\omega}^*)}][R + \frac{1}{\beta^s+\lambda^c}(1.3\varphi_c\lambda^c + \lambda^l)].
$$

1.B Additional Counterfactual Analysis

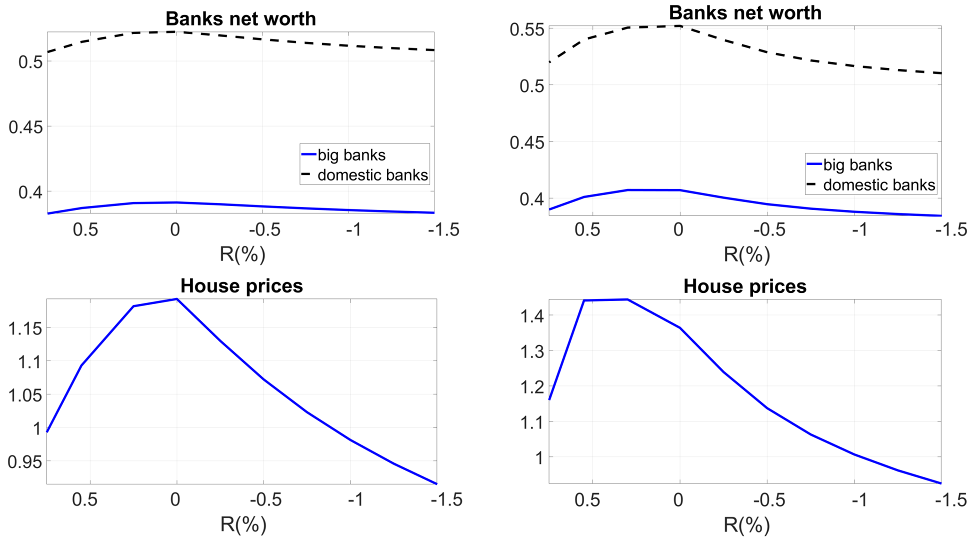
We study the impact of a stronger cash demand on banks' lending activity, which could illustrate the influences of staying in the low rate environment for too long.

1.B.1 Cash and Deposits as Perfect Substitutes

We assume that cash and deposits are perfect substitutes for the provision of liquidity services by setting ξ_c equal to 0.1. We choose this positive value rather than zero for ξ_c to avoid a corner solution where savers only hold deposits as long as $R > 0\%$ and fully switch to cash when $R < 0\%$. Panel (b) of Figure 1.13 shows that banks net worth and houses prices drop more sharply than in our baseline result when the policy rate turns negative. Intuitively, when cash competition becomes stronger banks lose deposits and and therefore curtail mortgage lending faster. As a result, the fall in both banks net worth and house prices from the peak is around 1.5 times larger than under the baseline setting.

We draw an important implication from our analysis. In cashless economies (as Denmark and Sweden), there is no flight from deposits in response to negative policy rates; however, credit expansion may also continue well into negative territory for the policy rate.

Figure 1.13: The Impact of Cash and Deposits Becoming Perfect Substitutes



(a) $\xi_c = 0.3$ (b) $\xi_c = 0.1$

1.C Robustness

This section discusses the generality of our main results by varying a set of key parameters, like growth rate of house prices and quantities of housing supply.

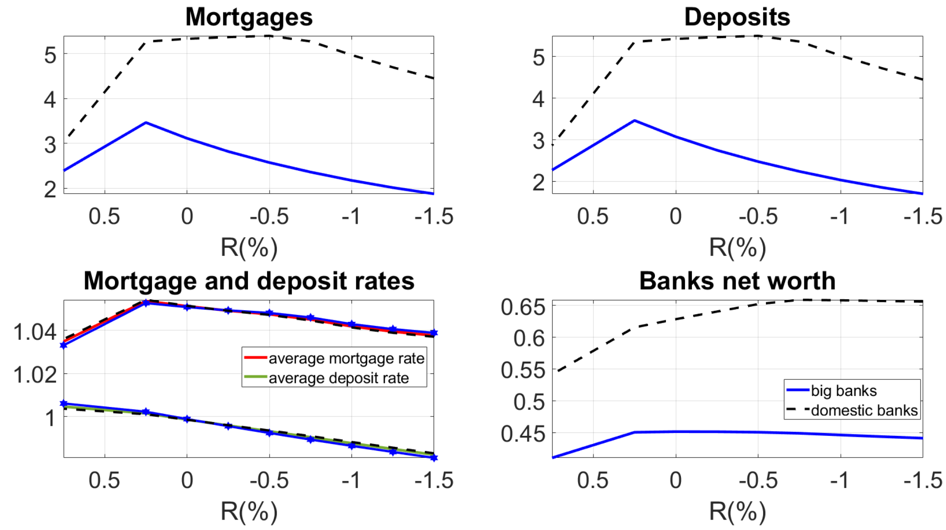
1.C.1 Growth Rate of House Prices

We fix the rate of growth of house prices from period 1 to 2 to be 0 in our baseline setting. To explore how this growth rate matters, we now calibrate it to be 0.5% and compare the simulated results. See Figure 1.14, the dynamics of these key variables are similar to that from our baseline calibration. The only difference is that a positive growth rate of house prices raises housing demand and then mortgage lending grows much faster, therefore capital constraint becomes binding earlier for both banks.

1.C.2 The Amount of Housing Supply

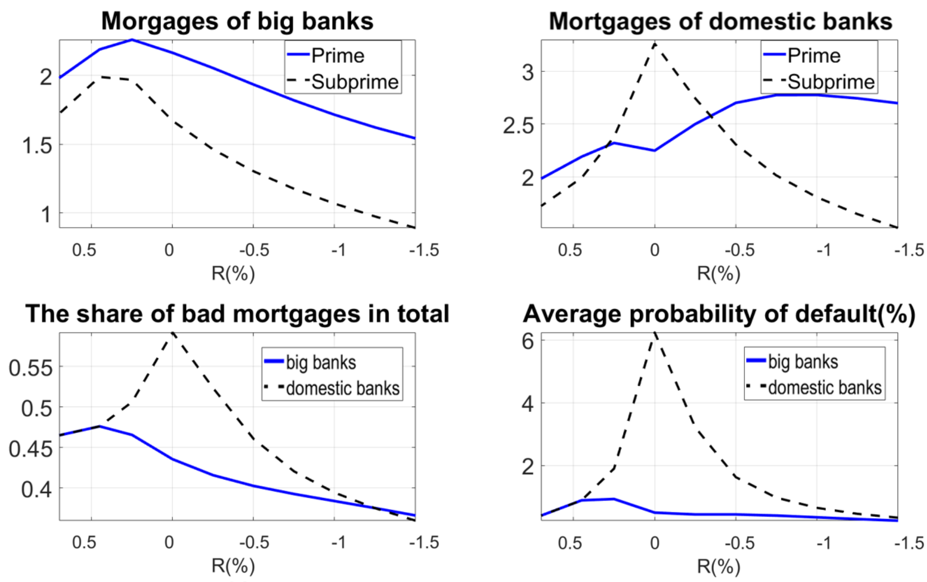
In Section 6.5, we allow good and bad borrowers compete for houses, and the total housing supply remains at the level of our baseline setting. A higher level of housing supply to these borrowers may allow them to borrow more from the banks. To explore how a different level of housing supply affect banks' mortgage supply and risk-taking behavior, we set total housing supply to 2 within the framework including subprime borrowers. See Figure 1.15, the result is very close to Figure 1.10. A larger housing supply implies a lower level of house prices, and banks' lending capacity are still limited by the capital constraints, thus mortgage supply to prime and subprime borrowers doesn't change much. The main result still holds that banks

Figure 1.14: When $g_q = 0.005$



prefer to increase lending to subprime borrowers before capital constraint binds, and small domestic banks take more risk than big banks because of less tightened capital constraint.

Figure 1.15: Risk-taking By Banks When Total Housing Supply Equals to 2

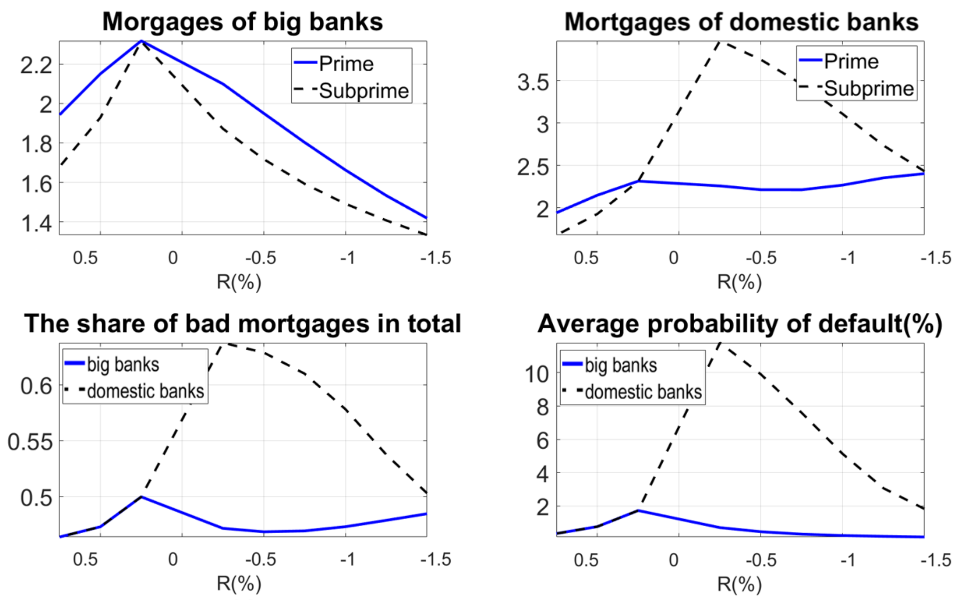


1.D Preference over Subprime Mortgages

There are a few differences between prime and subprime mortgages: first, risk weights in the capital constraint; second, markup setting; third, the idiosyncratic shock. To understand how these elements matter for banks' lending decisions, we would like to simulate our model with these differences out.

Firstly, we set γ^{lb} to 1, so that there is no additional risk weights on subprime mortgages relative to prime mortgages. Intuitively, without the difference in regulatory cost, banks would like to lend more to subprime borrowers. It is from Figure 1.16, especially for small domestic banks. The share of subprime mortgage in total loans increases by 10% and therefore default rate also goes up by 4%. To understand this result better, we compare the spread between subprime and prime mortgage rate in Figure 1.17. More loans to subprime borrowers means higher default risk, banks charge higher subprime mortgage rate as compensation. This price setting benefits these banks who have market power, since it raises the profits.

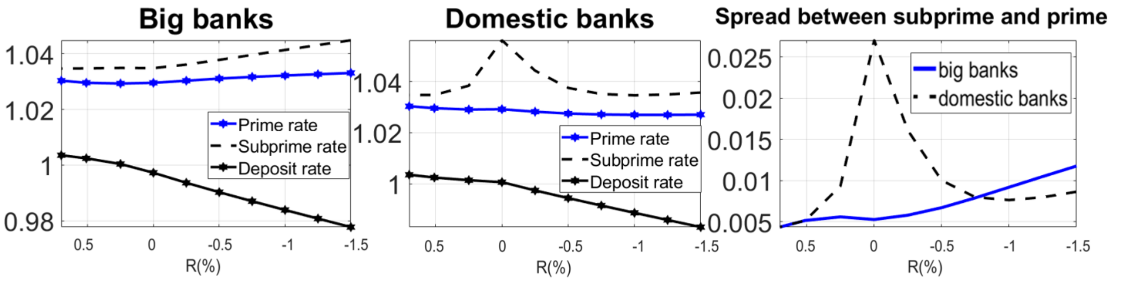
Figure 1.16: Capital Ratio on Subprime Mortgages



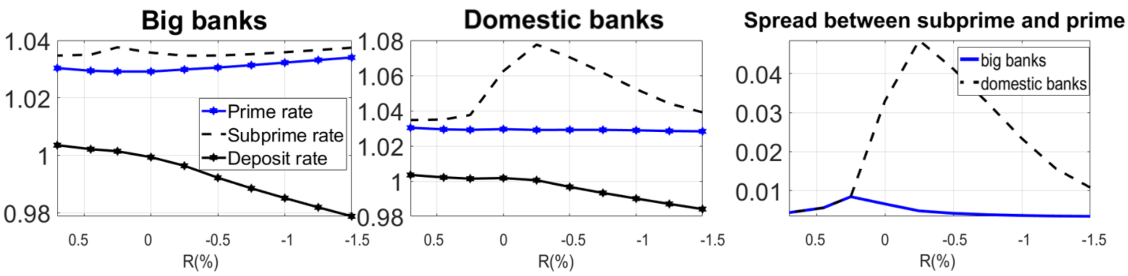
Then we take this process a step further by setting the markup on subprime mortgage be the same as on prime mortgages, thus difference in markup setting is also absent. In this case, banks would lend even more to subprime borrowers without this difference. See Figure 1.18, initially banks lend more than half of loans to subprime borrowers. As rate falls bank mainly raise the supply of subprime mortgages. The peak share of subprime mortgage in total goes up to around 70% for small domestic banks. As expected, the maximum default rate increases to 15%.

In general, it is these costs that prevents banks from issuing too much subprime mortgages.

Figure 1.17: Changes in Spread

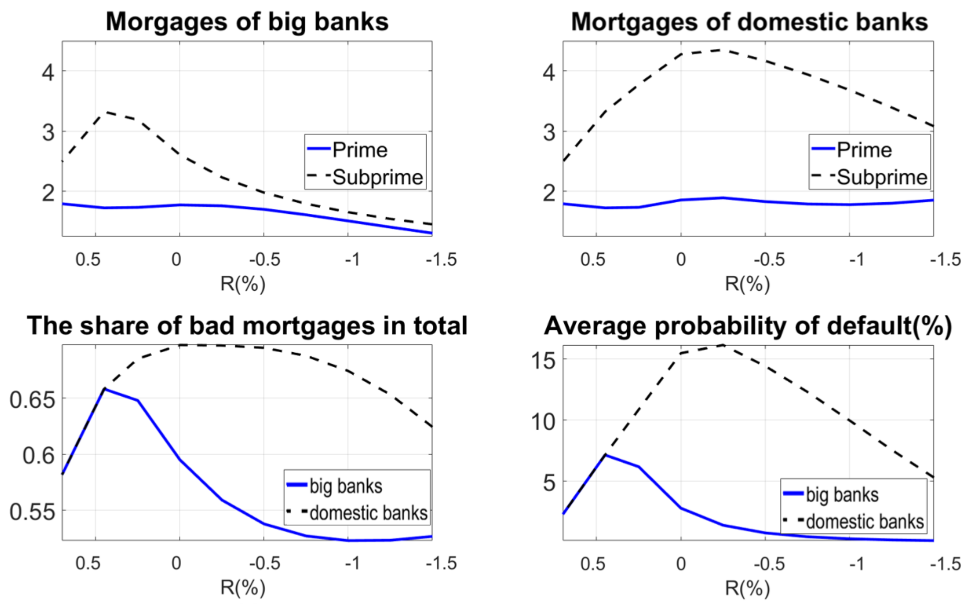


(a) Baseline



(b) Absent weight difference

Figure 1.18: No Differences in Markup



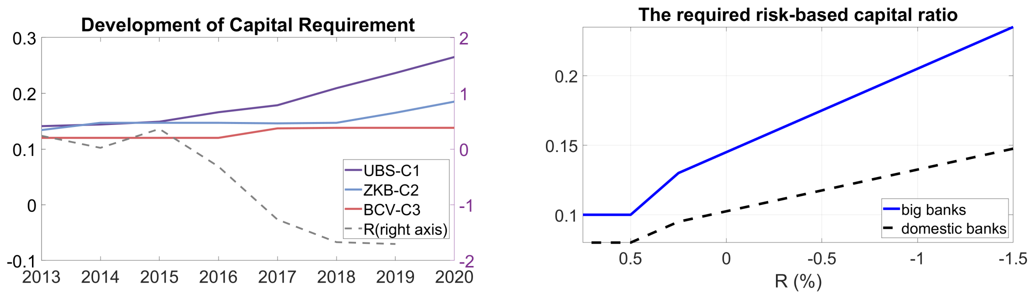
1.E Additional Data

1.E.1 Regulatory Development

According to Bichsel et al. (2019), capital requirements for the two big banks were tightened significantly, following the progressive introduction of revised international standards (Basel II) and the rescue out of global financial crisis. It is also true for most cantonal banks as their preferential treatment being removed in 2010, and for Raiffeisen banks as additional restrictions regarding capital quality were introduced. We can find that the severity of the capital requirements has been strongly strengthened over the period 2008-2010. Only the extent is different across banks.

The Basel Committee published a reform package in 2010 called Basel III to bolster capital and liquidity requirements. It came into effect in Switzerland since 2013. For the purpose of continuity, we plot the data of total required risk-weighted capital ratio over the period 2013-2020 in the left panel of Figure 1.19,[18] for G-SIFI (Globally Focused Systemically Important Banks) , D-SIFI (Domestically Focused Systemically Important Banks), , and banks assigned to category 3. G-SIFI are big banks (UBS and Credit Suisse) we referred to as, D-SIFI includes Zurich Cantonal Bank, Raiffeisen and PostFinance, we use data from the first two.[19] For bank assigned to category 3 we use the data from Vaud Cantonal Bank. All the data are from the relevant banks' annual reports. Besides we plot the real interest rates of the same period, as shown by the black dotted line. Two points are worth noting: First, capital constraint has been tightened continuously over the recent years as the policy rate falls, total risk-weighted capital ratios and the level of the real rate are negatively related; Second, more regulatory attention is clearly focused on the systemically important financial institutions, especially big banks.

Figure 1.19: Capital Requirements



(a) data (b) model

Notes: In panel (a), the purple line is for bank UBS (category 1), blue line for Zurich Cantonal Bank (category 2), red line for Banque Cantonale Vaudoise (category 3).

In the model, we assumed that total risk-weighted capital ratio in capital constraint is a

[18]The fully applied capital requirement must be met by 2020, hence we also plot the data for 2020.

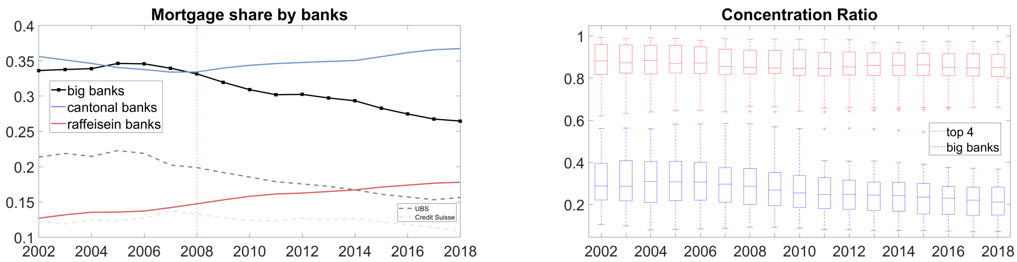
[19]PostFinance became a systematically important financial group at a relatively late stage in 2016, so we focus on the other two banks.

decreasing linear function of the real rate, and as the capital requirement on big bank is tightened with the falling policy rate more significantly than that on small domestic banks. As you can see in the right panel of Figure 1.19, it can roughly capture the two key features shown in the left panel.

1.E.2 Mortgage Market Structure

The Swiss mortgage market is concentrated. We calculate the cantonal level concentration ratio (CR) to measure the level of local competition. As seen in Figure 1.20, the average top4 CR across cantons is around 85%, indicating a highly oligopolistic market.

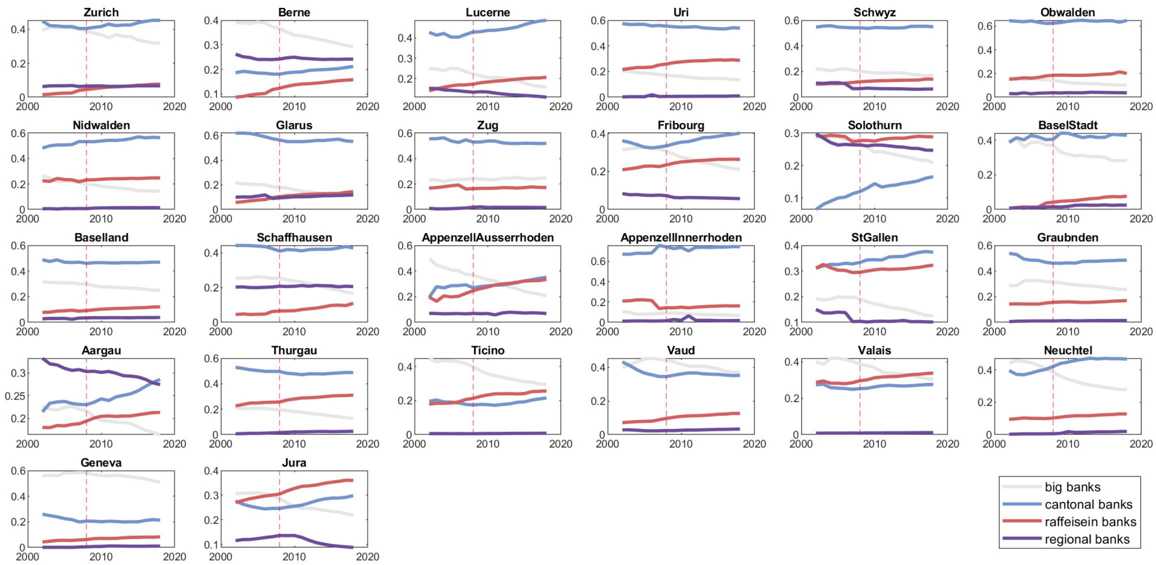
Figure 1.20: Market Concentration



Notes: Data are from the SNB. We calculate the cantonal level concentration ratio (CR) to measure the level of local competition. CR: the total market share of the serveral largest banks in the mortgage market. Top 4 indicates the four largest banks, and big banks refer to UBS and Credit Suisse.

Figure 1.21 show that big banks lose their market share in the mortgage market across cantons.

Figure 1.21: Mortgage Market Share Across Cantons



Notes: Mortgage data from the SNB and Cantonal GDP from Federal Statistical Office (FSO).

2 Bank Heterogeneity and Mortgage Supply under Negative Policy Rates

Joint work with Prof. Luisa Lambertini (EPFL)

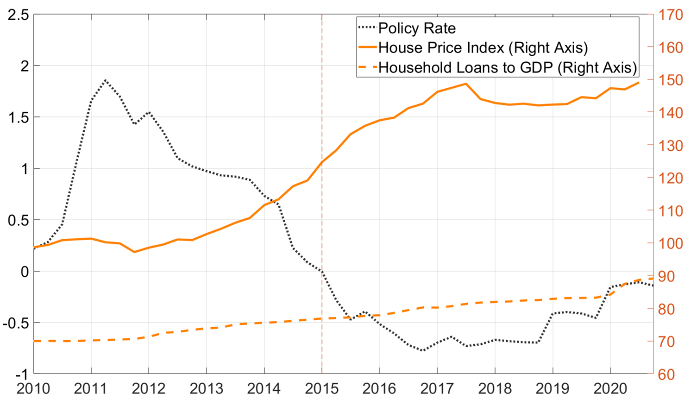
We use Swedish bank-level data and employ a triple diff approach to study the role played by specific bank features, such as reliance on deposits and covered bonds or capital surplus relative to the required level, in the transmission of negative rates. First, we find that high-deposit banks expand their mortgage supply less than low-deposit banks during negative rate periods; however, this pattern works only for weakly-capitalized banks, which have low capital buffer, i.e., capital in excess of requirement. Second, we show that banks more reliant on the covered bonds expand mortgage supply faster than their counterparts under negative rates, as they can shift into cheap deposits to reduce funding costs. We build up a general equilibrium model consistent with these empirical findings, featuring banks with different deposit and covered bond ratios that compete in the deposit and mortgage market. We use this model to study the implications of the Covid-19 pandemic for the mortgage market.

2.1 Introduction

A number of countries which have been keeping policy rate near/below zero have experienced a housing boom.[1] Figure 2.1 reports the empirical experience from Sweden. As the Swedish central bank lowered the policy rate into the negative territory, the ratio of household loans to GDP increased by 8 percentage points and the real house price index increased by 15 percentage points. These developments have been further strengthened in 2020, despite the Covid-19 pandemic. Alongside this mortgage expansion, we observe a rise in the dispersion of the lending distribution after the implementation of the negative rate policy, as shown in Figure 2.2. The gap between banks at the top 10% and banks at the bottom 10% of the lending growth distribution increased by 60%, which suggests that banks respond differently to the negative rate policy. To better understand the effects of the negative rate policy, it is important to identify which factors can explain banks' different lending responses and understand through which channels monetary-policy transmission occurs.

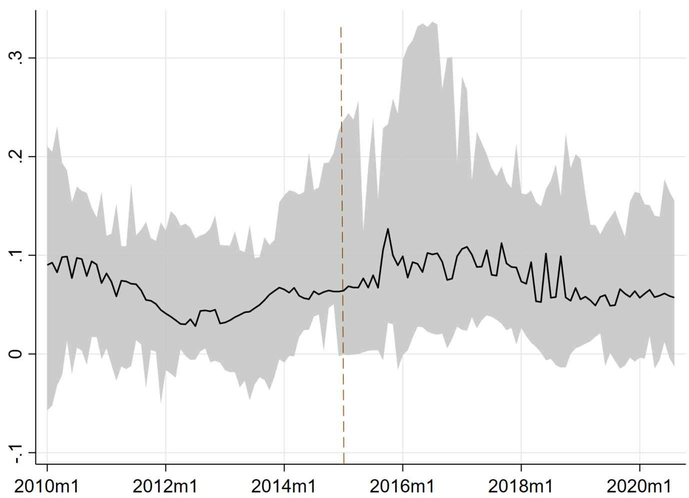
[1] See Figure 2.10 in the Appendix for the development in the housing market across European countries.

Figure 2.1: Swedish Housing Market under Low Rates



Notes: Policy Rates correspond to the Riksbank's repo rate; Real Residential Property Prices for Sweden are taken from the BIS. Household loans and Sweden GDP are from Sweden Statistical database. The vertical red line indicates the implementation of the negative rate policy.

Figure 2.2: Distribution of Lending Growth Rate



Notes: We plot the distribution of the average year-on-year growth rate of household loans given by banks. The solid line shows the median value, and the shaded area shows 90% of the distribution. The vertical red line indicates the implementation of the negative rate policy.

The role of reliance on deposits in the transmission of the negative rate policy has been the focus (Heider et al. (2019), Eggertsson et al. (2019)). As the policy rate moves into negative territory, banks are reluctant to set negative deposit rates, resulting in a squeezed net interest margin. To compensate for their loss, high-deposit banks raise their lending rates and reduce loan supply. Our analysis identifies two other essential factors: reliance on covered bonds and capital surplus relative to the required level. More precisely, we find that whether the deposit funding channel is at work or not depends on the capitalization level.

We employ a triple diff strategy on the Swedish bank-level data. Our first main finding is that high-deposit banks expand their mortgage supply less quickly relative to low-deposit banks under negative rates, confirming the well-documented deposit channel effect. However, this pattern works only for weakly-capitalized bank group, which do not have sufficient capital to absorb the loss from the reduced interest margins. Our second finding is that banks that are more reliant on covered bonds increase loan supply faster than their counterparts under negative rates. Banks highly reliant on covered bonds can switch out of covered bonds into cheaper deposit funding or lower the yields they pay on such bonds so as to further reduce funding costs.

Next, we develop a general equilibrium model with heterogeneous banks consistent with our empirical findings. In our model, banks get funding through deposit collection and the issuance of covered bonds and then lend to borrowers and buy safe assets. Capital and liquidity requirements are introduced to limit leverage and maintain a minimum amount of safe asset holdings in the banking sector. There are four types of banks: weakly- and well-capitalized banks with high and low deposit ratios, which compete imperfectly in the mortgage and deposit market. The differences between weakly- and well-capitalized banks are specified by the level of the capital requirement. Weakly-capitalized banks have to meet much tighter requirements and thereby face a more strongly binding capital constraint. The differences between high- and low-deposit banks are captured by consumers' weights on their services and adjustment costs for covered bonds. High-deposit banks are perceived to offer better depositing services by savers and pay a higher cost to issue covered bonds. The model is calibrated to match observed interest rates and regulatory requirements before the negative rate period.

We first show the long-run consequences of rate cuts for the real economy by presenting the steady state values of some key variables for different policy rate levels. A move into negative territory puts downward pressure on the net interest margin; this mechanism is more relevant for high-deposit banks. It reduces their profitability. Within the weakly-capitalized bank, the reduced net worth causes their capital constraints to bind at higher policy rates and it forces these banks not to expand their mortgage supply. Within the well-capitalized banks, the reduced interest margin does not lead to such a contractionary effect. These banks have sufficient capital buffers to absorb the profit reduction and they do not face binding constraints. Thus high-deposit well-capitalized banks typically experience more substantial lending growth than their low-deposit counterparts. Moreover, we show that an increase in liquidity saving preference of savers generates a much larger mortgage expansion and a significant dispersion of lending behavior between high- and low-deposit banks, which maps closely to the actual development.

We run several numerical simulations for the dynamic effects of a policy rate cut shutting down one bank heterogeneity at a time. Without any difference in whether the capital constraint is binding, high-deposit banks can increase lending more quickly than their counterparts despite the rate cut into a negative territory. Without any differences in covered bond costs and consumers' aggregator weights, high- and low-deposit banks would behave identically and have equivalent market power, resulting in increased competition and a smaller mortgage expansion. The differences in funding structure and capitalization are important in understanding the heterogeneous lending responses to the negative rate policy and their role in amplifying mortgage expansion.

Last, we use our modeling framework to draw some policy implications for the Covid-19 pandemic that has reinforced the developments in the housing market. We focus on two policies used to improve credit conditions during the pandemic: loosening the countercyclical capital requirements and buying covered bonds. Our simulated results suggest that both help to relax the capital constraints on weakly-capitalized banks and can strongly stimulate their mortgage supply. This leads house prices to increase further. A targeted policy on those well-capitalized banks during bad times may be more efficient in maintaining financial stability.

We proceed as follows. Section 2 reviews the relevant literature. Section 3 summarizes the Sweden bank data and empirical results. Section 4 and 5 present our baseline model and the calibration. Section 6 and 7 show simulated results and policy experiments. The final section concludes.

2.2 Literature

Our work relates to a rich literature that studies the monetary transmission mechanisms when interest rates are negative. The "deposit funding channel" has been well documented. In a negative rate environment, banks cannot pass the rate cuts on to depositors as the deposit rate already approaches zero lower bound, which reduces banks' net interest margin and profitability. Consequently, this limits bank lending capacity. Eggertsson et al. (2019) show that, as the policy rate turns negative, the usual transmission mechanism of monetary policy breaks down because of the importance of deposit funding and the zero lower bound on deposit rate. Ulate (2021) find that the move into negative policy rates leads to a decline in the deposit spread, leading to a reduction in bank equity and their credit supply. This effect is more pronounced for banks that rely heavily on retail deposits for funding.

This deposit channel has also been examined in substantial empirical contexts. Bech and Malkhozov (2016) and Claessens et al. (2018) show that a lower interest rate implies a lower net interest margin, which has an adverse effect on banks' profitability. Heider et al. (2019) provide evidence that banks highly reliant on deposit funding experience a lower reduction in their funding costs, a larger negative effect on their net worth, and therefore lend less once the policy rate becomes negative. Demiralp et al. (2019) and Ampudia and Van den Heuvel (2018) find similar evidence. However, Schelling et al. (2020) examine nonfinancial corporate lending in Switzerland before and after the introduction of negative rate using credit registry data, and they find that banks with high deposit ratios display a significant increase in their lending volume compared to banks with low deposit ratios. Lopez et al. (2020) suggest that the standard transmission mechanism still works for small and high-deposit banks. Tan (2019) compares the transmission to mortgage and corporate lending and documents that the relative increase in lending by high-deposit banks is driven entirely by mortgage lending. From the above empirical findings, we cannot draw a unified clue on the role of deposit funding in the transmission of the negative rate policy.

There is also a growing literature focusing on how the transmission is associated with other bank balance sheet characteristics. Basten and Mariathasan (2018) study the effect of negative rate exemption for reserves, and they find that more affected banks by the negative rate policy in Switzerland are those with liquid assets above the exemption threshold and need to shift their asset portfolios away from costly reserves and increase lending activity. Bottero et al. (2019) and Eisenshmidt and Smets (2019) also find evidence supporting this portfolio rebalance channel. Arce et al. (2018) focus on bank capital channel and observe that low-capitalized banks are more affected by the negative rate policy and therefore contract their credit supply, especially to risky firms.

Our paper, relative to these literature, deepens understanding of the deposit funding channel by showing that whether it is at work or not depends on bank capitalization level. A large capital buffer would allow banks to cushion the adverse impact on lending through the deposit funding channel. Additionally, we examine the role of reliance on other funding sources in the transmission of the negative policy rate. Banks issuing more covered bonds can shift away from it and increase deposit collection to continue lowering funding costs as the rate falls.

We introduce capital regulation into our modeling framework as an occasionally binding constraint. Our paper also relates to a number of papers that have captured this nonlinearity by allowing for the possibility that the balance sheet constraints do not always bind. Brunnermeier and Koby (2016) document the nonlinear responses of lending rate to a rate cut in a New Keynesian banking model. They find that the rate cut would become contractionary once the policy rate falls below a reversal interest rate and banks become capital constrained. Our paper uses this feature to differentiate weakly and well-capitalized banks and studies how they are differently affected by the negative rate policy.

Moreover, our theoretical framework introduces monopolistic bank competition, which can also help to explain why negative policy rates transmit differently across banks. Drechsler et al. (2017) and Polo (2018) show how market power helps the bank to stabilize deposit rate and how the slow adjustment of deposit rates amplifies the real effects of monetary policy changes on the economy. Wang et al. (2020) structurally estimate the importance of banks' market power, both on the lending and the funding side, for the transmission of monetary policy relative to financing and regulatory constraints. Our work embeds variable market power depending on banks' market share and examines the influences of different market structures on the monetary transmission across banks.

2.3 Empirical Strategy

This section summarizes the data we use, outlines the empirical strategy, and presents our findings on the differentiated impacts of the negative rate policy on mortgage lending across banks.

2.3.1 Data and Motivating Evidence

We use Swedish bank-level data from the Statistical Database (SCB) to document the differences in banks' lending responses to the negative rate policy. This database contains information on asset and liability items of monetary financial institutions from 1998M01 to 2020M09. Here, our bank definition refers to any credit institution with a license to receive deposits from customers. We focus on the bank-holding-company level for each independent bank, consolidating the balance sheets of the parent institution, subsidiaries, and banks acquired. Each bank in our sample can be treated as an independent entity. Our final database covers the major financial institutions in the Sweden mortgage market.

In addition to these balance sheet items, we obtain information on the required and actual risk-weighted capital ratios. The Finansinspektionen publishes the data on regulatory requirements for the large 9 banks. [2] We collect the regulatory data for the other banks in our sample manually from their own annual or quarterly reports.[3]

To avoid that outliers distort our results, we construct two share variables: total deposit and lending as a percentage of total assets, and winsorize these share variables at the 1% level (we drop outliers, typically defining those as observations outside the (1, 99) percentiles of the univariate distribution). To assess the impact of the negative rate policy, we focus on the period of 2014-2017, around two years before and after implementing the negative rate policy. Table 2.1 give a brief descriptive statistic depending on the bank type, so that we can compare the mean characteristics across bank groups.

First, we take a look at large and small banks. Note that large banks are further split into two groups, big 4 and mid 5, since they are still different in scale. Apart from the size measured

[2] The Finansinspektionen publishes reports on capital requirement from 2014, which covers the four major banks, Handelsbanken, Nordea, SEB and Swedbank, as well as Landshypotek, Länsförsäkringar, Kommuninvest, Svenskt Exportkredit (SEK), SBAB and Skandiabanken. Nordnet has been included since 2016.

[3] In total, we have data on capital regulation and capital buffer level for 25 banks in the sample.

Table 2.1: Summary Statistics

Variables	(1) Full sample	(2) Big 4	(3) Mid 5	(4) Small	(5) Well-	(6) Weakly-capitalized
A: Share of Total Assets						
Total deposit	0.60	0.47	0.40	0.76	0.58	0.62
from households	0.35	0.09	0.17	0.55	0.43	0.29
from firms	0.07	0.06	0.02	0.11	0.07	0.07
Covered bonds	0.13	0.17	0.37	0.00	0.14	0.12
Capital	0.16	0.16	0.11	0.19	0.18	0.14
Lending to households	0.36	0.23	0.45	0.38	0.39	0.34
Lending to firms	0.18	0.14	0.13	0.22	0.21	0.15
Liquid assets	0.15	0.16	0.16	0.15	0.13	0.17
B: Riskbased Requirements						
Required Capital Ratio	16.87	21.50	17.79	11.26	15.56	17.70
Capital Buffer	4.98	0.90	5.84	8.14	10.20	1.67
C: Market Share						
Lending to Households	100	80	15.6	4.4	10.3	89.7
Lending to Firms	100	89	7.1	3.9	19	81
N	210	48	52	110	92	118
D: Growth Rate (%, 2014-17)						
Lending to Households	2.90	1.26	3.24	3.43	3.38	2.53
Lending to Firms	0.28	0.73	-4.44	2.49	0.44	0.15
N	880	192	229	459	387	493

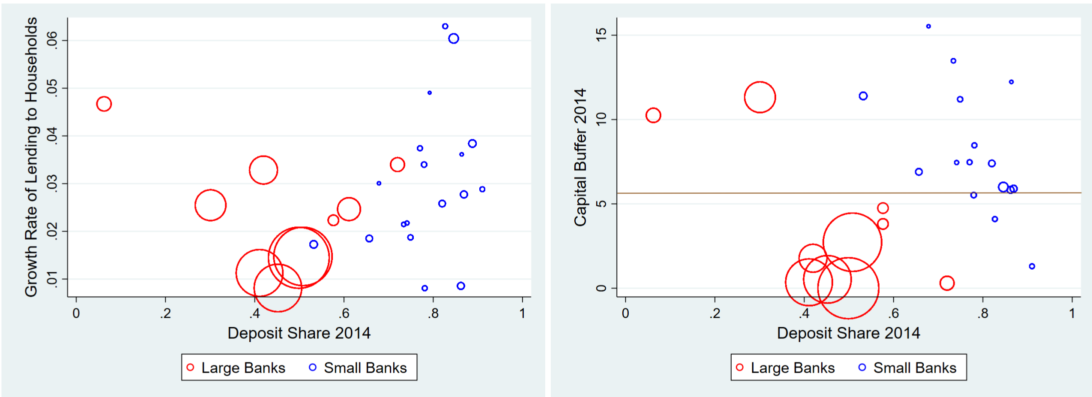
Notes: In panel A and B, each cell presents the mean value of different variables (noted in the first column) within the bank group at 2014 before the introduction of the negative rate policy. In panel C, each cell presents the total market share for each bank group at 2014. In panel D, we calculate the average 3m lending growth rate within each bank group across the period of 2014-2017. Monthly data from 25 banks. Outliers removed (observations beyond 1/99 percentiles).

by market share, the large and small bank groups differ in two aspects. First, while large banks get around 15%-35% of funding by issuing covered bonds (a measure of covered bond reliance), small banks are usually present in local markets and mainly rely on a large and stable household deposit base. Second, large banks face stricter capital requirements and maintain lower capital buffers than small banks. Additionally, big 4 have to satisfy an even tighter capital regulation relative to mid 5 under the Basel III standards since they are systematically important banks.

Then we divide the sample into well- and weakly-capitalized groups, measured by the amount of capital buffer (excess capital banks hold above the regulatory requirement). Well- and weakly-capitalized banks are defined as banks with above or below median capital buffer as of 2014. According to the mean value of the market share, deposit ratio, and capital buffer within each group, we can expect that the well-capitalized group is dominated by small banks and the weakly-capitalized group by large banks.

There is some motivating evidence on banks' different lending responses. First, panel (a) of Figure 2.3 shows that the growth rate of household loans is negatively correlated with deposit ratio during the negative rate period within large bank group; however, this relationship breaks down within small bank group. Panel (b) of Figure 2.3 plots the distribution of banks in deposit ratio and capital buffer. It indicates that large banks are mostly weak-capitalized banks with low capital buffers, whereas small banks are mainly well-capitalized banks. Putting them together suggests that high-deposit banks experiencing a lower growth rate of lending in a negative rate environment only apply to weak-capitalized banks. Second, in Figure 2.4, we observe that banks more reliant on covered bonds would experience a more extensive growth of household loans during the negative rate period.

Figure 2.3: Deposit Ratio, Capital Buffer, and Bank Lending

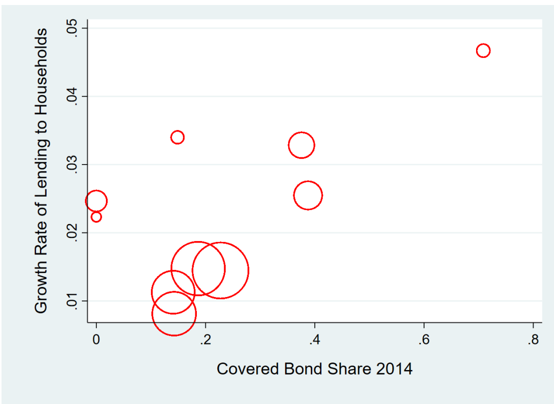


(a) Lending Growth and Deposit Share

(b) Capital buffer

Notes: The size of the circles indicate bank size, measured by mortgage market share in 2014. The solid horizontal line in panel (b) represents the median value of capital buffer across banks in 2014.

Figure 2.4: Covered Bonds and Bank Lending



Notes: The size of the circles indicate bank size, measured by mortgage market share in 2014.

Overall, we find substantial heterogeneity in bank size, funding structure, and capitalization level. This offers two testable possibilities to explain why banks are disproportionately affected by the negative rate policy:

- 1. High-deposit banks have to cut lending after the policy rate cut into negative territory. However, it works so only for these constrained banks that face stricter capital requirements.
- 2. Reliance on covered bonds could form a cushion against negative rate shock; banks highly reliant on covered bonds can lower the yields and source cheaper deposits to reduce funding costs, offsetting the negative impact on their net interest margins.

2.3.2 Differentiated Impact on Bank Lending

To test if these mechanisms are really at play, we run some bank-level regressions.

(i). Deposit Channel vs Capital Channel

We use a triple diff specification to test whether high-deposit banks will be affected more by the negative rate policy than low-deposit banks if they are well capitalized. The basis regression we use is

$$y_{i,t} = \beta_{d,q} \times P_t^{neg} \times D_{14,i} \times Qcap_{14,i} + \xi_i + \delta_t + \epsilon_{i,t}. \quad (2.1)$$

The dependent variable $y_{i,t}$ is 3-month lending growth rate of bank i at time t, measured by the log change of loans in 3 months ($\Delta log(L_{i,t})$). P_t^{neg} is a time dummy equal to one in the negative rate period since 2015M02. $D_{14,i}$ is banks' deposits to assets ratio in 2014, indicating banks' reliance on deposit financing. Banks are split into quartile according to their capital buffer level in 2014, and we set $Qcap_{14,i}$ as dummy variables indicating the quartile banks belong to. The higher category $Qcap_{14,i}$, the better capitalization level a bank is in. ξ_i and δ_t are comprehensive sets of bank- and year-specific fixed effects. Given that the key variable of interest is at the bank level, we cluster standard errors at bank level for the regressions. In this benchmark regression, $\beta_{d,q}$ captures the difference in credit growth between high- and low-deposit banks within quartile q during negative rate periods.

Table 2.2 presents the estimation results. Columns (1) and (2) report the benchmark estimates. After introducing the negative rate policy, high-deposit banks have significantly lower growth rates of household loans than low-deposit banks, consistent with the well-documented deposit channel effect. Interestingly, this pattern does not exist across all quartiles of capitalization. In the highest quartile of capitalization, high-deposit banks still stay ahead in the lending to households market and thus are not strongly affected by the negative rate policy. That is, the deposit channel effect depends on bank capitalization level.

In column (3), we add a type dummy $large$ taking value one for large banks, zero for small

Table 2.2: Negative Rate, Funding Structure, and Capitalization

Dependent Variable:	Growth Rate of Household Loans		
	(1)	(2)	(3)
$P^{neg}\#D_{14,i}$	-0.075***	-0.078***	-0.045*
	(0.016)	(0.015)	(0.026)
$P^{neg}\#\ Qcap_{14,i}=2$	-0.262*	-0.265*	0.561
	(0.150)	(0.151)	(0.512)
$P^{neg}\#\ Qcap_{14,i}=3$	0.020**	0.018**	0.154***
	(0.010)	(0.008)	(0.032)
$P^{neg}\#\ Qcap_{14,i}=4$	-0.032**	-0.034***	-0.033***
	(0.012)	(0.012)	(0.010)
$P^{neg}\#D_{14,i}\ \#\ Qcap_{14,i}=2$	0.315	0.318	-0.671
	(0.218)	(0.219)	(0.650)
$P^{neg}\#D_{14,i}\ \#\ Qcap_{14,i}=3$	0.015	0.018	-0.167***
	(0.018)	(0.017)	(0.042)
$P^{neg}\#D_{14,i}\ \#\ Qcap_{14,i}=4$	0.088***	0.091***	0.091***
	(0.024)	(0.023)	(0.026)
large=1 # $P^{neg}\#D_{14,i}$			-0.044*
			(0.026)
large=1 # $P^{neg}\#\ Qcap_{14,i}=2$			-0.285*
			(0.142)
large=1 # $P^{neg}\#\ Qcap_{14,i}=3$			-0.131***
			(0.029)
Year FE	yes	yes	yes
Bank FE	yes	yes	yes
Control		yes	yes
R-squared	0.142	0.142	0.153
Observations	880	880	880

Notes: standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01. Each column presents a coefficient from a separate regression of bank lending (noted in top row) on a time dummy variable, one for negative rate periods, zero for zero/positive rate periods, and its intersection with deposit ratios and quartile indicators for capitalization. Regressions are estimated with least squares on sample, including bank- and year- fixed effects. Robust standard errors (clustered by banks) included parenthetically. Monthly data from 25 banks, 2014–2017. Outliers removed (observations beyond 1/99 percentiles).

banks. All the above findings hold for small banks, but the only feature established for large banks is that high-deposit banks would cut lending during negative rate periods. The intuition is that large banks are mainly weakly-capitalized banks, staying in the lower quartile of distribution.

In Table 2.3, we provide additional estimation results to show better the aggregate differences between large and small banks responding to the negative rate policy. We split up the sample and separately re-run the regressions. In columns (1)-(2) and (4)-(5), we include one independent variable of interest (deposit ratio and capital buffer) at a time to compare which one matters for large and small banks' lending responses. The results show that high-deposit banks within the large bank group have significantly lower lending growth rates than their low-deposit counterparts during the negative rate period; this does not show up within the

Table 2.3: Large Banks vs Small Banks

Growth Rate of Household Loans	Large banks			Small banks		
	(1)	(2)	(3)	(4)	(5)	(6)
$P^{neg}\#D_{14,i}$	-0.135***		-0.073***	-0.143		-0.144
	(0.038)		(0.013)	(0.152)		(0.171)
P^{neg}#c.capbuffer14		0.003*			0.003	
		(0.002)			(0.004)	
P^{neg}#highCap_b=1			0.041*			-0.002
			(0.021)			(0.047)
P^{neg}#highCap_b=1#$D_{14,i}$			-0.123			
			(0.082)			
Year FE	yes	yes	yes	yes	yes	yes
Bank FE	yes	yes	yes	yes	yes	yes
Control	yes	yes	yes	yes	yes	yes
R-squared	0.122	0.091	0.133	0.142	0.138	0.151
Observations	421	421	421	459	459	459

Notes: standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01.
Each column presents a coefficient from a separate regression of bank lending (noted in top row) on a time dummy variable, one for negative rate periods, zero for zero/positive rate periods, and its intersection with dependent variable of interest (deposit ratio and capital buffer). In column (3) and (6) we add triple interaction between deposit ratio. Regressions estimated with least squares on sample, including bank- and year- fixed effects. Robust standard errors (clustered by banks) included parenthetically. Monthly data from 25 banks, 2014–2017. Outliers removed (observations beyond 1/99 percentiles).

small bank group. An increase in capital buffer won't cause any significant difference in lending responses across well-capitalized small banks. Still, it bears a positive effect for large banks to support their lending capacity. These findings are consistent with our results in Table 2.2.

In columns (3) and (6), we keep the triple intersection in regression (2.1) to explore the interaction between these two channels and replace the quartile indicator with a simplified dummy for capitalization level $highCap\_b$, which equals one for banks with capital buffer above the median level as of large bank group in 2014, zero otherwise. We find that, within both large and small bank groups, well-capitalized high-deposit banks do not behave differently from weakly-capitalized high-deposit ones, but the reason behind this is different. Most large banks do not even have high capital buffer; the difference between well and weakly capitalized within the group is not that significant. When we use the median level of capital buffer within large banks as a standard, most small banks will be defined as well-capitalized. Therefore the coefficient on the triple intersection is omitted for small banks.

(ii). The Role of Covered Bonds

As documented before, banks also differ significantly in covered bond reliance. Large banks can issue covered bonds, while small banks can not do. Within large bank group, the variation in covered bond reliance is also quite significant. We move on to test whether the reliance on covered bonds matter for banks' differential lending responses to the negative rate policy. The regression we run takes the form:

$$y_{i,t} = \beta \times P_t^{neg} \times CBond_{14,i} + \xi_i + \delta_t + \epsilon_{i,t} \tag{2.2}$$

We use $CBond_{14,i}$, the average share of covered bonds in total liability in 2014, as a measure of exposure to the introduction of negative policy rates. If banks more reliant on covered bonds have a larger credit growth, we would expect to find β in regression (2.2) to be significantly greater than zero. The regression results are in Table 2.4.

Table 2.4: Covered Bonds

	Growth Rate of Household Loans	Fund Shift
$P^{neg}\#CBond_{14,i}$	0.136***	0.334**
	(0.040)	(0.120)
Year FE	yes	yes
Bank FE	yes	yes
Control	yes	yes
R-squared	0.13	0.97
Observations	421	421

Notes: standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01. Each column presents a coefficient from a separate regression of bank lending (noted in top row) on a time dummy variable, one for negative rate periods, zero for zero/positive rate periods, and its intersection with the share of covered bond in total assets in 2014. Regressions estimated with least squares on sample, including bank- and year- fixed effects. Robust standard errors (clustered by banks) included parenthetically. Monthly data from large 9 banks, 2014–2017. Outliers removed (observations beyond 1/99 percentiles)

In column (1), we keep the lending to households as the dependent variable and only use a sub-sample of large banks since small banks did not have access to covered bonds in 2014. We find that banks more reliant on covered bonds have a higher growth rate of household loans entering the negative rate period. There could be two possible explanations. First, banks more reliant on covered bonds can lower the funding cost by shifting into cheaper deposits. Second, covered bond yields are set higher than deposit rates[4], allowing banks to continue lowering funding costs after introducing the negative rate policy. In column (2), we test the first mechanism by checking whether banks highly reliant on covered bonds switch out of debt issuing into deposit collection during the negative rate period. We use the difference between deposit ratio and debt ratio as the dependent variable. The results show that banks with more covered bonds implement such funding substitution more actively once the rate turns negative.

To summarize, the differentiated effects of the negative rate policy on lending to households across banks is related to their reliance on deposits and covered bonds, capitalization level,

[4]See Figure 2.11 for rates setting.

and the interactions between these features. We hope to provide a unified framework for these empirical findings.

2.4 The Model

This section presents our modeling framework. The policy rate is exogenous. All other prices and quantities are chosen optimally by the agents in the economy. The model features savers, borrowers and four types of banks. Savers consume final goods and invest on liquid assets, namely bonds, deposits and cash. Borrowers consume and finance their house purchases using mortgages. Banks collect deposits from savers and then lend to borrowers, and they operate under imperfect competition in the deposit and mortgage market.

2.4.1 Savers

The economy is populated by a saver family which consists of many individual savers. Each of them has his own investment choice on liquid assets. We further assume that a family leader will aggregate returns on all liquid assets and assign the amount of consumption evenly across members. Thus we focus on the behavior of the saver family in this subsection.

The goal of a saver family is to maximize the present discounted value of utility, given by:

$$max \quad E_0 \sum_{t=0} \beta_s^t [\ln C_{s,t} + j_h ln(h_{s,t}) + \frac{j_m}{1-\eta}(Liq_t)^{1-\eta} - \chi \frac{N_{s,t}^{1+\varphi}}{1+\varphi}],$$

where β_s is the discount factor, j_h and j_m governs the weight of utility from buying houses $h_{s,t}$ and holding liquid assets Liq_t relative to consumption, η is the intertemporal elasticity of substitution. $C_{s,t}$ is consumption goods, $N_{s,t}$ denotes labor supply, and liquidity assets are a combination of bond holdings B, deposit savings D and cash M according to a CES aggregator:

$$Liq(B,D,M) = \{\alpha_b B^{1-\frac{1}{\xi_m}} + [(D^{1-\frac{1}{\xi_c}} + M^{1-\frac{1}{\xi_c}})^{\frac{\xi_c}{\xi_c-1}}]^{1-\frac{1}{\xi_m}}\}^{\frac{\xi_m}{\xi_m-1}}, \tag{2.3}$$

ξ_m denotes the elasticity of substitution between bonds and deposits, ξ_c is the elasticity of substitution between cash and deposits. As data suggests, there is no substantial drop in the propensity to save in deposits even though the deposit rate is heading towards zero; hence, we assume $\xi_m > 1$ and $\xi_c > 1$, which implies that deposits, bonds and cash are not perfectly substitutes. Deposits and cash are of similar liquidity, and their liquidity measurements are normalized to 1. We assume $\alpha_b < 1$, which indicates the perceived liquidity of bonds is smaller relative to deposits and cash. [5]

[5] Please see the OECD data, the ratio of savings over total disposable income and the ratio of aggregate deposit to GDP have increased during the low rate period. For this reason, we keep bond holdings in the utility function. As the policy rate falls, savers switch out of bonds, and marginal utility of liquidity assets increase, motivating savers to put more money into deposits and cash and consume less. If there is no utility gain from bond holdings, savers would totally cut off bonds and substitute into deposits once the policy rate falls below deposit rate. As savers' deposit holdings go up, marginal utility from holding liquidity assets decrease, which motivates savers to

Savers receive returns on liquid asset holdings from the previous period and labor payment, and then use these resources to buy consumption goods, finance new investment on liquid assets and pay taxes. Their budget constraint is given by

$$C_{s,t} + D_t + M_t + B_t + q_{h,t} h_{s,t} + T_{s,t} = W_{s,t} N_{s,t} + R^d_{t-1} D_{t-1} + M_{t-1} + R_{t-1} B_{t-1} + q_{h,t} h_{s,t-1}. \quad (2.4)$$

The policy interest rate R_t is the return rate that applies to government bonds, R^d_t is the average deposit rate offered by banks and cash has no interest. $T_{s,t}$ is lump-sum tax paid to the government.

Maximizing the utility function subject to the above budget constraint, we derive the first-order conditions relative to $C_{s,t}$, B_t, D_t, M_t and $N_{s,t}$:[6]

$$\frac{1}{C_{s,t}} = \mu_{s,t}, \quad (2.5)$$

$$\mu_{s,t} = j_m (Liq_t)^{-\eta + \frac{1}{\xi_m}} \alpha_b B_t^{-\frac{1}{\xi_m}} + \beta E_t \mu_{s,t+1} R_{t+1}, \quad (2.6)$$

$$\mu_{s,t} = j_m (Liq)_t^{-\eta + \frac{1}{\xi_m}} D_t^{-\frac{1}{\xi_m}} + \beta E_t \mu_{s,t+1} R^d_{t+1}, \quad (2.7)$$

$$\mu_{s,t} = j_m (Liq)^{-\eta + \frac{1}{\xi_m}} M^{-\frac{1}{\xi_m}} + \beta E_t \mu_{s,t+1}. \quad (2.8)$$

$$\mu_{s,t} q_{h,t} = \frac{j_t}{h_{s,t}} + \beta^s E_t \mu_{s,t+1} q_{h,t+1} \quad (2.9)$$

$$\mu_{s,t} w_{s,t} = \chi N^{\varphi}_{s,t}, \quad (2.10)$$

where $\mu_{s,t}$ denotes savers' marginal utility of consumption. Equations (2.6) to (2.8) show savers' demand for bonds, deposits and cash. Equations (2.9) and (2.10) determine savers' housing demand and labor supply. These equations indicate that the saver family's liquid asset allocation depends on the relevant rates. The higher the return on one asset, the larger amount of investment into this. At positive rates, savers are more likely to put money into deposits and bonds than cash; when the policy rate is above the deposit rate, the saver family invests more in bonds rather than deposits. As the rate falls near/below zero, the spread between policy rate and deposit rate decreases or even reverses, leading savers to substitute bonds into deposits. If the deposit rate moves towards or below zero, cash then becomes a preferred option.

consume more rather than save.

[6] More details on how to solve the maximize problem are given in section 2.B of the Appendix.

2.4.2 Borrowers

We assume that borrowers' consumption is fully insured within the family against the risk in housing investment. A family leader aggregates the amount of housing and mortgages, and then divides the respective returns and consumption equally among household members.

Borrowers try to maximize their lifetime utility as follows:

$$max \quad E_0 \sum_{t=0} \beta_b^t [lnC_{b,t} + j_h ln(h_{b,t}) - \chi \frac{N_{b,t}^{1+\varphi}}{1+\varphi}],$$

Like savers, borrowers gain utility from consumption $C_{b,t}$ and housing services $h_{b,t}$. But borrowers have a lower discount factor than savers $\beta^b < \beta^s$, which implies that they are less patient than savers and therefore willing to borrow for current demand rather than saving.

In each period, borrowers take out loans from banks and earn some labor income to buy consumption goods and houses and pay back interest payments for the loans borrowed in the last period. However, an idiosyncratic shock affects the value of their houses, implying that some borrowers may choose to default on their previous loans. Following Bernanke et al. (1998) we assume that this shock is independently and identically distributed across borrower members within the family and follows the log-normal distribution:

$$ln(\omega) \sim N(-\frac{\sigma_\omega^2}{2}, \sigma_\omega^2) \ .$$

Once the shock value is realized, borrowers decide whether to default or not by comparing the housing value against mortgage payment. This leads to a threshold of this idiosyncratic shock denoted by:

$$\bar{\omega}_t = \frac{R_{t-1}^l L_{t-1}}{q_{h,t} h_{b,t-1}} \tag{2.11}$$

at which borrowers are indifferent between default and repaying. More specifically, when the idiosyncratic shock ω is smaller than $\bar{\omega}$, the aftershock housing value ($\omega q_{h,t} h_{b,t-1}$) is below mortgage payment and thus borrower will default. If borrowers default on their mortgages, banks will repossess their houses; if not, borrowers can keep their houses and sell them in order to repay their mortgages and consume. $1 - F(\bar{\omega})$ denotes the share of borrowers who repays, where

$$F(\bar{\omega}_t) = \int_0^{\bar{\omega}} f(\omega_t) d\omega,$$

and $1 - G(\bar{\omega})$ is the fraction of housing stock owned by repaying borrowers, where

$$G(\bar{\omega}_t) = \int_0^{\bar{\omega}} \omega_t f(\omega_t) d\omega.$$

We can rewrite the default threshold (2.11) as

$$\bar{\omega}_t = \frac{R^l_{t-1} x_{t-1}}{q_{h,t}/q_{h,t-1}}$$

where $x_t = \frac{L_t}{q_{h,t} h_{b,t}}$ denotes borrowers' leverage ratio. The higher the leverage level, the greater the default risk.

Summarizing, borrowers' budget constraint follows:

$$C_{b,t} + q_{h,t} h_{b,t} = L_t + W_{b,t} N_{b,t} + (1 - G(\bar{\omega}_t)) q_{h,t} h_{b,t-1} - (1 - F(\bar{\omega}_t)) R^l_{t-1} L_{t-1}. \tag{2.12}$$

Note that interest payment rate R^l_{t-1} is predetermined and depends on borrowers' leverage choice in the last period. Banks set mortgage rates taking the expected probability of default into consideration, which is associated with borrowers' leverage choice. For banks agreeing to lend out, borrowers need to incorporate banks' mortgage pricing for different possible leverage they can choose. We will describe banks' rate setting and derive the marginal impact on mortgage rate of one additional unit of leverage in subsection 2.4.4.

Maximizing borrowers' lifetime utility subject to budget constraint (2.12), and substituting $\bar{\omega}$ by (2.11), we obtain first-order conditions relative to $C_{b,t}, N_{b,t}, h_{b,t}, x_t$:

$$\frac{1}{C_{b,t}} = \mu_{b,t}, \tag{2.13}$$

$$\chi N^{\varphi}_{b,t} = \mu_{b,t} W_{b,t}, \tag{2.14}$$

$$\mu_{b,t}(1 - x_t) q_{h,t} = \frac{j_t}{h_{b,t}} + \beta^b E_t \mu_{b,t+1} [(1 - G(\bar{\omega}_{t+1})) q_{h,t+1} - (1 - F(\bar{\omega}_{t+1}) R^l_t x_t q_{h,t})], \tag{2.15}$$

$$\mu_{b,t} = \beta^b E_t \mu_{b,t+1} \{(1 - F(\bar{\omega}_{t+1}))[R^l_t + \frac{\partial R^l_t}{\partial x_t} x_t] + [-G'(\bar{\omega}_{t+1}) + F'(\bar{\omega}_{t+1}) R^l_t x_t] \frac{\partial \bar{\omega}_{t+1}}{\partial x_t}\}, \tag{2.16}$$

where $\mu_{b,t}$ denotes borrowers' marginal utility of consumption. Equation (2.14) decides borrowers' labor supply. Equation (2.15) shows borrowers' housing demand, saying that marginal utility of forgone consumption for buying one additional unit of housing with own money must equal marginal utility gain from housing service (the first term on the RHS), plus from consumption in the next period after selling the non-defaulted housing stock and paying interests. Equation (2.16) represents borrowers' leverage choice given banks' rate setting, which equalizes the marginal rate of substitution of consumption across the period to the actual cost of an additional unit of leverage.[7]

[7] The cost of one more unit of leverage involves marginal impact on repayment rate in case of no default (the first term on the RHS) and on $\bar{\omega}$ (the last two terms on the RHS).

2.4.3 Aggregation of Mortgages and Deposits

Saver and borrower family members establish their perception of which bank offers the most favorable depository and lending services, and they are reluctant to switch banks. This gives banks a degree of market power in rate setting, which we show in the next section. Here we describe the composition of family demand for mortgage and supply of deposits across banks.

Inspired by Allen and Gale (2004), we assume that members in the saver and borrower family are dispersed in a continuum of locations indexed by $i \in [0,1]$. Four types of banks offer differentiated depository and lending services at each location, including weakly- and well-capitalized banks with high and low deposit ratios, and we index them by Gh, Gl, Bh, Bl, respectively.[8] Borrower family's final mortgages demand is a CES aggregate of these banks' loans and similarly for deposits held by savers. As in previous work by Gerali et al. (2010), we assume that agents' demand for a particular bank's service depends on its rates. Local branches act atomistically; this is to say that when a branch sets its rates, it affects local mortgage granting and deposit collecting, but it does not affect the aggregate demand and rates. This helps us split savers' and borrowers' optimization problems into two parts: deciding the amount of consumption/housing service and savings/debt and choosing whichever bank to save in/borrow from. The first part has been addressed in the last two sections, and the second part is formed below.

Mortgage market: Aggregate mortgage is a CES aggregator of loans taken out by members at all locations:

$$L = [\int_0^1 L_i^{1-1/\rho_l} di]^{\rho_l/(\rho_l-1)}, \tag{2.17}$$

where ρ_l is the elasticity of substitution across locations. As standard, the aggregate mortgage rate R_t^l is defined as

$$R^l = [\int_0^1 (R_i^l)^{1-\rho_l} di]^{1/(1-\rho_l)}. \tag{2.18}$$

Minimizing total mortgage repayment over all locations $\int_0^1 R_i^l L_i$ subject to (2.18), we obtain mortgage demand function at location i:

$$L_i = (\frac{R_i^l}{R^l})^{-\rho_l} L. \tag{2.19}$$

At location i, a mortgage is a CES composite of differentiated loans supplied by weakly- and well-capitalized banks with high and low deposit ratios. Thus the local mortgage is formed

[8] Gh, Gl, Bh, Bl refer to weakly-capitalized high-deposit banks, weakly-capitalized low-deposit banks, well-capitalized high-deposit banks, and well-capitalized low-deposit banks.

according to the following function:

$$L_i = [\sum_{j=1}^{4} \alpha_{l,j}^{\frac{1}{\xi_l}} L_{i,j}^{1-\frac{1}{\xi_l}}]^{\frac{\xi_l}{\xi_l-1}}, \; j = \{Gh, Gl, Bh, Bl\}, \tag{2.20}$$

where ξ_l is the elasticity of substitution across banks. The aggregator weights satisfy $\sum_{j=1}^{4} \alpha_{l,j} = 1$ for all banks j. We allow these weights $\alpha_{l,j}$ to differ across banks, which match banks' mortgage market share at the steady state, and this is the first heterogeneity we introduce to differentiate banks in terms of size.

The average mortgage rate at location i is defined as

$$R_i^l = [\sum_{j=1}^{4} \alpha_{l,j} (R_{i,j}^l)^{1-\xi_l}]^{\frac{1}{1-\xi_l}}.$$

Again, minimizing mortgage repayment to each bank at location i subject to local CES mortgage constraint, yields demand for mortgages granted by bank j at location i as:

$$L_{i,j} = \alpha_{l,j} (\frac{R_{i,j}^l}{R_i^l})^{-\xi_l} L_i,$$

plugging (2.19) in, we can write it as

$$L_{i,j} = \alpha_{l,j} (\frac{R_{i,j}^l}{R_i^l})^{-\xi_l} (\frac{R_i^l}{R^l})^{-\rho_l} L, \quad j = \{Gh, Gl, Bh, Bl\}. \tag{2.21}$$

With $\xi_l > 1$, we see that the higher the mortgage rate $R_{i,j}^l$, the lower is mortgage demand $L_{i,j}$.

Deposit market: This nested CES setting is also applicable to the deposit market. Aggregate deposit supply and rate are respectively given by:

$$D = [\int_0^1 D_i^{1-1/\rho_d} di]^{\rho_d/(\rho_d-1)}, \quad R^d = [\int_0^1 (R_i^d)^{1-\rho_d} di]^{1/(1-\rho_d)}.$$

Maximizing the revenue of deposits over all locations $\int_0^1 R_i^d D_i$ subject to the above CES supply constraint gives the supply of deposits at location i as:

$$D_i = (\frac{R_i^d}{R^d})^{-\rho_d} D. \tag{2.22}$$

At each location, deposit supply is a composite of deposits supplied to local branches of weakly- and well-capitalized banks with high and low deposit ratios, taking the form of

$$D_i = [\sum_{j=1}^{4} \alpha_{d,j}^{\frac{1}{\xi_d}} D_{i,j}^{1-\frac{1}{\xi_d}}]^{\frac{\xi_d}{\xi_d-1}}, \ j = \{Gh, Gl, Bh, Bl\}. \tag{2.23}$$

The local deposit rate is denoted by

$$R_i^d = [\sum_{j=1}^{4} \alpha_{d,j} (R_{i,j}^d)^{1-\xi_d}]^{\frac{1}{1-\xi_d}}. \tag{2.24}$$

Maximizing returns on deposits from local banks subject to (2.23) generates the deposit supply to bank j, and then by plugging in (2.22) we obtain

$$D_{i,j} = \alpha_{d,j} (\frac{R_{i,j}^d}{R_i^d})^{-\xi_d} (\frac{R_i^d}{R^d})^{-\rho_d} D, \quad j = \{Gh, Gl, Bh, Bl\}. \tag{2.25}$$

With $\xi_d < -1$, the higher the deposit rate $R_{i,j}^d$, the larger is deposit supply $D_{i,j}$.

We assume that branches of each type of bank at different locations will behave symmetrically: $L_{i,j} = L_j$ and $D_{i,j} = D_j$. We can drop the index i going forward to focus on bank behavior of each type.

2.4.4 Banks

Banks invest in safe assets S_t and grant mortgage loans L_t to impatient households, by raising deposits D_t and issuing covered bonds B_t^{cv}. N_t is the net worth at the beginning of period t. Banks try to maximize the present value of accumulated net worth,

$$\begin{aligned} V(N_{j,t}) = max \quad & E_t \sum_{i=0} \beta^s \frac{\mu_{s,t+1+i}}{\mu_{s,t}} (1-\upsilon) \upsilon^i N_{j,t+1+i} \\ & = max \quad E_t \beta^s \frac{\mu_{s,t+1}}{\mu_{s,t}} [(1-\upsilon) N_{j,t+1} + \upsilon V(N_{j,t+1})], \end{aligned}$$

subject to the balance sheet constraint,

$$L_{j,t} + S_{j,t} = D_{j,t} + N_{j,t} + B_{j,t}^{cv}, \quad j = \{Gh, Gl, Bh, Bl\}. \tag{2.26}$$

where υ is the probability banks can live until the next period. We assume that banks are owned by savers, and thus they share the same discount factor.

The evolution of an individual bank's net worth depends on the returns from these investments net of funding costs, which can be written as

$$N_{j,t+1} = R_{j,t+1}^{l,b} L_{j,t} + R_t S_{j,t} - R_{j,t}^{cv} B_{j,t}^{cv} - R_{j,t}^d D_{j,t} - f(B_{j,t}^{cv}). \tag{2.27}$$

$R^{l,b}_{j,t+1}$ measures the return on loans in the next period. Safe assets receive a riskless interest rate R. R^{cv}_j and R^d_j are the costs on taking money from covered bond investors and depositors. $f(B^{cv}_{j,t})$ is an adjustment cost banks pay for deviating the target ratio of loan to covered bonds (parameterized by a coeffcient κ_j and proportional to covered bond holdings), and it follows

$$f() = \frac{\kappa_j}{2}(\frac{L_{j,t}}{B^{cv}_{j,t}} - \theta_j)^2 B^{cv}_{j,t}. \tag{2.28}$$

The more covered bonds a bank issues, the higher cost it pays to attract investors. Here comes our second heterogeneity in the banking sector – heterogeneity of covered bond cost, which originates from the assumption that some banks specialize in issuing covered bonds and thus set a lower target ratio of loans to covered bonds. We assume $\kappa_{Bh} > \kappa_{Bl} > 0$ and $\theta_{Bl} > \theta_{Bh} > 0$, such that covered bonds are less costly for low-deposit banks. This heterogeneity helps us to differentiate between high- and low-deposit banks.

The expected return on mortgages is

$$E_t R^{l,b}_{j,t+1} L_{j,t} \equiv E_t[(\frac{L_{j,t}}{L_t})\int_0^{\bar{\omega}_{t+1}} (1-\mu)\omega_{t+1} q_{h,t+1} h_{b,t} f(\omega_{t+1}) d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^l_{j,t} L_{j,t} f(\omega_{t+1}) d\omega],$$

which comprises repayments from non-defaulting borrowers (the second term on the RHS), plus the proceeds from seizing the housing stock of defaulting borrowers, net of monitoring cost as a proportion μ of the housing value (the first term on the RHS). Since the borrower family holds a composite mortgage, in case of default, each bank seizes the fraction $\frac{L_j}{L}$ of the defaulted housing stock.[9] Using $\bar{\omega}_{t+1} q_{h,t+1} h_{b,t} = R^l_t L_t$ to replace the value of houses, we can rewrite the gross return as

$$\begin{aligned} E_t R^{l,b}_{j,t+1} L_{j,t} &= E_t[(\frac{L_{j,t}}{L_t})\int_0^{\bar{\omega}_{t+1}} (1-\mu)\omega_{t+1} \frac{R^l_t L_t}{\bar{\omega}_{t+1}} f(\omega_{t+1}) d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^l_{j,t} L_{j,t} f(\omega_{t+1}) d\omega] \\ &= E_t[\int_0^{\bar{\omega}_{t+1}} (1-\mu)\omega_{t+1} \frac{R^l_t}{\bar{\omega}_{t+1}} f(\omega_{t+1}) d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^l_{j,t} f(\omega_{t+1}) d\omega] L_{j,t}, \end{aligned}$$

and thus the expected return rate should be

$$E_t R^{l,b}_{j,t+1} = E_t[\int_0^{\bar{\omega}_{t+1}} (1-\mu)\omega_{t+1} \frac{R^l_t}{\bar{\omega}_{t+1}} f(\omega_{t+1}) d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^l_{j,t} f(\omega_{t+1}) d\omega]$$

Banks set a fraction of mortgages as cover pool assets (collateral) and commit that these bondholders have priority claim on these assets to issue covered bonds. In practice, if the bank cannot meet its payment obligations to investors, there is a risk that it will be placed in bankruptcy. In such a situation, the assets in the cover pool are kept together and separate from the other assets and liabilities of the bankruptcy estate to pay interest as contractually agreed. For simplicity, we assume that the value of the assets in the cover pool pays off the

[9] The housing stock seized by each type of bank is dependent on the bank's share in the mortgage market.

bondholders, but they need to spend some cost μ^{cv} to exert the right, and banks have to satisfy the participation constraint of them:

$$E_t[(\frac{B^{cv}_{j,t}}{L_t})\int_0^{\bar{\omega}_{t+1}}(1-\mu^{cv})(1-\mu)\omega_{t+1}\frac{R^l_t L_t}{\bar{\omega}_{t+1}}f(\omega_{t+1})d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^{cv}_{j,t}B^{cv}_{j,t}f(\omega_{t+1})d\omega] \geq R^d_t B^{cv}_{j,t}.$$

The overall expected return to covered bond holdings must be at or above the deposit rate since these investors have the option to invest in risk-free deposits.

Macroprudential Regulations: Banks are subject to two constraints, capital constraint and liquidity constraint, as follows

$$\varphi^c_j L_{j,t} \leq N_{j,t+1}, \tag{2.29}$$

$$\varphi^l_j (D_{j,t} + B^{cv}_{j,t}) \leq S_{j,t}. \tag{2.30}$$

These constraints show that the value of the bank should cover risk-weighted assets, and a fraction of total liability should be invested in safe assets to maintain sufficient liquidity.[10]

Finally, we can write banks' optimal problem as

$$\begin{aligned}
\max_{R^L_{j,t}, R^d_{j,t}, B^{cv}_{j,t}} \quad & E_t\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}\{(1-v)[R^{l,b}_{j,t+1}L_{j,t} + R_t S_{j,t} - R^{cv}_{j,t}B^{cv}_{j,t} - R^d_{j,t}D_{j,t} - f()] + vV(N_{j,t+1})\} \\
& + \lambda^b_{j,t}\{D_{j,t} + B^{cv}_{j,t} + N_{j,t} - L_{j,t} - S_{j,t}\} \\
& + \lambda^c_{j,t}\{N_{j,t+1} - \varphi^c_j L_{j,t}\} + \lambda^l_{j,t}\{S_{j,t} - \varphi^l_j(D_{j,t} + B^{cv}_{j,t})\} \\
& + \lambda^{cv}_{j,t}\{\int_0^{\bar{\omega}_{t+1}}(1-\mu^{cv})(1-\mu)\omega_{t+1}\frac{R^l_t}{\bar{\omega}_{t+1}}f(\omega_{t+1})d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^{cv}_{j,t}f(\omega_{t+1})d\omega - R^d_t\} \\
& + \lambda^m_{j,t}\{L_{j,t} - \alpha_{l,j}(\frac{R^l_{i,j}}{R^l_i})^{-\xi_l}(\frac{R^l_i}{R^l})^{-\rho_l}L_t\} + \lambda^d_{j,t}\{D_{j,t} - \alpha_{l,j}(\frac{R^d_{i,j}}{R^d_i})^{-\xi_d}(\frac{R^d_i}{R^d})^{-\rho_d}D_t\}, \quad j = \{Gh, Gl, Bh, Bl\}.
\end{aligned}$$

where $\lambda^b_{j,t}$, $\lambda^c_{j,t}$, $\lambda^l_{j,t}$, $\lambda^{cv}_{j,t}$, $\lambda^m_{j,t}$ and $\lambda^d_{j,t}$ are the Lagrangian multipliers on balance sheet constraint, capital constraint, liquidity constraint, participation constraint of covered bonds holders, mortgage demand, and deposit supply functions, respectively. Notice that the optimization problem is formed similarly for weakly and well-capitalized banks with only differences in the required capital ratio, which is lower for well-capitalized banks.

[10] After the financial crisis, these requirements have been tightened significantly based on the revised Basel III standards, which means that the required ratios φ^c_j and φ^l_j increased. During the Covid-19 pandemic, the countercyclical capital buffer requirement was removed, implying that φ^c_j decreased in 2020.

The first-order conditions with respect to $R^L_{j,t}$, $R^d_{j,t}$ and $B^{cv}_{j,t}$ are

$$R^l_{j,t} = E_t \underbrace{\frac{1}{1-\frac{1}{\epsilon^l_j}}}_{\text{markup}} \frac{1}{1-F(\bar{\omega}_{t+1})}[R_t - (1-\mu)\frac{G(\bar{\omega}_{t+1})}{\bar{\omega}_{t+1}}R^l_t + \kappa_j(\frac{L_{j,t}}{B^{cv}_{j,t}} - \theta_j)$$

$$+ \underbrace{\frac{\varphi^c_j \lambda^c_{j,t} + \lambda^l_{j,t}}{E_t \beta^s \frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'_b(N_{t+1})) + \lambda^c_{j,t}}}_{\text{regulation cost}}], \quad (2.31)$$

$$R^d_{j,t} = \underbrace{\frac{1}{1-\frac{1}{\epsilon^d_j}}}_{\text{markdown}} [R_t + \underbrace{\frac{(1-\varphi^l)\lambda^l_{j,t}}{E_t \beta^s \frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'_b(N_{t+1})) + \lambda^c_{j,t}}}_{\text{regulation cost}}], \quad (2.32)$$

$$\int_0^{\bar{\omega}_{t+1}} (1-\mu^{cv})(1-\mu)\omega_{t+1}\frac{R^l_t}{\bar{\omega}_{t+1}} f(\omega_{t+1})d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^{cv}_{j,t} f(\omega_{t+1})d\omega + \frac{\kappa_j}{2}(\frac{L_{j,t}}{B^{cv}_{j,t}} - \theta_j)^2 B^{cv}_{j,t}$$

$$-\kappa_j(\frac{L_{j,t}}{B^{cv}_{j,t}} - \theta_j)\frac{L_{j,t}}{B^{cv}_{j,t}} = R_t + \frac{(1-\varphi^l_{j,t})\lambda^l_{j,t}}{E_t \beta^s \frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'_b(N_{t+1})) + \lambda^c_{j,t}}, \quad (2.33)$$

where ϵ^l_j and ϵ^d_j denotes the semi-elasticity of demand for mortgages and deposits respectively. Following Atkeson and Burstein (2008), these are functions of bank's market share:

$$\epsilon^l_j = \xi_l(1-s^l_j) + \rho_l s^l_j,$$

$$\epsilon^d_j = \xi_d(1-s^d_j) + \rho_d s^d_j,$$

where s^l_j and s^d_j denotes the share of bank j in the mortgage and deposit market, which is the ratio of mortgages/deposits granted by it relative to the total mortgages/deposits granted by all banks. With $\xi_l > \rho_l$ the elasticity ϵ^l_j is a decreasing function of bank's market share and thus markup is an increasing function of that. With $\xi_d < \rho_d$ the elasticity ϵ^d_j is an increasing function of bank's market share and thus markdown is a decreasing function of that. Accordingly, banks with bigger market share have larger market power, and are able to set a relatively higher markup and a lower markdown.

The envelop condition is

$$V'_b(N_{j,t}) = E_t \beta^s \frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'_b(N_{j,t+1}))R_t + \lambda^c_{j,t}R_t + \lambda^l_{j,t}, \quad (2.34)$$

and the Kuhn-Tucker conditions are

$$\lambda^c_{j,t}(N_{j,t+1} - \varphi^c_j L_{j,t}) = 0, \quad (2.35)$$

$$\lambda^l_{j,t}(S_{j,t} - \varphi^l_j D_{j,t} - \varphi^l_j B^{cv}_{j,t}) = 0, \tag{2.36}$$

$$\lambda^c_{j,t} \geq 0, \tag{2.37}$$

$$\lambda^l_{j,t} \geq 0. \tag{2.38}$$

Banks' optimal rate settings are given by equations (2.31) and (2.32), indicating that banks set a higher mortgage rate when the expected default rate increases or borrowers choose higher leverage. As mentioned before, borrowers embed this pricing rule into their optimization problems. The derivative of the mortgage rate with respect to the leverage will show us marginal effects of one additional unit of leverage:

$$\frac{\partial R^l_{j,t}}{\partial x_t} = \frac{1}{1-\frac{1}{\epsilon^l_j}}\{[\frac{1}{1-F(\bar{\omega}_{t+1})}]'\frac{\partial\bar{\omega}_{t+1}}{\partial x_t}[R_t - (1-\mu)\frac{G(\bar{\omega}_{t+1})}{\bar{\omega}_{t+1}}R^l_t + \frac{\varphi^c_j\lambda^c_{j,t} + \lambda^l_{j,t}}{E_t\beta^s\frac{\mu_{s,t+1}}{\mu_{s,t}}(1 - \upsilon + \upsilon V'_b(N_{t+1})) + \lambda^c_{j,t}}]$$
$$+ \frac{1}{1-F(\bar{\omega}_{t+1})}[-(1-\mu)(\frac{G(\bar{\omega}_{t+1})}{\bar{\omega}_{t+1}})'R^l_t\frac{\partial\bar{\omega}_{t+1}}{\partial x_t} - (1-\mu)\frac{G(\bar{\omega}_{t+1})}{\bar{\omega}_{t+1}}\frac{\partial R^l_t}{\partial x_t}]\}.$$

where the derivative of the default threshold with respect to leverage should be

$$\frac{\partial\bar{\omega}_{t+1}}{\partial x_t} = \frac{R^l_t}{q_{h,t+1}/q_{h,t}} + \frac{x_t}{q_{h,t+1}/q_{h,t}}\frac{\partial R^l_t}{\partial x_t}.$$

Plugging in $R^l = [\int_0^1 (R^l_i)^{1-\rho_l} di]^{1/(1-\rho_l)}$ and $R^l_i = [\sum_{j=1}^4 \alpha_{l,j}(R^l_{i,j})^{1-\xi_l}]^{\frac{1}{1-\xi_l}}$, we can rewrite the derivative of the mortgage rate with respect to leverage as following[11]

$$\frac{\partial R^l}{\partial x_t} = \sum_{j=1}^4 \frac{L_j}{L}\frac{\partial R^l_{i,j}}{\partial x_t},$$

which is an average of banks' marginal rate weighted by their market share.

2.4.5 Firms

Firms hire labor from households to produce final goods as $Y_{c,t} = A_t(N_{s,t} + N_{b,t})$. The first order conditions for the labor provided by patient and impatient households are

$$w_{b,t} = w_{s,t} = \frac{Y_{c,t}}{N_t},$$

where $N_t = N_{s,t} + N_{b,t}$ denotes total labor supply.

[11] Details can be found in the Section of Mathematical Derivations in the Appendix.

2.4.6 Markets Clearing

Equilibrium in the goods market requires that production of the final good equals aggregate demand:

$$Y_{c,t} = C_{s,t} + C_{b,t}. \tag{2.39}$$

For simplicity, we assume there is a fixed housing supply each period and normalize it to 1

$$h_{s,t} + h_{b,t} = 1, \tag{2.40}$$

which implies that the competition between savers and borrowers for housing determines its price.

Government supplies bonds elastically to savers and banks, and pay back with lump-sum tax.

$$B_t + S_t + T_{s,t} = R_t(B_{t-1} + S_{t-1}). \tag{2.41}$$

The policy rate is exogenous and taken as given by all the agents of the economy.

$$R_t = R_0 * exp(e_{r,t}). \tag{2.42}$$

The total output is defined as

$$Y_t = C_{s,t} + C_{b,t} + \mu G(\omega_{t+1}) q_{h,t} h_{b,t-1}. \tag{2.43}$$

Equilibrium: Given the policy rate exogenously chosen by the central bank, an equilibrium is a set of prices (mortgage rates, deposits rates and house prices) and quantities (consumption, housing services, cash, deposits, bonds, mortgages and covered bonds) such that savers, borrowers and banks optimize, and all markets clear.

2.5 Parameters

We calibrate our model at the quarterly frequency using bank-level data and standard parameter values in the literature. All parameter values are specified in Table 2.5 and are calibrated to match the average value of relevant variables in 2013, which presents the state before the introduction of the negative rate policy. We will show the targeted moments and summarize the calibration.

Targets: We use the balance sheet data to pin down two measurable sources of heterogeneity across banks: bank size and funding structure. We split the banks into four groups: weakly- and well-capitalized banks with low and high deposit ratios, and then calculate the market shares and balance sheet ratios for each of them. The average market shares in the mortgage market are around 87.5%, 2.5%, 8%, and 2%. The ratios of deposit over total assets are 42.5%, 78.8%, 30.3%, and 82.1%. The ratios of covered bonds over total assets are 22.5%, 3.8%, 32.1%, and 0.1%. The share of lending to households in total assets are 36.5%, 30.8%, 36.4%, and 38.7%.

We use the hand-collect data of the required risk-weighted capital ratios to construct capital requirements. Here we focus on the difference between weakly- and well-capitalized bank groups since each group's differences are relatively small. The average value of the required risk-weighted capital ratio for weakly- and well-capitalized banks in 2014 were 19.6% and 11.25%, respectively. These requirements were strengthened to 24.5% and 13.65% in 2019.

We also take some aggregate data from the Swedish Statistics Database. We calculate the share of the mortgage in GDP for measuring the aggregate loan size, which is 85.3%. The ratio of government debt to GDP is around 45%. The average annual lending rate to households of all new and renegotiated agreements is 3.6%, the average yearly deposit rate by households of all accounts is 0.4%, the average yearly covered bond yield is 1.3%, and the policy rate is around 0.75%.

Table 2.5: Model Parameters

Parameter	Value	Description	Targets
β_s	0.97	discount factor for savers	deposit rate 0.4%
β_b	0.96	discount factor for borrowers	mortgage rate 3.6%
χ	3	weight on labor supply in savers' utility	
φ	1	the inverse of Frisch elasticity	
j_m	0.04	weight on liquidity in savers' utility	
η	1	utility curvature in liquid assets	
ξ_m, ξ_c	10, 5	elasticity of substitution between bonds, cash and deposits	
α_b	0.9	liquidity quality of bonds	bond-to-deposit ratio 0.38
j_h	0.075	weight on housing in borrowers' utility	Iacoviello and Neri (2010)
φ_B^c	0.2	capital constraint for weakly-capitalized banks	required capital ratio 0.196
φ_S^c	0.1	capital constraint for well-capitalized banks	required capital ratio 0.11
φ^l	0.15	liquidity constraint	average liquid asset ratio
ρ_d	-10	elasticity of substitution of deposits across locations	
ρ_l	10	elasticity of substitution of mortgages across locations	
ξ_d	-540	elasticity of substitution of deposits across banks	markdown 0.996
ξ_l	340	elasticity of substitution of mortgages across banks	markup 1.018
$\alpha_{l,Bh}, \alpha_{l,Bl}$	0.04, 0.92	mortgage aggregator weight	market share Gh Gl Bh Bl
$\alpha_{l,Gh}, \alpha_{l,Gl}$	0.002, 0.028	mortgage aggregator weight	
$\alpha_{d,Bh}, \alpha_{d,Bl}$	0.26, 0.7	deposit aggregator weight	
$\alpha_{d,Gh}, \alpha_{d,Gl}$	0.015, 0.025	deposit aggregator weight	
κ_h, κ_l	0.05	adjustment cost of covered bond for high and low-deposit banks	
θ_h	8	ratio of loan to covered bond for high-deposit banks	covered bond ratio 0.16
θ_l	3	ratio of loan to covered bond for low-deposit banks	covered bond ratio 0.3
μ	0.12	liquidation cost for banks	Forlati and Lambertini (2011)
σ_ω	0.12	std of idiosyncratic shock	Forlati and Lambertini (2011)
μ^{cv}	0.3	liquidation cost for covered bond holders	covered bond yield 1.3%

Calibrated parameters: The discount factors of savers and borrowers are set to be 0.97 and 0.96, respectively, implying an annual saving and borrowing interest rate around 0.4% and 4%. We set $\varphi = 2$ for a Frisch elasticity of labor supply of 0.5. To match the initial share of government debt and total household loans in GDP, we set the measurement of bonds' relative liquidity quality α_b to be 0.9, the weight on liquid assets in the savers' utility function to be $j_m = 0.04$, and borrower's housing preference to be $j_h = 0.075$. The curvature parameter of savers' utility with respect to liquid assets η affects the pass-through of changes in the policy rate to deposit rates, and we set it equal to 1, implying log utility from liquidity.

The mortgage and deposit aggregator weights and covered bond adjustment cost related parameters are jointly calibrated to be in line with each type of banks' market share size and reliance on the covered bonds. We set the across-location and across-bank elasticity of substitution to match a steady-state markup and markdown of 2% and 0.4%, which is also in line with Cuciniello and Signoretti (2014). μ is set to 0.12 as in Forlati and Lambertini (2011) so that the monitoring cost after default is 12 percent of housing value. μ^{cv} is set to 0.2 to match the average covered bond yields 1.3%. The standard deviation of idiosyncratic shock σ_ω is at 0.16 to reach an average default rate of around 1%.

2.6 Model Evaluation

In this section, we first characterize the long-run consequences of policy rate changes for the economy by showing steady states for different policy rate levels. Then, we try to disentangle how the differentiated effects of a rate cut across banks are related to heterogeneity in capitalization and deposit reliance.

2.6.1 Steady-state Analysis

This subsection analyzes the aggregate effects of a falling policy rate across steady-states. We adjust the level of the policy rate R to match the actual changes over the period 2013-2018 and then present the steady-state values of mortgages, deposits, the relevant rates, and other macro variables below in Figure 2.5. For all plots, the horizontal axis shows the time, and the vertical axis measures the steady-state levels of these variables.

In panel (a), banks lower their lending rates following the rate cuts. Cheaper mortgages drive up borrowers' housing demand, leading to an increase in mortgage lending. Meanwhile, savers shift away from bonds into deposits since deposit savings become better remunerated than bonds. This generates an increase in bank deposits, which forms the basis for banks to lend out more as the rate falls. Both weakly and well-capitalized banks take more deposits and then issue more mortgages. Borrowers get more credit to finance their consumption and housing demand. Consequently, house prices go up. However, as the rate goes deeper into negative territory, savers' bond holdings will become increasingly scarce, and cash may dominate liquid savings as deposit rates have been kept low. This tends to dampen the increases in deposit savings. Hence, banks will lose support from increased funding and cannot sustain mortgage expansion. House price appreciation will gradually slow down.

Heterogeneity leads some banks to be more affected by the rate cuts than others, as shown in panel (b). First, weakly-capitalized banks will expand mortgage supply at a slower pace than well-capitalized ones. Intuitively, banks are reluctant to pass the negative rate onto depositors because of cash competition, thereby decreasing their net interest margins. Moreover, banks have to hold safe assets under liquidity requirements; when the policy rate turns negative, banks make a loss from holding safe assets. All these would translate into a deterioration of banks' net worth, triggering capital constraints to become binding. As weakly-capitalized banks have low capital buffers, the constraints on them bind first. From that point on, the value of net worth will cap their lending capacity. As bank profitability further goes down, weakly-capitalized banks have to reduce mortgage supply and deposit collection. Therefore, a fraction of mortgages shifts from weakly- to well-capitalized banks, raising the latter's market share.

Second, high-deposit banks will lose their competitive advantage once the rate turns negative. High-deposit banks are usually perceived to offer better deposit services by savers and need to pay higher costs to attract covered bond investors. Given that, they use less costly covered bonds and capital to finance their lending and thus entail lower funding costs than low-deposit banks. This cost advantage enables high-deposit banks to charge a lower lending rate and increase loan supply faster during positive rate periods. However, this competitive advantage will disappear as the rate falls near/below zero. Since negative rates can not be passed onto depositors and deposit rates have been kept low, high-deposit banks will run out of room to reduce the interest expenses and face a reduced net interest margin. In contrast, low-deposit banks still have space to lower funding costs; they can either continue to lower the covered bond yields or shift away from covered bonds into cheap deposit funding. Therefore, the reduced margin would eat into high-deposit banks' cost advantage entering a negative rate period.

Notably, losing this competitive advantage makes a difference within the weakly-capitalized group but not within the well-capitalized group. In the weakly-capitalized group, the decreased net interest margin leads to high-deposit banks' net worth growing at a reduced rate. Consequently, their capital constraints bind sooner and more intensively. Afterward, high-deposit banks' lending capacity is capped, whereas low-deposit banks can continue expanding mortgage supply in response to further rate reductions. In the well-capitalized group, banks have sufficient capital buffers to offset any losses from the reduced interest margin. Therefore capital constraints would not quickly bind. High-deposit banks can still take advantage of lower funding costs and charge lower lending rates to stay ahead in the mortgage market.

Overall, our model can rationalize the empirical findings presented in Section 3. High-deposit banks expand their mortgage supply more quickly relative to low-deposit banks during normal rate periods; once the policy rate turns negative, this pattern remains unchanged for well-capitalized banks but is reversed for weakly-capitalized banks.

Figure 2.6 provides a visualization of these empirical findings. We split our data sample into four groups based on banks' capital buffer levels and deposit ratios, and show the index level of average mortgage volume for each group. To do so, we detrend mortgage data by dividing it with GDP and normalize the data in 2013 to 1. It is clear that our simulated result matches the disparity but underestimates the increase in mortgage supply by each bank group relative to the actual data. In the data, the total deposits continued to grow rapidly after 2015; in our model, banks can only rely on savers switching out of bonds into deposits to lend out more. Thus we have difficulty matching the scale.

2.6.2 Liquidity Saving Preference

The OECD data has shown that people's saving demand has gradually increased as the rate went down in Sweden.[12] The rise of saving preference could generate an increase in the total size of bank funding, influencing the transmission of negative policy rates across banks. To show the effects of a rising saving preference, we set savers' liquidity saving preference j_m to be larger and the elasticity of substitution between deposits and cash ξ_c lower than before, and replot the steady-state levels for the same change in the policy rate R in Figure 2.7.

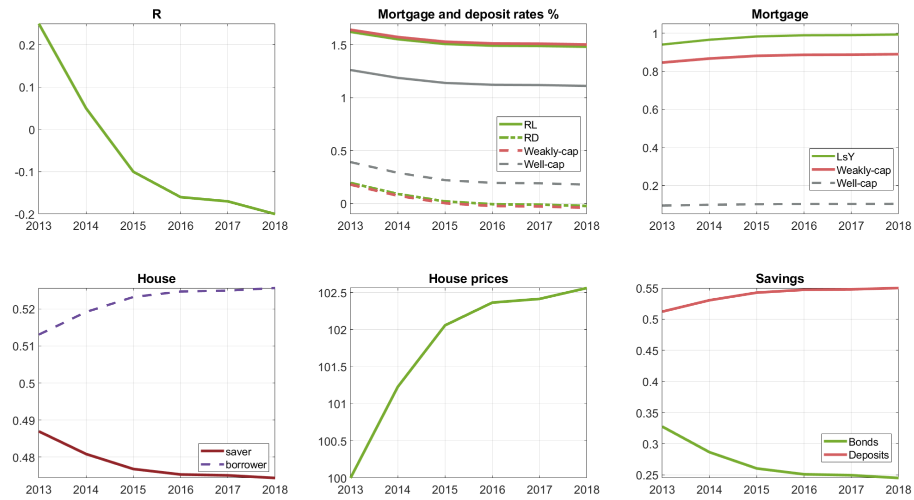
Relative to the baseline result, the total mortgage expansion and house price appreciation go up by 4% and 2% respectively, and the lending disparity between high- and low-deposit banks becomes even more prominent. Intuitively, when savers have a stronger liquidity saving demand and become more reluctant to switch between deposits and cash, banks can collect enough deposits to satisfy borrowing demand and have some extra funding saved into safe assets as excess reserves. As the rate falls, borrowing demand increases. Banks can transfer these excess reserves into loan supply, resulting in a much larger mortgage expansion. Note that the effect of an increased deposit supply on lending is heterogeneous across banks. Within the well-capitalized group, high-deposit banks can make use of deposit expansion to expand their mortgage lending even faster. However, within the weakly-capitalized group, high-deposit banks still face binding capital constraints and can not vastly increase mortgage supply. In the end, this mortgage expansion will slow down. Because of cash competition, banks will lose funding and lack excess reserves to achieve this asset reallocation.

In this case, aggregate mortgage expansion and different lending responses of four types of banks to rate cuts map closely to the evolution of actual data. It is worth mentioning that strong liquidity preference powers some banks to set deposit rate below zero, especially these weakly-capitalized banks. As they account for a large amount of market share, the average deposit rate is also pushed below zero, which may not be able to track the real data well.[13]

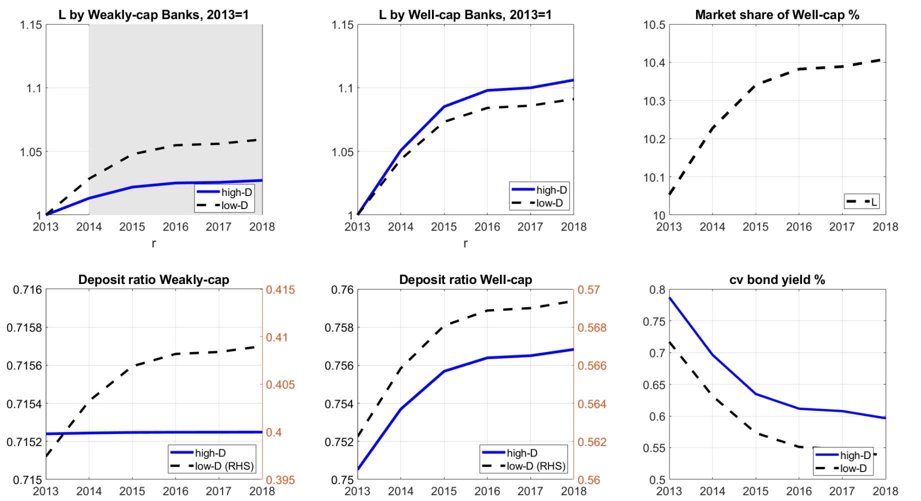
[12]The ratio of household savings over total disposable income has increased by 10% after 2010. Check data from the OECD.

[13]The Riskbank published the average lending and deposit rates, see Figure 2.11 in the Appendix

Figure 2.5: SS Analysis - Policy Rate Falls



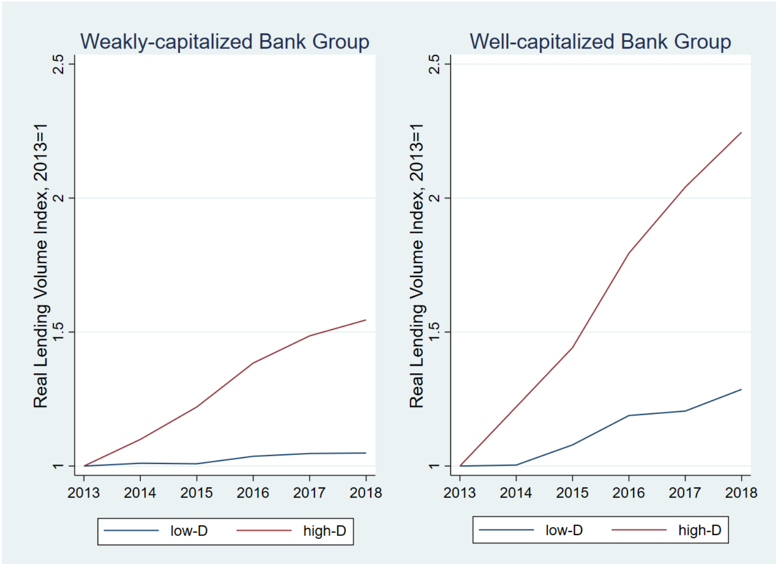
(a) Aggregate Effects on the Economy



(b) Differences across Banks

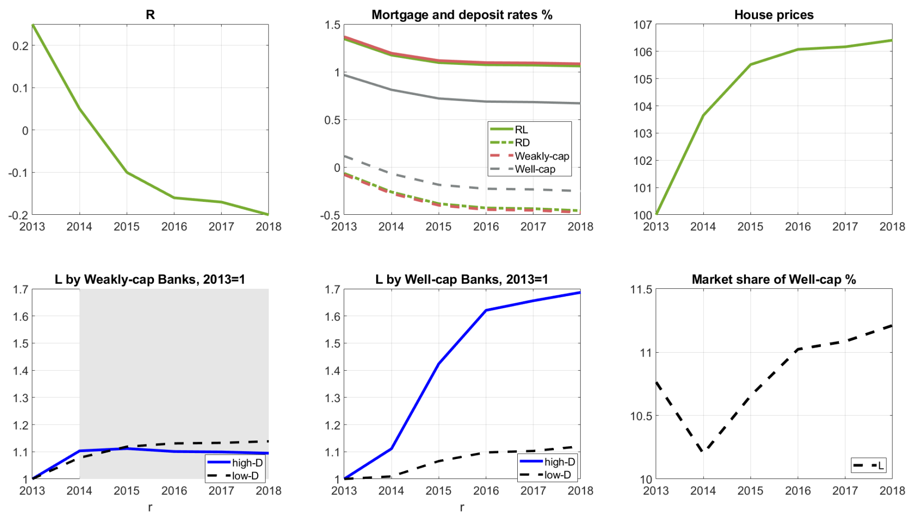
Notes: This figure show how the value of important variables change as rate falls. All variables are plotted in levels. Dark area in the panel(b) indicates that capital constraint binds for high-deposit banks in the weakly-capitalized group.

Figure 2.6: Mortgage Volume Index



Notes: The horizontal axis shows the year. The vertical axis shows the index level of real mortgage loan.

Figure 2.7: Stronger Preference on Liquidity Savings



Notes: We plot the steady state values of lending and rate settings in an economy where savers' liquidity preference is much stronger than in benchmark economy.

2.6.3 Impulse Responses

The results above show that banks respond differently to a falling policy rate. To fully understand the importance of these heterogeneities in the banking sector, we compare the dynamics after a rate cut in the economies with different banking features. We start with our benchmark economy, which is a fully heterogeneous one with different aggregator weights, capital requirements, and covered bond adjustment costs across banks, and then shut down these heterogeneities one at a time to develop step-wise intuition.

Figure 2.8 plots the impulse response functions (IRFs) of important macroeconomic variables to a negative monetary policy shock for different cases.[14] The magnitude of the shock is equal to the rate cuts into negative territory altogether. All variables are showed in percent deviations from the steady state except for rate settings and default threshold, which are expressed in level directly. Table 2.6 documents the cumulative percent changes of some aggregate variables in five periods after the shock.

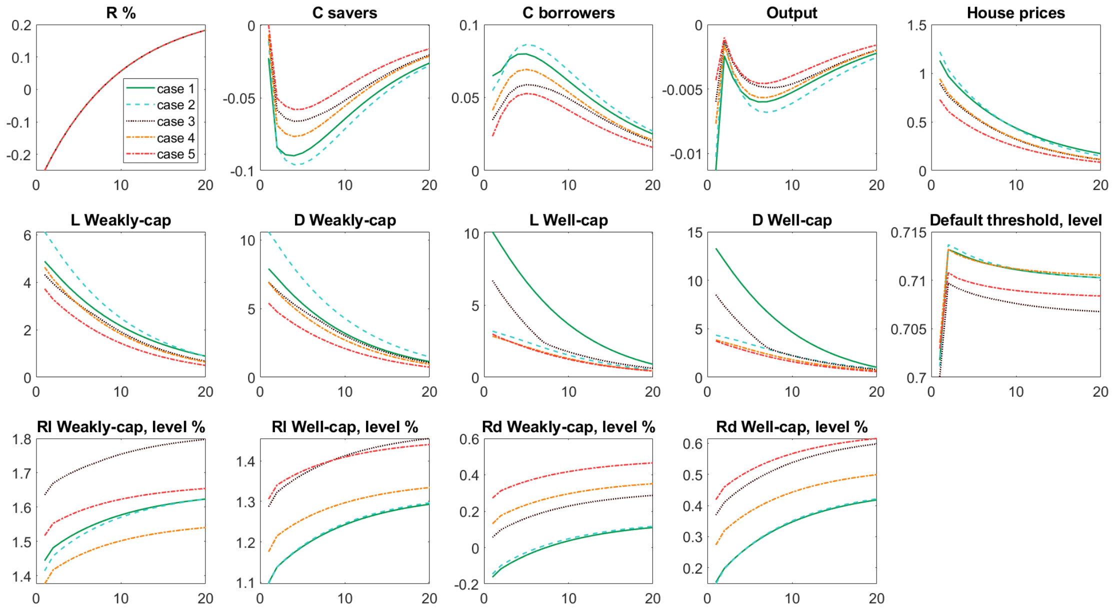
Case 1 represents the benchmark economy. In case 2, weakly-capitalized banks face a looser capital requirement so that they also have sufficient capital buffers above the required. In case 3, high- and low-deposit banks pay the same adjustment cost of using covered bonds. In case 4, the CES aggregator weights on high- and low-deposit banks are the same, implying that the two are perceived to offer similar services by customers. In case 5, we remove differences in both covered bond costs and aggregator weights between high- and low-deposit banks.

In the benchmark economy, banks reduce lending rate after the shock, driving up borrowing demand. As bonds become less attractive, banks are able to collect more deposits from savers and then increase loan supply. In particular, those well-capitalized banks are not constrained by a binding capital constraint and thus increase lending at a much larger pace. Within this well-capitalized group, high-deposit banks take advantage of a lower funding cost and increase loan supply more quickly than low deposit banks. However, within the weakly-capitalized group, the loss from the reduced interest margin causes capital constraint to bind. High-deposit banks are exposed to that first since they have very limited space to continue lowering interest expenses; their mortgage expansion is therefore smaller than low-deposit banks.

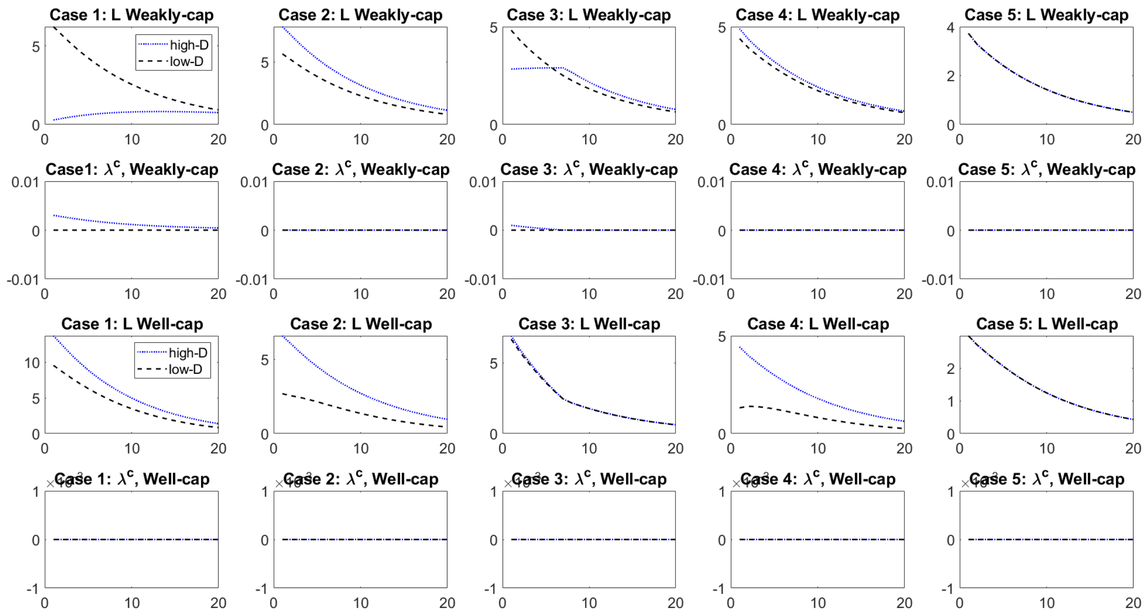
In case 2, weakly-capitalized banks have sufficient capital above the requirement so that they are not constrained and can increase mortgage supply more than in the benchmark economy. This happens at the expense of well-capitalized banks; their competitive advantage from the regulatory side in the benchmark case disappears, and thus mortgage expansion becomes smaller than before. As weakly-capitalized banks occupy most of the market share in the mortgage market, the total credit expansion increases relative to the benchmark case, resulting in a larger increase in house prices. Additionally, without the binding constraint, high-deposit banks can increase mortgage supply faster than low-deposit banks in both weakly and well-capitalized groups.

[14]The model is solved using a DynareOBC toolkit, which is build up by Tom Holden and uses pruned perturbation approximations to handle occasionally binding constraints. See Holden (2016).

Figure 2.8: IRFs to a Negative Monetary Policy Shock for Different Cases



(a) Aggregate Effects on the Economy



(b) Different Responses of High and Low Deposit Banks

Notes: This figure plots the impulse responses of some key variables to a negative monetary policy shock for different cases. The vertical axis shows the percentage deviations of all variables except for rates, Lagrangian multipliers and default threshold, which are plotted in levels. Case 1, the benchmark economy. Case 2, a looser capital constraint on weakly-capitalized banks. Case 3, high- and low-deposit banks pay the same covered bond adjustment cost. Case 4, consumers put same aggregator weights on high- and low-deposit banks. Case 5, there is no difference in both covered bonds adjustment cost and aggregator weights.

In case 3, we assume that low-deposit banks set the same target ratio of loans over covered bonds as high-deposit banks do. That is, they need to reduce reliance on covered bonds. The main effect is that lending dispersion between high- and low-deposit banks gets smaller than in the benchmark economy. There are two reasons. First, competition for deposits increases, leading banks to offer higher deposit rates. The increased cost then forces banks to charge higher lending rates, and therefore, overall mortgage expansion becomes smaller relative to the benchmark economy. Second, higher weights given by savers on high-deposit banks' services offer them a significant advantage in the competition for deposits, reducing the lending dispersion between high- and low-deposit banks.

In case 4, we assume that consumers put the same weights on the depositing and lending services offered by high- and low-deposit banks. Given that, these two types of banks account for equivalent market share. As discussed above, an intensified competition would, in general, lead to a smaller mortgage expansion than in case 1. Interestingly, capital constraints on those weakly-capitalized high-deposit banks become not binding. As weakly-capitalized banks' market share gets bigger than in case 1, their market power increases and allows them to charge a more extensive spread. This increased profitability helps relax capital constraints. Therefore, we observe that high-deposit banks can increase lending more quickly than low-deposit banks in both weakly and well-capitalized groups.

Case 5 goes back to a representative bank model setting. Without any differences in covered bond costs and aggregator weights put by consumers, high- and low-deposit banks behave identically, increasing deposit collection and loan supply by the same amount. Notice that this also implies further intensified competition, forcing up deposit rates. Banks increase lending rates to make up for increased funding costs, resulting in the smallest mortgage expansion in all cases.

Table 2.6: Cumulative Percentage Deviations From Steady State in Five Periods

Cases	Cs	Cb	Y	Ph	L	D
1. benchmark	-0.3736	0.3687	-0.0288	4.4717	22.4603	35.3153
2. a looser capital constraint on weakly-capitalized banks	-0.3788	0.3669	-0.0269	4.7433	24.5986	41.6261
3. same covered bond cost	-0.2608	0.2474	-0.0186	3.5095	18.9452	29.5724
4. same CES weights	-0.3021	0.2953	-0.0231	3.6280	18.5702	27.5243
5. same CES weights and covered bond cost	-0.2212	0.2116	-0.0163	2.7871	14.9138	21.4843

Taken together, the differences in capitalization and funding structure we introduced into the banking sector amplify mortgage expansion and can help explain why banks respond differently to the negative rate policy, as seen in Figure 2.2.

2.7 Policy Implications

In this section, we will use our modeling framework to provide some policy implications for the recent Covid-19 crisis. This pandemic plunged the economies worldwide into a recession; however, housing markets boomed. A combination of housing supply shortage, intensified desire for more space, and historically low mortgage rates have led to a large increase in house prices. In Sweden, the housing price index went up by 4% in 2020.

We plan to model the impact of Covid-19 on the housing market and assess the effects of two policy tools that target on improving credit conditions during the pandemic. First, the Finansinspektionen decided to lower the countercyclical buffer (CCyB) requirement to support banks' lending activities and thus the economy. Second, the Riksbank intends to purchase securities in an amount of up to SEK 700 billion up to December 2021. The purchases aim to keep interest rates at a low level and contribute to an efficient credit supply. The currently applicable purchases include covered bonds.[15]

The average growth rate of production in construction was about -3% in 2020.[16] We use a negative shock to the total housing supply ϵ_h, to capture the influence of Covid-19 on the housing market,

$$h_{s,t} + h_{b,t} = 1 + \epsilon_h.$$

Figure 2.9 plots the impulse response functions to this negative supply shock. All variables are showed in percent deviations from the steady state except for rate settings and default threshold, expressed as levels directly. Case 1 represents the benchmark economy. In case 2, we introduce the policy of lowering the CCyB requirement and specify it as a temporary reduction in the required capital ratios φ_j^c for all banks upon impact. In case 3, we embed the covered bonds purchasing program as a shock ϵ_{cv}, triggering relaxation of participation constraint on covered bond investors,

$$E_t[(\frac{B_{j,t}^{cv}}{L_t})\int_0^{\bar{\omega}_{t+1}}(1-\mu^{cv})(1-\mu)\omega_{t+1}\frac{R_t^l L_t}{\bar{\omega}_{t+1}}f(\omega_{t+1})d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R_{j,t}^{cv} B_{j,t}^{cv} f(\omega_{t+1})d\omega] \geq \epsilon_{cv} R_t^d B_{j,t}^{cv}.$$

All these shocks follow a simple autoregressive stochastic process.

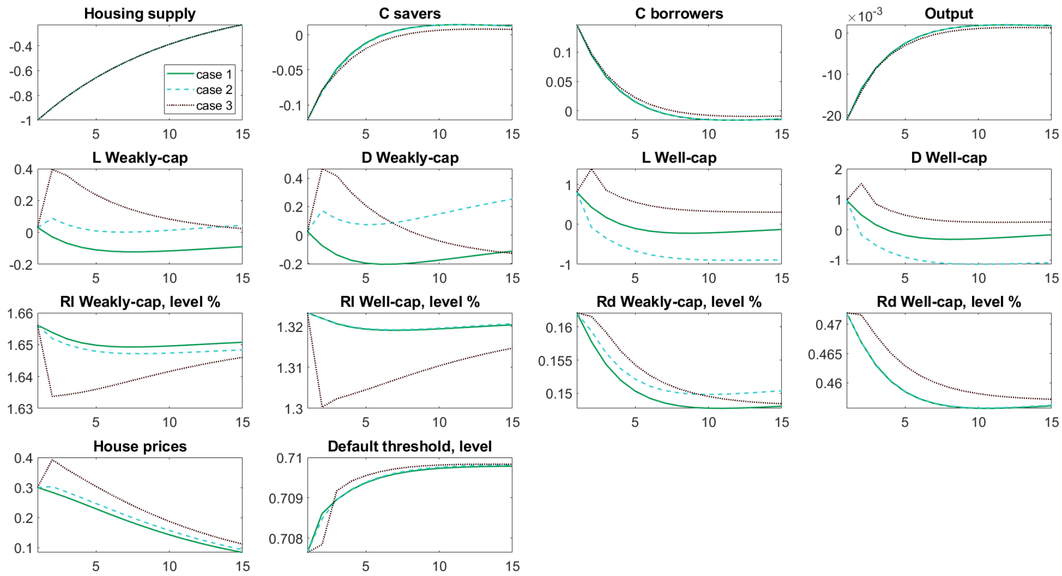
A decrease in housing supply results in higher house prices, which implies a decrease in default risk. Banks, therefore, charge a lower risk premium for lending rate, leading to an increase in borrowers' housing demand. Banks take more deposits from savers and lend out more to borrowers. As the binding capital constraints constrain weakly-capitalized banks' lending capacity, well-capitalized banks mainly contribute to the increase in loan supply; they offer a cheaper lending rate and higher deposit rate. The consumption of borrowers increases because of cheaper credit. The consumption of savers falls because they save more on deposits. As a result, the total output drops slightly.

In case 2, a reduction in the required capital ratios helps relax the constraint on weakly-capitalized banks' lending capacity. These banks begin to charge lower lending rates and increase mortgage supply. Well-capitalized banks bear the cost of this policy, cutting back on loan supply. Compared to the benchmark case, borrowers can get more loans from the large weakly-capitalized banks for housing purchase, leading house prices to increase further.

[15] See the Riskbank' s website for more details on the Covid-19 stimulus package.

[16] Data is from the Eurostat.

Figure 2.9: IRFs to a Negative Housing Supply Shock



Notes: This figure plots the impulse responses of some key variables to a 1% negative housing supply shock for different cases. The vertical axis shows the percentage deviations of all variables except for rates and default threshold, which are plotted in levels. Case 1, benchmark economy. Case 2, countercyclical capital buffer requirements are removed after the shock. Case 3, covered bonds buying program is activated after the shock.

In case 3, the covered bonds purchasing program lowers the yields banks pay on issuing covered bonds. The decreased funding costs allow banks to charge lower lending rates and issue more covered bonds to finance the rising borrowing demand. Both weakly- and well-capitalized banks benefit from this program and lend out more. Therefore, borrowers receive more loans for house purchases, and house prices go up rapidly.

To sum up, these policies targeted at counteracting the deterioration of credit conditions can fuel mortgage expansion and accelerate house price appreciation in the low rate environment. It is important to point out that these policies are more favorable to weakly-capitalized banks, enlarging their lending capacity. Policies targeted at expanding well-capitalized banks' lending capacity might be more efficient to maintain financial stability.

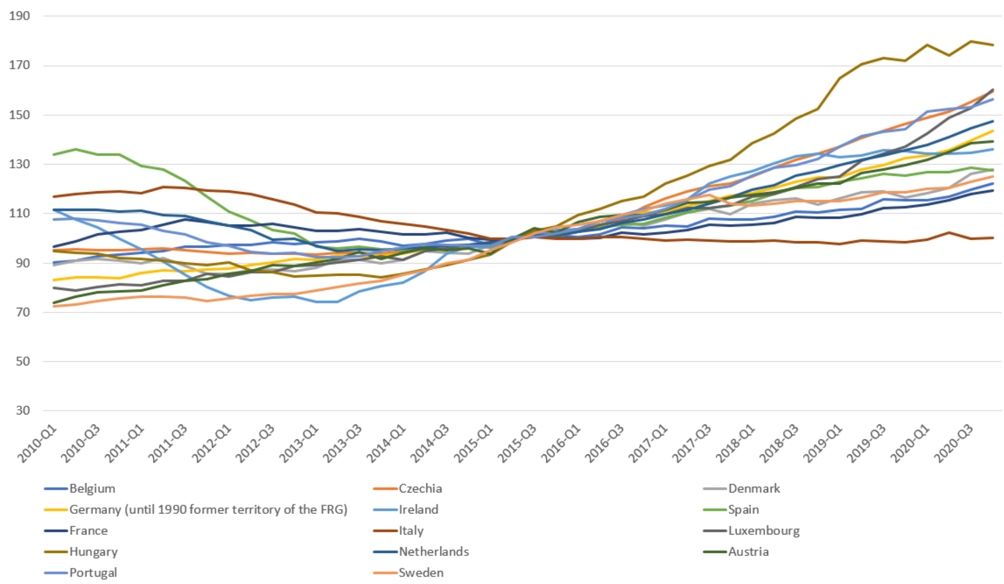
2.8 Conclusions

Our paper looks into the heterogeneous effects of the negative rate policy on mortgage supply across banks. We first empirically examine the transmission channels of the negative rate policy using Sweden bank data. We find that, once the rate turns negative, high-deposit banks do not necessarily have to increase the lending rate and cut loan supply as argued in the previous studies; this depends on the bank's capitalization level. Additionally, the issuance of covered bonds gives banks more space to continue lowering interest expenses in a negative rate environment, as they can actively shift out of covered bonds into cheap deposits. Then, we propose a general equilibrium model with different types of banks to be consistent with these empirical findings. Our simulation results show that the differences in funding composition and capitalization level are essential to explain why banks respond differently to the negative rate policy in the mortgage market. Finally, we analyze the effects of policies used during the Covid-19 pandemic and find that lowering the countercyclical capital requirement and purchasing covered bonds can vastly increase bank lending and drive up house prices further.

Our modeling framework remains stylized. We see some interesting extensions. It is possible to analyze the impact of the negative rate policy on bank lending behavior for other European countries featuring different banking structures. We also plan on introducing an endogenous policy, targeting only a specific group of banks during bad times.

2.A Data

Figure 2.10: House Price Index



Notes: This figure plots the house price index for European countries. Data are taken from the Eurostat. The ECB lowered the rate applicable to its deposit facility (DFR) to -0.10% in June 2014.

2.B Mathematical Derivations

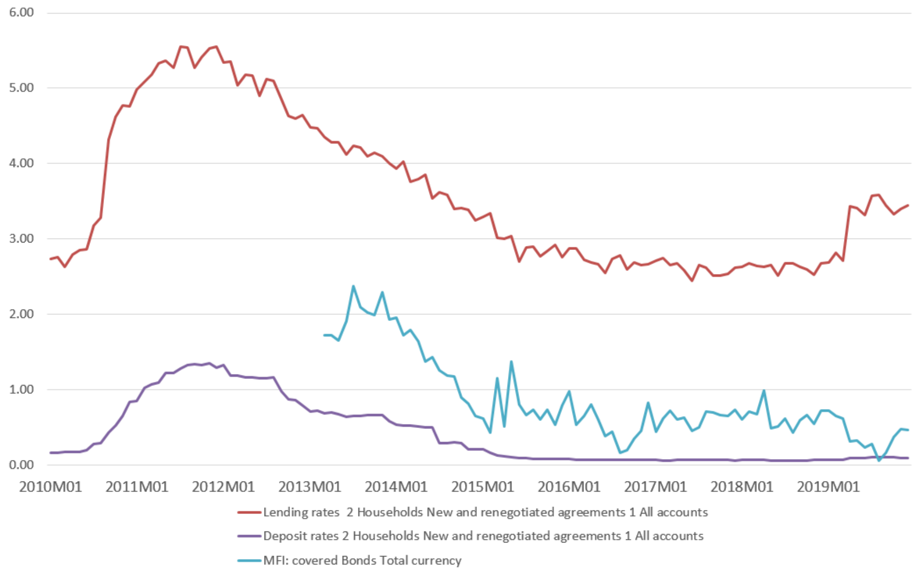
Savers: maximize their lifetime utility subject to the budget constraint, the dynamic programming is given by

$$\begin{aligned} max \quad E_0 \sum_{t=0} \beta_s^t [\ln C_{s,t} + j_h ln(h_{s,t}) + \frac{j_m}{1-\eta}(Liq_t)^{1-\eta} - \chi \frac{N_{s,t}^{1+\varphi}}{1+\varphi} \\ + \mu_{s,t}(W_{s,t}N_{s,t} + R_{t-1}^d D_{t-1} + M_{t-1} + R_{t-1}B_{t-1} - C_{s,t} - D_t - M_t - B_t - T_{s,t})] \end{aligned}$$

Taking derive the first-order conditions relative to $C_{s,t}$, B_t, D_t, M_t and $N_{s,t}$ give the optimization equations for savers (2.5)-(2.10).

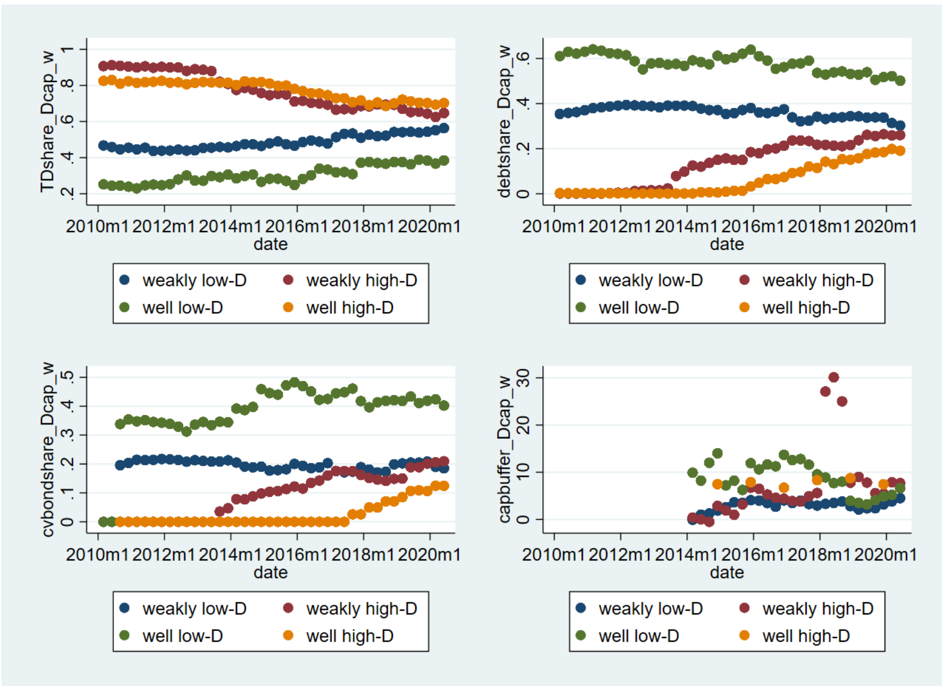
Borrowers: maximize their lifetime utility subject to the budget constraint and banks' pricing

Figure 2.11: Rates Setting



Notes: This figure plots the average rates of lending to households and household deposits, and covered bond yields.

Figure 2.12: Bank Funding Structure



Notes: The figure shows how different types of banks' funding structure evolve over time. The upper panel plots the share of total deposit and debt issued in total assets respectively. The bottom left panel plots the share of covered bonds in total assets. The bottom right panel show the capital buffer levels.

Table 2.7: List of Financial Institutions

Bank	Mortgage Market Share	Deposit Ratio	Capital Buffer %
Falkenbergs Sparbank	.0014542	.7810327	8.47
Handelsbanken	.2320385	.5080285	2.725
ICA Banken AB	.0029119	.8620104	5.83
Ikano Banken AB (Publ)	.0026738	.6567094	6.9
Landshypotek AB	.0133116	.0623246	10.25
Länsförsäkringar	.0525214	.4196894	1.775
Nordea	.1484625	.4108077	.35
Nordnet Bank AB	.0013677	.8268253	4.1
Resurs Bank AB	.0025938	.8201353	7.4
SBAB	.0635639	.301034	11.325
Santander Consumer Bank	.0070252	.5763267	4.75
Skandiabanken AB	.0125111	.7199339	.3
Skandinaviska Enskilda Banken	.1534623	.452002	.525
Sparbanken Alingsås AB	.0009237	.7412198	7.45
Sparbanken Lidköping AB	.0005412	.6783483	15.53
Sparbanken Nord	.0029702	.8688024	5.9
Sparbanken Rekarne AB	.001354	.9100118	1.3
Sparbanken Skåne AB	.0055591	.8458475	6
Swedbank	.2532239	.4988333	0
Swedbank Sjuhärad AB	.0017224	.7795112	5.52
Sörmlands Sparbank	.0014272	.7702704	7.47
Varbergs Sparbank AB	.0016091	.74909	11.2
Volvofinans Bank AB	.003486	.5321308	11.4
Westra Wermlands Sparbank	.0010999	.7339637	13.48
Ölands Bank AB	.0005966	.863865	12.23

Note: Each cell shows the average value of different variables (noted in the first row) in 2014 for the bank.

function of mortgage rate, the dynamic programming is given by

$$max \quad E_0 \sum_{t=0} \beta_b^t [lnC_{b,t} + j_h ln(h_{b,t}) - \chi \frac{N_{b,t}^{1+\varphi}}{1+\varphi} +$$

$$\mu_{b,t}(L_t + W_{b,t}N_{b,t} + (1-G(\frac{R_{t-1}^l x_{t-1}}{q_{h,t}/q_{h,t-1}}))q_{h,t}h_{b,t-1} - (1-F(\frac{R_{t-1}^l x_{t-1}}{q_{h,t}/q_{h,t-1}}))R_{t-1}^l L_{t-1} - C_{b,t} - q_{h,t}h_{b,t})]$$

Taking derive the first-order conditions relative to $C_{b,t}, N_{b,t}, h_{b,t}, x_t$ give the optimization decisions of borrowers (2.13)-(2.16).

Banks: choose their rates and implied quantities to maximize their lifetime net worth:

$$max \quad E_t\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}\{(1-v)[R^{l,b}_{j,t+1}L_{j,t}+R_tS_{j,t}-R^{cv}_{j,t}B^{cv}_{j,t}-R^d_{j,t}D_{j,t}-f()]+vV(N_{j,t+1})\}$$
$$+\lambda^b_{j,t}\{D_{j,t}+B^{cv}_{j,t}+N_{j,t}-L_{j,t}-S_{j,t}\}$$
$$+\lambda^c_{j,t}\{R^{l,b}_{j,t+1}L_{j,t}+R_tS_{j,t}-R^{cv}_{j,t}B^{cv}_{j,t}-R^d_{j,t}D_{j,t}-f()-\varphi^c_jL_{j,t}\}$$
$$+\lambda^l_{j,t}\{S_{j,t}-\varphi^l_j(L_{j,t}+S_{j,t}-B^{cv}_{j,t}-N_{j,t})\}$$
$$+\lambda^{cv}_{j,t}\{\int_0^{\bar{\omega}_{t+1}}(1-\mu)\omega_{t+1}\frac{R^l_t}{\bar{\omega}_{t+1}}f(\omega_{t+1})d\omega+\int_{\bar{\omega}_{t+1}}^{\infty}R^{cv}_{j,t}f(\omega_{t+1})d\omega]-R^d_t\}$$
$$+\lambda^m_{j,t}\{L_{j,t}-\alpha_{l,j}(\frac{R^l_{i,j}}{R^l_i})^{-\xi_l}(\frac{R^l_i}{R^l})^{-\rho_l}L_t\}+\lambda^d_{j,t}\{D_{j,t}-\alpha_{l,j}(\frac{R^d_{i,j}}{R^d_i})^{-\xi_d}(\frac{R^d_i}{R^d})^{-\rho_d}D_t\}, \quad j=\{Gh,Gl,Bh,Bl\}.$$

We take first-order conditions with respect to $L_{i,j}$ and $R^l_{i,j}$:

$$[\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'(N_{j,t+1}))+\lambda^c_{i,j}]\{[(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l+(1-F(\bar{\omega}))R^l_{i,j}]-R\}-\lambda^c_{i,j}\varphi^c_{i,j}-\lambda^l_{i,j}+\lambda^m_{i,j}=0\,,$$

$$[\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'(N_{j,t+1}))+\lambda^c_{i,j}][(1-F(\bar{\omega}))]L_{i,j}-\lambda^m_{i,j}\{-\xi_l\alpha_{l,j}(\frac{R^l_{i,j}}{R^l_i})^{-\xi_l-1}(\frac{R^l_i}{R^l})^{-\rho}L\frac{1}{R^l_i}$$
$$+(-\rho+\xi_l)\alpha_{l,j}(R^l_{i,j})^{-\xi_l}(R^l)^{\rho}L(R^l_i)^{-\rho+\xi_l-1}\frac{\partial R^l_i}{\partial R^l_{i,j}}\}=0\,.$$

Plugging the local mortgage demand function (2.21) into the first-order condition to $R^l_{i,j}$ we get

$$[\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'(N_{j,t+1}))+\lambda^c_{i,j}][(1-F(\bar{\omega}))]L_{i,j}-\lambda^m_{i,j}\{-\xi_lL_{i,j}(R^l_{i,j})^{-1}$$
$$+(-\rho+\xi_l)L_{i,j}(R^l_{i,j})^{-1}s^l_{i,j}\}=0\,.$$

This implies

$$\lambda^m_{i,j}=\frac{[\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'(N_{j,t+1}))+\lambda^c_{i,j}][(1-F(\bar{\omega}_{t+1}))]R^l_{i,j}}{\xi_l-(-\rho+\xi_l)s^l_{i,j}}\,.$$

Substituting this $\lambda^m_{i,j}$ into the first-order condition to $L_{i,j}$ yields the optimal mortgage rate chosen by the bank:

$$R^l_{i,j} = \underbrace{\frac{1}{1-\frac{1}{\epsilon^l_{i,j}}}}_{\text{markup}} \frac{1}{1-F()}[R-(1-\mu)\frac{G(\bar{\omega})}{\bar{\omega}}R^l + \underbrace{\frac{\varphi^c_{i,j}\lambda^c_{i,j}+\lambda^l_{i,j}}{\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'(N_{j,t+1}))+\lambda^c_{i,j}}]}_{\text{regulation cost}} ,$$

where

$$\epsilon^l_{i,j} = \xi_l(1-s^l_{i,j}) + \rho s^l_{i,j} .$$

Similarly, by combining first-order conditions with respect to $D_{i,j}$ and $R^d_{i,j}$ we get the optimal deposit rate set by the bank:

$$R^d_{i,j} = \underbrace{\frac{1}{1-\frac{1}{\epsilon^d_{i,j}}}}_{\text{markdown}} [R + \underbrace{\frac{(1-\varphi^l)\lambda^l_{i,j}}{\beta_s\frac{\mu_{s,t+1}}{\mu_{s,t}}(1-v+vV'(N_{j,t+1}))+\lambda^c_{i,j}}]}_{\text{regulation}} ,$$

where

$$\epsilon^d_{i,j} = \xi_d(1-s^d_{i,j}) + \rho s^d_{i,j} .$$

Participation constraint on covered bond holders helps to pin down the yields

$$\int_0^{\bar{\omega}_{t+1}} (1-\mu)\omega_{t+1}\frac{R^l_t}{\bar{\omega}_{t+1}} f(\omega_{t+1})d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} R^{cv}_{j,t} f(\omega_{t+1})d\omega] - R^d_t = 0.$$

The final step of taking derivative of mortgage rate with respect to leverage choice is proceeded as follows:

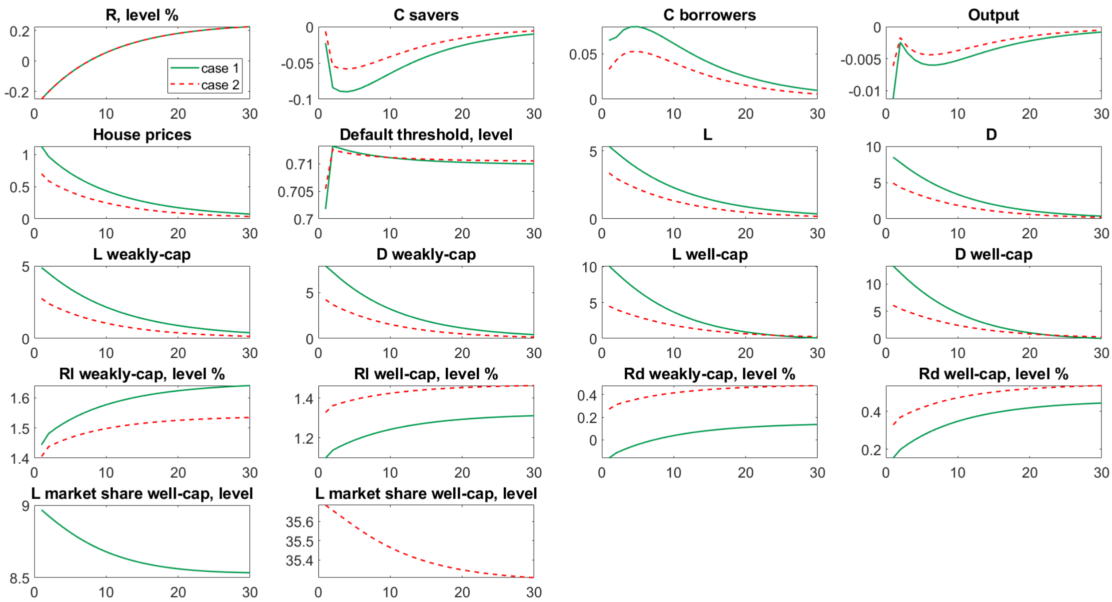
$$\begin{aligned}
\frac{\partial R^l}{\partial x_t} &= \frac{1}{1-\rho_l}[\int_0^1 (R^l_i)^{1-\rho_l} di]^{\rho_l/(1-\rho_l)}\,(1-\rho_l)(R^l_i)^{-\rho_l}\frac{\partial R^l_i}{\partial x_t} \quad = (\frac{R^l}{R^l_i})^{\rho_l}\frac{\partial R^l_i}{\partial x_t} \\
&= (\frac{R^l}{R^l_i})^{\rho_l}\frac{1}{1-\xi_l}[\sum_{j=1}^4 \alpha_{l,j}(R^l_{i,j})^{1-\xi_l}]^{\frac{\xi_l}{1-\xi_l}}[\sum_{j=1}^4 \alpha_{l,j}(1-\xi_l)(R^l_{i,j})^{-\xi_l}\frac{\partial R^l_{i,j}}{\partial x_t}] \\
&= (\frac{R^l}{R^l_i})^{\rho_l}[\sum_{j=1}^4 \alpha_{l,j}(\frac{R^l_i}{R^l_{i,j}})^{\xi_l}\frac{\partial R^l_{i,j}}{\partial x_t}] \\
&= \sum_{j=1}^4 \frac{L_j}{L}\frac{\partial R^l_{i,j}}{\partial x_t}.
\end{aligned}$$

2.C Additional Tests

2.C.1 Different Banking Structure

Other countries which implemented negative rate policy have different banking systems. For example, well-capitalized small banks have equivalent mortgage market share as weakly-capitalized big banks in Switzerland. We plan to make a comparison of the responses to a rate cut in economies with different banking structures, our benchmark calibrated economy and one where well-capitalized accounting for 35% of market share. This can shed some lights on the transmission of negative rate policy conditional on local lending market structure.

Figure 2.13: IRFs when well-capitalized banks account for a larger market share



Notes: We plot the percent deviation from steady state for consumption, output, loan and deposits by different banks, and the level of rate settings. Case 1 (Solid green line): benchmark economy. Case 2 (Dashed red line): the size of well-capitalized bank group is bigger than in case 1.

The green lines in Figure 2.13 present the impulse responses in benchmark economy, which matches the Swedish banking structure. The red lines plot the impulse responses in an economy where the size of well-capitalized banks are bigger, it could be considered as an application of Swiss banking system. As well-capitalized banks' market share increase, they have stronger market power and could set a higher lending rate to increase their interest margins. This depresses borrowing demand and therefore well-capitalized banks' mortgage expansion becomes smaller than in benchmark case. Additionally, because of intensified competition, weakly-capitalized banks have to offer a higher deposit rate to attract savers, reducing their interest margin and profitability. Under the binding capital constraint, the reduced profitability constrains weakly-capitalized banks' lending capacity even further, and thereby their mortgage expansion gets smaller as well. Overall, the aggregate lending goes up less, and house prices increase less than in baseline case.

3 Housing Price, Land Finance, and Investment

A notable development over the past decade in China was rapid growth in house prices at an annual rate around 4 percent. The house-price dynamics was accompanied by a positive co-movement with residential investment, and a negative one with nonresidential investment. Accordingly the share of residential investment in GDP rose to 9 percent in 2016. In this paper, we study the impact of house price dynamics on business investment. We extend the work of Iacoviello and Neri (2010) embedding governments' revenue from land and housing firms' credit constraints, and calibrate the model to match Chinese economy. We find that land-use conversion and land finance propagate and amplify the crowding out effects of house price dynamics on the non-housing sector.

3.1 Introduction

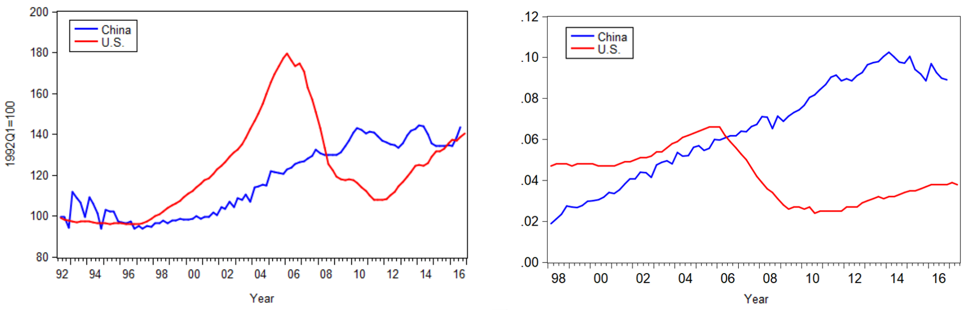
Thanks to housing market privatization, the Chinese housing market has been growing with dazzling speed since 1998 (see Figure 3.1). In 2016, the Chinese house price index reached the same level as that in the United States, and real estate investments contributed to 9% of GDP,[1] which is even higher than the level in the U.S. before the financial crisis. How does this decade-long housing boom affect household and firm behavior? Through which channels does the transmission of housing price dynamics to the economy occur? Addressing these questions is crucial for understanding business cycles and providing policy recommendations for stabilizing the housing market.

The empirical evidence from China suggests a crowding out effect on non-residential investment. The correlation coefficients for the detrended data of housing price, residential investment, and non-residential investment are shown in Table 3.1.[2] All series are percentage changes since the previous year. We observe a strong positive co-movement between house

[1] Rogoff and Yang (2020) document that the ratio of total real estate investment over GDP has increased to around 15% by 2016. Here we plot the share of fixed capital formation in residential buildings of GDP.

[2] The de-trending of the variables is done using the Hodrick-Prescott filter, which separates the growth component from the cycle component of a time series.

Figure 3.1: Housing Market Development



(a) Housing Price Index

(b) Residential Investment as % of GDP

Notes: The house price series are the price index of newly-built residential housing in the 70 largest cities from National Bureau of Statistics of China (NBSC henceforth) and the S&P/Case-Shiller U.S. National Home Price Index from the FRED. Residential investment data are total investment in residential buildings from the NBSC and Gross private domestic investment: Fixed investment: Residential from the FRED.

prices and residential investment and a weak negative co-movement between house prices and non-residential investment, which is consistent with the findings in Chen and Wen (2017).

Table 3.1: Correlation coefficients between residential investment I_h, nonresidential investment I_c and house prices Q

	I_h	I_c
$Corr(Q,)$	0.3127	-0.0848
$Corr(Q_{t-1},)$	0.4302	-0.0545

Notes: Non-residential investment is calculated by subtracting residential investment from completed investment in fixed asset which is also from NBSC.

What factors can explain this negative relationship? First, we observe a substantial increase in the share of real-estate loans in total loans, which have grown to 25% in 2016, nearly double that of 2006, which stood at 14% .[3] This is close to the level in the U.S. before the financial crisis (see Panel (a) of Figure 3.2).[4] Banks lend for residential investment purposes against land and housing as collateral. An increase in housing and land prices affects the collateral value and therefore borrowing capacity. In particular, 65% of exposure to the housing sector is given to the property developers, and other firms pledged with property or land in China.[5]

Second, a persistent increase in housing prices has been accompanied by soaring land prices.[6] This has caused a large increase in fiscal revenue because land is purchased from the local

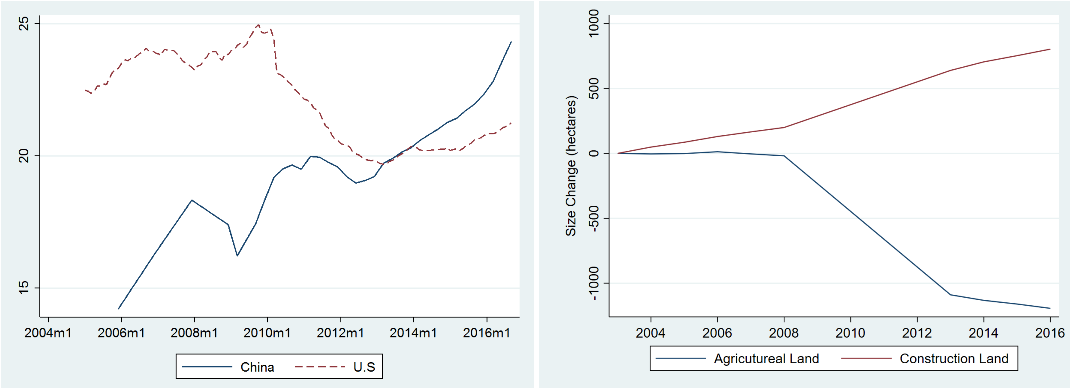
[3] Data are from the PBOC: Sources and Uses of Funds of Financial Institutions (in RMB and Foreign Currency).

[4] The ratio is calculated by dividing real estate loans by loans and leases in bank credit for all commercial banks. Data are from the FRED.

[5] Source: Deutsche bank (2016) report.

[6] The role of production material and collateral asset makes land demand go up, land price has increased rapidly from 1182 yuan per m^2 in 2004Q1 to 3826 yuan per m^2 in 2016Q4.

Figure 3.2: Contributing Factors



(a) Real Estate Loans as % of Total Loans

(b) Land Supply Control by the Government

Data source: PBOC and FRED.

governments; In 2016, taxes associated with land and real estate accounted for 11.81% and land-transferring fees accounted for 23.83% of the local government's fiscal revenue.[7] This has become one of the most important channels of fiscal revenue, motivating local governments to confiscate agricultural land at a low price and transform it into residential land at a high price. As argued by Han and Kung (2015), local governments have shifted their effort in fostering industrial growth to urbanizing localities. Land supply policy is preferable for residential investment, as seen in Panel (b) of Figure 3.2.

To analyze the consequences of fluctuations in the housing sector and to examine the role of land finance in the transmission of housing price dynamics, we extend the two-sector real business cycle model in Iacoviello and Neri (2010) to include government as land suppliers. Local governments distribute land to housing and non-housing sectors. Using capital, labor, and land, the housing sector produces new homes, and the non-housing sector produces consumption goods and capital. Housing firms can take a loan pledging the construction land they hold. There are two types of households that differ in terms of their discount factor: patient households work and save, and impatient ones borrow against the value of their houses to finance current consumption demand. We calibrate the model to match China's major macroeconomic features, such as GDP growth and the share of consumption and investment in GDP. In our model, a positive housing demand shock drives up house prices, boosting the purchase of land and capital in the housing sector. As a result, land prices and capital return go up, raising the costs for the non-housing sector. Additionally, a relaxation of credit constraints driven by increasing housing and land prices allows households to buy more houses and housing firms to invest more in production inputs. All these together lead non-housing producers to reduce investment and production. In the absence of collateral constraints on borrowers and housing firms, the drop in capital investment and production in the non-housing sector becomes smaller.

[7] Data are taken from the NBSC and Tax Year Book of China.

To regulate land supply, the central government has set up a land-use plan and requires that the total amount of arable land in China should be kept at a minimum of 1800 million acres. We introduce a lower bound on the stock of agricultural land to study the effects of this policy and find it alleviates the crowding out effect on the non-housing sector.

This paper proceeds as follows. Section 2 reviews the relevant literature. Section 3 presents our model. Section 4 shows the calibration. Section 5 analyzes the transmission of an increase in housing demand to the real economy. Section 6 studies the effects of a land-use constraint. Section 7 concludes.

3.2 Literature Review

Understanding the effects of house price fluctuations on other economic activities has attracted a great deal of attention. Many papers have confirmed the importance of the collateral channel in the transmission of house price dynamics. As Kiyotaki and Moore (1997) pointed out, the variation in durable goods price does not only change the value of agent's wealth but also influences how much they can borrow.

A large body of empirical research (Mian and Sufi (2011), and Duca et al. (2011)) find a strong link between housing and other economic activities through the borrowing channel using the US data. There are positive effects of an increase in housing price to non-housing consumption because of collateral constraints. Chaney et al. (2012) show that a positive real estate shock can also have a large positive impact on aggregate investment through the collateral channel. Wu et al. (2015) provide empirical evidence for China. Chen et al. (2017) show that real estate booms help to mitigate land-holding firms' financing constraints, crowding out financing to non-land-holding firms. This then causes a loss in aggregate TFP. Chen and Wen (2017) also document a misallocation of capital under financial frictions.

On the theoretical side, Iacoviello and Neri (2010) model housing as collateral for the households. They find that a positive demand shock drives up consumer and asset prices, thereby increasing the borrowing capacity of the household and allowing them to consume and invest more. Using a similar setting, Monacelli (2009) confirms the spillover effect on non-durable goods consumption. Liu et al. (2013) introduces land as a collateral asset for firms. A shock that drives up land prices raises firms' borrowing capacity and facilitates an expansion in investment and production. Their model also features a land reallocation channel and reinforce with the collateral channel, triggering competing demand for land. That drives up the land prices further.

Some other transmission mechanisms have also been documented. Rogoff and Yang (2020) examine real estate's linkage to the economy through the supply chain and show that the housing boom can generate large and positive demand spillovers to the real estate linked industries, driving up their price and profitability. Lambertini et al. (2017) study the role of default risk variation in the transmission. A fall in house prices prompts an increase in mortgage delinquency, leading to a credit crunch. Limited credit and higher mortgage lending rates can reduce consumers' demand for both durable and non-durable goods.

Our contribution relative to the previous literature is twofold. First, we try to combine credit constraints on households and firms based on the modeling work of Iacoviello and Neri (2010). We show that a relaxation of these two financial constraints can strengthen the housing boom and enable housing firms to get more funding to finance the acquisition of production inputs, intensifying the crowding our effects on non-housing activities. Iacoviello (2015) also includes two sets of financial frictions but focus on that faced by banks and firms in obtaining funds. Second, we consider the land allocation channel as proposed by Liu et al. (2013), but take a look at the land distribution by local governments between housing and non-housing sectors, which influences the supply side of the housing market.

3.3 Empirical Evidence

To further understand the key empirical relationships between housing, land, bank lending and investment, we present a vector auto-regression (VAR) analysis in Figure 3.3. We use floor space sold ($FSSold$) for housing demand, and floor space started (FSS) for residential investment. We also include house prices (Q), land price (QL), real estate outstanding loans (L_h), non-residential loans (L_c)[8], consumption (C) and non-residential investment. All variables are annual growth rates.

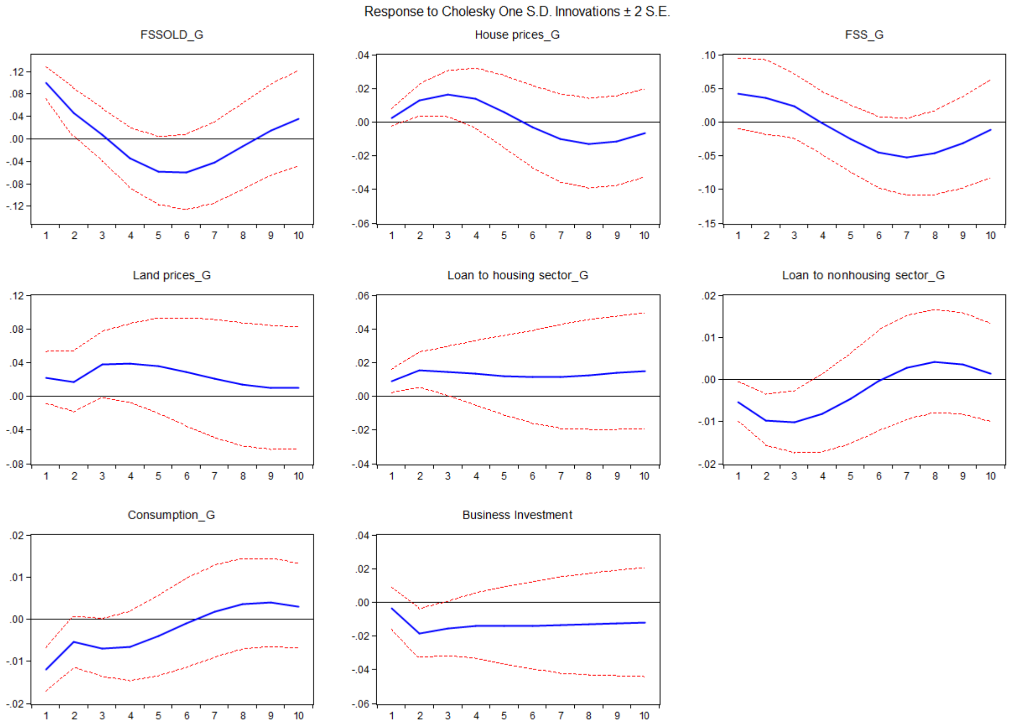
The Cholesky ordering of the variables is: $FSSold$, Q, FSS, QL, L_h, L_c and C from left to right. We put $FSSold$ first because we allow a shock in housing demand to affect all other variables contemporaneously. The house price and residential investment are next because prices and housing supply take some time to respond. Then house demand influence land demand which could also be used as collateral, loans change to finance the production of new houses. Last consumption and business investment take further time to respond. The impulse responses to a positive shock in floor space sold show us an increase in housing price and floor space started (housing supply), an increase in bank loans to the housing sector, and a decrease in loans to the non-housing sector. The VAR evidence points to the crowding out effect caused by a reduction in bank lending to the non-housing industry.

3.4 The Model

Consistent with the empirical findings, we develop a two-sector real business cycle model based on the work of Iacoviello and Neri (2010). There are three types of agents in the economy: patient and impatient households, housing and non-housing firms, and government. Patient households work, consume and save in bonds and capital; impatient households work and borrow to finance consumption and housing demand. Using labor, capital, and land,

[8] Non-residential loans are calculated by substracting real estate loans from total outstanding loans.

Figure 3.3: VAR: A Positive Shock to Housing Demand



Note: VAR estimated for 2000Q1 to 2016Q4. The dashed lines indicate the +/–2 analytic asymptotic standard error bands. The Cholesky ordering is floor space sold ($FSSold$) for housing demand, house prices (Q), floor space started (FSS) for residential investment, land price (QL), real estate outstanding loans (L_h), non-residential loans (L_c) consumption (C) and non-residential investment. The vertical axis shows the percent deviation from the baseline.

housing firms produce new houses, and non-housing firms produce consumption goods. Local governments control land supply.

3.4.1 Households

There is a continuum of measure 1 of agents in both patient and impatient households, and we index them by s, b respectively. Their objective is to maximize the lifetime utility function given as

$$maxE_t \sum_{i=0}^{\infty} (\beta_j G_j^c)^i [\ln C_{j,t+i} + jh_{t+i} \ln h_{j,t+i} - \chi \frac{N_{j,t+i}^{1+\varphi}}{1+\varphi}], \quad j = \{s, b\} .$$

where β_j is the discount factor; impatient households have a lower discount factor, implying that they are more willing to borrow rather than saver relative to patient households. $C_{j,t}$ and $h_{j,t}$ denote the consumption goods and housing services households buy. Consumption grows at the rate G_j^c on the balanced growth path. The term j_t represents a shock to the household's housing preference

$$\ln jh_t = (1-\rho_{jh})\ln jh + \rho_{jh}\ln jh_{t-1} + \mu_t.$$

φ measures the inverse of the Frish labor supply elasticity, and χ governs the weight of disutility from supplying labors. Aggregate labor supply $N_{j,t}$ consists of labor hours in the housing sector and labor hours in the consumption sector by the following form:

$$N_{j,t} = [(N^h_{j,t})^{1+\rho_l} + (N^c_{j,t})^{1+\rho_l}]^{\frac{1}{1+\rho_l}}, \tag{3.1}$$

ρ_l is the elasticity of substitution between hours in the housing sector and hours in the consumption sector.

Patient Households: Each period, they receive wage payment and the returns on capital and bond holdings from previous period, and with these money they can consume final goods, buy housing, purchase bonds S_t, and finance capital investment $K_{c,t}$ and $K_{h,t}$ in the final goods and housing sector respectively. The budget constraint is given by

$$\begin{aligned} &C_{s,t} + \frac{K_{c,t}}{A_{kc,t}} + \frac{K_{h,t}}{A_{kh,t}} + P_{h,t}h_{s,t} + S_t = w^c_{s,t}N^c_{s,t} + w^h_{s,t}N^h_{s,t} \\ &+ (R_{c,t} + \frac{1-\delta_k}{A_{kc,t}})K_{c,t-1} + (R_{h,t} + \frac{1-\delta_k}{A_{kh,t}})K_{h,t-1} - \phi_{k,t} + (1-\delta_h)P_{h,t}h_{s,t-1} + R_tS_{t-1} - T_t. \end{aligned} \tag{3.2}$$

where R_t denotes the price of bond holdings in period t and it pays off one unit of consumption good in period t+1, $w_{c,t}$ and $w_{h,t}$ denote wages per labor unit in the final goods and housing sector respectively, and $P_{h,t}$ is the price of housing. δ_k is the depreciation rate, $A_{kc,t}$ and $A_{kh,t}$ represent investment technology shocks, and $\phi_{k,t}$ is the adjustment cost for capital.

Patient households maximizes their expected lifetime utility subject to the budget constraint. The first-order conditions for this optimization problem are:

$$\frac{1}{C_{s,t}} - \mu_{s,t} = 0, \tag{3.3}$$

$$\frac{j_t}{h_{s,t}} - \mu_{s,t}P_{h,t} + E_t\mu_{s,t+1}\beta G^c_s(1-\delta_h)P_{h,t+1} = 0, \tag{3.4}$$

$$\mu_{s,t}(\frac{1}{A_{kc,t}} + \frac{\partial\phi_{k,t}}{\partial K_{c,t}}) = E_t\beta G^c_s\mu_{s,t+1}[R_{c,t+1} + \frac{1-\delta_k}{A_{kc,t+1}} - \frac{\partial\phi_{k,t+1}}{\partial K_{c,t}}], \tag{3.5}$$

$$\mu_{s,t}(\frac{1}{A_{kh,t}} + \frac{\partial\phi_{k,t}}{\partial K_{h,t}}) = E_t\beta G^c_s\mu_{s,t+1}[R_{h,t+1} + \frac{1-\delta_k}{A_{kh,t+1}} - \frac{\partial\phi_{k,t+1}}{\partial K_{h,t}}], \tag{3.6}$$

$$\mu_{s,t} = E_t\beta G^c_s\mu_{s,t+1}R_t, \tag{3.7}$$

$$\mu_{s,t} w^c_{s,t} = \chi N_t^{\varphi-\rho_l} (N^c_{s,t})^{\rho_l}, \tag{3.8}$$

$$\mu_{s,t} w^h_{s,t} = \chi N_t^{\varphi-\rho_l} (N^h_{s,t})^{\rho_l}. \tag{3.9}$$

$\mu_{s,t}$ denotes marginal utility of consumption. Equations (3.4)-(3.7) represent patient households' demand for housing, capital and bonds. Equations (3.8)-(3.9) determine patient households' labor supply to these two sectors.

Impatient Households: To finance current consumption and housing demand, they are willing to supply labor and also borrow from patient households. Every period the budget constraint is given by

$$C_{b,t} + P_{h,t} h_{b,t} + R_{t-1} B_{b,t-1} = w^c_{b,t} N^c_{b,t} + w^h_{b,t} N^h_{b,t} + (1-\delta_h) P_{h,t} h_{b,t-1} + B_{b,t}. \tag{3.10}$$

Because of information frictions in the credit market, impatient households need to use house holdings as collateral assets, and thereby facing a borrowing constraint as follows

$$B_{b,t} \le \omega^b E_t \frac{P_{h,t+1} h_{b,t}}{R_t}. \tag{3.11}$$

where ω^b denotes the loan-to-value ratios for impatient households.

Maximizing expected lifetime utility subject to the budget constraint and borrowing constraint gives the first-order conditions for impatient households' optimization problem:

$$\frac{1}{C_{b,t}} - \mu_{b,t} = 0, \tag{3.12}$$

$$\frac{j_t}{h_{b,t}} - \mu_{b,t} P_{h,t} + E_t \mu_{b,t+1} \beta G^c_b (1-\delta_h) P_{h,t+1} + E_t \lambda^b_t \frac{\omega^b P_{h,t+1}}{R_t} = 0, \tag{3.13}$$

$$\mu_{b,t} = E_t \beta G^c_b \mu_{b,t+1} R_t + \lambda^b_t, \tag{3.14}$$

$$\mu_{b,t} w^c_{b,t} = \chi N_t^{\varphi-\rho_l} (N^c_{b,t})^{\rho_l}, \tag{3.15}$$

$$\mu_{b,t} w^h_{b,t} = \chi N_t^{\varphi-\rho_l} (N^h_{b,t})^{\rho_l}. \tag{3.16}$$

$\mu_{b,t}$ denotes marginal utility of consumption, λ^b_t is the Lagragian multiplier on borrowing constraint. Equations (3.13)-(3.16) represent households' demand for housing and supply of labor to these two sectors.

3.4.2 Firms

There are two types of firms: consumption goods and housing producers, and we index them by c, h respectively. Their objective is also to maximize lifetime utility:

$$maxE_t \sum_{i=0}^{\infty} (\beta^{'} G_j^c)^i lnC_{j,t+i} \quad j = c, h,$$

where $\beta^{'}$ is firms' discount factor, $C_{j,t}$ denotes firm j's consumption that grows at the rate G_j^c on the balanced growth path.

Non-housing Firms: They purchase land $Land_{c,t}$, rent capital $K_{c,t}$ and hire labor $N_{c,t}$ from households as inputs, and their production technology is

$$Y_{c,t} = K_{c,t-1}^{\alpha_c} (Z_{c,t} Land_{c,t-1})^{\phi_c} (A_{c,t} N_{c,t})^{1-\alpha_c-\phi_c}. \tag{3.17}$$

$Z_{c,t}$ denotes the utilization rate of land in the non-housing sector, $A_{c,t}$ denotes the productivity of labor in the non-housing sector, and the parameters α_c and ϕ_c measure the output elasticities of these production inputs. Each period, non-housing firms can consume what's left over after paying for labor, capital and land purchase:

$$C_{c,t} = Y_{c,t} - w_{c,t} N_{c,t} - R_{c,t} K_{c,t-1} - P_{lc,t}(Land_{c,t} - Land_{c,t-1}) - a(Z_{c,t}) Land_{c,t-1}. \tag{3.18}$$

Firms can adjust the quality of land which determines the utilizing intensity, and this entails a utilization cost of $a(Z_{c,t}) Land_{c,t-1}$, where

$$a(Z_{c,t}) = \kappa_1 (Z_{c,t} - 1) + \frac{\kappa_2}{2} (Z_{c,t} - 1)^2.$$

Maximizing the utility gives the first order conditions as

$$\mu_{c,t} = \frac{1}{C_{c,t}}, \tag{3.19}$$

$$w_{c,t} = (1 - \alpha_c) \frac{Y_{c,t}}{N_{c,t}}, \tag{3.20}$$

$$R_{c,t} = \alpha_c \frac{Y_{c,t}}{K_{c,t-1}}, \tag{3.21}$$

$$P_{lc,t} = E_t \beta^{'} G_c^c \frac{\mu_{c,t+1}}{\mu_{c,t}} [\phi_c \frac{Y_{c,t+1}}{Land_{c,t}} + P_{lc,t+1} - a(Z_{c,t+1})], \tag{3.22}$$

$$\phi_c \frac{Y_{c,t}}{Z_{c,t} Land_{c,t-1}} = \kappa_1 + \kappa_2 (Z_{c,t} - 1). \tag{3.23}$$

$\mu_{c,t}$ denotes marginal utility of consumption. Equations (3.20)-(3.22) determine non-housing firms' demand for labor, capital and land. Equation (3.23) shows the land utilization rate non-housing firms can make.

Housing Firms: They produce using similar technology as follows:

$$Y_{h,t} = K_{h,t-1}^{\alpha_h}(Z_{h,t}Land_{h,t-1})^{\phi_h}(A_{h,t}N_{h,t})^{1-\alpha_h-\phi_h}. \tag{3.24}$$

Assume that land does not depreciate and housing firms can use it as collateral to borrow from households. Due to imperfect contract enforcement, the amount that housing firms can borrow is limited by a fraction of the land value.

$$B_{h,t} \leq \omega^h E_t \frac{P_{lh,t+1}Land_{h,t}}{R_t}. \tag{3.25}$$

Each period, combining loans and production profits, housing firms are able to pay wages, fiance capital and land purchases, and buy consumption goods. Land utilization process also entails a cost of $a(Z_{h,t})Land_{h,t-1}$. The budget constraint is given by:

$$C_{h,t} = P_{h,t}Y_{h,t} - w_{h,t}L_{h,t} - R_{h,t}K_{h,t-1} + B_{h,t} - R_{t-1}B_{h,t-1} - P_{lh,t}(Land_{h,t} - Land_{h,t-1}) - a(Z_{h,t})Land_{h,t-1}. \tag{3.26}$$

The first-order conditions for housing firms' decision problems are

$$\mu_{h,t} = \frac{1}{C_{h,t}}, \tag{3.27}$$

$$w_{h,t} = (1-\alpha_h-\phi_h)P_{h,t}\frac{Y_{h,t}}{L_{h,t}}, \tag{3.28}$$

$$R_{h,t} = \alpha_h P_{h,t}\frac{Y_{h,t}}{K_{h,t-1}}, \tag{3.29}$$

$$P_{lh,t} = E_t\{\beta' G_h^c \frac{\mu_{h,t+1}}{\mu_{h,t}}[\phi_h P_{h,t+1}\frac{Y_{h,t+1}}{Land_{h,t}} + P_{lh,t+1} - a(Z_{h,t})] + \frac{\lambda_t^h}{\mu_{h,t}}\frac{\omega^h P_{lh,t+1}}{R_t}\}, \tag{3.30}$$

$$\phi_h \frac{P_{h,t}Y_{h,t}}{Z_{h,t}Land_{h,t-1}} = \kappa_1 + \kappa_2(Z_{h,t}-1), \tag{3.31}$$

$$\mu_{h,t} = E_t\beta' G_h^c \mu_{h,t+1}R_t + \lambda_t^h. \tag{3.32}$$

$\mu_{h,t}$ denotes marginal utility of consumption and λ_t^h the Lagrangian multiplier for borrowing constraint. Equations (3.28)-(3.30) represent firms' demand for labor, capital and land. Equations (3.32) determine firms' borrowing demand.

3.4.3 Government

Land supply is controlled by local governments, and total land grows at a fixed rate γ_L over time.

$$lnLand_t = t * ln(1+\gamma_L) + lnZ_{L,t}, lnZ_{L,t} = \rho_k lnZ_{L,t-1} + \mu_{L,t}.$$

Each period, local governments covert into the land that can be used in the non-housing and housing sectors. Lands used in these two sectors are not perfect substitute, so they are aggregated in the following form

$$Land_t = [(1-\alpha_{l,h})^{\frac{1}{\xi_l}} Land_{c,t}^{1-\frac{1}{\xi_l}} + \alpha_{l,h}^{\frac{1}{\xi_l}} Land_{h,t}^{1-\frac{1}{\xi_l}}]^{\frac{\xi_l}{\xi_l - 1}}, \tag{3.33}$$

where ξ_l is the elasticity of substitution across two sectors. Later we calibrate $\alpha_{l,h}$ to match initial share of residential land in total land.

Local governments get revenue from selling land

$$Rev_t = P_{lh,t}(Land_{h,t} - Land_{h,t-1}) + P_{lc,t}(Land_{c,t} - Land_{c,t}),$$

Government use lump-sum tax to finance its spending g_t that grows at γ_c, any land revenue is simply added to the spending

$$g_t = \varepsilon_t^g (1+\gamma_c) * g_{t-1}.$$

Governments choose the amount of land supply to these two sectors to maximize their revenue

$$maxE_t \sum_{i=0}^{\infty} (\beta G_c)^i \mu_{s,t+i} Rev_{t+i}.$$

the first order condition for land supply is

$$(\mu_{s,t} P_{lh,t} - E_t \beta G_c \mu_{s,t+1} P_{lh,t+1}) \frac{1}{\alpha_{l,h}^{\frac{1}{\xi_l}} Land_{h,t}^{-\frac{1}{\xi_l}}} = (\mu_{s,t} P_{lc,t} - E_t \beta G_c \mu_{s,t+1} P_{lc,t+1}) \frac{1}{(1-\alpha_{l,h})^{\frac{1}{\xi_l}} Land_{c,t}^{-\frac{1}{\xi_l}}}. \tag{3.34}$$

3.4.4 Markets Clearing

The consumption goods and housing markets clear

$$Y_{c,t} = C_{s,t} + C_{b,t} + C_{c,t} + C_{h,t} + I_{kc,t}/A_{kc,t} + I_{kh,t}/A_{kh,t} + g_t, \tag{3.35}$$

$$Y_{h,t} = h_t - (1-\delta_h) h_{t-1}. \tag{3.36}$$

The total savings of households is equal to the total debt of firms:

$$B_{b,t} + B_{h,t} = S_t. \tag{3.37}$$

The total output is defined as $Y_t = Y_{c,t} + P_{h,t} Y_{h,t}$.

3.4.5 Trends and Balanced Growth

Trends in productivity in the consumption and housing sector:

$$lnA_{c,t} = t * ln(1+\gamma_{ac}) + lnZ_{c,t}, lnZ_{c,t} = \rho_{ac} lnZ_{c,t-1} + \mu_{c,t};$$

$$lnA_{h,t} = t * ln(1+\gamma_{ah}) + lnZ_{h,t}, lnZ_{h,t} = \rho_{ah} lnZ_{h,t-1} + \mu_{h,t};$$

$$lnA_{kc,t} = t * ln(1+\gamma_{kc}) + lnZ_{kc,t}, lnZ_{kc,t} = \rho_k lnZ_{kc,t-1} + \mu_{kc,t};$$

$$lnA_{kh,t} = t * ln(1+\gamma_{kh}) + lnZ_{kh,t}, lnZ_{kh,t} = \rho_k lnZ_{kh,t-1} + \mu_{kh,t}.$$

Since variables like $Y_c, ph * Y_h, pl * Ld, C, Ce, \frac{K_c}{A_{kc}}, \frac{K_h}{A_{kh}}$ grow at the same rate along the balanced growth path, we can get growth rates of the real variables as follows:

$$G_c = G_{q*yh} = 1 + \frac{1-\alpha_c-\phi_c}{1-\alpha_c}\gamma_{ac} + \frac{\phi_c}{1-\alpha_c}\gamma_{lc} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc},$$

$$G_{kc} = 1 + \frac{1-\alpha_c-\phi_c}{1-\alpha_c}\gamma_{ac} + \frac{\phi_c}{1-\alpha_c}\gamma_{lc} + \frac{\gamma_{kc}}{1-\alpha_c},$$

$$G_{kh} = 1 + \frac{1-\alpha_c-\phi_c}{1-\alpha_c}\gamma_{ac} + \frac{\phi_c}{1-\alpha_c}\gamma_{lc} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc} + \gamma_{kh},$$

$$G_{yh} = 1 + (1-\alpha_h-\phi_h) * \gamma_{ah} + \phi_h * \gamma_{lh} + \alpha_h * (\frac{1-\alpha_c-\phi_c}{1-\alpha_c}\gamma_{ac} + \frac{\phi_c}{1-\alpha_c}\gamma_{lc} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc} + \gamma_{kh}),$$

$$G_{ph} = 1 + G_c - G_{yh}$$

$$G_{plc} = 1 + \frac{1-\alpha_c-\phi_c}{1-\alpha_c}\gamma_{ac} + \frac{\phi_c}{1-\alpha_c}\gamma_{lc} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc} - \gamma_{lc},$$

$$G_{plh} = 1 + \frac{1-\alpha_c-\phi_c}{1-\alpha_c}\gamma_{ac} + \frac{\phi_c}{1-\alpha_c}\gamma_{lc} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc} - \gamma_{lh},$$

$$G_{lh} = 1 + \gamma_{lh} = 1 + \gamma_{lc}.$$

3.5 Calibration

Some of parameters are set to match calibration target, and some are taken from previous literature. Table 3.2 reports our calibration result.

We set $\beta = 0.98$ for an annual real interest rate of about 7 percent. The depreciation rate for housing $\delta_h = 0.01$ and the weight of housing in the utility function $j_h = 0.2$ jointly set the ratio of residential investment over the total output to be 8 percent. Combined with the capital shares in the production $\alpha_c = \alpha_h = 0.3$, the depreciation rate for capital pins down the ratio of business investment over total output at 28 percent. For the land share, we fix it at 0.1 and 0.15 in the consumption goods and housing production function, respectively, to match that the value of land purchased by housing firms is 1 percent of GDP. The LTV ratio ω is chosen to be 0.6 because in China for the first mortgage downpayment is about 20-30% of housing value, and for the second it is around 50%.

The adjustment cost parameters ϕ_{kc} and ϕ_{kh} are broadly in line with Iacoviello and Neri (2010)'s estimation. For the shock relevant parameters, we also take the values directly from their work. All types of shocks share the same distribution; the persistence parameter ρ is around 0.8, and the standard deviation of the innovations is 0.01. Turning to the labor supply, we choose the inverse elasticity of substitution between two sectors at 1 and the elasticity of total labor supply at 1.3 ($\varphi = 0.75$).

Table 3.2: Calibration

Parameter	Description	Value	Source
β	discount factor	0.98	annual interest rate
α_c, α_h	share of capital in production	0.3, 0.35	ss investment rate
ϕ_{lc}, ϕ_{lh}	share of land in production	0.1, 0.2	ss land value
δ, δ_h	depreciation rates	0.025, 0.01	Iacoviello (2005)
ϕ_{kc}, ϕ_{kh}	adjustment cost on investment	10	Iacoviello (2005)
j_h	utility of housing holding	0.2	ss residential investment
ρ_l	inverse elasticity of substitution of labor supply	1	Iacoviello (2005)
φ	inverse Frisch elasticity of total labor supply	0.75	
ω	LTV ratio	0.6	ss credit value
ρ	shock persistence	0.8	standard parameter
σ	shock standard deviation	0.01	standard parameter

Steady State Targets

	Ratios to GDP	Model	Data (2016)
$\frac{C+Ce}{Y}$	consumption	0.48	0.49
$\frac{I}{Y}$	business investment	0.34	0.29
$\frac{G}{Y}$	government spending	0.11	0.13
$\frac{ph*Y_h}{Y}$	residential investment	0.07	0.09

3.6 Results

3.6.1 Statistics: Growth Rate on Balanced Growth Path

The first step toward characterizing equilibrium dynamics is solving the model's balanced growth path (BGP). We have a multi-sector model in which the trend growth rate of productivity varies across sectors. A balanced growth path exists because preferences and all production functions have a Cobb–Douglas form. The gross trend growth rates of different variables are described in Table 3.3. Overall, these developments in consumption, capital investment, and housing price are consistent with a general equilibrium model. However, the growth of residential investment and residential land prices are larger than that along the BGP in a general equilibrium model.

Table 3.3: Growth Rate: Data vs Model at Balanced Growth Path

	Model	Data	Growth Rate
G_{ac}	2.5	3.08	technology in nonhousing sector
G_{ah}	0.75	1.0	technology in housing sector
G_{kc}	2.5	2.25	business investment in nonhousing sector
G_{kh}	3.8	4.5	business investment in housing sector
G_c	2.1	2.15	consumption
G_{ph*yh}	2.1	4.4	residential investment
G_{ph}	0.4	0.42	house prices
G_{plc}	1.25	0.95	agriculture land prices
G_{lc}	0.65	0.55	agriculture land supply
G_{plh}	1.25	1.75	residential land prices
G_{lh}	0.65	0.625	residential land supply

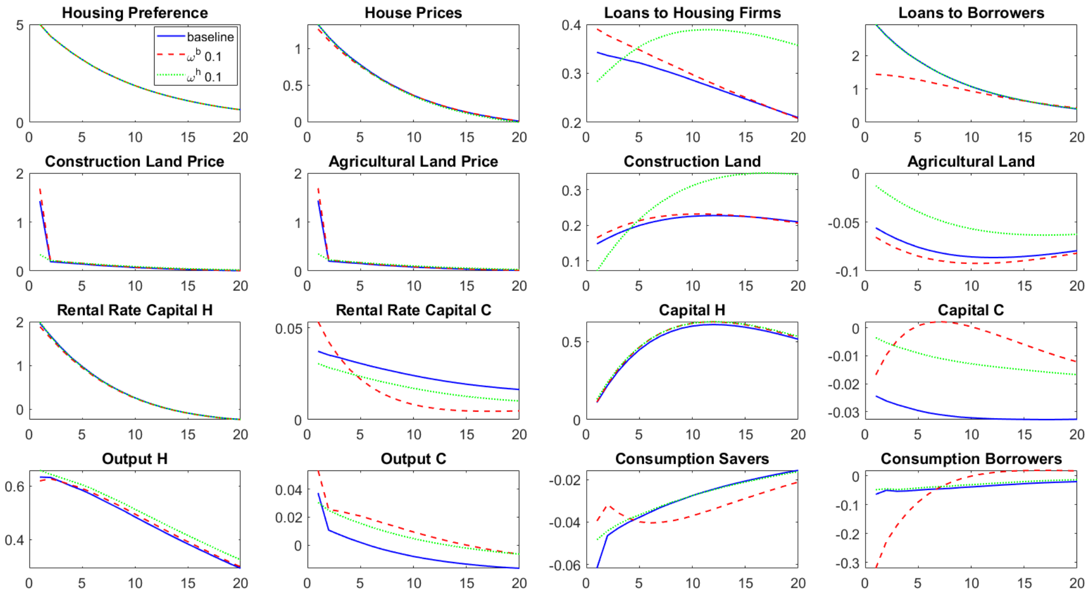
3.6.2 Impulse Responses to a Housing Preference Shock

Following the discussion in Liu et al. (2013), we introduce a housing demand shock as the primary driving force behind housing price changes, which also work through credit constraints. Figure 3.4 plots the impulse responses of the model economy to a positive shock to housing preference.

From the simulation result, we see that an increase in housing demand reduces capital investment and output in the non-housing sector. There are several contributing factors. First, a positive housing preference shock drives up housing prices; rising returns to housing investment encourage housing firms to purchase more capital and construction land for production, causing the cost of capital investment to increase for the non-housing sector. Second, rising housing prices relax the borrowing constraints for impatient households, spurring further housing demand. Third, construction land prices go up as a response to higher land demand from housing firms. On the one hand, this motivates local governments to convert agricultural land into construction land; on the other hand, housing firms' borrowing constraints also relax, allowing them to borrow more for housing production. Together, the rising costs of production inputs and the reduced land supply result in lower capital investment and output for non-housing firms.

To reveal the role of collateral constraints in the transmission, we plot the impulse responses in economies featuring small loan-to-value ratios for borrowers and housing firms. When the borrowing capacity of impatient households becomes small, the boosting effects of an increased housing price on their demand through credit constraint is attenuated. Thus housing prices rise more slowly, and housing firms' demand for capital and land gets weaker. When housing firms can only borrow a small fraction against the value of land, they receive less funding to compete to acquire production inputs. In both cases, the drop in capital investment and output in the non-housing sectors become smaller. To summarize, these two collateral constraints amplify and propagate the crowding out effect of a housing demand shock on the non-housing sector.

Figure 3.4: IRFs: A Positive Shock to Housing Preference



Notes: We plot the impluse responses to a positive shock to housing preference. The vertical axis shows the percentage deviations of all variables. The blue line is in our baseline model; the red line is in an economy featuring a small loan-to-value ratio for borrowers 0.1; the green line is in an economy featuring a small loan-to-value ratio for housing firms 0.1.

3.7 Policy Analysis

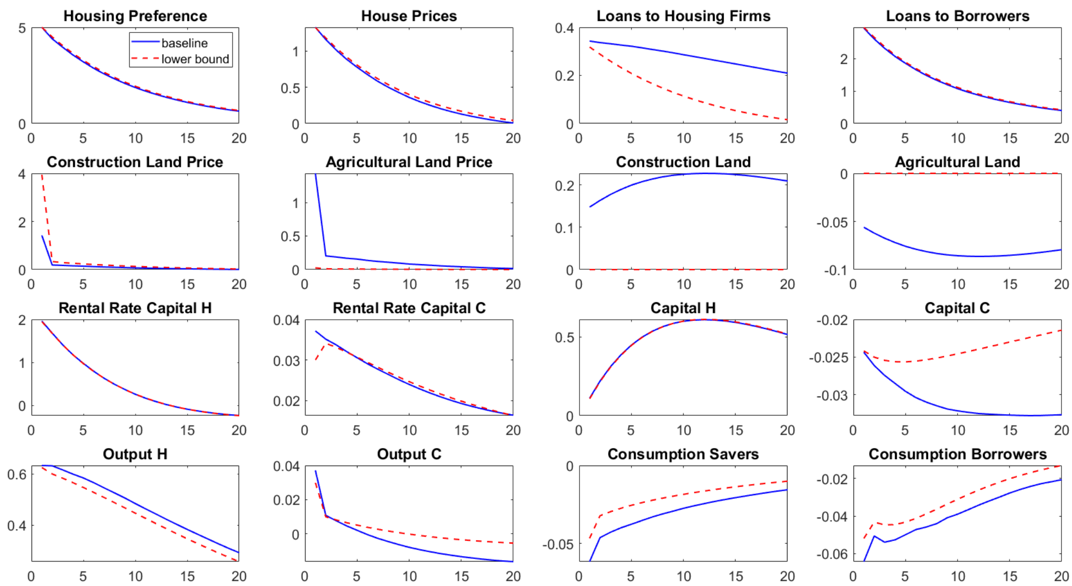
The National Land Use Plan of 2006–2020 required that land available for construction in urban and rural areas be limited to 506.25 million acres by 2010 and 508.7 million acres by 2020, and the total amount of agricultural land should be kept at a minimum of 1800 million acres. The objectives of this policy were to avoid unrestricted exploitation of land for non-agricultural use and stabilize the housing market and the economy.

In this section, we evaluate the effectiveness of this policy using our model. To do this, we introduce a lower bound on the stock of agricultural land, which constrains local governments from converting it into construction land

$$Land_{c,t} - \underline{Land_c} \geq 0,$$

then we compare the impulse responses to a positive housing preference shock in our benchmark model and in the economy with this lower bound. The results are plotted in Figure 3.5.

Figure 3.5: IRFs with a Lower Bound on Agricultural Land



Notes: We plot the impluse responses to a positive shock to housing preference. The vertical axis shows the percentage deviations of all variables. The blue line is in our baseline model; the red line is in an economy where a lower bound on agricultural land is put.

As housing demand goes up, housing firms need more construction land for the production process, motivating local governments to convert agricultural land into residential use. In a case that the lower bound on the stock of agricultural land is hit, local governments cannot supply more construction land to housing firms. Consequently, housing firms receive fewer loans to finance the acquisition of production inputs and produce less relative to the benchmark economy. The reduced competition in labor, capital, and land market reduces the increase of costs, and therefore non-housing firms' capital investment and output drop less than in the benchmark model. That is, this land-use constraint policy helps mitigate the crowding out effect of a housing demand shock on non-housing activities.

3.8 Conclusions

This paper builds on a business cycle housing model in the tradition of Iacoviello and Neri (2010). In the model, we add the government as the supplier of land to housing and non-housing firms and credit constraints on the housing firms to examine the crowding out effect of housing price dynamics on the non-housing sector. Our analysis shows that the growth of residential investment and construction land price are larger than those in the BGP in a general equilibrium model. We introduce a positive housing demand shock to explain changes in the housing market. Following increased housing and land prices, we find that relaxation of collateral constraints on home buyers and housing firms propagates and amplifies the crowding out effect on the non-housing sector. The converting agricultural land into residential land by local governments for fiscal revenue also strengthens the crowding out effect.

3.A Mathematical derivations

3.A.1 The Model

The patient households maximize their lifetime utility subject to the above constraint, the dynamic programming is given by

$$maxE_t \sum_{i=0}^{\infty} (\beta G_c)^i \{\ln C_{s,t+i} + j h_{t+i} \ln h_{s,t+i} - \chi \frac{N_{s,t+i}^{1+\varphi}}{1+\varphi} + \mu_{s,t+i}[w_{s,t+i}^c N_{s,t+i}^c + w_{s,t+i}^h N_{s,t+i}^h +$$
$$+(R_{c,t+i}+\frac{1-\delta_k}{A_{kc,t+i}})K_{c,t+i-1}+(R_{h,t+i}+\frac{1-\delta_k}{A_{kh,t+i}})K_{h,t+i-1}-\phi_{k,t+i}+(1-\delta_h)P_{h,t+i}h_{s,t+i-1}+R_{t+i}S_{t+i-1}-C_{s,t+i}-$$
$$\frac{K_{c,t+i}}{A_{kc,t+i}} - \frac{K_{h,t+i}}{A_{kh,t+i}} - P_{h,t+i}h_{s,t+i} - S_{t+i} - \phi_{k,t+i} - T_{t+i}],\}$$

where the adjustment cost on capital $\phi_{k,t}$ is

$$\phi_{k,t} = \frac{\phi_{kc}}{2}(\frac{K_{c,t}}{K_{c,t-1}} - G_{kc})^2 \frac{K_{c,t-1}}{(1+\gamma_{kc})^t} + \frac{\phi_{kh}}{2}(\frac{K_{h,t}}{K_{h,t-1}} - G_{kh})^2 \frac{K_{h,t-1}}{(1+\gamma_{kh})^t}.$$

The first-order conditions of the household's maximization problem are

$$\frac{1}{C_{s,t}} - \mu_{s,t} = 0,$$

$$\frac{j_t}{h_{s,t}} - \mu_{s,t}P_{h,t} + E_t\mu_{s,t+1}\beta G_s^c(1-\delta_h)P_{h,t+1} = 0,$$
$$\mu_{s,t}(\frac{1}{A_{kc,t}} + \frac{\partial\phi_{k,t}}{\partial K_{c,t}}) = E_t\beta G_s^c\mu_{s,t+1}[R_{c,t+1} + \frac{1-\delta_k}{A_{kc,t+1}} - \frac{\partial\phi_{k,t+1}}{\partial K_{c,t}}],$$
$$\mu_{s,t}(\frac{1}{A_{kh,t}} + \frac{\partial\phi_{k,t}}{\partial K_{h,t}}) = E_t\beta G_s^c\mu_{s,t+1}[R_{h,t+1} + \frac{1-\delta_k}{A_{kh,t+1}} - \frac{\partial\phi_{k,t+1}}{\partial K_{h,t}}],$$
$$\mu_{s,t} = E_t\beta G_s^c\mu_{s,t+1}R_t,$$
$$\mu_{s,t}w_{s,t}^c = \chi N_t^{\varphi-\rho_l}(N_{s,t}^c)^{\rho_l},$$
$$\mu_{s,t}w_{s,t}^h = \chi N_t^{\varphi-\rho_l}(N_{s,t}^h)^{\rho_l}.$$

The impatient households maximize their lifetime utility subject to the above constraint, the dynamic programming is given by

$$maxE_t \sum_{i=0}^{\infty} (\beta G_c)^i \{\ln C_{b,t+i} + j h_{t+i} \ln h_{b,t+i} - \chi \frac{N_{b,t+i}^{1+\varphi}}{1+\varphi} + \mu_{b,t+i}[w_{b,t+i}^c N_{b,t+i}^c + w_{b,t+i}^h N_{b,t+i}^h +$$
$$+ (1-\delta_h)P_{h,t+i}h_{b,t+i-1} + B_{b,t+i} - C_{b,t+i} - P_{h,t+i}h_{b,t+i} - R_{t+i-1}B_{b,t+i-1}]$$
$$+ \lambda_{t+i}^b[\omega^b \frac{P_{h,t+i+1}h_{b,t+i}}{R_{t+i}} - B_{b,t+i}]\}.$$

The first-order conditions for impatient households' optimization problem are:

$$\frac{1}{C_{b,t}} - \mu_{b,t} = 0,$$

$$\frac{j_t}{h_{b,t}} - \mu_{b,t} P_{h,t} + E_t \mu_{b,t+1} \beta G_b^c (1-\delta_h) P_{h,t+1} + E_t \lambda_t^b \frac{\omega^b P_{h,t+1}}{R_t} = 0,$$

$$\mu_{b,t} = E_t \beta G_b^c \mu_{b,t+1} R_t + \lambda_t^b,$$

$$\mu_{b,t} w_{b,t}^c = \chi N_t^{\varphi-\rho_l} (N_{b,t}^c)^{\rho_l},$$

$$\mu_{b,t} w_{b,t}^h = \chi N_t^{\varphi-\rho_l} (N_{b,t}^h)^{\rho_l}.$$

The housing firms' decision program is given by

$$maxE_t \sum_{i=0}^{\infty} (\beta' G_{ce})^i \{ lnC_{h,t+i} + \mu_{h,t+i} [P_{h,t+i} Y_{h,t+i} - w_{h,t+i} N_{h,t+i} - R_{h,t+i} K_{h,t-1+i} + B_{h,t+i} - R_{t+i-1} B_{h,t-1+i}$$
$$- P_{lh,t+i} (Land_{h,t+i} - Land_{h,t-1+i}) - C_{h,t+i} - a(Z_{h,t+i}) Land_{h,t+i-1}] + \lambda_{t+i}^h [\omega^h \frac{P_{lh,t+i+1} Land_{h,t+i}}{R_{t+i}} - B_{h,t+i}]\}.$$

The first-order conditions are

$$\mu_{h,t} = \frac{1}{C_{h,t}},$$

$$w_{h,t} = (1-\alpha_h - \phi_h) P_{h,t} \frac{Y_{h,t}}{L_{h,t}},$$

$$R_{h,t} = \alpha_h P_{h,t} \frac{Y_{h,t}}{K_{h,t-1}},$$

$$P_{lh,t} = E_t \{ \beta' G_h^c \frac{\mu_{h,t+1}}{\mu_{h,t}} [\phi_h P_{h,t+1} \frac{Y_{h,t+1}}{Land_{h,t}} + P_{lh,t+1} - a(Z_{h,t})] + \frac{\lambda_t^h}{\mu_{h,t}} \frac{\omega^h P_{lh,t+1}}{R_t} \},$$

$$\phi_h \frac{P_{h,t} Y_{h,t}}{Z_{h,t} Land_{h,t-1}} = \kappa_1 + \kappa_2 (Z_{h,t} - 1),$$

$$\mu_{h,t} = E_t \beta' G_h^c \mu_{h,t+1} R_t + \lambda_t^h.$$

3.A.2 BGP

We first transform growing variables into ones stable around steady state and then calculate the net growth rates for these variables X_j. From the production function we know $X_Y = (1-\alpha_c) * \gamma_{ac} + \alpha_c * X_{kc}$ and we know those variables grow at the same rate: $Y_c, P_h Y_h, C, Ce, \frac{K_c}{A_{kc}}, \frac{K_h}{A_{kh}}$, combining with $X_Y = X_{kc} - \gamma_{kc}$ we can find

$$X_Y = \gamma_{ac} + \frac{\alpha_c}{1-\alpha_c} \gamma_{kc},$$

$$X_{kc} = \gamma_{ac} + \frac{\gamma_{kc}}{1-\alpha_c},$$

$$X_{kh} = \gamma_{ac} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc} + \gamma_{kh},$$

using the production function of housing

$$X_h = (1-\alpha_h-\phi_h) * \gamma_{ah} + \alpha_h * X_{kh} + \phi_h * \gamma_L$$

$$X_h = (1-\alpha_h-\phi_h) * \gamma_{ah} + \alpha_h * (\gamma_{ac} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc} + \gamma_{kh}) + \phi_h * \gamma_L$$

$$X_h = (1-\alpha_h-\phi_h) * \gamma_{ah} + \alpha_h * \gamma_{ac} + \frac{\alpha_c\alpha_h}{1-\alpha_c}\gamma_{kc} + \alpha_h * \gamma_{kh} + \phi_h * \gamma_L.$$

then

$$X_{ph} = X_Y - X_h = (1-\alpha_h)\gamma_{ac} + \frac{\alpha_c(1-\alpha_h)}{1-\alpha_c}\gamma_{kc} - (1-\alpha_h-\phi_h) * \gamma_{ah} - \alpha_h * \gamma_{kh} - \phi_h * \gamma_L,$$

$$X_{ql} = X_Y - X_l = \gamma_{ac} + \frac{\alpha_c}{1-\alpha_c}\gamma_{kc} - \gamma_L.$$

3.B Data

- House prices: 70 large and medium cities in the new housing price index
- Land: At the enterprise level we have total value of land (100 million yuan) and land space purchased (10000 sq.m) of enterprises for real estate development to calculate land purchase price(NBSC).
- Residential and non-residential investment: Total Investment in Residential Buildings in Real Estate Development, Accumulated (100 million yuan). Data from China's National Bureau of Statistics
- Loans: Loanh refers to loans of all forms provided by financial institutions to housing firms for development of real estate. Data are from the People's Bank of China.
- Real Estate: Floor Space of commercialized Residential Buildings completed and Sold, Accumulated(10000 sq.m). From China's National Bureau of Statistics

4 Gender Effects of the Covid-19 Pandemic in the Swiss Labor Market

Joint work with Prof. Luisa Lambertini (EPFL) and Dr. Corinne Dubois (University of Fribourg)

We use the Swiss Labor Force Survey data to study how the Covid-19 pandemic affected the labor market activity of men and women. We employ a diff-in-diff identification to test whether the gender gap in labor market outcomes, such as employment, unemployment and non-active status, reliance on short-time working scheme, hours worked and family leave, has changed during the Covid-19 pandemic. Our results suggest that women have been more likely to exit the labor market altogether or to use short-time working schemes than their male counterparts. Contrary to the evidence in other countries, family related factors play a positive role in improving the participation of female into the Swiss labor market during the pandemic. Occupation type, however, helps explain the disproportionate negative effect of Covid-19 on women.

4.1 Introduction

The Covid-19 pandemic and the policy measures to contain it have created a major economic recession worldwide. This pandemic has also been a great magnifier of inequalities in many countries. Previous studies (Alon et al. (2020), Collins et al. (2021), Bluedorn et al. (2021) among others) reveal that gender inequality in the labor market, in particular, has increased due to the Covid-19 crisis. For this reason, the term "she-cession" has been used by researchers and the media to characterize the pandemic-fueled recession of 2020. Our paper is inspired by these novel findings on the gendered consequences of the Covid-19 pandemic in the labor market. We aim to understand whether Switzerland has also experienced a she-cession during the Covid-19 crisis and explore which factors can account for it.

We start by documenting the gender gap in labor market outcomes in terms of indicators such as labor market participation, unemployment, working hours, leaves of absence, and short-time work, and examining whether the gap has changed during the Covid-19 pandemic. To do this, we employ a diff-in-diff approach on the Swiss labor force survey data and control for usual labor market confounders, including age, education, location, sector, and occupation. Our results suggest a significant and persistent increase in the gender gap in labor market non-participation (extensive margin), but rather a closing of the gap in the number of working hours (intensive margin), which is in line with findings in other countries (Bluedorn et al. (2021)). However, we find no evidence of a gender gap in unemployment in Switzerland. This may be related to the massive usage of short-time work, a temporary reduction of working activity while maintaining the employment relationship. We provide evidence on a large gender gap of that; women have been more likely to engage in short-time work than men during Covid-19. To understand the gender effects fully, we also look into labor market flows and find two factors contributing to the increased gender gap of being non-active. First, the transition from unemployment to inactivity increases more for women than men upon impact. Second, women tend to remain non-active during the recovery.

An important reason that has been documented for the disproportionate negative effect on women is increased family responsibilities due to school closures (Fabrizio et al. (2021), Zamarro and Prados (2021), Andrew et al. (2020)). The empirical evidence for Switzerland, however, challenges this view. Our results suggest that being married or having children has been associated with a reduction of the gender gap in non-participation and short-time work during the pandemic. This may be due to a family insurance mechanism, where women keep or take new employment or increase their working hours to make up for the potential income loss of their partners.

We then turn our attention to the role of occupation and telework availability as a factor to explain the gender gap. When controlling for the Covid-19 specific occupation and sector effects, we find that the gender gap of being non-active disappears, suggesting that the gap is mainly due to industry and occupation differences. After categorizing occupations by telework availability, we also find that the gender gap of being non-active disappears for respondents having high-telework jobs but still exists among respondents having low telework jobs. This result is in line with international findings in Alon et al. (2021) and Shibata (2020), who argue that the increase of telework availability can reduce gender inequalities in the labor market.

Finally, we provide some suggestive evidence on the increased gender income gap between 2019 and 2020. Women having jobs with low telework availability have been more severely affected by the pandemic and are more likely to experience an income loss than their male counterparts. This contributes to an increase in the overall gender income gap.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 and 4 describe the labor force survey data and our regression design. Section 5 presents changes in labor market status. Section 6 discusses the reliance on short-time working scheme. Section 7 focuses on the effects on working behavior of employed respondents. Section 8 shows changes in gender pay gap. Section 9 concludes.

4.2 Literature

The Covid-19 pandemic and the containment measures had a major impact on labor markets in many countries. Many studies document a decline in working hours and job losses during the crisis (Cajner et al. (2020), Bick and Blandin (2020)). Coibion et al. (2020), for example use large-scale household survey data in the U.S. to document an extraordinary decline in the labor force participation rate, due to a great number of jobs lost and the fact that many of the newly unemployed did not look for new work. Forsythe et al. (2020) analyze unemployment insurance (UI) claims and vacancy data in the U.S. and find a significant drop in job vacancy postings and a spike in UI claims between February and April 2020, regardless of the timing of containment measures taken in each of the states. Juranek et al. (2020) consider North-European coutries and show that Sweden, where containment policies were the mildest, experienced significantly lower unemployment and furlough spells compared to neighboring countries. Accounting for cross-state variation in the timing of business closures and stay-at-home mandates, Gupta et al. (2020) suggest that the employment rate fell by about 1.7 percentage points for every extra 10 days that a state experienced a stay-at-home mandate in March and April 2020.

A subset of this literature studies the heterogeneous effects of the Covid-19 crisis across sectors, occupations and worker characteristics. Leibovici et al. (2020) and Mongey and Weinberg (2020) focus on occupation types and classify them by work-from-home or personal-proximity measures. Using decomposition techniques, Montenovo et al. (2020) quantify the gross differences in job losses across demographic subpopulations, defined by age, gender, race, parental status, and education. Our analysis confirms there is a large effect of the Covid-19 crisis on the Swiss labor market, but we rather focus on the differential impact for male and female workers.

Recent literature provides evidence that the current Covid-19 crisis has a disproportionate negative effect on women. One important reason for differential gendered impact is that women bear the brunt of increased childcare needs due to school and daycare closures. Summarizing the distribution of family types, Alon et al. (2020) find that there are more single mothers than single fathers, and among couples women have a lower occupancy rate. Taken together, more women than men will be strongly affected by the rise in child care needs. Collins et al. (2021) use the US Current Population Survey to examine the impact of Covid-19 pandemic on working hours and find that mothers with young children have reduced their working hours four to five times more than fathers. On the other hand, Farré et al. (2020) and Sevilla and Smith (2020) suggest that the childcare allocation within households may have slightly improved during the crisis in couples where the father could work from home. Our results for Switzerland contrast with most previous findings, as we find that motherhood actually contributes to decrease the gender gap during the Covid-19 crisis.

Another potential reason for an increase in the employment gender gap during Covid-19 is that women may be over-represented in the most affected sectors and occupations. Mongey and Weinberg (2020) suggest that social distancing rules had the biggest effect on more female-dominated sectors, namely the service industry. Alon et al. (2021) provide a decomposition analysis and show that the differential occupation distribution accounts for 12 percent of the gender gap in the employment decline. Our results are consistent with these findings, as we document that the gender gap in non-activity status is mainly explained by gender differences in the distribution across occupations and sectors.

This paper also relates to the literature on labor market policies effectiveness in cushioning the consequences of the Covid-19 crisis. During this crisis, a prominent feature in policy has been the introduction and increased use of furloughing and short-time-working schemes. Kopp and Siegenthaler (2017), Hijzen and Venn (2011) and Abraham and Houseman (2014) study the effectiveness of short-time work schemes during the Great Recession and suggest it helped stabilizing employment. Adams-Prassl et al. (2020) compare the impact of the Covid-19 crisis in the U.K., the U.S. and Germany and find that German employees were substantially less affected by the crisis thanks to short-time work policy. Our analysis shows that short-time work in Switzerland was used massively, but that women were significantly more likely to be put on it than men.

4.3 Data and Descriptive Statistics

The Swiss Labor Force Survey (SLFS) is a quarterly survey conducted in Switzerland since 1991 among residents aged 15 and older. It aims to provide information on the structure of the labor force and employment behavior patterns. The survey is carried out by telephone on a representative sample of the population (around 120'000 annual interviews). The SLFS sample is a 4-wave rotating panel: the persons who participate in the survey are interviewed four times throughout 15 months.[1] The SLFS includes questions on current and previous employment, unemployment, working conditions, occupation, salary, job seeking, as well as general questions on education, household composition and other demographic characteristics. Our dataset includes quarterly data for the period 2019Q1 to 2020Q4; it contains a total of 231'667 observations, i.e., approximately 30'000 observations per quarter.

Figure 4.1 reports the dynamics of labor market status by gender between 2019Q1 and 2020Q4, and it displays asymmetric effects of the pandemic on men and women. Female labor market participation fell sharply in the second quarter of 2020 and returned to its pre-pandemic level by the end of the year. In contrast, the reduction in male labor market participation is less severe. Interestingly, the female unemployment rate did not increase in 2020Q2, but it jumped by 1.2 percentage points in 2020Q3; on the other hand, the male unemployment rate increased continuously over the two quarters. This evidence suggests that women were more likely than men to drop out of the labor market at the height of the pandemic and to return as unemployed in the next quarter. Our paper sheds light on the reasons behind this

[1] The interviews are conducted with a gap of 3 months between the first and the second interview, 9 months between the second and the third, and 3 months again between the third and the fourth.

gender-specific labor market response.

Figure 4.1: Labor Market Status by Gender

(a) Participation Rate

(b) Unemployment Rate

Notes: The participation rate is measured as the number of respondents who are in the labor force as a percentage of the total number of respondents. The unemployment rate is calculated as the number of respondents who are currently unemployed as a percentage of the total number of respondents in the labor force. These indicators are broken down by gender group and are measured as a percentage of each gender group.

We use the KOF stringency index, which records the stringency of Covid-19 policy measures in Switzerland, to capture the Covid-19 pandemic in our setting. The index is available at the cantonal level daily; we construct the national index as the (population) weighted average of the cantonal indices and convert daily to quarterly values by averaging. The value of the index ranges from 0 (= no measures) to 100 (= full lockdown); details on how to calculate the stringency index are provided in section 4.A. The national KOF stringency index is normalized into a scale of 1 and shown in Figure 4.2; stringency measures peaked in the second quarter of 2020, reaching the value of 0.75; they were reduced in the third quarter and raised again in the fourth quarter of 2020.

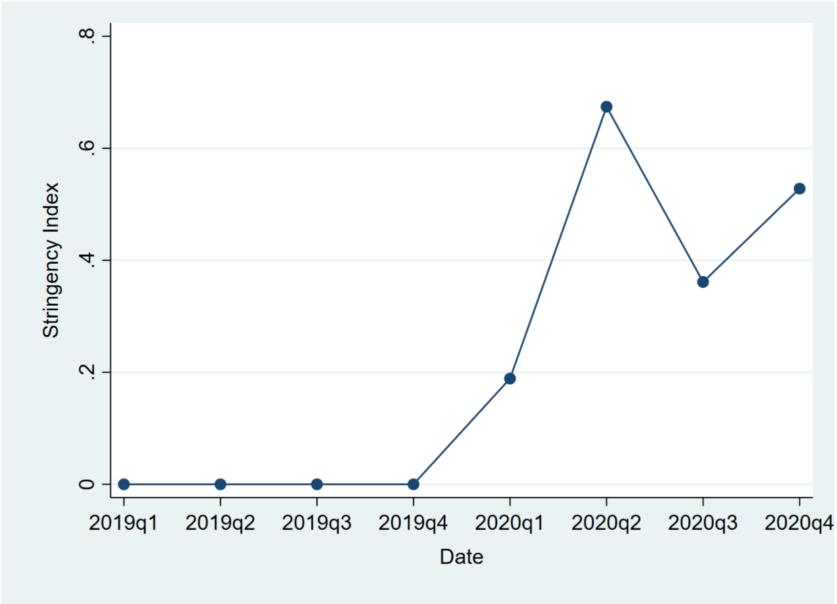
4.4 Regression Design

We use a diff-in-diff specification to study whether Covid-19 impacted differently men and women on the labor market. The typical regression specification looks as follows:

$$y_{i,t} = \gamma_1 female_i + \gamma_2 CovInd_t + \gamma_{cov} female_i \times CovInd_t + X_{i,t} + \epsilon_{i,t}, \tag{4.1}$$

where $y_{i,t}$ is the dependent variable of interest, including labor market status, short-time work, searching for jobs, having worked last week, working hours, and taking family leave. $female_i$ is a binary variable equal to one if the respondent is female. $CovInd_t$ is the Covid-19 stringency index shown in Figure 4.2; $X_{i,t}$ is a vector of covariates, including age cohort, indicators for occupation, location, sector of economic activity and the level of education. Suppose $y_{i,t}$ is the labor market status of the respondent, which is set as a dummy equal to

Figure 4.2: KOF Stringency Index



Notes: The index record the stringency of Covid-19 policy measures in Switzerland. It is constructed as the (population) weighted average of the cantonal indexes. The values range from 0 (=no measures) to 1 (=full lockdown). Source: KOF Swiss Economic Institute.

one for employed and zero for unemployed and non-active. Then γ_1 measures the differential likelihood of female respondents to be employed relative to male respondents. γ_2 is the differential likelihood of both male and female respondents to be employed during the Covid-19 crisis relative to normal times; γ_{cov} is our parameter of interest, it captures the employment gender gap differential caused by Covid-19.[2]

To capture the effect of a specific factor $z_i \in X_i$ on female's differential likelihood of being employed during Covid-19, we use a triple diff regression of the following type:

$$\begin{aligned} y_{i,t} = & \gamma_1 female_i + \gamma_2 CovInd_t + \gamma_3 z_{i,t} + \gamma_4 female_i \times z_{i,t} + \gamma_5 CovInd_t \times z_{i,t} \\ & + \gamma_{cov} female_i \times CovInd_t + \gamma_{cov,z} female_i \times CovInd_t \times z_{i,t} + X_{i,t} + \epsilon_{i,t}, \end{aligned} \tag{4.2}$$

where $z_{i,t}$ is the specific independent variable of interest, which is part of the vector of co-variates $X_{i,t}$, including family type, sector code, and occupation level. $\gamma_{cov,z}$ captures the differential effect of $z_{i,t}$ on a female's differential likelihood of being employed during Covid-19.

[2]To check the robustness of our estimations, we replace the KOF stringency index by a Covid dummy that equals one for quarters two, three and four of 2020 and report the results in section 4.B.

4.5 Covid-19 and Labor Market Status

We start our empirical analysis by studying how the Covid-19 pandemic impacted the labor market status of male and female respondents and which characteristics help explain the differential effects.

4.5.1 Effect of Gender and Covid-19 on Labor Market Status

Table 4.1 presents the estimates based on regression (4.1) with labor market status as the dependent variables. Labor market status is set as a dummy with value 1 if the person is employed (column 1), unemployed (column 2), or non-active (column 3); we control for the respondent's age, level of education, canton of residence, type of occupation (ISCO code) and the type of economic activity as measured by NOGA 1st level code.[3] In this regression, we only consider working-age population, i.e. respondents aged less than 65 years old.

Several findings in Table 4.1 are worth mentioning. First, women are more likely to exit the labor market and be non-active during Covid-19, both relative to men and relative to women during normal times. All respondents are more likely to be non-active when lockdown measures are in place, but female respondents are significantly more likely to be so. Since we do not control the respondent's previous status,[4] this suggests that women either become discouraged and stop searching for new jobs or remain out from the labor market during the pandemic. Second, lockdown measures raise the probability of men being unemployed but do not affect that of women. Third, in normal times, women are less likely to be employed and more likely to be non-active than men. Overall, these findings confirm the well-known lower female participation in the Swiss labor market and suggest significantly higher exit rates for women during Covid-19.

To further analyze how the probability of being non-active evolves over time for men and women, we run the following regression:

$$y_{i,t} = \gamma_1 Q_t + \gamma_2 X_{i,t} + \epsilon_{i,t}, \tag{4.3}$$

where $y_{i,t}$ is the dummy variable equal to one if the respondent is non-active, Q_t are quarterly dummies and $X_{i,t}$ is the same vector of covariates as in regression (4.1). The coefficient of interest, γ_1 indicates the differential propensity to be non-active over the quarters compared to the baseline level in 2019Q1. The regression is run separately for male and female respondents, and the coefficient estimates of the quarterly dummies are plotted in Figure 4.3.

[3]For some of the survey respondents, the information on occupation and sector is not available; In particular, among the non-active respondents, only about half of the respondents report these information. We ensure that we keep all participants in the regression by inputting a generic code for all missing observations of these two variables. Results are robust to only including participants with information sector and occupation, as shows in Appendix section 4.B.

[4]We restrict our sample to respondents for whom we know previous labor market statuses and show how the pandemic affects their labor market transitions between different statuses in Table 4.2

Table 4.1: Covid-19 and Labor Market Status

	Employed	Unemployed	Non-active
female	-0.0408***	-0.00166	0.0412***
	(0.00232)	(0.00139)	(0.00205)
CovInd	-0.0165***	0.00556***	0.0117***
	(0.00278)	(0.00211)	(0.00252)
female × CovInd	-0.00165	-0.00461	0.00583*
	(0.00385)	(0.00292)	(0.00350)
constant	0.727***	0.0291	0.243***
	(0.0396)	(0.0233)	(0.0350)
Age FE	YES	YES	YES
Canton FE	YES	YES	YES
Education FE	YES	YES	YES
NOGA FE	YES	YES	YES
ISCO FE	YES	YES	YES
Observations	186881	186881	186881
R^2	0.417	0.0423	0.459

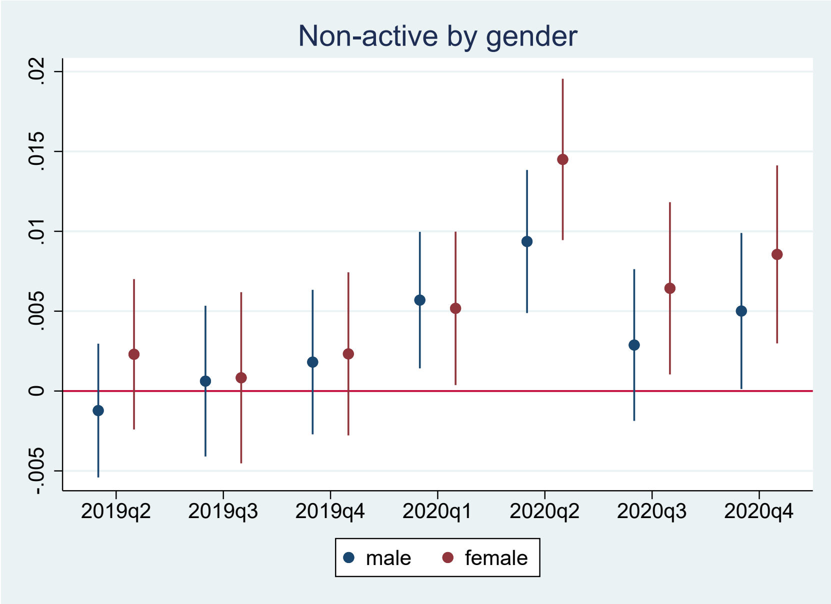
Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.1) of labor market status on a constant, female dummy (1 for women and 0 otherwise), Covid-19 stringency index and its intersection with the female dummy. Sample includes respondents aged 15 to 64. Regressions estimated with linear probability model, including random effects. Robust standard errors in parentheses.

First, we observe that the probability of being non-active increased during Covid-19 and peaked in the second quarter of 2020 when the strictest lockdown measures were adopted. Second, we find that there is a gender gap of being non-active during the Covid-19 periods. In the second quarter of 2020, men were 0.9% more likely to be non-active relative to 2019Q1, while women were about 1.5% more likely to be so. The non-active probability for both men and women falls in 2020Q3, when sanitary measures were relaxed, but increases again in quarter 4, following the resurgence of the pandemic in the Fall. While the dynamic is similar for men and women, the effect for women remains above that of men until the end of 2020. This evidence suggests that Covid-19 has persistently increased the gender gap between men and women probability of being non-active.

4.5.2 Labor Market Transitions by Gender

To better understand the influence of Covid-19 on the labor market, we take a look at the respondent's previous working status and quantitatively assess changes in labor market flows during the pandemic. We calculate the average transition probabilities between different labor market statuses for two consecutive periods, and do so separately for men and women respondents over time. In Table 4.2, row (a) reports the average probabilities in normal times, and rows (b) and (c) show the changes relative to that during the Covid-19 periods. *E*, *U* and *NA* refer to respondents' current labor market statuses of being employed, unemployed and non-active respectively; *L.E*, *L.U* and *L.NA* indicate their previous statuses.

Figure 4.3: Non-active Over Time for Men and Women



Notes: Estimates from regression (4.3) of non-active dummy on quarterly dummies, run separately for men (blue) and women (red), with 95% confidence intervals. Regressions estimated with linear probability model, including random effects.

In normal times, the probability of moving out of the labor market and remaining non-active are all higher for women than men, which is consistent with the lower female participation in the labor market. At the start of the pandemic (2020Q2), transitions from employment and unemployment to inactivity increase for all the respondents relative to normal times, and the effect is stronger for women. The probability of remaining non-active also goes up more for women than men. Entering the recovery phase of the pandemic (2020Q3-Q4), the probability of moving from unemployment to employment increase more quickly for women; however, women are less likely to return into the labor force from inactivity, as the probability of transitions from non-active to employment and unemployment are lower for women.

Comparing labor market transitions between normal times and the pandemic suggests two driving forces behind the higher likelihood of women being non-active during Covid-19. On the one hand, women are more likely to moving from unemployment into inactivity upon impact. On the other hand, women tend to remain non-active during the recovery.

4.5.3 Labor Market Status and Marital Status

A question arises as to what factors can account for the different labor market responses of men and women to the Covid-19 pandemic. To answer this, we first take a look at family related characteristics. Here we analyze whether marital status is related to the differentiated impact of the pandemic using regression (4.2). The dependent variables are still the labor

Table 4.2: Labor Market Transition Probabilities

	Men				Women			
		E	U	NA		E	U	NA
(a). PreCovid	L.E	96.59	0.96	2.45	L.E	95.74	1.02	3.24
	L.U	32.97	50.88	16.15	L.U	33.62	44.58	21.79
	L.NA	8.08	2.43	89.49	L.NA	6.64	2.47	90.89
		E	U	NA		E	U	NA
(b). Changes in 2020Q2	L.E	-0.29	0.19	0.1	L.E	-0.47	0	0.48
	L.U	-7.97	4.97	3	L.U	-9.48	4.85	4.65
	L.NA	-0.3	-0.63	0.93	L.NA	-1.19	-0.5	1.69
		E	U	NA		E	U	NA
(c). Changes in 2020Q3-Q4	L.E	-0.02	0.16	-0.14	L.E	0.31	0	-0.31
	L.U	-4.9	7.12	-2.23	L.U	0.68	5.2	-5.87
	L.NA	0.86	1.09	-1.95	L.NA	0.22	0.31	-0.53

Notes: E=employed; U=unemployed; NA=non-active. L.E, L.U, L.NA show previous statuses. Row (a) shows the average transition probabilities in normal times from 2019Q1 to 2020Q1. Row (b) and Row (c) present changes in the transition probabilities during Covid-19 relative to normal times. The results here are showed in percentage points.

market status dummies (*Employed*, *Unemployed* and *Non-active*); we add to the explanatory variables of Table 4.1 the marital status dummy (1 for married or in a registered relationship and 0 otherwise), its interaction with the female dummy and the Covid-19 index, as well as the triple interaction of female, Covid-19 index and marital status.

Table 4.3 reports the estimates. In normal times, unmarried women are less likely to be unemployed, but more likely to be non-active than men. In regard to marital status, the probability of being non-active or unemployed is higher and the probability of being employed is lower for married women relative to unmarried ones. These findings confirm the well-known lower participation of Swiss women in the labor force relative to their male counterparts, and suggest that marriage status is a contributing factor. Interestingly, marriage has played a positive role in motivating women to work during the pandemic. Our results show that while the pandemic magnified the gender gap in employment and non-participation between unmarried men and women, its effect on the married gender gap was significantly milder. Marriage therefore plays a different role in normal and crisis times: it amplifies the gender gap in labor market participation in normal times but rather tends to decrease it during the crisis. This result indicates a form of family insurance during the pandemic. Prior to Covid-19, married women are more likely to drop out of the labor force; it can be either that they have the flexibility in participating in the labor force or that they have to take family care responsibilities. During Covid-19, the probability of married women being employed has increased, possibly to offset the income loss of their partners.

4.5.4 Labor Market Status and Child Care

We continue to test whether having children influences men's and/or women's labor market response to the Covid-19 pandemic using regression (4.2). We add to our starting set of

Table 4.3: Covid-19, Labor Market and Marital Status

	Employed	Unemployed	Non-active
female	-0.00362	-0.00551***	0.00864***
	(0.00325)	(0.00197)	(0.00288)
CovInd	-0.0157***	0.00737**	0.0103***
	(0.00413)	(0.00313)	(0.00375)
female × CovInd	-0.0115**	-0.00586	0.0162***
	(0.00576)	(0.00437)	(0.00523)
married	0.0311***	-0.0134***	-0.0166***
	(0.00323)	(0.00196)	(0.00286)
married × female	-0.0692***	0.00732***	0.0603***
	(0.00559)	(0.00424)	(0.00508)
married × CovInd	-0.00110	-0.00373	0.00225
	(0.00559)	(0.00424)	(0.00508)
married × female × CovInd	0.0176**	0.00256	-0.0185***
	(0.00776)	(0.00589)	(0.00704)
Constant	0.706***	0.0329	0.260***
	(0.0395)	(0.0234)	(0.0350)
Age FE	YES	YES	YES
Canton FE	YES	YES	YES
Education FE	YES	YES	YES
NOGA FE	YES	YES	YES
ISCO FE	YES	YES	YES
Observations	186881	186881	186881
R^2	0.419	0.0429	0.460

Notes: * p<0.1, ** p<0.05, *** p<0.01
Estimates from regression (4.1) of labor market status on a constant, female dummy (1 for women and 0 otherwise), Covid-19 stringency index, marital status dummy(1 for married/in a registered relation and 0 otherwise), the interactions of female and Covid-19 stringency index, female and civil status dummies, Covid-19 stringency index and marital status dummy and the triple interaction of female and marital status dummies and Covid-19 stringency index. Sample includes respondents aged 15 to 64. Regressions estimated with linear probability model, including random effects. Robust standard errors in parentheses.

explanatory variables a dummy *child0-6*, that equals 1 if the respondent has children 6 years old or younger, and a dummy *child7-14*, that is equal to 1 if the respondent has children between 7 and 14 years old;[5] we also include the interaction of our two children dummies with the female dummy, their interaction with the Covid-19 index, and the triple interaction of female, Covid-19 index and children dummies.

Table 4.4 displays the estimates. In normal times, women are overall less likely to be employed but more likely to be non-active than men, and the presence of children largely increases these disparities, especially when said children are under 7 years old. During Covid-19, this gender gap in families with children aged between 7 and 14 is unaffected; while the probability of being non-active decreases and that of being employed increases for women in families with children under 7 years old. The results suggest that the presence of young children in the family plays a positive role in the labor market status differential of women during the

[5]The children dummies refer to the age of the youngest child in the household.

pandemic.

It is important to note that our findings differ from previous studies, which found that the gender gap in employment worsened with the presence of children during the Covid-19 crisis. There are several factors at play in reducing the gap. First, school/kindergarten closure policies are relatively lenient in Switzerland. For example, daycare centers were required by the government to remain open during the pandemic, which allows mothers of young children to work as usual. Second, mothers in Switzerland usually work part-time during normal times, which means that they can more easily hold on to their job during the crisis. Third, men can help share child care responsibilities during a lockdown, reducing the heavy burdens on the partner's shoulder.

The results have thus far shown that in Switzerland, women are more likely to leave the labor market than men during Covid-19. This may happen because women became discouraged from job searching. Therefore we examine the role of family factors in affecting worker's willingness to search for a new job. The last column of Table 4.4 focuses on people who have not been seeking new employment. The dependent variable is a dummy equal to 1 if the worker has stopped the job search for family reasons, 0 for other reasons. We find that women are more likely to stop the job search because of family duties, such as caring for children, than men; however, this disparity has been reduced during Covid-19. This is in line with what we found earlier; increased family responsibilities have not negatively impacted the differential likelihood of women searching for new jobs.

4.5.5 Labor Market Status and Occupation

Next, we turn to explore whether work related characteristics can explain the labor market responses of men and women to the Covid-19 pandemic using regression (4.2). There is evidence that some sectors and occupations have been affected differently by the Covid-19 pandemic. For this reason, we keep the labor market status dummies (*Employed*, *Unemployed* and *Non-active*) as dependent variables and add the interactions of dummies for occupations/sectors and the Covid-19 index as control variables, through which we account for the Covid specific sector-occupation effects. Table 4.5 reports the estimates. The insignificant estimates of the interaction between the female dummy and the Covid-19 index suggest that the observed differential effects on the labor market status of men and women in Table 4.1 are entirely due to industry and occupation differences.

We further test whether the availability of telework for a given occupation relates to the differentiated impact of the Covid-19 pandemic. We add to the explanatory variables of Table 4.1 a telework dummy *LowTele*, the interaction of this telework dummy with the female dummy and with the Covid-19 index, and the triple interaction of the female dummy, the Covid-19 index, and the telework dummy. The telework dummy *LowTele* equals 1 if respondents have a low probability of working from home, and it equals 0 otherwise. Figure 4.4 displays the percentage of workers who worked from home, either occasionally or regularly, during the last four weeks

Table 4.4: Covid-19, Labor Market Status and Child Care Responsibility

	Employed	Unemployed	Non-active	Nosearch_family
female	-0.0173***	-0.00726***	0.0230***	0.191***
	(0.00276)	(0.00167)	(0.00244)	(0.00651)
CovInd	-0.0167***	0.00449*	0.0129***	-0.00229
	(0.00335)	(0.00254)	(0.00304)	(0.0119)
female × CovInd	-0.00990**	-0.00409	0.0135***	-0.0328**
	(0.00466)	(0.00354)	(0.00423)	(0.0145)
child0-6	0.0309***	-0.0153***	-0.0165***	
	(0.00448)	(0.00279)	(0.00398)	
child7-14	0.0353***	-0.0162***	-0.0191***	
	(0.00457)	(0.00288)	(0.00407)	
child0-6 × female	-0.110***	0.0233***	0.0881***	
	(0.00604)	(0.00376)	(0.00537)	
child7-14 × female	-0.0429***	0.0142***	0.0294***	
	(0.00612)	(0.00384)	(0.00544)	
child0-6 × CovInd	-0.00218	0.00586	-0.00375	
	(0.00821)	(0.00622)	(0.00745)	
child7-14 × CovInd	0.00714	0.000584	-0.00723	
	(0.00841)	(0.00638)	(0.00763)	
child0-6 × female × CovInd	0.0453***	-0.00794	-0.0343***	
	(0.0112)	(0.00853)	(0.0102)	
child7-14 × female × CovInd	-0.000995	0.00734	-0.0101	
	(0.0115)	(0.00874)	(0.0104)	
Constant	0.714***	0.0384	0.247***	-0.0578
	(0.0410)	(0.0245)	(0.0363)	(0.107)
Age FE	YES	YES	YES	YES
Canton FE	YES	YES	YES	YES
Education FE	YES	YES	YES	YES
NOGA FE	YES	YES	YES	YES
ISCO FE	YES	YES	YES	YES
Observations	175360	175360	175360	27404
R^2	0.422	0.0426	0.462	0.315

Notes: * p<0.1, ** p<0.05, *** p<0.01
Estimates from regression (4.2) of labor market status and non job search for family reasons on a constant, female dummy (1 for women and 0 otherwise), Covid-19 stringency index, child dummies (child0-6 for having child(ren) under 7 years old, child7-14 for having school age child(ren)), the interactions of female dummy and Covid-19 stringency index, female and child dummies, Covid-19 stringency index and child dummies, and the triple interaction of female and child dummies and Covid-19 stringency index. Sample includes respondents aged 15 to 64. Regressions estimated with linear probability model, including random effects. Robust standard errors in parentheses.

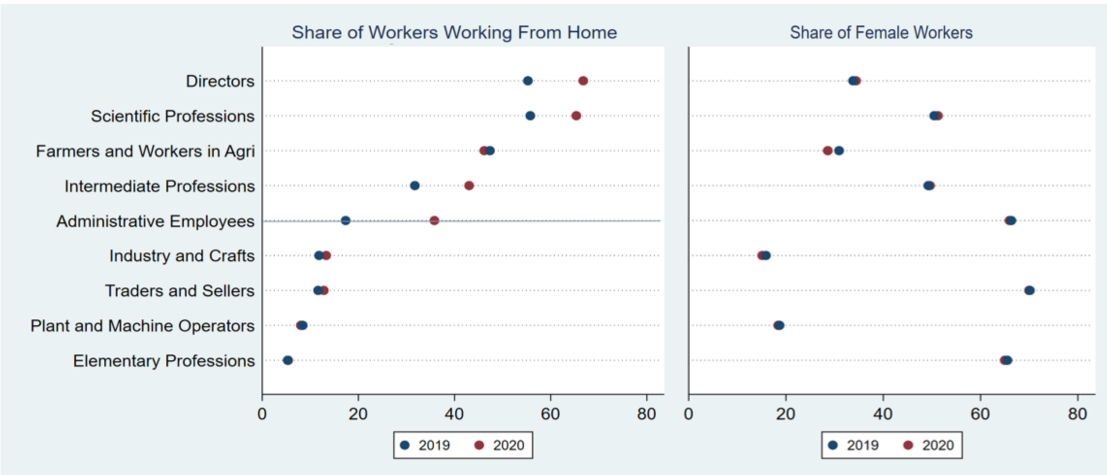
by occupation in 2019 and 2020. There is much variation in the probability of working from home across occupations. Directors, Scientific Professions, Farmers, Intermediate Professions, and Administrative Employees are much more likely to work from home, and that probability increased from 2019 to 2020 more than for other occupations. Hence, *LowTele* is equal to 0 if respondents work in the above occupations. Note that, occupations with a low likelihood of telework are typically blue-collar jobs, requiring physical labor and receiving less payment. However, they are not necessarily female-dominated, with the share of female workers ranging from 17% to 68%.

Table 4.5: Covid-19, Labor Market Status and Occupation

	Employed	Unemployed	Non-active
female	-0.0410***	-0.00251*	0.0423***
	(0.00236)	(0.00143)	(0.00209)
CovInd	0.0626	-0.0112	-0.0627
	(0.0958)	(0.0716)	(0.0869)
female × CovInd	-0.000766	-0.000875	0.000807
	(0.00431)	(0.00327)	(0.00391)
Constant	0.712***	0.0305	0.259***
	(0.0436)	(0.0269)	(0.0387)
Age FE	YES	YES	YES
Canton FE	YES	YES	YES
Education FE	YES	YES	YES
NOGA FE	YES	YES	YES
ISCO FE	YES	YES	YES
NOGA × CovInd	YES	YES	YES
ISCO × CovInd	YES	YES	YES
Observations	186881	186881	186881
R^2	0.417	0.0428	0.459

Notes: * p<0.1, ** p<0.05, *** p<0.01
We show estimates from regression (4.1) of labor market status after adding the intersection of the Covid-19 stringency index and dummies for occupations and sectors as controls. Regressions estimated with linear probability model, including random effects. Robust standard errors in parentheses.

Figure 4.4: Telework Availability and Female Share by Occupation



Notes: The share of workers working from home (telework) is measured as the number of respondents who can work from home as a percentage of the total number of respondents in each occupation group. The share of female workers is calculated as the number of respondents who are female as a percentage of the total number of respondents in each occupation group. We rank occupations in a descending order of telework in 2020.

Table 4.6 reports the estimates. In normal times, women are less likely to be unemployed but more likely to be non-active than men. This gender gap in employment is larger among respondents with jobs that have little opportunity for telework. During the Covid-19 crisis,

Table 4.6: Covid-19, Labor Market Status and Occupation

	Employed	Unemployed	Non-active
female	-0.0413***	0.00300*	0.0370***
	(0.00289)	(0.00164)	(0.00248)
CovInd	-0.0101***	0.00346	0.00739**
	(0.00354)	(0.00252)	(0.00299)
female × CovInd	-0.00357	-0.000196	0.00336
	(0.00490)	(0.00350)	(0.00415)
LowTele	-0.0137***	0.00803***	0.00508*
	(0.00358)	(0.00210)	(0.00306)
LowTele × female	-0.0176***	-0.00170	0.0195***
	(0.00479)	(0.00281)	(0.00410)
LowTele × CovInd	-0.0159**	0.0117***	0.00433
	(0.00623)	(0.00442)	(0.00527)
LowTele × female × CovInd	-0.00325	-0.0122*	0.0163**
	(0.00890)	(0.00631)	(0.00753)
Constant	0.883***	0.0230***	0.0942***
	(0.00786)	(0.00445)	(0.00674)
Age FE	YES	YES	YES
Canton FE	YES	YES	YES
Education FE	YES	YES	YES
NOGA FE	YES	YES	YES
Observations	171218	171218	171218
R^2	0.0611	0.0787	0.0415

Notes: * p<0.1, ** p<0.05, *** p<0.01
We shows estimates from regression (4.2) of labor market status on a constant, female dummy (1 for women and 0 otherwise), Covid-19 stringency index, LowTele dummy (1 for occupations with low telework and 0 otherwise), the interactions of female dummy and Covid-19 stringency index, female and LowTele dummies, Covid-19 stringency index and LowTele dummy and the triple interaction of female and LowTele dummies, and Covid-19 stringency index. Regressions estimated with linear probability model, including random effects. Robust standard errors in parentheses.

women with jobs of high telework availability are no more likely to have changed labor market status than men in identical jobs; however, women with low-telework jobs have become more likely to exit the labor market and less likely to be employed than their male counterparts. This suggests that women in occupations with low telework availability have been hit harder by the pandemic, driving higher exiting rates.

4.6 Covid-19 and Short-time Work

The analysis of section 4.5 showed that the Covid-19 crisis had a positive but mild effect on the unemployment rate in Switzerland. One important reason behind the mild response of unemployment is the massive usage of short-time work. This section reviews how the short-time work policy has evolved in Switzerland and analyzes whether there is a gender gap in the short-time work scheme during Covid-19.

4.6.1 Short-time Work in Switzerland

Short-time Work Before Covid-19

Short-time working (STW) is a public policy that allows firms facing a fall in demand to keep their employees while transferring the cost to the government. It is generally due to economic factors and can also be caused by the authorities or other measures beyond the employers' control. Unemployment insurance temporarily covers a proportion of the salary costs of employers whose employees are affected by short-time working. The short-time working compensation is paid to the employer after a waiting period of 2 days. It amounts to 80% of the loss of earnings attributable to the reduction in working hours, up to a maximum insured gain of 148'200 CHF yearly. The aim is to prevent redundancies resulting from unavoidable, short-term work stoppages. Note that employees have the right not to accept the short-time working compensation. In this case, the employer must continue paying their full salary. These employees are, however, at a higher risk of being laid off.

Changes to the Short-time Work Policy During the Covid-19 Crisis

In March 2020, the federal government decided to simplify and expedite the administrative procedures for requesting STW. The required justification and accounting were reduced, the 10-day notice for requesting STW was abolished, and the maximal validity extended from 3 to 6 months. Moreover, the government decided to broaden the access to short-time work. In particular, apprentices and employees on fixed-term contracts were excluded from STW before Covid-19 and were granted access to it in March 2020.

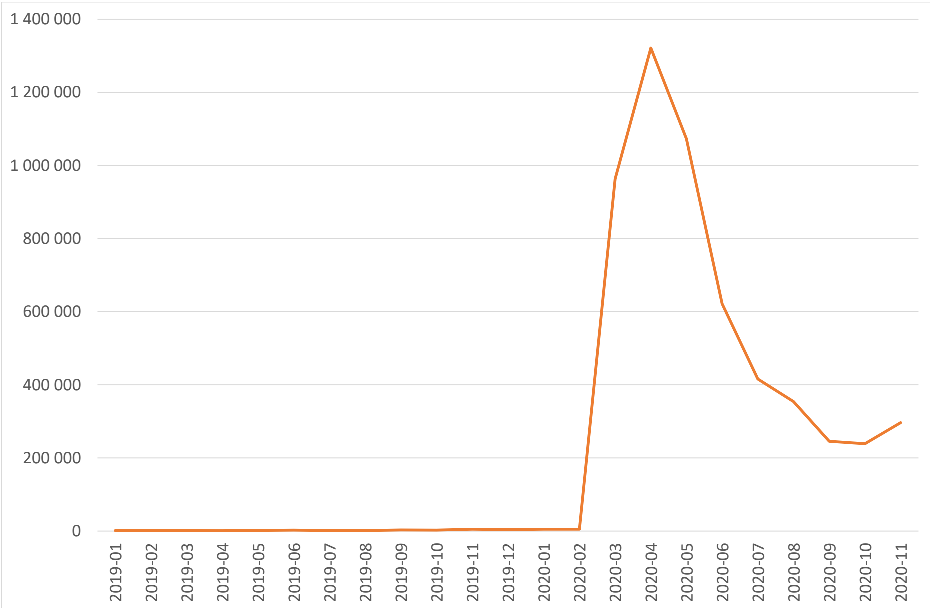
Employees in Short-time Work in Switzerland

Figure 4.5 shows the number of employees in short-time work in Switzerland in 2019 and 2020. In 2019, there were on average about 2000 employees in short-time work every month. This number jumped to about 1'000'000 in March 2020 due to the lockdown imposed by the government and peaked in April 2020. Following the relaxation of lockdown measures in May and June 2020, the recourse to short-time work diminished but remained two orders of magnitude higher than in 2019.

Figure 4.6 reports the number of employees in STW in April 2020 by canton, as a percentage of the number of employed persons in that canton. We observe significant variations in the share of employees in STW across cantons, ranging from less than 15% for Basel-city to almost 50% for Tessin. On average, the German-speaking cantons were less affected than the French and Italian-speaking cantons.

Finally, Figure 4.7 plots the share of employees in STW by economic sector in April 2020. The Covid-19 crisis and lockdown measures had differentiated effects across sectors. Lockdown measures included the complete shutdown of restaurants, non-essential shops, cinemas,

Figure 4.5: Employees in Short-time Work



Note: Data from the State Secretariat for Economic Affairs (SECO)

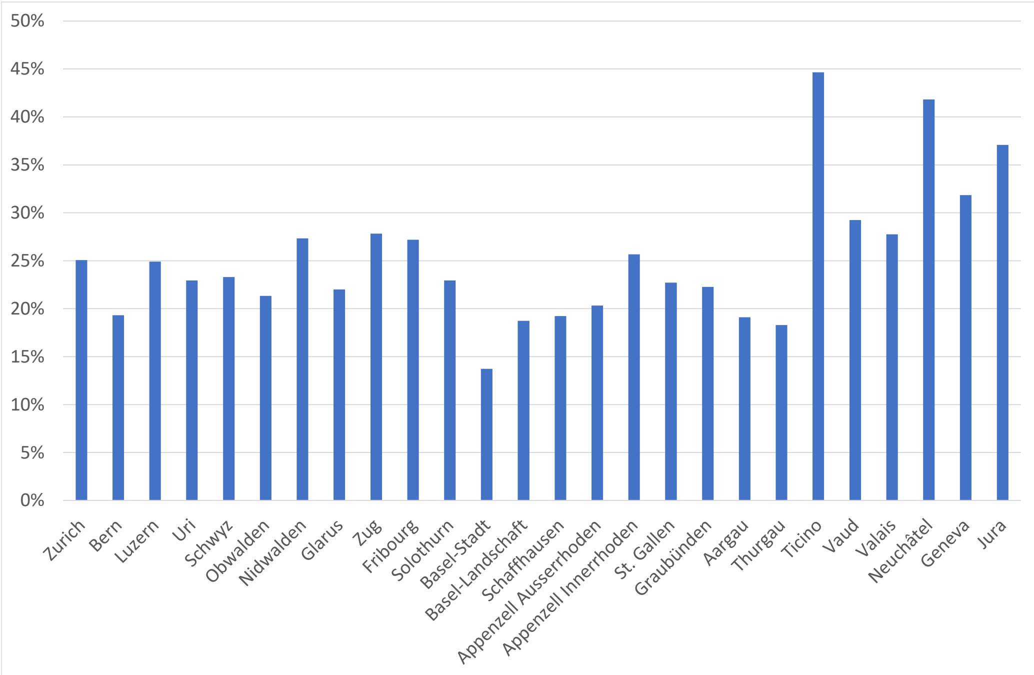
theaters, etc. Therefore, accommodation, food services, arts, and entertainment sectors were most severely affected. Sectors dealing with essential goods, such as agriculture and electricity, were affected little. Sectors, where most of the work could be done remotely, were also little affected, for example, the financial services sector.

4.6.2 Effect of Gender and Covid-19 on Short-time Work

This section analyzes how gender affects the probability of engaging in short-time work during the Covid-19 crisis. Table 4.7 displays the estimates from regressions where the dependent variable is a dummy that equals 1 if the person is on short-time work and 0 if not. Column (1) includes the Covid-19 index, the female dummy, and the interaction between the two, and controls for age, education, occupation type, sector of work, and canton of residence. The results confirm that the Covid-19 crisis strongly increased levels of short-time work for both men and women. The positive and significant coefficient on the interaction between *female* and *CovInd* indicates that women were more likely to be put on short-time work during the crisis, even after controlling for the usual labor market confounders.

Column (2) explores the role of the presence of children in the household. We include children dummies and their interactions with the female dummy and the Covid-19 index. We find that for men, the presence of children in the household does not significantly alter the probability

Figure 4.6: Employees in Short-time Work by Canton (% of Total Wmployees)



Note: Number of employees in STW in April 2020 (Source: SECO), divided by the total number of employees in each canton in 2018 (Source: Swiss federal statistical office).

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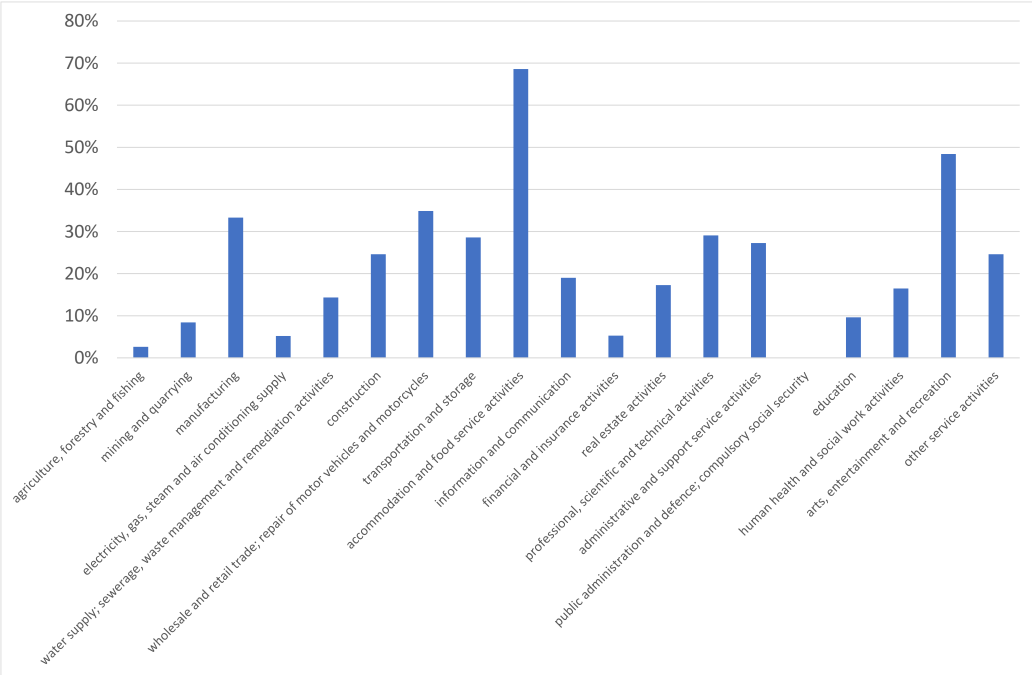
of being on short-time work during Covid-19. For women with children, the effect on STW is negative. The results suggest that while women have been overall more subject to short-time work during the Covid-19 crisis, the presence of children in the household does not explain the effect.

Column (3) addresses the effect of professional activity within couples on the short-time work levels. We restrict the sample to married couples and couples in a registered partnership and include a measure of family professional activity, which indicates the work arrangement of both respondent and his/her partner. We set a dummy *M-more*, that is equal to 1 if the man works a higher percentage than the woman, and another dummy *F-more*, equal to 1 if the woman works more than the man. The reference group is for egalitarian couples, in which men and women work the same amount. The coefficient on *female* when interacting with *CovInd* is insignificant, suggesting that for couples where the man and women work the same amount, there is no differential effect between men and women. The interaction effect is, however, positive and strongly significant between *female*, *CovInd* and *M-more*. This implies that women in relationships where the men work more are significantly more likely to be on short-time work during Covid-19. On the other hand, a woman in a couple where she works

Figure 4.7: Employees in Short-time Work by Sector (% of Total Employees)



Note: Number of employees in STW in April 2020 (Source: SECO), divided by the total number of employees in each sector in 2018 (Source: Swiss federal statistical office).

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more is less likely to take short-time work. Note that couples in which the man works more are more common than couples with an egalitarian distribution of work; couples, where the woman works more, are a small minority, as can be seen in Table 4.15 in the Appendix. It is interesting to observe that within couples where the woman works more, we do not find that men have significantly increased their reliance on short-time work during Covid-19. This suggests a difference in reaction to shocks within couples, with women being more likely to adjust. Therefore, the occupation model within couples is an important factor behind the differential effect of Covid-19 between men and women.

Another important factor that could explain the differential effect of Covid-19 on workers is the type of occupation, and in particular, whether a given occupation can be done remotely. Column (4) considers the role of telework availability of an occupation on recourse to short-time work. We add the dummy variable *LowTele*, as defined in subsection 4.5.5. The results show that having a job with low telework availability increases the probability of engaging in short-time work during the Covid-19 crisis. This effect is, however, significantly larger for women than for men, as can be seen in the positive and significant coefficient on the triple interaction term between *female*, *LowTele* and *CovInd*. Note that women in high-telework occupations are still more likely than men to be on short-time work. The telework availability of occupation is therefore an important driver of the short-time work gap, but does not entirely explain it. The results suggest that women, especially those who cannot work remotely, are more likely to engage in short-time work.

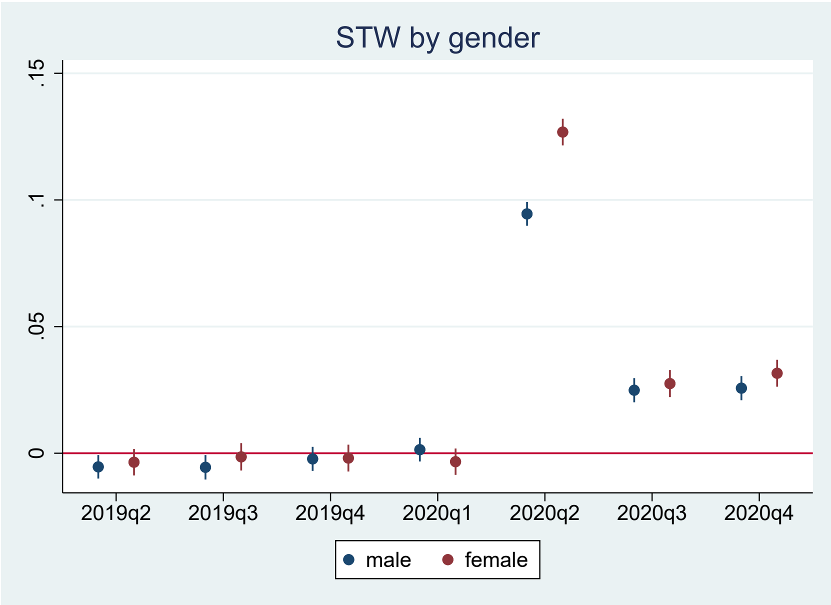
Table 4.7: The Effect of Covid-19 and Gender on STW

	In Short-time Work			
	(1)	(2)	(3)	(4)
female	0.000416	-0.000910	-0.000168	0.00154
	(0.00139)	(0.00172)	(0.00331)	(0.00160)
CovInd	0.112***	0.113***	0.124***	0.105***
	(0.00251)	(0.00309)	(0.00628)	(0.00304)
female × CovInd	0.0311***	0.0370***	0.0119	0.0198***
	(0.00360)	(0.00443)	(0.00892)	(0.00430)
child0-6 × CovInd		0.00167		
		(0.00731)		
child7-14 × CovInd		0.00130		
		(0.00752)		
female × child0-6 × CovInd		-0.0204*		
		(0.0105)		
female × child7-14 × CovInd		-0.0177*		
		(0.0106)		
M-more × CovInd			-0.0139*	
			(0.00742)	
F-more × CovInd			0.0178	
			(0.0189)	
female × M-more × CovInd			0.0283***	
			(0.0107)	
female × F-more × CovInd			-0.0385*	
			(0.0227)	
LowTele				-0.000404
				(0.00207)
female × LowTele				-0.00146
				(0.00285)
LowTele × CovInd				0.0241***
				(0.00540)
female × LowTele × CovInd				0.0438***
				(0.00787)
Constant	0.0146	0.0157	-0.00790	0.00246
	(0.0220)	(0.0238)	(0.0526)	(0.00396)
Age FE	YES	YES	YES	YES
Canton FE	YES	YES	YES	YES
Education FE	YES	YES	YES	YES
NOGA FE	YES	YES	YES	YES
ISCO FE	YES	YES	YES	
Observations	158250	148431	88254	158162
R^2	0.0466	0.0480	0.0483	0.0474

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.2) of STW dummy on a constant, female dummy, Covid-19 stringency index, child dummies (column 2), couple occupation dummies (column 3, M-more for man works more than woman, F-more for woman works more than man), low telework dummy (column 4) . The sample is restricted to respondents who are employed or apprentices, and further restricted to couples in column 2. Regressions estimated with linear probability model, including random effects. Standard errors in parentheses.

We further analyze how the probability of engaging in short-time work evolves by running regression (4.3) separately for men and women with the short-time work dummy as a dependent variable. The coefficient estimates of the quarterly dummies are plotted in Figure 4.8. The figure shows that the effect of Covid-19 on the probability of being on short-time work is very large in the second quarter of 2020, and then falls substantially in the third and fourth quarters, but remains well above the pre-covid levels. The figure also shows a large economically and statistically significant difference between men and women in the second quarter of 2020: women have more than 3% higher probability of engaging in short-time work in this quarter. The gender gap persists, but to a much smaller extent in the third and fourth quarters.

Figure 4.8: STW Over Time for Men and Women



Notes: Estimates from regression (4.3) of STW dummy on quarterly dummies, run separately for men (blue) and women (red). Regressions estimated with linear probability model, including random effects.

4.7 Covid-19 and Employment Behavior

This section focuses on respondents who are employed or apprenticing, and explores how they have adjusted their employment behavior in response to the Covid-19 pandemic.

4.7.1 Covid-19 and Worked Last Week

We first examine the effect of the Covid-19 crisis on the probability of having worked in the past week. In this regression, the dependent variable is a dummy equals to 1 if the respondent had worked in the past week and 0 otherwise. Note that in this section, we restrict the sample to employed respondents only. Some of the employed workers did not do any work in the previous week, possibly because they were on paid or unpaid leave, on short-time work, or because they work on an irregular schedule. The explanatory variables are the female dummy, the Covid-19 index and their interaction. We control for age, education, occupation type, sector of work and canton of residence. The results are summarized in Table 4.9. The results in column (1) show that, in normal times, women are less likely than men to have worked in the past week. The results suggest that in normal times, employed women are more likely to be absent from work than employed men. During Covid-19, the probability of having worked in the past week went down for both men and women, but the effect is four times larger for women. This result could be partly explained by the higher probability of being in STW for women relative to men, documented in section subsection 4.6.2.

Column (2) addresses how the presence of children in the household has affected men and women during the crisis. We find that, in normal times, the presence of children reduces the probability of having worked in the past week, and the effect is strongest for women with children under 7 years old. The result suggests that in normal times, it is the woman who is more likely to take a leave of absence from work to take care of a child when it is needed. There is, however, no differential effect between men and women with children during Covid-19. This indicates than men and women have shared the extra childcare needs due to Covid-19 restrictions more equally. Therefore, the presence of children does not explain why women are less likely to have worked in the past week during Covid-19.

Column (3) explores the role of professional activity within couples. We find that the model of professional activity within couple does not affect the probability of women having worked in the past week, either in normal times or during Covid-19.

In the last column, we consider the role of telework availability. We find that having a low-telework occupation has a strong negative impact on the probability of having worked in the past week for all respondents. However, this effect is twice as large for women as for men in occupations with low telework availability. Note that females with low-telework occupations are more likely to have worked in the past week in normal times. The results suggest that the effect of telework availability becomes important only during the Covid-19 crisis.

4.7.2 Covid-19 and Hours of Work

Then we check whether respondents adjust their working time during Covid-19. We set the dependent variable as the respondent's working hours in the past week. The explanatory variables are the female dummy, the Covid-19 index, and their interaction. We control for age, education, occupation type, sector of work, and canton of residence. Table 4.9 displays the results. Column (1) shows that women work fewer hours than men in normal times; during the pandemic, all respondents reduced their working hours, but women reduced their working time to a less extent. The intuition is that women usually work part-time; they don't need to cut working hours as much as men did during the crisis.

Column (2) estimates how the presence of children in the household affects the flexibility of men and women in adjusting their working hours during the crisis. In normal times, having children under 7 years old reduces working hours for both men and women, and this is more so for women. During Covid-19, this trend reversed somewhat; women have been able to increase their working hours. There are two possible explanations. One is that fathers stay

Table 4.8: The Effect of Covid-19 and Gender on Having Worked Last Week

	Worked Last Week			
	(1)	(2)	(3)	(4)
female	-0.0289***	-0.0191***	-0.0401***	-0.0358***
	(0.00245)	(0.00296)	(0.00572)	(0.00282)
CovInd	-0.00928**	-0.0187***	-0.0147	0.0113**
	(0.00433)	(0.00525)	(0.0109)	(0.00524)
female × CovInd	-0.0317***	-0.0297***	-0.0152	-0.0151**
	(0.00620)	(0.00753)	(0.0154)	(0.00741)
child0-6		-0.0103**		
		(0.00472)		
child7-14		-0.0184***		
		(0.00490)		
female × child0-6		-0.0621***		
		(0.00665)		
child7-14 × CovInd		0.0460***		
		(0.0128)		
female × child0-6 × CovInd		0.00257		
		(0.0179)		
female × child7-14 × CovInd		-0.0123		
		(0.0181)		
M-more			-0.0160***	
			(0.00469)	
F-more			-0.0297**	
			(0.0117)	
female × M-more × CovInd			-0.0267	
			(0.0186)	
female × F-more × CovInd			0.0114	
			(0.0394)	
LowTele				-0.0121***
				(0.00365)
female × LowTele				0.0234***
				(0.00500)
LowTele × CovInd				-0.0648***
				(0.00932)
female × LowTele × CovInd				-0.0666***
				(0.0136)
Constant	0.786***	0.793***	0.979***	0.783***
	(0.0390)	(0.0410)	(0.0909)	(0.00701)
Age FE	YES	YES	YES	YES
Canton FE	YES	YES	YES	YES
Education FE	YES	YES	YES	YES
NOGA FE	YES	YES	YES	YES
ISCO FE	YES	YES	YES	
Observations	158242	148423	88250	158154
R^2	0.0194	0.0225	0.0156	0.0204

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.2) of work last week on a constant, female dummy, Covid-19 stringency index, child dummies (column 2), couple occupation dummies (column 3, M-more for man works more than woman, F-more for woman works more than man), low telework dummy (column 4) . The sample is restricted to respondents who are employed or apprentices, and further restricted to couples in column 2. Regressions estimated with linear probability model, including random effects. Standard errors in parentheses. Some insignificant estimates are eliminated for brevity.

at home to help share child care responsibilities; the other is that mothers usually work part-time and thus have more flexibility to adjust their workload. With school-age children in the household, men can increase their working hours while women work less in normal times, and this dispersion did not change much during the pandemic.

Column (3) addresses the role of professional activity within couples and documents the "family insurance" effect. Men increase their working hours in couples where the women work more, and women behave similarly in couples where the men work more during the pandemic.

Column (4) checks how occupation type influences individuals' flexibility in adjusting their working hours. The Covid-19 pandemic has caused a reduction in working hours for men and women in jobs with both high and low telework availability. Interestingly, women with an occupation that can be done remotely reduced working hours less than their male counterparts. The Covid-19 pandemic thus reduces the gender gap in working hours among respondents with high telework availability occupations.

4.7.3 Covid-19 and Family Leave

The Swiss federal government imposed complete school closure between March 16 and May 11, 2020 (8 weeks). It is therefore possible that some workers, if not entitled to short-time work, would request a leave of absence to care for their children. Table 4.10 displays estimates from a regression that takes as dependent variable a dummy with value 1 if the person is on family leave and 0 if not.

Column (1) displays regression results, including the Covid-19 index, the female dummy, and their interaction, as well as the usual labor market controls. The estimates emphasize that in normal times, women are more likely to be on family leave. The Covid-19 crisis has significantly increased the recourse to family leave for both men and women, but without any significant difference between the two.

Column (2) addresses the role of children in the household. We include children dummies and their interactions with the female dummy and the Covid-19 index. The coefficient on the female dummy is positive and significant, suggesting that women are more likely to ask for family leave in normal times, even if they do not have children under 15. The coefficients on children aged 0-6 and 7-14 also carry a positive and significant coefficient; having children in the households increases the likelihood of taking family leaves in normal times, while this effect is more substantial for women with young children. These results go in the same direction as those on working in the previous week, discussed in subsection 4.7.1. During the Covid-19 crisis, having children under 7 years old increased the probability of being on family leave without any significant difference between men and women. However, in households with children aged 7 to 14, women were more likely to be on family leave during the crisis.

Columns (3) and (4) consider respectively professional activity model within couples and

Table 4.9: The Effect of Covid-19 and Gender on Working Hours

	Working Hours in the Previous Week			
	(1)	(2)	(3)	(4)
female	-8.999***	-6.626***	-3.360***	-9.148***
	(0.128)	(0.152)	(0.343)	(0.146)
CovInd	-2.979***	-3.067***	-3.370***	-2.700***
	(0.187)	(0.229)	(0.560)	(0.222)
female × CovInd	0.514*	0.120	-0.564	0.616*
	(0.270)	(0.330)	(0.807)	(0.318)
child0-6		-0.585**		
		(0.232)		
child7-14		0.426*		
		(0.240)		
female × child0-6		-8.887***		
		(0.332)		
female × child7-14		-7.430***		
		(0.333)		
female × child0-6 × CovInd		1.417*		
		(0.771)		
female × child7-14 × CovInd		1.015		
		(0.770)		
M-more × CovInd			0.971	
			(0.661)	
F-more × CovInd			4.847***	
			(1.704)	
female × M-more × CovInd			2.466**	
			(0.971)	
female × F-more × CovInd			-3.000	
			(2.072)	
LowTele				-0.915***
				(0.192)
female × LowTele				-2.473***
				(0.263)
LowTele × CovInd				-0.803*
				(0.416)
female × LowTele × CovInd				-0.723
				(0.614)
Constant	50.21***	51.05***	54.22***	43.48***
	(2.117)	(2.156)	(2.719)	(0.417)
Age FE	YES	YES	YES	YES
Canton FE	YES	YES	YES	YES
Education FE	YES	YES	YES	YES
NOGA FE	YES	YES	YES	YES
ISCO FE	YES	YES	YES	
Observations	133583	125218	46821	133502
R^2	0.223	0.250	0.337	0.209

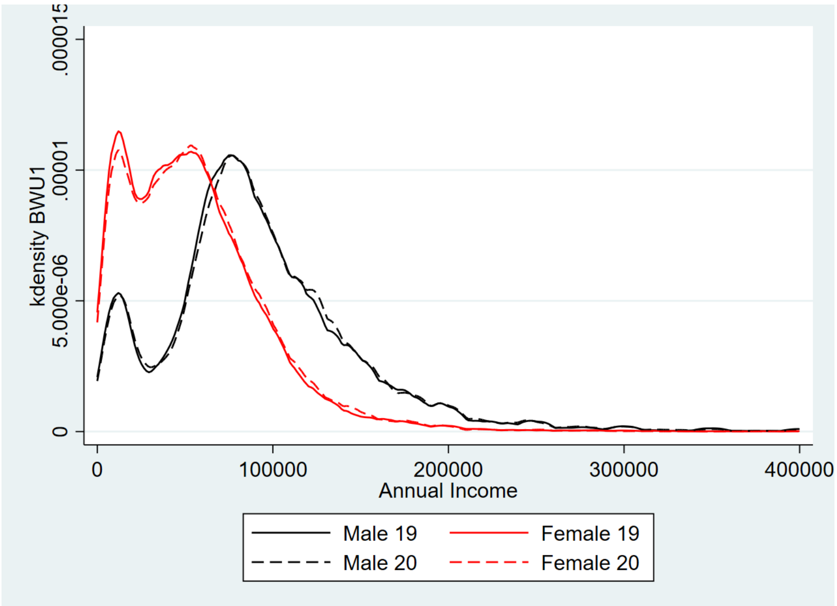
Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.2) of working hours last week on a constant, female dummy, Covid-19 stringency index, child dummies (column 2), couple occupation dummies (column 3, M-more for man works more than woman, F-more for woman works more than man), low telework dummy (column 4) . The sample is restricted to respondents who are employed or apprentices, and further restricted to couples in column 2. Regressions estimated with linear model, including random effects. Standard errors in parentheses. Some insignificant estimates are eliminated for brevity.

telework availability of an occupation. In normal times, women in couples where she works more are less likely to take family leave; men in couples where the woman works more are more likely to take family leave. Column (3) indicates professional activity model within couples does not drive a gender gap in family leave during Covid-19. Column (4) indicates that telework availability of a given occupation does not affect family leave, either in normal or in Covid-19 times.

4.8 The Gender Income Gap

We finally turn our attention to the gender income gap. As shown in Figure 4.9, men's annual income is skewed to the right relative to women, indicating that men's average income is much higher than women's in Switzerland. In this section, we try to investigate how much of this large gender gap could be explained by these observable factors and whether the pandemic affects this income gap.

Figure 4.9: Annual Income Distribution by Gender and Year



Notes: This figure plots kernel density of the income distribution of men and women in 2019 and 2020. The black line is for men and red line is for women. The solid and dashed lines correspond to the data in 2019 and 2020 respectively.

We show how the changes in earnings spread across gender and occupations in Figure 4.10. We restrict the sample to respondents for whom we know his/her income level in 2019 and 2020 and plot the percentage of respondents whose income level has decreased from 2019 to 2020 by occupation and gender. Among individuals having jobs with low telework availability, women are more likely to experience a reduction in income level during the Covid-19 period. Among

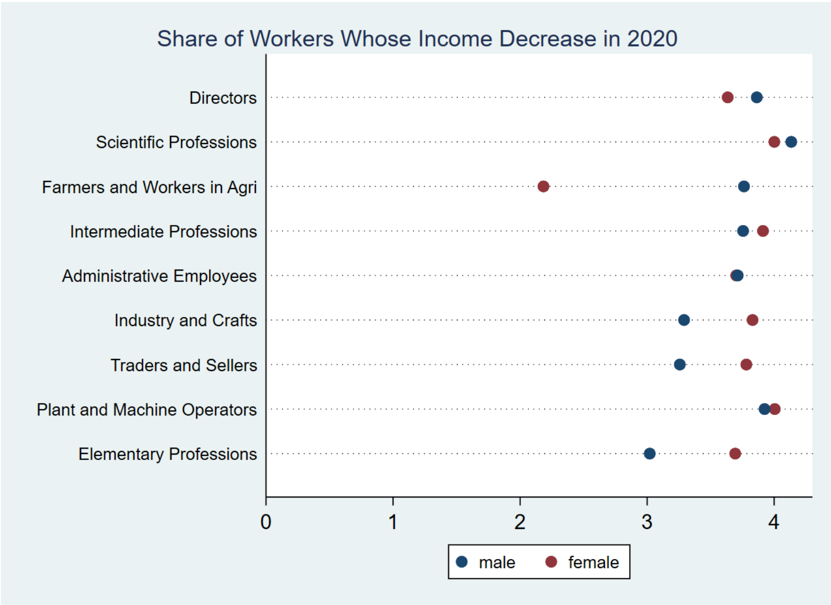
Table 4.10: The Effect of Covid-19 and Gender on Family Leave

	Request a Family Leave			
	(1)	(2)	(3)	(4)
female	0.00236***	0.00138***	0.00298**	0.00268***
	(0.000422)	(0.000518)	(0.00119)	(0.000488)
CovInd	0.00238***	-0.000105	0.00439*	0.00306***
	(0.000802)	(0.000973)	(0.00236)	(0.000972)
female × CovInd	0.00157	0.000102	0.00124	0.00172
	(0.00115)	(0.00139)	(0.00335)	(0.00137)
child0-6		0.00275***		
		(0.000827)		
child7-14		0.00227***		
		(0.000858)		
female × child0-6		0.00667***		
		(0.00117)		
female × child7-14		0.00148		
		(0.00118)		
child0-6 × CovInd		0.0151***		
		(0.00230)		
child7-14 × CovInd		0.00247		
		(0.00237)		
female × child0-6 × CovInd		0.000233		
		(0.00331)		
female × child7-14 × CovInd		0.00800**		
		(0.00335)		
M-more			0.00162*	
			(0.000977)	
F-more			0.00639***	
			(0.00246)	
female × F-more			-0.00599**	
			(0.00297)	
female × M-more × CovInd			0.000628	
			(0.00402)	
female × F-more × CovInd			-0.00969	
			(0.00848)	
LowTele				0.000956
				(0.000631)
female × LowTele				-0.00143
				(0.000869)
LowTele × CovInd				-0.00213
				(0.00172)
female × LowTele × CovInd				-0.000850
				(0.00251)
Constant	0.000685	0.00260	0.000151	0.00190
	(0.00652)	(0.00701)	(0.0194)	(0.00118)
Age FE	YES	YES	YES	YES
Canton FE	YES	YES	YES	YES
Education FE	YES	YES	YES	YES
NOGA FE	YES	YES	YES	YES
ISCO FE	YES	YES	YES	
Observations	158250	148431	88254	158162
R^2	0.00191	0.00600	0.00323	0.00193

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.2) of family leave dummy on a constant, female dummy, Covid-19 stringency index, children dummies (column 2), couple occupation dummies (column 3, M-more for man works more than woman, F-more for woman works more than man), low telework dummy (column 4) . The sample is restricted to respondents who are employed or apprentices, and further restricted to couples in column 2. Regressions estimated with linear probability model, including random effects. Standard errors in parentheses.

people with high-telework jobs, there are no big gender differences in experiencing income loss during the Covid-19 pandemic. This is consistent with the insights that women having low-telework jobs are more likely to become non-active or be put on short-time working schemes relative to men doing the same kind of jobs and thus are more likely to experience an income loss.

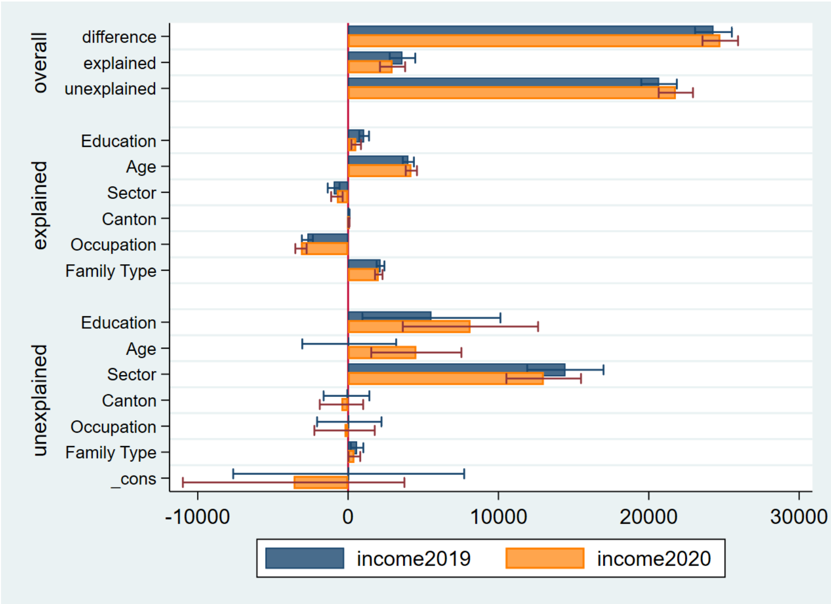
Figure 4.10: Income Reduction by Gender



Notes: We restrict the sample to respondents with income information in both 2019 and 2020, calculate the percentage of respondents whose income has decreased from 2019 to 2020, and then break it down by occupation types and gender. Occupations are ranked in descending order of telework in 2020.

We then explore how much of the large gender income gap has been explained by other observed worker and job characteristics, like education level, age, sector, and cantonal location. We also check whether the decomposition of the gender income gap has changed during the Covid-19 period. We use the Oaxaca-Blinder model and run it only for full-time workers to exclude the impact of the low occupancy rate of women on the gender income gap. Figure 4.11 shows the decomposition results. In normal times, gender differences in the above factors explain around a quarter of the gender income gap, suggesting that other factors we can not capture in this regression also play an important role in driving gender gaps. Alternatively, if we only consider factors that carry a positive explanation, such as education, age, and family type, we account for about 40% of the gender income gap. In other words, adjusting women's education level, age level, and family type to the levels of men would reduce the gender income gap by 40 percent. Sector and occupation have a negative contribution, which means that the overall income gap would be even larger if the professional level of men and women were the same or women moved towards men-dominated sectors. During Covid-19, the overall gender income gap has slightly increased, and the explained portion of the gender income gap has decreased. The intuition is that the gender income gap in occupations with low telework

Figure 4.11: What Explains the Gender Income Gap in 2019 and 2020



Notes: This figure plots the results of the Oaxaca-Blinder decomposition, which decomposes the gender income gap into explained and unexplained terms by the observed worker and job characteristics. like education level, age, sector-occupation information and cantonal location.

availability is usually small but has increased during the pandemic, contributing to an increase in the overall gender income gap.

4.9 Conclusion

This paper provides empirical evidence that the Covid-19 pandemic has resulted in a "she-cession" in the Swiss labor market. Women are more likely to have dropped out of the labor market or put on short-time work than their male counterparts during the pandemic. Interestingly, we find that increased family care responsibilities are not the cause; the sector-occupation difference is. During Covid-19, women who are married or have children are less likely to have exited the labor market or to have engaged in short-time work than their male counterparts, and women tend to work more to compensate for their partners' loss. Women with jobs that have a low telework availability are more likely to be non-active than men, which explains higher exit rates of women during Covid-19. Moreover, we provide suggestive evidence for the impact on the gender income gap. As occupations with low telework availability featuring a small gender pay gap have been affected more severely by the pandemic, the overall gender income gap may have increased.

4.A Data

This section documents all survey variables we used in the regressions and figures reported in this paper.

4.A.1 Definition of Variables

KOF stringency index: The indices are composite measures including different lockdown policies, such as school and workplace closure. The values range from 0 (= no measures) to 100 (= full lockdown). The data is available at the national level and for all individual 26 cantons of Switzerland from January 2020 onwards. The construction largely follows the code book of the Oxford Covid-19 Government Response Tracker.

Labor market status (B0000): The survey asks the respondent's status in the labor market. Possible options: Active, Apprentice, Unemployed according to the ILO, Not active, No response.

Age (AGE64): The respondent's age along five category: 15-24; 25-39; 40-54; 55-64; 65+.

Education (TBQ2): Education describes the highest education level the respondent has achieved: middle school, high school and college.

Canton (B017): Canton describes the location of the respondent.

Occupation (BFU7): The respondent needs to fill out his/her profession according to ISCO international classification(ISCO-08 at 1 position).

Sector (BMU3): The respondent is asked about the sector where he/ she works based on the NOGA-2008 standard.

Marital status (IS03): Marital status describes whether the respondent is married (married and in a partnership relationship) or not.

Family type (FAMTYP2): The respondent is asked whether he/she has children, and if yes, how old the youngest kid is.

Professional activity patterns in couples (BKU6): Households are asked about their family

members' working schedule. Possible answers:
1 - Both full-time partners
2 - Male full time / female part time 50-89%
3 - Full-time male / part-time female 1-49%
4 - Full-time man / woman without professional activity
5 - Male part-time 50-89% / female full-time
6 - Both partners part-time 50-89%
7 - Male part-time 50-89% / female part-time 1-49%
8 - Male part-time 50-89% / female without professional activity
9 - Male part-time 1-49% / female full-time
10 - Male part-time 1-49% / female part-time 50-89%
11 - Both part-time partners 1-49%
12 - Part-time man 1-49% / woman without professional activity
13 - Man without professional activity / woman full time
14 - Man without professional activity / woman part-time 50-89%
15 - Man without professional activity / woman part-time 1-49%
16 - The two partners without professional activity

We form dummy variables for couple work type out of the answers. One is a dummy indicating whether the respondent and his/her partner work full-time or not, taking value 0 for both work part time, 1 for both full-time, 2 for male full-time, 3 for female full-time and 4 for both without professional activity. The other is a dummy for a simplified version, equal to 0 if the man and the woman work the same amount of hours, 1 if the man works more than the woman and 2 if the woman works more than the man.

Reduced working hours and reasons behind (EK09, EK101): The respondent is asked whether his/her actual working time last week is more/ less than usual / contract duration, and why he/she has to reduce working time. We construct dummies for sick leave, family reason, STW.

Job search (BD08, BD131, BD132, BD133): The respondents are asked whether and why they are not looking for a job in the last four weeks.

Annual income (BWU1, BWU11K): Gross annual professional income of the interviewer: amount in CHF/quintiles.

4.A.2 Summary Statistics

The number of observations by labor market status, education, family type, occupation and work model within couple are given respectively in Table 4.11, Table 4.12, Table 4.13, Table 4.14 and Table 4.15.

Table 4.11: Number of Observations by Labor Market Status (B0000), Gender and Quarter

	Men				Women			
	Employed	Appr.	Unempl	Non-active	Employed	Appr.	Unempl	Non-active
2019q1	9848	498	409	3548	9622	333	497	5364
2019q2	9675	505	376	3155	9339	349	399	4873
2019q3	9267	456	390	3159	8808	358	400	4611
2019q4	9383	479	349	3168	9186	364	379	4690
2020q1	9610	505	390	3237	9448	369	398	4863
2020q2	9869	492	428	3606	9510	338	397	5325
2020q3	9768	464	480	3461	9309	349	504	4924
2020q4	9844	492	443	3360	9532	360	469	4886

Table 4.12: Number of Observations by Education (TBQ2), Gender and Quarter

	Men			Women		
	Mandatory school	High school	University	Mandatory school	High school	University
2019q1	2284	5867	6152	3061	7630	5125
2019q2	2139	5587	5985	2818	7116	5026
2019q3	1835	5613	5824	2473	6961	4743
2019q4	1918	5603	5858	2572	7182	4865
2020q1	2082	5588	6072	2742	7264	5072
2020q2	2164	5900	6331	2857	7379	5334
2020q3	1984	5954	6235	2580	7209	5297
2020q4	2012	5813	6314	2666	7206	5375

Table 4.13: Number of Observations by Family Type (FAMTYP2), Gender and Quarter

	Men			Women		
	No Child	Child 0-6	Child 7-14	No Child	Child 0-6	Child 7-14
2019q1	8217	1247	1116	8890	1502	1426
2019q2	10522	1690	1499	11257	1904	1799
2019q3	10208	1595	1469	10757	1749	1671
2019q4	10342	1551	1486	11100	1800	1719
2020q1	8201	1222	1166	8797	1372	1364
2020q2	11145	1671	1579	11789	1931	1850
2020q3	10943	1632	1598	11529	1830	1727
2020q4	10867	1639	1633	11674	1832	1741

4.B Robustness

Table 4.16 presents a robustness check where we only include respondents for which we have complete information on occupation type (ISCO) and economic sector (NOGA). For non-active respondents, this question is only answered by participants who had been employed over the previous 8 years. The sample in this robustness check therefore excludes

Table 4.14: Number of Observations by Occupation Type, Gender and Quarter

	Men		Women	
	HighTele	LowTele	HighTele	LowTele
2019q1	8126	4149	8508	3868
2019q2	8064	4018	8277	3660
2019q3	7761	3851	7801	3443
2019q4	7859	3855	8121	3645
2020q1	8068	3980	8452	3723
2020q2	8345	4146	8686	3746
2020q3	8228	4045	8435	3587
2020q4	8369	4040	8675	3599

Table 4.15: Number of Observations by Quarter and Professional Activity Model in Couple

	Equal	M-more	F-more
2019q1	2791	6747	759
2019q2	3616	8759	942
2019q3	3457	8275	914
2019q4	3480	8414	974
2020q1	2750	6517	717
2020q2	3824	8898	1015
2020q3	3655	8648	1057
2020q4	3603	8674	1059

non-active respondents who never worked or exited the labor market more than 8 years ago. The regression estimates are consistent with those presents in the Table 4.1.

We also tried to run the baseline regression using a simplified dummy for Covid-19 period, $Covid$ is a time dummy, which is equal to one starting in 2020Q2, and zero before. Table 4.17 presents the estimates based on regression (4.1) that takes as dependent variable the labor market statuses. The results are again consistent with what we have seen in Table 4.1. Women are more likely to exit the labor market during Covid-19 both relative to men and relative to women during normal times.

Table 4.18 reports the regression results on short-time work, work last week and family leave using the Covid-19 dummy instead of the Covid-19 stringency index. The results are consistent. In Table 4.19, we run our baseline regression again but include $NOGA \times CovInd$ and $ISCO \times CovInd$ fixed effects. The results are consistent with those in the main text.

4.C Additional Tests

In Table 4.20, we examine the effect of the Covid-19 crisis on the respondent's work-time percentage. The estimates show that the work-time percentage of women is 19.4% lower than that of men in normal times; this confirms the high part-time employment rate of women in Switzerland. During the pandemic, the presence of children in the household plays a positive role in motivating women to work for a higher percentage. The related family insurance

Table 4.16: Covid-19 and Labor Market Status

	Employed	Unemployed	Non-active
female	-0.0402***	0.00104	0.0375***
	(0.00254)	(0.00142)	(0.00218)
CovInd	-0.0148***	0.00650***	0.00928**
	(0.00288)	(0.00204)	(0.00244)
female × CovInd	-0.00502	-0.00310	0.00805**
	(0.00406)	(0.00287)	(0.00343)
constant	0.713***	0.0324	0.253***
	(0.0421)	(0.0230)	(0.0362)
Age FE	YES	YES	YES
Canton FE	YES	YES	YES
Education FE	YES	YES	YES
NOGA FE	YES	YES	YES
ISCO FE	YES	YES	YES
Observations	170619	170619	170619
R^2	0.0422	0.0108	0.0445

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.1) of labor market status on a constant, female dummy (1 for women and 0 otherwise), Covid-19 stringency index and its intersection with the female dummy. Sample includes respondents aged 15 to 64. Regressions estimated with linear probability model, including random effects. Robust standard errors in parentheses.

mechanism is confirmed, men increase their work-time percentage in couples where the women work more, and women behave similarly in couples where the men work more during the pandemic.

Table 4.17: Robustness: Replacing Covid Stringency Index by Covid Dummy

	Employed	Unemployed	Non-active
female	-0.0399***	-0.00247*	0.0412***
	(0.00230)	(0.00137)	(0.00203)
Covid	-0.00763***	0.00348***	0.00470***
	(0.00151)	(0.00114)	(0.00137)
female × Covid	-0.00328	-0.000605	0.00336*
	(0.00210)	(0.00158)	(0.00190)
Constant	0.726***	0.0291	0.244***
	(0.0396)	(0.0233)	(0.0350)
Age FE	YES	YES	YES
Canton FE	YES	YES	YES
Education FE	YES	YES	YES
NOGA FE	YES	YES	YES
ISCO FE	YES	YES	YES
Observations	186881	186881	186881
R^2	0.417	0.0423	0.459

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.1) of labor market status on a constant, female dummy (1 for women and 0 otherwise), Covid-19 dummy and its intersection with the female dummy. Regressions estimated with linear probability model, including random effects. Robust standard errors in parentheses.

Table 4.18: Robustness: Replacing Covid Stringency Index by Covid Dummy

	dumSTW	work_last_week	work_hours	dumfamleave
female	0.00218	-0.0292***	-8.991***	0.00239***
	(0.00135)	(0.00238)	(0.126)	(0.000407)
Covid	0.0517***	-0.0128***	-1.466***	0.00116***
	(0.00133)	(0.00230)	(0.101)	(0.000422)
female × Covid	0.0137***	-0.0176***	0.270*	0.000832
	(0.00191)	(0.00329)	(0.146)	(0.000603)
Constant	0.0188	0.788***	50.15***	0.000762
	(0.0220)	(0.0390)	(2.117)	(0.00652)
Age FE	YES	YES	YES	YES
Canton FE	YES	YES	YES	YES
Education FE	YES	YES	YES	YES
NOGA FE	YES	YES	YES	YES
ISCO FE	YES	YES	YES	YES
Observations	158250	158242	133583	158250
R^2	0.0392	0.0201	0.223	0.00189

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.1) of STW (column 1), work last week (column 2), working hours last week (column 3) and family leave (column 4) on a constant, female dummy and Covid-19 dummy. The sample is restricted to respondents who are employed or apprentices. Regressions estimated with linear probability model, including random effects. Standard errors in parentheses.

Table 4.19: Robustness: Adding NOGA× CovInd and ISCO× CovInd

	dumSTW	work_last_week	work_hours	dumfamleave
female	0.000907	-0.0321***	-8.934***	0.00210***
	(0.00144)	(0.00255)	(0.131)	(0.000442)
CovInd	0.125	0.0212	-2.248	0.000953
	(0.0864)	(0.150)	(6.298)	(0.0275)
female × CovInd	0.0286***	-0.0177**	0.223	0.00275**
	(0.00401)	(0.00695)	(0.303)	(0.00129)
Constant	0.0188	0.788***	50.12***	0.000762
	(0.0220)	(0.0390)	(2.449)	(0.00652)
Age FE	YES	YES	YES	YES
Canton FE	YES	YES	YES	YES
Education FE	YES	YES	YES	YES
NOGA FE	YES	YES	YES	YES
ISCO FE	YES	YES	YES	YES
NOGA×CovInd FE	YES	YES	YES	YES
ISCO×CovInd FE	YES	YES	YES	YES
Observations	158250	158242	133583	158250
R^2	0.0577	0.0227	0.224	0.00224

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.1) of STW (column 1), work last week (column 2), working hours last week (column 3) and family leave (column 4) on a constant, female dummy and Covid-19 stringency index. The sample is restricted to respondents who are employed or apprentices. Regressions estimated with linear probability model, including random effects. Standard errors in parentheses.

Table 4.20: The Effect of Covid-19 and Gender on Occupancy Rate

	Occupancy Rate		
female	-19.40***	-14.18***	-7.870***
	(0.204)	(0.235)	(0.388)
CovInd	-0.278	-0.0646	0.264
	(0.172)	(0.212)	(0.490)
female × CovInd	0.0130	-0.589*	-3.692***
	(0.247)	(0.304)	(0.697)
child0-6		0.407	
		(0.330)	
child7-14		1.838***	
		(0.331)	
female × child0-6		-18.33***	
		(0.470)	
female × child7-14		-15.56***	
		(0.464)	
female × child0-6 × CovInd		1.756**	
		(0.700)	
female × child7-14 × CovInd		1.263*	
		(0.706)	
M-more			3.388***
			(0.305)
F-more			-22.14***
			(0.748)
female × M-more			-32.02***
			(0.444)
female × F-more			15.13***
			(0.911)
M-more × CovInd			-0.793
			(0.580)
F-more × CovInd			11.34***
			(1.533)
female × M-more × CovInd			7.302***
			(0.840)
female × F-more × CovInd			-9.761***
			(1.838)
Constant	93.31***	91.21***	97.59***
	(3.577)	(3.611)	(3.895)
Age FE	YES	YES	YES
Canton FE	YES	YES	YES
Education FE	YES	YES	YES
NOGA FE	YES	YES	YES
ISCO FE	YES	YES	YES
Observations	148744	139527	52694
R^2	0.320	0.362	0.583

Notes: * p<0.1, ** p<0.05, *** p<0.01.
Estimates from regression (4.2) of occupancy rate on a constant, female dummy, Covid-19 stringency index, child dummies (column 1), couple occupation dummies (column 2, M-more for man works more than woman F-more for woman works more than man), low telework dummy (column 3) . The sample is restricted to respondents who are employed or apprentices, and further restricted to couples in column 2. Regressions estimated with linear probability model, including random effects. Standard errors in parentheses.

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