Monetary policy, asset purchase programmes and household heterogeneity

DISSERTATION
of the University of St. Gallen,
School of Management,
Economics, Law, Social Sciences
and International Affairs
to obtain the title of
Doctor of Philosophy in Economics and Finance

submitted by
Marc-Antoine Ramelet
from
Orbe (Waadt)

Approved on the application of
Prof. Dr. Winfried Koeniger
and
Prof. Luisa Lambertini, PhD

Dissertation no. 4962
Difo-Druck GmbH, Untersiemau, 2020

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The University of St.Gallen, School of Management, Economics, Law, Social Sciences and International Affairs hereby consents to the printing of the present dissertation, without hereby expressing any opinion on the views herein expressed.

St.Gallen, November 15, 2019

The President:

Prof. Dr. Thomas Bieger

Contents

1 Acknowledgements and summary

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Marc-Antoine Ramelet

Summary

This dissertation investigates the transmission and effects of monetary policy. The conduct of monetary policy is often categorized into conventional and unconventional measures. The first and second chapters assess the effectiveness and distributional consequences of an extensively-used unconventional measure, namely asset purchase programmes. By contrast, the third chapter documents the transmission of conventional monetary policy to heterogeneous households.

The first chapter analyzes the transmission of central bank asset purchase programmes (so-called quantitative easing measures, QE). To do so, I embed a corporate credit market imperfection in a New Keynesian model. The transmission is different than that of conventional policy: it operates via investment instead of private consumption. Importantly, QE is equally effective at the zero lower bound. My setting hence provides support to the usefulness of QE as a policy instrument when conventional measures become impotent. Estimating the model with US data, I show that the QE measures carried out in the US had large and persistent accommodating aggregate effects.

The second chapter assesses some of the distributional consequences of central bank asset purchases. To this end, I nest the above credit friction in a model which contains rich household heterogeneity. While central bank purchases overall improve labor market conditions, the corresponding welfare gains vary considerably at the individual level. Younger households benefit the most from improved employment prospects. Because the gains are mostly driven by improved employment prospects, both the employed and the unemployed experience a similar increase in welfare. The gains obtained by older households instead rely on accumulated wealth and are therefore more sensitive to the ex-post employment path. In particular, households who face unemployment spells closer to retirement benefit the least.

The third chapter provides empirical evidence on the transmission of conventional monetary policy in Germany and Switzerland. This is done by using two household panels together with policy rate shocks identified from high-frequency data. The shocks transmit to the mortgage rates that are typically contracted in both countries. Accommodating policy accordingly incentivizes existing renters to switch housing tenure status. In line with this, the home ownership rate is meaningfully impacted by unexpected movements in the respective policy rates. The Swiss dataset also reveals heterogeneous responses in non-housing consumption to conventional monetary policy shocks.

Zusammenfassung

Die vorliegende Dissertation untersucht den Transmissionsmechanismus und die Auswirkungen der Geldpolitik.

Das erste Kapitel dokumentiert den Transmissionsmechanismus der Geldpolitik bei Ankaufprogrammen für Zentralbank-Vermögenswerte (so genannte quantitative Lockerungsmaßnahmen, kurz QL). Die Studie bettet die Unvollkommenheit eines Unternehmenskreditmarktes in ein neu-keynesianisches Modell ein. Der Transmissionsmechanismus unterscheidet sich vom Mechanismus bei konventioneller Geldpolitik: Die Transmission erfolgt durch Investitionen anstelle des privaten Konsums und QL kann auch bei Nullzinsen wirksam angewendet werden. Mein Modell unterstützt daher den Schluss, dass QL auch als Instrument genutzt werden kann, wenn konventionelle Maßnahmen wirkungslos sind. Die Schätzung des Modells anhand von US-Daten zeigt, dass die durchgeführten QL-Maßnahmen große und anhaltende Auswirkungen hatten.

Im zweiten Kapitel werden einige Konsequenzen der Umverteilung von Vermögenskäufen von Zentralbanken beurteilt. Zu diesem Zweck wird die oben genannte Kreditfriktion in ein Modell mit reichhaltiger starker Heterogenität der Haushalte untersucht. Während die Zukäufe der Zentralbank die Arbeitsmarktbedingungen insgesamt verbessern, variieren die entsprechenden Wohlfahrtsgewinne auf individueller Ebene erheblich. Jüngere Haushalte profitieren am meisten von verbesserten Beschäftigungsaussichten. Da die Zuwächse größtenteils von verbesserten Beschäftigungsperspektiven abhängen, verzeichnen sowohl die Beschäftigten als auch die Arbeitslosen einen ähnlichen Wohlfahrtszuwachs. Die Gewinne der älteren Haushalte basieren auf dem angesammelten Vermögen und reagieren daher stärker auf den Beschäftigungspfad ex post. Insbesondere profitieren arbeitslose Haushalte, welche kurz vor dem Ruhestand stehen, am wenigsten.

Das dritte Kapitel liefert empirische Belege für den Transmissionsmechanismus der konventionellen Geldpolitik in Deutschland und der Schweiz. Dazu werden zwei Haushalts-Datensätze zusammen mit Leitzinsschocks verwendet, die anhand von Hochfrequenzdaten identifiziert werden. Die Schocks übertragen sich auf die in beiden Ländern meist genutzten Hypothekenzinssätze. Die expansive Geldpolitik bietet dementsprechend Anreize für bestehende Mieter, die Wohnbesitzverhältnisse anzupassen. Dementsprechend wird die Wohneigentumsquote signifikant durch die Entwicklung der jeweiligen Leitzinsen beeinflusst. Die Schweizer Daten zeigen außerdem heterogene Reaktionen im Nichtwohnkonsum auf konventionelle geldpolitische Schocks.

2 Quantitative easing effectiveness with a corporate credit market imperfection

This chapter is single-authored.

Abstract:
This paper presents a novel mechanism to the transmission of central bank purchases of government bonds (so-called quantitative easing measures). The effectiveness of central bank purchases relies on an imperfection in the corporate credit market, which implies that the propagation of quantitative easing measures differs from that of conventional monetary policy. Central bank purchases directly improve firms' borrowing conditions, in turn impacting investment decisions. Embedding such a mechanism in a general equilibrium model and estimating it with US data, I find that the three rounds of purchases carried out by the Federal Reserve had sizeable and long-lasting accommodative effects on both quantities and prices. The magnitude of the effects is in the upper range of previous estimates obtained with models that rely on reduced-form assumptions. I show that the effectiveness of quantitative easing measures is not diminished at the zero lower bound, and discuss some implications.

Keywords: Unconventional monetary policy, Quantitative easing, Monetary policy transmission.
JEL-codes: E52, E44.

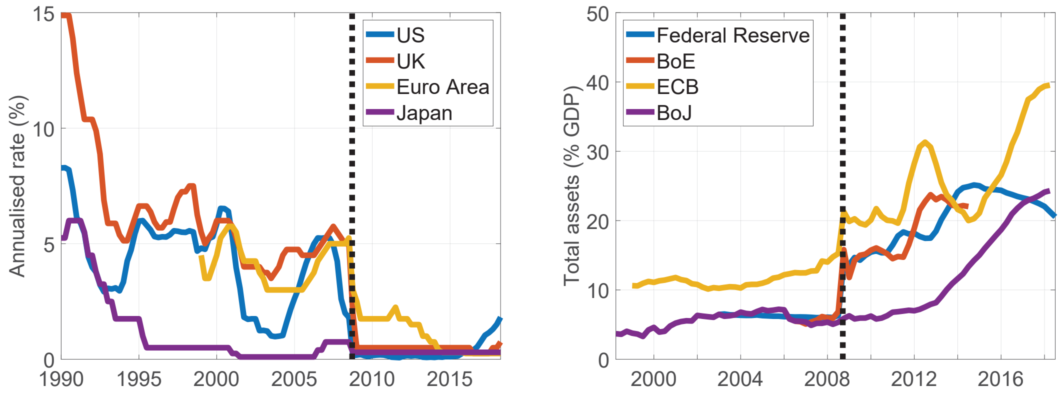
2.1 Introduction

Interest rates in advanced economies have displayed a clear downward trend over the past decades. The gradual decline was further exacerbated by the latest financial crisis, during which short-term rates reached all-time low levels. The conventional monetary policy tool, the policy rate, was quickly exhausted as policy makers faced the constraint of the zero lower bound (ZLB). This is highlighted for several advanced economies in panel (a) in Figure 2.1. A binding ZLB, whether brought by a structural decline in interest rates or by a large and persistent contractionary shock, poses a challenge for monetary policy. A central bank then cannot further stimulate the economy by cutting its policy rate below the ZLB.[1]

In an attempt to further stimulate the economy, central banks instead resorted to unconventional policy measures. This included large-scale purchases of long-dated assets, which were financed by issuing excess reserves. Panel (b) in Figure 2.1 shows that central banks expanded their balance sheets when policy rates approached the ZLB. Such an expansion has been unprecedented and is often discussed in the public debate. In light of sustained low rates and the more frequently binding constraint of the ZLB, it is relevant to understand to which extent asset purchases can be used to effectively stimulate the economy. Indeed, what was considered unconventional policy at the outset of the financial crisis is increasingly referred to as an integral part of the policy toolkit - by commentators and policymakers alike.

While the transmission of conventional monetary policy is well-documented, there is currently no established consensus on the effects of large-scale asset purchase programmes. This paper contributes to building an understanding of how these measures transmit to the wider economy. To do so, I highlight an intuitive transmission mechanism for the central bank purchases of government bonds (so-called quantitative easing measures). The mechanism I propose relies on the well-documented fact that the corporate loan market is imperfect. By purchasing government bonds, the central bank alters the investment opportunities of the banking sector. This reduces the bargaining power that banks have when lending to firms, in turn improving the firms' borrowing conditions. An increase in economic activity then results via more standard channels.

[1] Household deposits earn the policy rate. When deposits earn a return smaller or equal to zero, they become strictly dominated by any other asset with a positive return (say, government bonds). Lowering the policy rate any further is thus ineffective as households do not then alter their deposit holdings. Moreover, if the deposit return becomes sufficiently negative, households will eventually hold their cash outside of banks. This generates large undesired outflows from the banking system (i.e., bank runs).



(a) Policy rates (%)

(b) Central banks' total assets (% GDP)

Panel (a): *Sources:* FRED. US uses the effective federal funds rate (*FEDFUNDS*). UK uses the BoE policy rate (*BOERUKM*). EA uses the marginal lending facility rate (*INTDSREZQ193N*). Japan uses the "less than 24 hours" short rate (*IRSTCB01JPQ156N*). Panel (b): *Sources:* FRED. Total assets for Federal Reserve (*WALCL*), BoE (*UKASSETS*), ECB (*ECBASSETS*) and BoJ (*JPNASSETS*). Annualised nominal GDPs for US (*GDP*), UK (*CPMNACNSAB1GQUK*), EA-19 countries (*EUNNGDP*) and Japan (*JPNNGDP*). Vertical line for Lehman Brother's bankruptcy (15 September 2008).

Figure 2.1: *Policy rates and monetary authorities' assets*

I embed the proposed mechanism in a New Keynesian model that is then estimated by Bayesian methods. I use the model to evaluate the effects of quantitative easing measures, both outside and at the ZLB. I show that the three rounds of quantitative easing carried out in the US had both sizeable and long-lasting accommodative effects. To illustrate, the cumulative Federal Reserve purchases generate the same output response than that of a 125bps unexpected policy rate cut in normal times. This is substantially accommodative policy when compared to the standard 25bps policy rate shock typically used in the literature and observed in the data. Importantly, the proposed mechanism suggests that quantitative easing measures are equally effective at the ZLB.

The next section motivates my contribution and provides some intuition for the core transmission mechanism, which is then nested in the richer model presented in Section 2.3 and estimated in Section 2.4. The estimation reveals that the corporate loan market is far from being perfectly competitive, in turn providing traction to central bank purchases. Section 2.5 then details the transmission of quantitative easing measures to the wider economy, both away from and at the ZLB. I then discuss some implications for the pricing of financial instruments as well as for credit easing measures. I also detail how the presented transmission of central bank purchases departs from the irrelevance theorem of Wallace (1981). Section 2.6 concludes.

2.2 Motivation and related literature

Episodes of quantitative easing (QE) have so far only taken place following extraordinary distressed times, jointly with other policy measures. Asset purchases were used once the ZLB has been binding after the financial crisis. Nonetheless, the constraint of an occasionally binding ZLB also arises from longer-term fundamental changes. Several structural factors have contributed to the downward trend in interest rates that is observed across advanced economies. For the US, Del Negro et al. (2017) list slower economic growth, excess global savings and an increased demand for safe and liquid assets. Declines in productivity are discussed in Gordon (2015) and changing demographics in Summers (2014). Lower productivity implies a lower rate of transformation, in turn lowering interest rates. Population ageing seems to have impacted potential levels of output via lower working-age population to retiree ratios. Among others, Laubach and Williams (2016) and Eggertsson et al. (2017) suggest that the resulting larger proportion of savers pushed down the interest rates that prevail in advanced economies. Likewise, Kiley and Roberts (2017) argue that the ZLB could become more frequently binding. Using one of the main forecasting model of the Federal Reserve, they show that the bound could be binding between 30% to 40% of the time going forward. Unconventional monetary policy measures, including asset purchases, are therefore likely to remain in the policy mix.

Empirical evidence shows that asset purchases have similar effects on the aggregates than accommodative conventional monetary policy. Central bank purchases increased asset prices in the US and the UK (Joyce et al., 2012). Aggregate economic activity also increases after such measures; VAR-based evidence is provided by Weale and Wieladek (2016) for the US and the UK and by Gambetti and Musso (2017) for the Euro area. Nevertheless, the exact transmission channels of QE are still actively debated. Transmission mechanisms are best evaluated in general equilibrium frameworks as to account for the feedback of policy measures on prices. In the benchmark New Keynesian model, QE measures are irrelevant to the real allocation, as was initially suggested by Wallace (1981) and later described by Eggertsson and Woodford (2003).[2] The argument relies on the fact that any asset can be replicated by a combination of other assets under complete markets. Asset purchases by the central bank become irrelevant as varying

[2]The argument is similar to the one exposed in Modigliani and Miller (1958).

the relative supply of assets does not impact their prices. Expanding the central bank balance sheet is thus totally ineffective, as highlighted in Curdia and Woodford (2011).

A strand of literature achieves effectiveness of asset purchases by overcoming the strong (yet rigorous) assumptions underlying the irrelevance result. Several transmission mechanisms have been explored in the representative agent New Keynesian setting. The preferred habitat assumption stipulates that investors have a preference for holding assets of various maturities (as in Vayanos and Vila, 2009). This is an illustration of Tobin (1958)'s imperfect asset substitution: central bank purchases can affect asset prices by reducing their relative supply. In Ellison and Tischbirek (2014), Harrison (2012) and Alpanda and Kabaca (2019), preferred habitat is captured by an asset-in-the-utility motive. Aggregate demand is then affected by QE measures via changes in bond prices. Similar results are obtained by introducing a transaction cost for trading long-dated bonds in Chen et al. (2012), Falagiarda and Marzo (2012) and Falagiarda (2014). While the above results rely on reduced-form assumptions, central bank purchases are also effective in the presence of a financial accelerator mechanism (Carlstrom et al., 2017). In the influential paper of Gertler and Karadi (2013), banks earn excess returns because of an enforcement problem. By purchasing an asset, the central bank reduces its excess return, which in turn decreases the equilibrium borrowing costs of firms. In the model presented in the next section, QE measures instead become effective as *firms* also have some market power in the corporate loan market. In contrast to the preferred habitat literature listed above, I also provide a micro-founded transmission mechanism with effective central bank asset purchases.

The data shows that sellers of assets to the central bank re-balanced their portfolios towards riskier assets such as corporate bonds in the US and the UK (Carpenter et al., 2015 and Joyce et al., 2014). Capital expenditure is mostly financed by corporate debt; this will be the case in my model. Frictions in corporate debt markets are well-documented in the literature and motivate my proposed transmission mechanism. Imperfect competition in the corporate loan market is empirically plausible as borrowers and lenders tend to form long-term relationships. For instance, Chen and Song (2013) document that corporate loan contracts are more easily signed with prior counter-parts in the US. Likewise, they show that geographical preferences matter when matching a lender with a borrower. In line with this, Hubbard et al. (2002) show that it is costly for US firms to change lenders. Den Haan et al. (2003) also list empirical studies that motivate matching frictions and long-lasting relationships in the corporate loan market.[3]

[3]Another key friction identified in corporate credit arises from asymmetric information. This is not the focus of this paper; see Crawford et al. (2018) for a recent application.

Consistent with the empirical evidence, Wasmer and Weil (2004) applied the celebrated search and matching friction of Mortensen and Pissarides (1994) to a general credit market. More specifically, Den Haan et al. (2003) introduced a matching friction in the corporate loan market.

Motivated by this literature, I consider a matching friction between the banking and the production sectors. The economic intuition of the proposed transmission mechanism can be shown in a simplified version of the model that is presented in the next section. At the core of the model, a bank chooses how to invest household savings. The bank can provide a corporate loan l to a firm, for which it receives the rate i^f. The bank also has an outside option: it can invest in other available assets, which deliver an average return ξ. The firm has a production function $f(l)$ and must rent the corporate loan l. Consider the partial equilibrium that obtains in the credit market. The equilibrium rate i^f depends on the prevailing degree of competition. Under perfect competition, both the firm and the bank take i^f as given. In equilibrium, i^f equals the marginal product of a loan: $i^f = f_l(l)$.

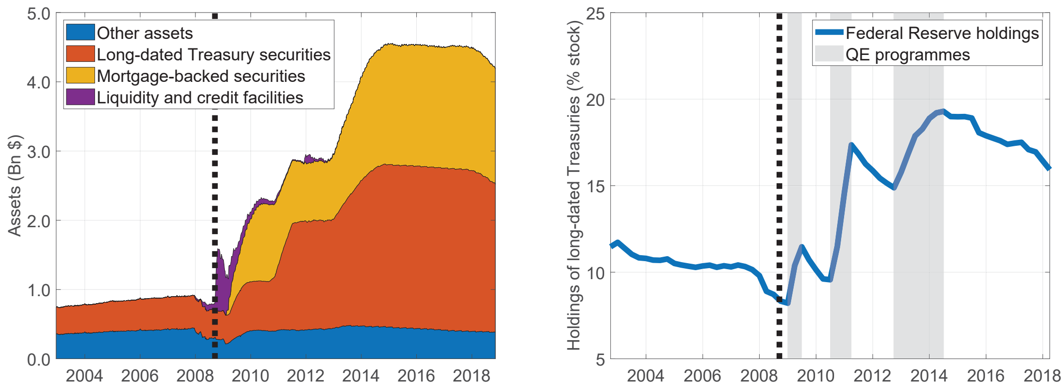
As discussed above, empirical evidence shows that corporate credit markets are not perfectly competitive; long-lasting lending relationships arise due to non-trivial switching costs. If the bank and the firm each have some market power (i.e., a bilateral monopoly), the equilibrium rate i^f will depend on their respective bargaining powers. Suppose that they bargain over the total net surplus $S(i^f)$ of a loan. The net surplus of the firm is then given by $f_l(l) - i^f$ and that of the bank by $i^f - \xi$. Using $S(i^f) = (i^f - \xi)^\lambda (f_l(l) - i^f)^{1-\lambda}$, in which λ denotes the bargaining power of the bank, the Nash bargaining solution for i^f will be:

$$i^f = \lambda f_l(l) + (1 - \lambda)\xi \ . \tag{2.1}$$

When carrying out QE measures, the central bank purchases existing assets by issuing excess reserves. This alters the outside option ξ of the bank in two ways. First, the stock of assets available to the bank on secondary markets is reduced. Second, the amount of excess reserves (which earn a smaller return) is increased. Both effects reduce the average return ξ. As long as the firm has *some* bargaining power ($\lambda < 1$), QE measures have traction: the equilibrium rate i^f is decreased, in turn pushing up the firm's demand for corporate loans. Production therefore increases. By contrast, the irrelevance property of Wallace (1981) only holds for two special cases: under perfect competition (in which case $i^f = f_l$, regardless of the central bank actions) or when the bank has *full* market power over the firm in the credit market ($\lambda = 1$).

In both cases, the bank's outside option ξ has no effect on the pricing of the corporate loan.

I embed this mechanism is a fully-fledged New Keynesian model, and use US data to quantify the effects of QE measures. In the US, the monetary authority resorted to three large-scale asset purchases (LSAP) programmes since the financial crisis. As shown in panel (a) in Figure 2.2, this resulted in a six-fold expansion of its balance sheet. The Federal Reserve first bought both mortgage-backed securities and long-dated government bonds in late 2008. The government bonds purchased, often denoted LSAP1, effectively totalled \$297bn over a year. In 2010, additional purchases of government bonds (LSAP2) were announced: the programme cumulated \$795bn, spread over three quarters. A last round in 2012 involved open-ended purchases of both types of assets (LSAP3) and effectively spread over two years. Panel (b) in the figure shows that the three rounds were sizeable: the central bank acquired a cumulative fraction of 2.7%, 7.8% and 3.9% of the outstanding stock of long-dated US Treasuries, respectively. Section 2.5 will use these proportions to quantify the effects of government bond purchases. The next section derives the model used for the quantification.



(a) Assets (Bn$) *(b) Long-dated Treasuries' holdings (%)*

Panel (a): *Sources:* Board of Governors of the Federal Reserve System, Factors Affecting Reserve Balances (Table H.4.1, week averages). Long-dated Treasury securities (*RESPPALGUOMN.XAW.N.WW*) are Notes (maturity of 1 to 10 years) plus Bonds (maturity of 10 to 30 years). Central bank swap instruments (*RESH4SCS.XAW.N.WW*) are added to liquidity and credit facilities (*RESPPALD.XAW.N.WW*). Mortgage-backed securities use the series *RESPPALGASMO.XAW.N.WW*. Other assets sum up the remaining instruments from Table H.4.1, including Treasury bills (maturity of 1 year or less). Panel (b): *Sources:* Board of Governors of the Federal Reserve System, Financial Accounts, Table Z.1. Federal Reserve holdings of long-dated Treasury securities are the Monetary Authority's holdings of Treasury securities (*FL713061103.Q*) minus its holdings of Treasury bills (*FL713061113.Q*), which have a maturity of 1 year or less. Outstanding long-dated Treasury securities are the Federal Government's total Treasury securities liabilities (*FL313161105.Q*) minus its Treasury bills's liabilities (*FL313161110.Q*). Holdings are shown as a (%) of the outstanding amount. Vertical line for Lehman Brother's bankruptcy (15 September 2008). Shaded areas show episodes of central bank purchase programmes.

Figure 2.2: *Federal Reserve: assets and holdings of long-dated US Treasuries*

2.3 Model

I propose a stylised New Keynesian model with a search friction in the credit market. At the core of the model, a firm and a bank bargain over corporate loans. The model also features a representative household, a government and a central bank. In addition, a standard nominal friction is introduced by retailers as to make results comparable to the existing literature. For ease of exposition, the exogenous shocks are ommited when deriving the model. The shocks will be described subsequently when estimating the model in Section 2.4.

2.3.1 Firm

A firm has a production function $f(l_t, n_t)$ that requires the use of corporate loans l_t and labor n_t. In the model, corporate loans l_t are equivalent to physical capital. The firm rents the capital stock; the loans l_t are therefore one-period contracts, for which the firm is charged an interest rate i_t^f. Bank lending is the only source of external financing. This is motivated by the fact that market debt, such as corporate bonds, is only available to large corporations in real life.[4] Likewise, I do not model retained earnings as investment in physical capital is mostly financed externally in reality. For the rest of the text, l_t thus denotes both corporate loans and physical capital. Acquiring new corporate loans is costly and not guaranteed. The firm faces a cost function $\gamma(o_t)$ when it searches for a loan offer o_t today, hoping that it will be matched with a counterpart on the credit market. In line with empirical evidence on firm debt leverage,[5] the cost function is convex: $\gamma_o(o_t) > 0$ and $\gamma_{oo}(o_t) > 0$. The probability $k^f(\theta_t)$ that the firm obtains a loan depends on the credit market tightness θ_t, which the firm takes as given. A successful loan offer o_t transforms into a unit of capital that can be used for production in the next period. Newly issued loans (which correspond to investment in physical capital) are hence given by $k^f(\theta_t)\ o_t$. Physical capital (and so the existing stock of loans) depreciates at rate δ. The law of motion for corporate loans thus satisfies:

$$l_{t+1} = (1 - \delta)l_t + k^f(\theta_t)o_t \ .$$

[4] Bank lending also represents a sizeable proportion of large corporations' total debt. Using a panel of large US firms, Becker and Ivashina (2014) calculate that the bank debt to total debt ratio averaged around 35% between 1990 and 2010. Dembiermont et al. (2013) show that this ratio is even higher in other advanced economies (see their graph 3 on page 78).

[5] Görtz et al. (2017) show that US firms increase their debt leverage slowly and persistently after large investment decisions. This is consistent with a convex cost as it is then optimal for the firm to smooth its loan search over time.

Knowing this, the firm searches for loan offers o_t today as to obtain the loan stock l_{t+1} that it desires to rent in the next period. The firm's problem is written in units of the final good, which price p_t is discussed in Subsection 2.3.5.[6] The firm hires labor at the real wage w_t and sells its output at the given relative price p_t^f. The firm's recursive problem reads:

$$\max_{\{n_t\ ,\ o_t\ ,\ l_{t+1}\}} \quad : \quad \widetilde{\Pi}_t^f = p_t^f f(l_t, n_t) - w_t n_t - (i_t^f + \delta) l_t - \gamma(o_t) + \mathbb{E}_t\left[\Lambda_{t+1}\ \widetilde{\Pi}_{t+1}^f\right]$$

$$\text{s.t.} \qquad l_{t+1} = (1-\delta) l_t + k^f(\theta_t) o_t\ .$$

The firm belongs to the representative household and values profits accordingly: Λ_t denotes the household's stochastic discount factor (derived in Subsection 2.3.4). The firm's endogenous state variable is existing loans l_t. The firm's first-order conditions for the control variables $\{n_t, o_t, l_{t+1}\}$ are, respectively:

$$\begin{aligned} w_t &= p_t^f f_n(l_t, n_t) \\ \gamma'(o_t) &= \mu_t^f k^f(\theta_t) \\ \mu_t^f &= \mathbb{E}_t\left[\Lambda_{t+1}\left(p_{t+1}^f f_l(l_{t+1}, n_{t+1}) - (i_{t+1}^f + \delta) + (1-\delta)\mu_{t+1}^f\right)\right]\ , \end{aligned}$$

where μ_t^f is the multiplier attached to the loans' law of motion. Inserting the first-order condition with respect to o_t in that with respect to l_{t+1} gives:

$$\gamma'(o_t) = k^f(\theta_t)\ \mathbb{E}_t\left[\Lambda_{t+1}\left(p_{t+1}^f f_l(l_{t+1}, n_{t+1}) - (i_{t+1}^f + \delta) + \frac{(1-\delta)\gamma'(o_{t+1})}{k^f(\theta_{t+1})}\right)\right]\ . \tag{2.2}$$

Equation (2.2) reveals the firm's dynamic motive when searching for a loan. At the optimum, the firm equalises the marginal cost $\gamma'(o_t)$ of searching for a loan to its expected marginal benefit, which depends on the probability of a match $k^f(\theta_t)$ multiplied by the expected lifetime marginal profits generated by a successful match. Lifetime profits are given by the $t+1$ marginal profit plus the continuation value for the non-depreciated fraction $(1-\delta)$ of the loan. Indeed, a successful match today reduces the need (and the associated cost) to search for loans in the following periods: $\frac{\gamma'(o_{t+1})}{k^f(\theta_{t+1})}$.

[6] The prices of capital (and hence of the corporate loan) and consumption are both p_t as this is a one-sector model.

2.3.2 Bank

The credit market counterpart to the firm is a bank, which is also owned by the household. The bank's only liability is household deposits, which earn a net return i_t. Received end-of-period deposits d_{t+1} are invested in either of the three assets available to the bank: a corporate loan l_{t+1}, a government bond b^b_{t+1} and central bank reserves m_{t+1}. The bank's portfolio choice depends on the present discounted values of holding the assets. These values are denoted by V^l_t, V^b_t and V^m_t, respectively.

The bank invests its liabilities by following a sequential search. This is motivated by the fact that the value of holding an asset naturally depends on its return. The bank has some power in the corporate loan market (this is detailed in the next subsection), where it thus earns an excess return $i^f_t - i_t > 0$ over what it pays for its liabilities. The bank therefore strictly prefers to invest in the loan than in any of the two remaining assets: $V^l_t > V^b_t$ and $V^l_t > V^m_t$. Likewise, the bank strictly prefers to invest in the government bond than in reserves when the bond yield-to-maturity i^b_t is higher than the return on reserves i^m_t. This is the case empirically,[7] hence I consider $i^b_t > i^m_t$ in the model so that $V^b_t > V^m_t$.

When investing new funds, the bank consequently first goes to the corporate loan market. There, it faces a probability $k^b(\theta_t)$ of matching with the firm, in which case it obtains the value V^l_t. If the match is unsuccessful, the bank instead obtains the value V^u_t. In that case, the bank first goes to the market for government bonds, where it faces a probability $1 - x_t$ of finding such a bond.[8] If the bank is once again unsuccessful, it is left to invest in reserves. The probability that the bank holds central bank reserves, after an unsuccessful round in the loan market, is therefore given by x_t. I explain in Section 2.3.7 why the equilibrium probability x_t depends on central bank purchases of government bonds.

The respective values of holding the assets are defined by the above timing. The value of the outside investment option, V^u_t, depends on the availability of the two remaining assets:

$$V^u_t = (1 - x_t)V^b_t + x_t V^m_t \ . \tag{2.3}$$

[7]Reserves in the model correspond to *excess* reserves in the data.
[8]Bonds are issued by the government and are therefore in finite supply.

The values of holding government bonds, V_t^b, and central bank reserves, V_t^m, depend on the obtained returns plus their continuation values. With probability $k^b(\theta_t)$, these funds will be successfully matched with the firm at the end of the period and hence deliver a value of V_{t+1}^l in the next period. The current values are hence given by:

$$V_t^b = \ i_t^b - i_t + \mathbb{E}_t\left[\Lambda_{t+1}\left(k^b(\theta_t)V_{t+1}^l + \left(1 - k^b(\theta_t)\right)V_{t+1}^u)\right)\right] \tag{2.4}$$

$$V_t^m = i_t^m - i_t + \mathbb{E}_t\left[\Lambda_{t+1}\left(k^b(\theta_t)V_{t+1}^l + \left(1 - k^b(\theta_t)\right)V_{t+1}^u)\right)\right] , \tag{2.5}$$

in which the bank uses the household's stochastic discount factor Λ_{t+1}. The current government bond yield-to-maturity i_t^b is further detailed in Subsection 2.3.4.

When holding corporate loans, the bank earns a return differential of $i_t^f - i_t$. The bank will also get a continuation value of V_{t+1}^l for the fraction $1 - \delta$ of the underlying physical capital that did not depreciate and accordingly does not require a new search.[9] While the firm still pays back the remaining fraction δ to the bank, it is realistic to assume that the bank cannot re-invest it in the corporate loan market within the same period. The bank accordingly gets its outside investment option V_{t+1}^u for the fraction δ. The value V_t^l of holding a corporate loan is thus given by:

$$V_t^l = i_t^f - i_t + \mathbb{E}_t\left[\Lambda_{t+1}\left((1-\delta)V_{t+1}^l + \delta V_{t+1}^u\right)\right] . \tag{2.6}$$

2.3.3 Corporate loan market equilibrium

The corporate loan market is not perfectly competitive. In the model, there is a bilateral monopoly: both the firm and the bank may have some bargaining power when they negociate a loan contract. To assess the extent of these respective market powers, the strategic interaction between the firm and the bank is resolved by using Nash bargaining.[10] The equilibrium corporate loan rate i_t^f will be the result of bargaining over the total net surplus $S_t(i_t^f)$ of a successful match. The net surplus of a corporate loan is given by $V_t^l - V_t^u$ for the bank and by $J_t - V_t^c$ for the firm, where J_t denotes the value of having

[9] The estimation carried out in the next section allows to recover the unconditional variance of l_t. The variance is such that $l_{t+1} > (1-\delta)l_t$ always holds for the considered parameter values.

[10] The Nash bargaining solution satisfies axioms which correspond to the loan market setting presented here: invariance fo affine transformations of the payoffs (here, the equilibrium labor level n_t impacts the marginal product of loans $f_l(n_t, l_t)$), independence of irrelevant alternatives, symmetry (here, both the firm and the bank are profit-maximizers), no incentives to deviate (Nash, 1950). Using Nash-bargaining is popular in the search and matching literature as it allows to obtain an analytical solution; see Wasmer and Weil (2004) for an application to the credit market.

acquired a loan and V_t^c is the value of searching for a loan offer. Free entry in searching loan offers implies that $V_t^c = 0$. The value of holding an additional loan to the firm, J_t, is the corresponding marginal benefit. It is readily obtained from the firm's problem:

$$J_t = p_t^f f_l(l_t, n_t) - (i_t^f + \delta) + (1-\delta)\mathbb{E}_t\big[\Lambda_{t+1} J_{t+1}\big] \ .$$

The value J_t depends on the current marginal profit of a loan plus its continuation value for the non-depreciated fraction $1-\delta$. Leading this equation by one period and applying the household's stochastic discount factor, we obtain:

$$\mathbb{E}_t\big[\Lambda_{t+1} J_{t+1}\big] = \mathbb{E}_t\big[\Lambda_{t+1}\big(p_{t+1}^f f_l(l_{t+1}, n_{t+1}) - (i_{t+1}^f + \delta)\big)\big] + \mathbb{E}_t\big[(1-\delta)\Lambda_{t+2} J_{t+2}\big] \ ,$$

which naturally becomes the firm's first-order condition, equation (2.2), when equating the marginal cost of searching for an offer to its expected marginal benefit: $\frac{\gamma'(o_t)}{k^f(\theta_t)} = \mathbb{E}_t\big[\Lambda_{t+1} J_{t+1}\big]$. The firm's net surplus can hence be written as:

$$J_t - V_t^c = J_t = p_t^f f_l(l_t, n_t) - (i_t^f + \delta) + (1-\delta)\frac{\gamma'(o_t)}{k^f(\theta_t)} \ . \tag{2.7}$$

Combining equations (2.3) to (2.6), the bank's net surplus can be expressed as:

$$V_t^l - V_t^u = i_t^f - (1-x_t)i_t^b - x_t i_t^m + \big(1-\delta-k^b(\theta_t)\big)\mathbb{E}_t\big[\Lambda_{t+1}\big(V_{t+1}^l - V_{t+1}^u\big)\big] \ . \tag{2.8}$$

The total net surplus is then given by $S_t(i_t^f) = \big(V_t^l(i_t^f) - V_t^u(i_t^f)\big)^\lambda \big(J_t(i_t^f)\big)^{1-\lambda}$, where λ dictates the bank's bargaining power. Maximizing the total net surplus with respect to the loan rate i_t^f yields the well-known constant sharing rule:

$$\begin{aligned} \lambda J_t &= (1-\lambda)\big(V_t^l - V_t^u\big) \\ \iff \lambda &= \frac{V_t^l - V_t^u}{S_t} \ . \end{aligned} \tag{2.9}$$

The bank obtains a fraction λ of the total net surplus of a corporate loan. As a corollary, whenever the bank has some bargaining power ($\lambda > 0$), the value of holding a corporate loan V_t^l dominates that of holding any of the two other available assets (given by V_t^u). While the bank strictly prefers to invest in corporate loans, it will nonetheless still invest some of the household deposits in the two other assets. This is because, in equilibrium, the firm only demands a finite amount of corporate loans for a given i_t^f. The bank is then better off investing the remaining household deposits into either the government bond or reserves as the two assets can earn interest, whereas sitting on retained earnings would yield a return of zero.[11]

In equilibrium, the corporate loan market tightness depends on how many funds are matched. The bank's liabilities consist of nominal household deposits d_{t+1}. The firm's corresponding loan searches are given by $p_t o_t$ in nominal terms, so that a measure of credit tightness is given by $\theta_t = \frac{p_t o_t}{d_{t+1}}$. Nominal corporate loans are matched via the constant returns to scale function $\mathcal{M}_t = (d_{t+1})^{\mu}(p_t o_t)^{1-\mu}$. As such, the probability that the firm finds a loan is given by $k^f(\theta_t) = \frac{\mathcal{M}_t}{p_t o_t} = \theta_t^{-\mu}$ whereas the probability that the bank matches with the firm is $k^b(\theta_t) = \frac{\mathcal{M}_t}{d_{t+1}} = \theta_t^{1-\mu}$. Inserting equations (2.7) and (2.8) into (2.9), we get:

$$\lambda\left(p_t^f f_l(l_t, n_t) - (i_t^f + \delta) + (1-\delta)\frac{\gamma'(o_t)}{k^f(\theta_t)}\right) = (1-\lambda)\left(i_t^f - (1-x_t)i_t^b - x_t i_t^m + \big(1-\delta-k^b(\theta_t)\big)\left(\frac{\lambda}{1-\lambda}\right)\frac{\gamma'(o_t)}{k^f(\theta_t)}\right)$$

$$\iff \lambda\big(p_t^f f_l(l_t, n_t) - (i_t^f + \delta)\big) = (1-\lambda)\big(i_t^f - (1-x_t)i_t^b - x_t i_t^m\big) - \lambda\gamma'(o_t)\frac{k^b(\theta_t)}{k^f(\theta_t)}$$

$$\iff i_t^f = \lambda\big(p_t^f f_l(l_t, n_t) - (\delta - \gamma'(o_t)\theta_t)\big) + (1-\lambda)\big((1-x_t)i_t^b + x_t i_t^m\big)\ , \tag{2.10}$$

where $\theta_t = \frac{k^b(\theta_t)}{k^f(\theta_t)}$ due to constant returns to scale. Equation (2.10) highlights that in equilibrium, corporate loans deliver a hybrid return that depends on the two agents' respective bargaining powers. The return is a weighted average of that on (what would be) equity and public financial claims (consisting here of government bonds and central bank reserves). The return on corporate debt i_t^f depends on the marginal product of the firm, net of the loan's replacement cost, as well as on the outside option of the bank, which is given by the average return $(1-x_t)i_t^b + x_t i_t^m$. When $\lambda \to 1$, the bank extracts all of the total net surplus from the firm, whereas when $\lambda \to 0$ the bank only gets its outside option.

Equation (2.10) contains the same core transmission mechanism that was initially presented via equation (2.1). Central bank purchases of government bonds reduce the probability $1-x_t$ that the bank finds a (finitely-supplied) bond. Likewise, the probability x_t that the bank invests in reserves increases. In other words, the bank is more frequently left to invest its liabilities in reserves after an unsuccessful match in the corporate loan market. By purchasing bonds, the central bank therefore lowers the bank's outside option (denoted by ξ in equation 2.1), which in turn decreases the equilibrium corporate loan rate i_t^f. This gives an incentive for the firm to acquire more corporate loans, as will be discussed in Section 2.5.

[11] When $i_t^m = 0$, the bank would be indifferent between holding reserves and retaining earnings; the bank would then still hold the reserves in equilibrium.

2.3.4 Representative household

Both the firm and the bank are owned by a representative household. The household maximizes its expected lifetime utility subject to a budget constraint:

$$\max_{\{c_t, n_t, d_{t+1}, b_{t+1}^h\}} \; : \; U_t = u(c_t, n_t) + \beta \mathbb{E}_t \Big[U_{t+1} \Big]$$
$$\text{s.t.} \qquad d_t(1+i_t) + b_t^h(1+\kappa q_t) + \Pi_t + p_t w_t n_t = p_t c_t + d_{t+1} + q_t b_{t+1}^h + p_t t_t \; .$$

The overall price index is denoted by p_t. The household can accumulate bank deposits d_{t+1} that earn the gross rate $1 + i_t$. It can also hold a government bond b_t^h that delivers a decaying coupon $\kappa \in (0,1)$. This bond, purchased at price q_t, follows the perpetuity specification of Woodford (2001), in which the coupon κ dictates the duration. This parsimonious formulation assumes that the long-dated bond can be sold on a secondary market in each period.[12] The gross payoff of this bond can be written as $1 + \kappa q_t$ in the household budget constraint. The net yield-to-maturity is then given by $i_t^b = 1/q_t + \kappa - 1$ (see Appendix 2.7.1 for the derivations). The household provides hours worked n_t that earn labor income $p_t w_t$, receives realised profits from all of the other agents, Π_t,[13] and pays lump-sum taxes $p_t t_t$. The household discount rate is denoted by β. Maximization yields the well-known labor supply condition and Euler equations:

$$\begin{aligned} u_n(c_t, n_t) &= w_t u_c(c_t, n_t) \\ 1 &= \mathbb{E}_t \Big[\Lambda_{t+1} \big(1 + i_t\big) \Big] \\ q_t &= \mathbb{E}_t \Big[\Lambda_{t+1} \big(1 + \kappa q_{t+1}\big) \Big] \; , \end{aligned}$$

where $\Lambda_{t+1} = \beta \frac{u_c(c_{t+1}, n_{t+1})}{u_c(c_t, n_t)} \frac{1}{1+\pi_{t+1}}$ is the household's stochastic discount factor, which depends on the discount rate β, on the ratio of the marginal utilities and on the future (net) inflation rate $\pi_{t+1} = \log\left(\frac{p_{t+1}}{p_t}\right)$ that is derived in the next subsection. At the optimum, the household invests in the two available assets until their risk-adjusted returns are equalized. Deposits and bonds are therefore perfect substitutes.

[12] As shown in Appendix 2.7.3, the transmission of QE measures is not sensitive to realistic bond durations (captured via κ). See Chatterjee and Eyigungor (2012) for a two-parameter bond specification that distinguishes duration from coupon payments.

[13] The equilibrium is not affected if the household has instead access to securities that deliver the profits Π_t (see Appendix 2.7.2).

2.3.5 Retailers and final good producer

A standard nominal friction is introduced via retailers. This allows to compare the effects of QE measures to those of conventional monetary policy, which typically rely on price stickiness in the existing literature.[14] A continuum of monopolistically competitive retailers package the firm's output $y_t = f(l_t, n_t)$. Retailer j sells its production $y(j)_t$ at price $p(j)_t$ to a final good producer. The final good producer simply bundles the retailers' individual outputs $y(j)_t$. Taking the overall price index p_t as given, the final good producer's maximization problem reads:

$$\max_{\{y(j)_t \in [0,1]\}} \; : \; \Pi_t^g = p_t y_t - \int_0^1 p(j)_t y(j)_t dj \qquad \text{s.t.} \qquad y_t = \left[\int_0^1 y(j)_t^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}} ,$$

where ϵ is the retailer goods' elasticity of substitution. The first-order condition with respect to $y(j)_t$ gives the demand function used below by the retailers, $y(j)_t = \left(\frac{p(j)_t}{p_t}\right)^{-\epsilon} y_t$. The overall price index $p_t = \left[\int_0^1 p(j)_t^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}$ then results from the zero-profit condition.

The relative price of the firm's output was denoted by p_t^f, hence retailers buy the output at the given price $p_t p_t^f$. Retailer j then sets its price $p(j)_t$, for which it occurs a Rotemberg (1982) cost. I use the cost formulation in Lütticke (2018). Retailer j faces the demand function $y(j)_t = \left(\frac{p(j)_t}{p_t}\right)^{-\epsilon} y_t$, taking as given total output y_t and the overall price index p_t. Using the household's stochastic discount factor, the retailer maximises its lifetime profits:

$$\begin{aligned} \max_{\{p(j)_t\}} \; &: \Pi(j)_t^r = \left(p(j)_t - p_t p_t^f \right) y(j)_t - \frac{\epsilon}{2\varphi} \left(\log \frac{p(j)_t}{p(j)_{t-1}} \right)^2 p_t y_t + \mathbb{E}_t \left[\Lambda_{t+1} \Pi(j)_{t+1}^r \right] \\ \text{s.t.} \; &: y(j)_t = \left(\frac{p(j)_t}{p_t} \right)^{-\epsilon} y_t \; . \end{aligned}$$

The first-order condition with respect to $p(j)_t$ is:

$$\left(1 - \epsilon \left(\frac{p(j)_t - p_t p_t^f}{p_t} \right) \left(\frac{p(j)_t}{p_t} \right)^{-1} \right) \left(\frac{p(j)_t}{p_t} \right)^{-\epsilon} y_t - \frac{\epsilon}{\varphi} \log \left(\frac{p(j)_t}{p(j)_{t-1}} \right) \frac{p_t y_t}{p(j)_t} + \frac{\epsilon}{\varphi} \mathbb{E}_t \left[\Lambda_{t+1} \log \left(\frac{p(j)_{t+1}}{p(j)_t} \right) \frac{p_{t+1} y_{t+1}}{p(j)_t} \right] = 0 \; .$$

Because retailers are symmetric, they all charge the same price $p(j)_t = p_t$ in equi-

[14] In contrast to conventional monetary policy, the transmission of QE measures does not entirely rely on the nominal friction. Most of the transmission takes place regardless of price stickiness (see Appendix 2.7.3).

librium. Using the net inflation rate $\pi_t = \log\left(\frac{p_t}{p_{t-1}}\right)$, we get:

$$\begin{aligned}
&\big(1-\epsilon(1-p_t^f)\big)y_t - \frac{\epsilon}{\varphi}\pi_t y_t + \frac{\epsilon}{\varphi}\mathbb{E}_t\Big[\Lambda_{t+1}(1+\pi_{t+1})\pi_{t+1}y_{t+1}\Big] = 0 \\
\iff\ & \pi_t = \varphi\left(p_t^f - \frac{\epsilon-1}{\epsilon}\right) + \mathbb{E}_t\left[\Lambda_{t+1}(1+\pi_{t+1})\pi_{t+1}\frac{y_{t+1}}{y_t}\right] . \qquad (2.11)
\end{aligned}$$

Equation (2.11) is the standard New Keynesian Phillips curve under Rotemberg pricing. The slope of the curve is dictated by φ whereas ϵ defines the steady-state mark-up charged by retailers.[15]

2.3.6 Government and central bank

The model has two public institutions: a government and an independent central bank. Government revenues rely on lump-sum real taxes t_t and on a constant stock of long-dated bonds b, traded at price q_t.[16] Real public spending is a fraction g of output.[17] Budget balance is obtained via lump-sum taxes:

$$q_t b + p_t t_t = (1+\kappa q_t)b + p_t g y_t \ .$$

The central bank carries out both conventional and unconventional monetary policy measures. Because of the nominal friction, the deposit rate i_t becomes crucial for model determinacy (Galí, 2015). Conventional monetary policy takes the form of interest rate targeting. In particular, the policy rate i_t follows a standard Taylor rule augmented for the ZLB:

$$i_t = \max\ :\ \big\{\ (1-\phi_i)(1/\beta-1) + \phi_i i_{t-1} + \phi_\pi \pi_t\ ,\ 0\ \big\}\ ,$$

where ϕ_π dictates the strength of the central bank response to inflation and ϕ_i captures the inertia that is typically observed in interest rate setting. In the steady-state, $\pi = 0$ so that the real rate is given by $r = 1/\beta - 1$.

[15] In the steady-state, $\pi = 0 \rightarrow p^f = \frac{\epsilon-1}{\epsilon}$. The mark-up over the firm's price is thus $\frac{\epsilon}{\epsilon-1}$. The Rotemberg (1982) and Calvo (1983) pricing mechanisms are observationally equivalent up to a first-order approximation: both price dispersion (under Calvo pricing) and the budget constraint's Rotemberg cost vanish when taking a first-order approximation. Here, the equivalence is given by $\varphi = (1-\theta)(1-\theta\beta)/\theta$, where θ is the Calvo probability that a firm does not reset its price in a given period (see Rupert and Sustek, 2019).

[16] There is no growth in the model. The constant issuance is used to simplify the calculation of the probability $1 - x_t$ that the bank finds a government bond. See Subsection 2.3.4 and Appendix 2.7.1 for the derivations related to the bond.

[17] Public spending is formulated as in Smets and Wouters (2003) for the estimation; see Section 2.4.

As for unconventional monetary policy, the central bank can purchase government bonds b_{t+1}^{cb} at price q_t on the secondary market. Purchases $q_t b_{t+1}^{cb}$ are financed by issuing reserves m_{t+1}, which may earn the rate i_t^m.[18] In the baseline case used for the estimation, I set $i_t^m = 0$ as excess reserves did not earn interest until recently; the role played by i_t^m is further discussed in Subsection 2.5.5. It is convenient to express central bank purchases as a fraction x_t of the outstanding stock b of government bonds, so that $m_{t+1} = q_t b_{t+1}^{cb} = q_t b x_t$. In Section 2.5, x_t follows a carefully calibrated exogenous process as to assess the effectiveness of central bank asset purchases.

2.3.7 General equilibrium

In general equilibrium, the agents' optimal decisions are consistent with prices and markets clear. Clearing in the government bond market implies that $b = b_t^{cb} + b_t^b + b_t^h$. As discussed in Subsection 2.3.4, deposits and government bonds are perfect substitutes. The household's bond holdings b_t^h are thus indeterminate as the household is indifferent between which assets it holds.[19] As the equilibrium is consistent with any b_t^h, I normalize $b_t^h = 0$ so that the amount of bonds available to the bank only depend on central bank purchases: $q_t b_{t+1}^b = q_t(b - b_{t+1}^{cb}) = q_t b(1 - x_t)$. In equilibrium, the bank invests $q_t b_{t+1}^b$ in bonds and m_{t+1} in reserves. The probability that the bank invests a unit of household deposits in the bond (*after* an unsuccessful match on the corporate loan market) then solely depends on the fraction x_t taken away by the central bank. This is seen by using the central bank's balance sheet ($m_{t+1} = q_t b x_t$):

$$\frac{q_t b_{t+1}^b}{q_t b_{t+1}^b + m_{t+1}} = \frac{q_t b(1 - x_t)}{q_t b(1 - x_t) + q_t b x_t} = 1 - x_t \ . \tag{2.12}$$

In equilibrium, the representative household receives all profits: $\Pi_t = \Pi_t^g + \int_0^1 \Pi(j)_t^r dj + p_t \Pi_t^f + \Pi_t^b + \Pi_t^{cb}$.[20] Consolidating the agents' budget constraints gives the resource constraint:

$$f(l_t, n_t)\big(1 - g - \frac{\epsilon}{2\varphi}\pi_t^2\big) = c_t + \gamma(o_t) + k^f(\theta_t) o_t \ ,$$

[18] In equilibrium, the central bank ex-post profits $\Pi_t^{cb} = (1 + \kappa q_t) b_t^{cb} + m_{t+1} - q_t b_{t+1}^{cb} - (1 + i_t^m) m_t = (1 + \kappa q_t - (1 + i_t^m) q_{t-1}) b_t^{cb}$ are rebated to the household.

[19] When consolidating the resource constraint, b_t^h vanishes. This contrasts to the preferred habitat literature, in which investors have an additional non-pecuniary motive to hold specific assets. This extra motive, which is often necessary to depart from the irrelevance theorem in the literature, is not needed in my framework due to market segmentation. This is discussed in Section 2.5.

[20] From Subsection 2.3.1, $\Pi_t^f = p_t^f f(l_t, n_t) - w_t n_t - (i_t^f + \delta) l_t - \gamma(o_t)$.

where the total number of (real) matches satisfies $k^f(\theta_t)o_t = \frac{\mathcal{M}_t}{p_t} = l_{t+1} - (1-\delta)l_t$. Because $m_{t+1} = q_t b^{cb}_{t+1}$, bank deposits equal corporate loans plus outstanding government bonds in the equilibrium of a closed economy. Consequently, market tightness in the corporate credit market is given by $\theta_t = \frac{p_t o_t}{d_{t+1}} = \frac{p_t o_t}{p_t l_{t+1} + q_t b} = \frac{o_t}{l_{t+1}}$ when also normalizing $b = 0$.[21] General equilibrium then consists of a collection of policy functions for the 11 control variables $\{y_t, l_{t+1}, n_t, c_t, p^f_t, \pi_t, o_t, \theta_t, i^f_t, i^b_t, i_t\}$ that satisfies the following 11 equations:

$$\frac{u_n(c_t,n_t)}{u_c(c_t,n_t)} = p^f_t f_n(l_t,n_t) \tag{2.13}$$

$$f(l_t,n_t) = f(l_t,n_t)\big(g + \frac{\epsilon}{2\varphi}\pi_t^2\big) + c_t + \gamma(o_t) + l_{t+1} - (1-\delta)l_t \tag{2.14}$$

$$\gamma'(o_t) = k^f(\theta_t)\ \mathbb{E}_t\Bigg[\Lambda_{t+1}\Bigg(p^f_{t+1} f_l(l_{t+1},n_{t+1}) - (i^f_{t+1}+\delta) + \frac{(1-\delta)\gamma'(o_{t+1})}{k^f(\theta_{t+1})}\Bigg)\Bigg] \tag{2.15}$$

$$i^f_t = \lambda\big(p^f_t f_l(l_t,n_t) - (\delta - \gamma'(o_t)\theta_t)\big) + (1-\lambda)\big((1-x_t)i^b_t\big) \tag{2.16}$$

$$\theta_t = \frac{o_t}{l_{t+1}} \tag{2.17}$$

$$1 = \mathbb{E}_t\Big[\Lambda_{t+1}\big(1+i_t\big)\Big] \tag{2.18}$$

$$q_t = \mathbb{E}_t\Big[\Lambda_{t+1}\big(1+\kappa q_{t+1}\big)\Big] \tag{2.19}$$

$$i^b_t = 1/q_t + \kappa - 1 \tag{2.20}$$

$$\pi_t = \varphi\bigg(p^f_t - \frac{\epsilon-1}{\epsilon}\bigg) + \mathbb{E}_t\Big[\Lambda_{t+1}(1+\pi_{t+1})\pi_{t+1}\frac{y_{t+1}}{y_t}\Big] \tag{2.21}$$

$$i_t = \max\ :\ \big\{\ (1-\phi_i)(1/\beta - 1) + \phi_i i_{t-1} + \phi_\pi \pi_t\ ,\ 0\ \big\} \tag{2.22}$$

$$y_t = f(l_t,n_t)\ , \tag{2.23}$$

where $\Lambda_{t+1} = \beta\frac{u_c(c_{t+1},n_{t+1})}{u_c(c_t,n_t)}\big(\frac{1}{1+\pi_{t+1}}\big)$. The exogenous variable x_t can be used to model the fraction of the outstanding government bond stock that is purchased by the central bank. Equation (2.16) uses $i^m_t = 0$ as this is assumed throughout the rest of the text; this is further discussed in Subsection 2.4.3.

I use standard functional forms. The utility function is additive separable $u(c_t,n_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{n_t^{1+\eta}}{1+\eta}$ and the production function is Cobb-Douglas $f(l_t,n_t) = (l_t)^\alpha(n_t)^{1-\alpha}$. The search cost function is quadratic: $\gamma(o_t) = \frac{\gamma}{2}o_t^2 y_t$. The matching function has constant returns to scale and becomes $\mathcal{M}_t = p_t(l_{t+1})^\mu(o_t)^{1-\mu}$ in equilibrium; accordingly, $k^f(\theta_t) = \theta_t^{-\mu}$.

[21] The bond supply *level* plays little role in the model (see Subsection 2.4.3).

2.4 Estimation

The credit market search friction relies on parameters that are not directly measured in the literature. Accordingly, I estimate the model with US data. In the model, the search friction parameters explicitly shape the response of the corporate loan rate and are thus crucial to the transmission of shocks. I therefore resort to Bayesian estimation, which makes use of the full information provided by the model via maximum likelihood.[22] This contrasts to partial information estimation methods, such as calibration and the generalized method of moments, which solely focus on matching some of the model's moments with what is observed in the data.

2.4.1 Exogenous shocks

Estimation is only feasible if there are at least as many shocks as variables that can be mapped to the data. I consider a collection of eight exogenous shocks $\boldsymbol{\varepsilon}_t$ that are known to affect business cycles. The shocks follow the same formulation than Smets and Wouters (2007) and Smets and Wouters (2003). A total factor productivity shock ε_t^{tfp} shifts production: $y_t = e^{\varepsilon_t^{tfp}}(l_t)^\alpha(n_t)^{1-\alpha}$. Government spending shocks ε_t^g affect the otherwise constant fraction of output devoted to public spending: $g_t = g + \varepsilon_t^g$. An investment shock ε_t^{inv} affects the (real) corporate loan matching function: $e^{\varepsilon_t^{inv}}(l_{t+1})^\mu(o_t)^{1-\mu}$. A positive shock hence increases the probability of a match. Labor supply shocks ε_t^{lab} affect the disutility of work: $e^{\varepsilon_t^{lab}}\left(\frac{n_t^{1+\eta}}{1+\eta}\right)$. A demand shock ε_t^{beta} affects household patience by multiplying the discount rate: $e^{\varepsilon_t^{beta}}\beta$.[23] A monetary policy shock ε_t^{int} and a cost-push shock ε_t^{infl} linearly enter, respectively, the Taylor rule and the New Keynesian Phillips curve. Last, a risk premium shock ε_t^{rp} directly affects the deposit rate i_t faced by the household. The central bank has no control over this shock as it does not enter the Taylor rule. The various shocks ε_t are allowed to follow first-order auto-regressive processes:

$$
\begin{aligned}
\varepsilon_t^{tfp} &= \rho_{tfp}\varepsilon_{t-1}^{tfp} + \epsilon_t^{tfp} \quad &, \quad \epsilon_t^{tfp} &\sim \mathcal{N}(0, \sigma_{tfp}^2) \\
\varepsilon_t^{g} &= \rho_{g}\varepsilon_{t-1}^{g} + \epsilon_t^{g} \quad &, \quad \epsilon_t^{g} &\sim \mathcal{N}(0, \sigma_{g}^2) \\
\varepsilon_t^{inv} &= \rho_{inv}\varepsilon_{t-1}^{inv} + \epsilon_t^{inv} \quad &, \quad \epsilon_t^{inv} &\sim \mathcal{N}(0, \sigma_{inv}^2) \\
\varepsilon_t^{lab} &= \rho_{lab}\varepsilon_{t-1}^{lab} + \epsilon_t^{lab} \quad &, \quad \epsilon_t^{lab} &\sim \mathcal{N}(0, \sigma_{lab}^2) \\
\varepsilon_t^{beta} &= \rho_{beta}\varepsilon_{t-1}^{beta} + \epsilon_t^{beta} \quad &, \quad \epsilon_t^{beta} &\sim \mathcal{N}(0, \sigma_{beta}^2)
\end{aligned}
$$

[22] Setting priors helps because the likelihood function of medium to large-scale models is typically flat and/or irregular (Koop et al., 2013).

[23] A recent strand of literature looks at uncertainty shocks. Leduc (2016) shows that demand shocks provide similar results in a search and matching model.

$$\varepsilon_t^{int} = \rho_{int}\varepsilon_{t-1}^{int} + \epsilon_t^{int} \quad , \quad \epsilon_t^{int} \sim \mathcal{N}(0, \sigma_{int}^2)$$
$$\varepsilon_t^{infl} = \rho_{infl}\varepsilon_{t-1}^{infl} + \epsilon_t^{infl} \quad , \quad \epsilon_t^{infl} \sim \mathcal{N}(0, \sigma_{infl}^2)$$
$$\varepsilon_t^{rp} = \rho_{rp}\varepsilon_{t-1}^{rp} + \epsilon_t^{rp} \quad , \quad \epsilon_t^{rp} \sim \mathcal{N}(0, \sigma_{rp}^2) \ .$$

The structural parameters Ω then consist of the persistence parameters ρ, the shock variances σ^2 and the behavioral parameters used in Section 2.3.

2.4.2 Data

The model is mapped to the data via the observable variables $\left\{y_t, c_t, \frac{\mathcal{M}_t}{p_t}, n_t, i_t^b, i_t^f, i_t, \pi_t\right\}$. I use quarterly data from the FRED database, covering the period 1960Q1-2008Q3.[24] Output y_t is measured by real gross domestic product (*GDPC1*), consumption c_t by personal consumption expenditures (*PCEC*), investment $\frac{\mathcal{M}_t}{p_t}$ by investment in private non-residential fixed capital (*PNFI*) and hours worked n_t by non-farm business average weekly hours (*PRS85006023*).[25] The above real variables are seasonally adjusted and use chained 2009 prices (or are obtained by using the implicit price deflator index, *GDPDEF*). The yield-to-maturity i_t^b of the long-dated bond is measured by the 10-year government bond yield (*IRLTLT01USM156N*) and the policy rate i_t by the effective federal funds rate (*FEDFUNDS*). I approximate the corporate loan rate i_t^f by the Moody's seasoned Aaa corporate bond yield (*AAA*). This series covers the time period considered, whereas US firms' loan rates data is only available since 1997. Importantly, time variations in firms' loan rates are captured by corporate bond yields as the two measures are strongly correlated: the correlation coefficient between the *AAA* series and the US firms' average loan rate is 0.79.[26] All rates are transformed into quarterly rates. The inflation rate π_t is measured by quarterly changes in the implicit price deflator (*GDPDEF*).

The observables that I use are the same than in the pioneering work of Smets and Wouters (2003) and in their extension to the US economy (Smets and Wouters, 2007), to which I added the government and corporate bond yields. The rates i_t^b and i_t^f

[24] This is similar to Smets and Wouters (2003), who cover 1966Q1-2004Q4. I stop before the financial crisis (2008Q4) as it brought a discontinuity in the conduct of monetary policy, with the introduction of large-scale asset purchases among other unconventional measures.

[25] As in Chang, Gomes and Schrofheide (2002) and Smets and Wouters (2007), working hours are adjusted to reflect the limited coverage of the non-farm business sector. This is done by multiplying hours worked by the ratio of the civilian employment level (*CE16OV*) to the working age population (aged 15-64, *LFWA64TTUSM647N*).

[26] Using the weighted-average effective loan rate of all commercial banks for all commercial and industry loans series (*EEANQ*) available between 1997 and 2017. Although loan rates are on average higher than corporate bond yields, this does not affect the estimation as the data is de-trended.

are directly related via equation (2.10), which also contains the search friction parameters (λ, μ and γ). The two rates are hence relevant to identify the model-specific parameters. The measurement equation that maps the model to the data is given by Y^T:

$$Y^T = \begin{bmatrix} dl\ GDPC_t \\ dl\ PCEC_t \\ dl\ PNFI_t \\ l\ PRS_t \\ IRLT_t \\ AAA_t \\ FEDFUNDS_t \\ dl\ GDPDEF_t \end{bmatrix} = \begin{bmatrix} \log y_t - \log y_{t-1} \\ \log c_t - \log c_{t-1} \\ \log \frac{\mathcal{M}_t}{p_t} - \log \frac{\mathcal{M}_{t-1}}{p_{t-1}} \\ \log n_t - \log n \\ i_t^b \\ i_t^f \\ i_t \\ \pi_t \end{bmatrix},$$

where dl is 100 times the log-difference over a quarter. Because variables are stationary in the model, the data series measured in log-differences are net of their respective average growth rates. Likewise, the log of hours worked ($l\ PRS_t$) is in deviations from its stationary average value; the corresponding steady-state value in the model is n. The quarterly rates for $\left\{i_t^b, i_t^f, i_t, \pi_t\right\}$ are also multiplied by 100.[27] The resulting series are plotted in Figure 2.3.

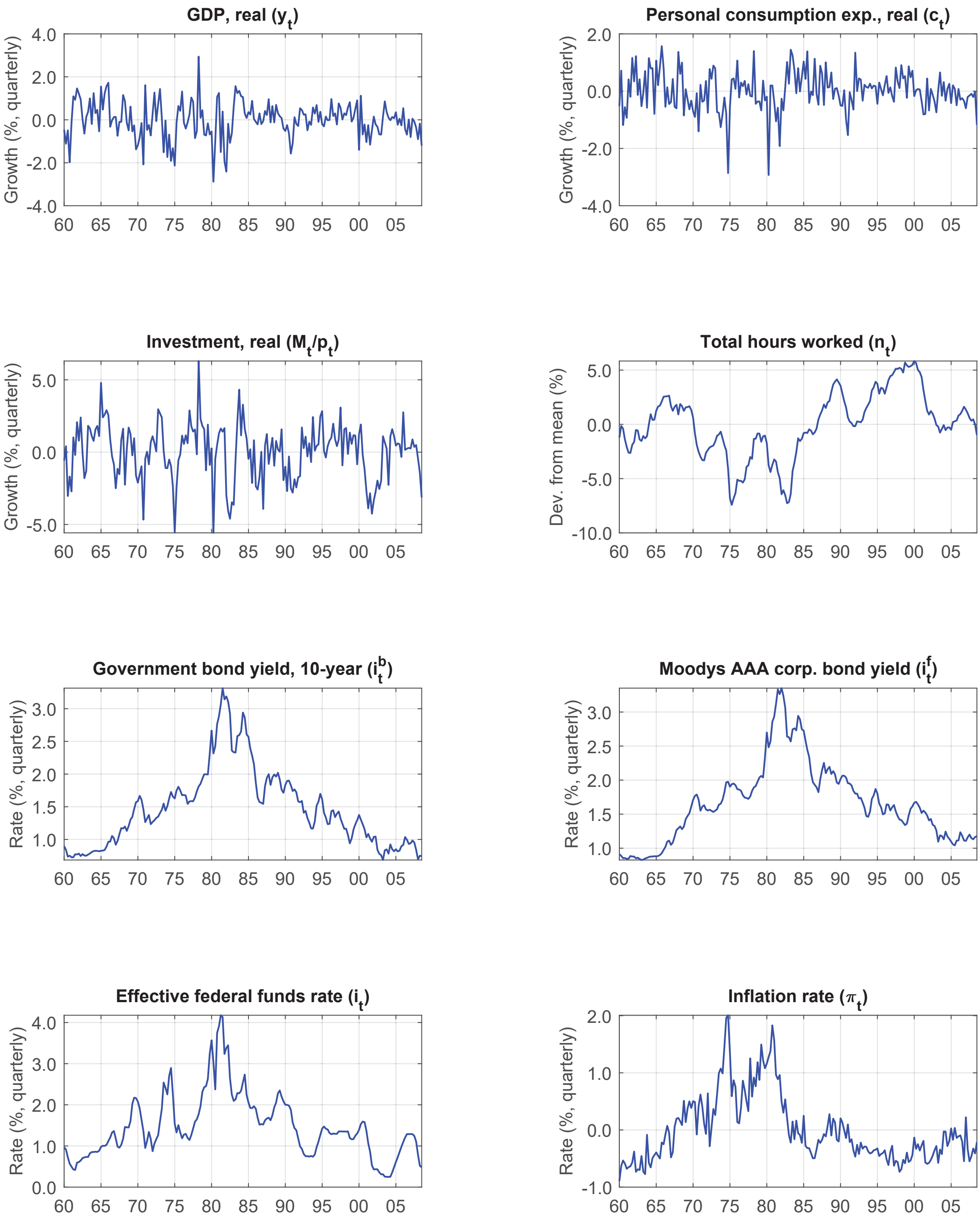
2.4.3 Estimation method, priors and posteriors

In line with much of the literature that quantifies the New Keynesian framework, I carry out Bayesian estimation. Linearising and re-writing the model in state-space form, one can compute the likelihood function $\mathcal{L}(\Omega|Y^T)$ of the structural parameters Ω given the observables Y^T. I assign prior distributions $p(\Omega)$ on the parameters. Given the observables Y^T, the posterior distribution $p(\Omega|Y^T)$ is obtained via Bayes' rule:

$$p(\Omega|Y^T) = \frac{\mathcal{L}(\Omega|Y^T)p(\Omega)}{\int \mathcal{L}(\Omega|Y^T)p(\Omega)d\Omega},$$

in which $p(Y^T) = \int \mathcal{L}(\Omega|Y^T)p(\Omega)d\Omega$ is the marginal data density used to assess the model fit. I choose prior distributions $p(\Omega)$ that cover a large range of possible parameter values. The first columns of Table 2.1 report the prior distributions assigned to the non-calibrated parameters.

[27] The 10-year government bond and the AAA corporate bond are long-dated, whereas the model cannot generate a steady-state term premium by construction. The $IRLT_t$ and AAA_t series are therefore adjusted by substracting the average difference (over the sample period) between 10-year government bond yields and the federal funds rate.



Sources: FRED (series references in the text). *Notes:* The series for $\{y_t, c_t, \frac{M_t}{p_t}, n_t, \pi_t\}$ are net of their average growth rates over the sample. The 10-year government bond yield i_t^b and the AAA corporate bond yield i_t^f series are adjusted for the term premium (see footnote 27).

Figure 2.3: *Data series used for estimation*

The credit market friction relies on five parameters. The quarterly depreciation rate of physical capital typically ranges between 0.01 and 0.025 in the literature. The prior for δ is therefore a Beta distribution[28] bounded between zero and one, with an average 0.015 and a standard deviation (SD) of 0.005. Forming priors for the other parameters is less straight-forward as these have no direct counter-parts in the existing literature. I therefore set loose priors. The parameters λ and μ are bounded between zero and one and also follow a Beta distribution with an average of 0.5 (the symmetric case) and a SD of 0.2. The cost function parameter γ is bounded between zero and ten, with an average of 5 and a SD of 2. This allows the steady-state cost $\frac{\gamma}{2}o^2$ to correspond to between 0% and 1.55% of output.

I use typical priors for the rest of the parameters, which are not specific to the credit market search friction. Prior averages reflect values of typical estimates found in the literature. The Cobb-Douglas share α has a prior mean of 0.3 and a SD of 0.1. The coefficient of relative risk aversion σ and the inverse of the Frisch elasticity η have prior means of 1 and SDs of 0.5. The inertia of the policy rate, governed by ϕ_{int}, has a prior mean of 0.5 and a SD of 0.2. The reactivity of the Taylor rule to inflation, ϕ_π, follows an inverse gamma distribution with a prior average of 2 and an infinite variance.[29] The slope of the Phillips curve, φ, follows a beta distribution bounded between 0.05 and 0.15 with an average of 0.1 and a SD of 0.025. The prior average of 0.1 is typically set in the literature regardless of the pricing mechanism at use.[30] The persistence coefficients of the shocks have a prior mean of 0.5 and a standard deviation of 0.2 as in Smets and Wouters (2007). For normally distributed shocks, the Inverse Gamma distribution is obtained as the marginal posterior distribution of an unknown (positive) variance. The priors for the shocks' variances are as in Smets and Wouters (2007), using a loose infinity prior variance.

The rest of the parameters are simply calibrated as they give the steady-state values of some variables. The discount factor β is set to match the average quarterly rate of 1.46% found in the federal funds rate series, so that $\beta = 0.9856$. The retailers' mark-up is given by $\frac{\epsilon}{\epsilon-1}$ in the steady-state. As in Kaplan et al. (2018), I set a conventional $\epsilon = 10$ that gives a mark-up of 11%. The constant share g of output devoted to government spending is set to 20%. The yield-to-maturity i_t^b of the government bond

[28] The Beta distribution is used in Bayesian statistics to describe the initial knowledge on bounded parameters.

[29] The Taylor rule reactivity matters for the model's determinacy. The inverse gamma distribution admits values $\phi_\pi \in (0, \infty)$, in turn not restricting determinacy.

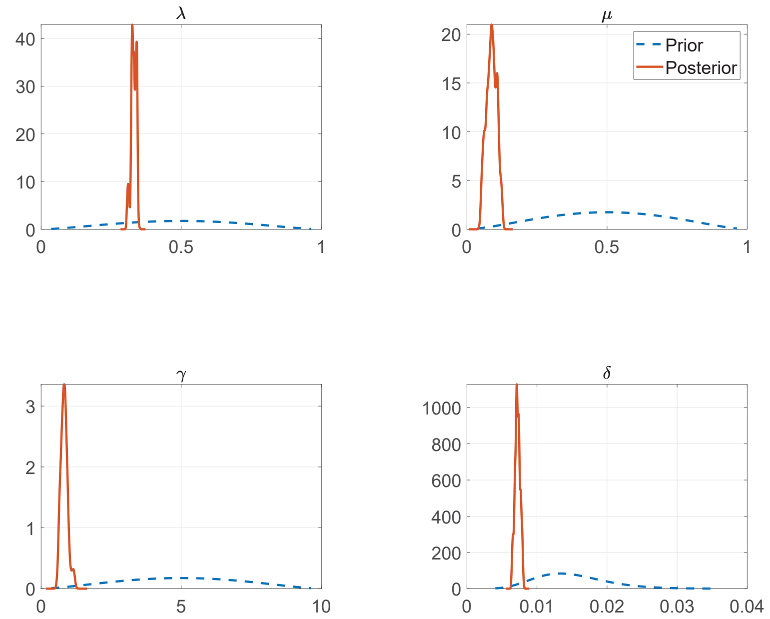
[30] See footnote 15 for the pricing mapping. Kehoe and Midrigan (2015) estimate an aggregate average price duration of around 4.07 quarters, which translates into $\varphi = 0.08$ when using the calibrated value for β. More recently, Kaplan et al. (2018) and Lütticke (2018) used $\varphi = 0.1$ and $\varphi = 0.09$ respectively.

is mapped to the data via the 10-year government bond yield. I hence use $\kappa = 0.9892$, which corresponds to a Macaulay duration of 10 years (see Appendix 2.7.1).[31] I set the government bond supply b to zero as it plays close to no role in the model. Indeed, the bond supply b only shapes the *level* of the *unobserved* credit market tightness θ_t so that the estimation is unaffected. Likewise, the probability $1 - x_t$ that the bank finds a government bond is invariant to b in equilibrium (see equation 2.12). Because lump-sum taxes are used to balance budget, b is also undefined in the government's budget constraint. The experiments carried out in Section 2.5 are therefore barely affected, as shown in Appendix 2.7.3. In the model, reserves m_t are only issued when the central bank resorts to unconventional policy measures. They therefore correspond to excess reserves in the data, which earned no interest during the time period considered for the estimation. I thus set the interest earned on reserves to zero ($i_t^m = 0$). Subsection 2.5.5 further discusses the role played by the interest on excess reserves. There were no QE episodes during the sample period; the estimation hence uses $x_t = 0$. Likewise, the ZLB was not binding during the covered time window.

The posterior distribution $p(\Omega|Y^T)$ is evaluated via 10 Monte Carlo Markov Chains (MCMC) of 100,000 draws each.[32] Computing the posterior mode required the use of a Monte Carlo optimisation routine. The acceptance ratio ranges between 11.6% and 12.4% across chains, indicating that the MCMC spanned the parameter domain.[33] Overall, the usual identification criteria are met. The test proposed by Iskrev (2010) reveals that the parameters are structurally identified.[34] Likewise, the data seems informative as the posteriors differ from the priors. Using the evaluated posterior distributions $p(\Omega|Y^T)$, Table 2.1 reports the posterior means and standard deviations, together with 90% credible sets. When the 90% ranges are narrow, I only refer to the posterior means in the text below.

Of key interest are the parameters that govern the credit market. Figure 2.4 shows their prior and posterior densities. I now discuss each parameter in turn. The posterior mean of λ is 0.330. This reveals a large and significant deviation from perfect competition (when $\lambda \to 1$) in the corporate loan market. According to the posterior estimate, the firm obtains a somewhat larger share of the surplus than the bank. In line with this, the outside option of the bank matters for the equilibrium corporate loan rate i_t^f. Then,

[31] The transmission of QE measures is not sensitive to realistic values of κ (see Appendix 2.7.3).
[32] The random-walk Metropolis-Hastings algorithm is used for the evaluation.
[33] The literature often favors low acceptance ratios, such as the 23.4% rule of thumb suggested in Roberts et al. (1997).
[34] That is, all analytical derivatives with respect to the parameters can be computed.



Notes: Posterior densities evaluated by MCMC.

Figure 2.4: *Credit market parameters: prior and posterior densities*

the elasticity of the matching function with respect to deposits, μ, displays a posterior mean of 0.088 with a credible set ranging between 0.056 and 0.116. As a result, loan offers o_t are relatively well matched: when $\mu \to 0$, all loan offers are matched from $\frac{\mathcal{M}_t}{p_t} = (l_{t+1})^{\mu}(o_t)^{1-\mu}$. This is not surprising given that the corporate bond yield series (AAA_t) consists of high-quality debt; well-established sizeable firms easily obtain credit. Next, the cost of searching for a loan offer, γ, has a non-trivial posterior mean of 0.825. The 90% credible set implies a steady-state cost that corresponds to between 0.46% and 0.63% of output. In light of the low estimate obtained for μ, the cost of searching for a loan reminds of a convex investment cost. The firm will hence have an incentive to smooth its loan search o_t over time. This will reinforce the persistence of any shocks that tilt the investment decisions of the firm. Last, the depreciation rate δ has a posterior mean of 0.007, corresponding to 0.028 at an annual frequency. Fully replacing a unit of corporate loan hence takes around 35 years. This is in line with the corporate bond yield series (AAA_t) used in the estimation, which itself uses bonds with maturities beyond 20 years.

The posteriors for the other behavioral parameters are similar to the landmark values obtained in Smets and Wouters (2007).[35] Given the similarity, I only discuss the parameters that directly shape the transmission of movements in the policy rate and hence the comparison made in the next section between conventional and unconventional policy measures. The posterior mean for the policy rate shock persistence ρ_{int} is 0.595. Although this is higher than the 0.12 obtained by Smets and Wouters (2007), shocks to the policy rate still remain short-lived. The conventional monetary shocks are nonetheless propagated through the estimated inertia of the Taylor rule, ϕ_{int}, which displays a posterior mean of 0.725. This is in line with both Smets and Wouters (2007) (with 0.81) and the typical values used in the New Keynesian literature (such as 0.8 in Lütticke, 2018). The estimated reaction of the Taylor rule to inflation, ϕ_{π}, has a posterior mean of 0.862. This is lower than both the typical value of 1.5 used in the theoretical literature and the estimate of 2.03 obtained by Smets and Wouters (2007). Due to the low reactivity of the Taylor rule, inflation will respond more strongly to shocks in the model. By contrast, the output responses shown in the next section are not affected quantitatively (see Appendix 2.7.3). Last, the slope of the New Keynesian Phillips curve has a posterior mean of $\varphi = 0.051$. This is lower than both empirical estimates and values used in the recent literature, which are closer to 0.1 (as in Kaplan et al., 2018 and Lütticke, 2018). The sensitivity of real quantities to inflation is dictated by φ. While a higher value $\varphi = 0.1$ generates a sharper trade-off between output and inflation for a given shock, this effect is not large quantitatively in the model. As shown in Appendix 2.7.3, the responses to monetary shocks shown in the next section are barely affected by φ.

[35] See their table 1A on page 593. My estimates of α and η are both in line with their results. I obtain a slightly higher value of 2.335 for σ, which is well within the range obtained in the empirical literature (see Conniffe and O'Neill, 2012).

Table 2.1: *Parameters: priors and posteriors*

		Prior		**Posterior**			
						HPD (90%)	
Parameter	*Distribution*	*Mean*	*S.D.*	**Mean**	**S.D.**	**Inf.**	**Sup.**
λ	beta	0.500	0.2000	0.330	0.0095	0.3182	0.3467
μ	beta	0.500	0.2000	0.088	0.0184	0.0558	0.1160
γ	beta	5.000	2.0000	0.825	0.1243	0.6132	1.0006
δ	beta	0.015	0.0050	0.007	0.0004	0.0067	0.0079
α	beta	0.300	0.1000	0.327	0.0072	0.3150	0.3384
σ	beta	1.000	0.5000	2.335	0.0386	2.2674	2.3869
η	beta	1.000	0.5000	1.943	0.0366	1.8935	2.0172
ϕ_{int}	beta	0.500	0.2000	0.725	0.0209	0.6962	0.7738
ϕ_{π}	invg	2.000	Inf	0.862	0.0727	0.7265	0.9753
φ	beta	0.100	0.0250	0.051	0.0011	0.0500	0.0528
ρ_{tfp}	beta	0.500	0.2000	0.566	0.0144	0.5426	0.5937
ρ_{g}	beta	0.500	0.2000	0.566	0.0121	0.5488	0.5854
ρ_{inv}	beta	0.500	0.2000	0.967	0.0167	0.9431	0.9922
ρ_{lab}	beta	0.500	0.2000	0.521	0.0183	0.4896	0.5500
ρ_{beta}	beta	0.500	0.2000	0.778	0.0160	0.7542	0.8053
ρ_{int}	beta	0.500	0.2000	0.595	0.0153	0.5691	0.6199
ρ_{infl}	beta	0.500	0.2000	0.806	0.0205	0.7703	0.8339
ρ_{rp}	beta	0.500	0.2000	0.877	0.0093	0.8610	0.8920
σ_{tfp}	invg	0.010	Inf	0.013	0.0008	0.0122	0.0147
σ_{g}	invg	0.010	Inf	0.027	0.0014	0.0244	0.0291
σ_{inv}	invg	0.010	Inf	0.049	0.0049	0.0410	0.0566
σ_{lab}	invg	0.010	Inf	0.163	0.0108	0.1450	0.1800
σ_{beta}	invg	0.010	Inf	0.078	0.0057	0.0689	0.0874
σ_{int}	invg	0.010	Inf	0.003	0.0002	0.0028	0.0035
σ_{infl}	invg	0.010	Inf	0.002	0.0001	0.0017	0.0020
σ_{rp}	invg	0.010	Inf	0.011	0.0008	0.0094	0.0119

Notes: Posterior distributions generated by Metropolis-Hastings algorithm. Highest probability density (HPD) credible sets at 90% level. The standard deviations of the shocks must be multiplied by 100 to be comparable to those in Smets and Wouters (2007).

2.5 The transmission of QE

The estimated model allows to quantify some of the effects of central bank purchases of government bonds. Panel (a) in Figure 2.2 showed how the fraction x_t of long-dated government bonds held by the Federal Reserve was altered by QE measures. The fraction increases during the purchases and then mechanically decreases as bonds gradually reach maturity and as the government issues new debt. In line with some of the existing literature, central bank purchases can be modelled by a first-order auto-regressive process for x_t:

$$x_t = \rho_x x_{t-1} + \varepsilon_t^x \ .$$

Equipped with this process, I evaluate the transmission of QE both outside and at the ZLB. Doing so allows to disentangle the role played *by* the ZLB for the transmission.

2.5.1 Transmission outside the ZLB

As a first experiment, I compare the effects of a QE shock to that of conventional monetary policy in normal times. That is, I let the Taylor rule react to both shocks. Although QE so far only took place when the ZLB was binding, analyzing a hypothetical QE shock outside the ZLB sheds some light on the transmission mechanism.

A typical accommodative shock takes the form of an unexpected (annualized) 25bps decrease in the policy rate i_t.[36] It is more intricate to build a meaningful QE shock. While central banks typically alter their policy rates by 25bps, there is no systematic precedent for asset purchases. This also makes it difficult to compare results to the existing literature. To overcome this, I set an initial innovation of $\varepsilon_t^x = 8\%$ with a persistence ρ_x that generates the same output response than that of a standard 25bps policy rate cut. The idea is to compare how the two monetary policies propagate to the wider economy *for a given output response*.

Figure 2.5 compares the effects of the conventional and unconventional policy shocks. The two monetary policies operate through different transmission mechanisms. In New Keynesian models, a policy rate cut initially transmits through the inter-temporal

[36] Using high-frequency US data as in Nakamura and Steinsson (2018), Wong (2018) obtains a series of policy rate shocks with a standard deviation of around 25-35bps.

substitution of consumption.[37] Savings become relatively less attractive, hence the household finds it optimal to increase current consumption. The resulting uptake in aggregate demand encourages the firm to produce more; labor demand goes up. The increase in private consumption directly translates into inflation as retailers increase their prices. Investment only marginally increases in equilibrium and the corporate loan rate i_t^f is barely affected.

The transmission of QE differs from that of conventional policy as it transmits through a *different* component of aggregate demand: namely, the investment decisions of the firm. The shock is initially propagated to the corporate credit market via the equilibrium loan rate i_t^f:

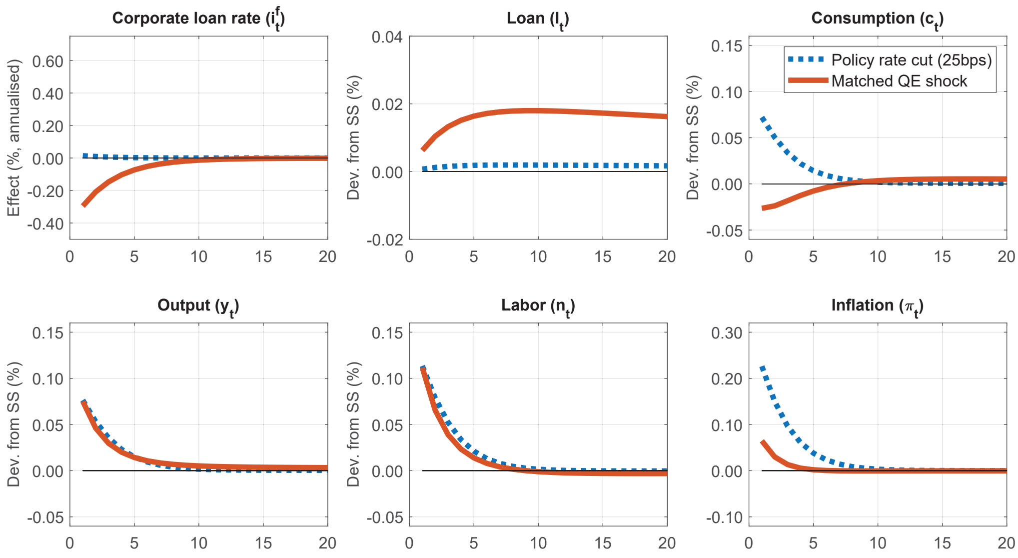
$$i_t^f = \lambda\big(p_t^f f_l(l_t, n_t) - (\delta - \gamma'(o_t)\theta_t)\big) + (1-\lambda)\big((1-x_t)i_t^b + x_t i_t^m\big) \ . \tag{2.24}$$

By purchasing government bonds, the central bank reduces the probability $1-x_t$ that the bank finds the bond (i.e., less is available to the bank). In equilibrium, this simultaneously increases the corresponding share of reserves x_t that the bank invests in. Both effects reduce the bank's outside investment option as the return on reserves is less than that of the government bond. Because the firm has *some* bargaining power ($\lambda < 1$), the worsened bank's outside option pushes down the equilibrium corporate loan rate i_t^f. This gives the firm an incentive to search for additional loans and so more matches take place. The resulting larger loan accumulation contrasts sharply to that of the conventional policy shock. By complementarity, the increase in loans also stimulates labor demand. Overall, output goes up.[38] Retailers push up prices due to the overall increase in aggregate demand. For a given effect on output, the inflationary pressure nevertheless remains less pronounced than after a policy rate cut. Consumption initially falls. This is because the policy rate mechanically goes up via the Taylor rule as to fight the generated inflation. The fact that conventional policy tries to offset the QE shock highlights that the two policy tools work in the same direction. The consumption drop will be muted at the ZLB when the policy rate cannot react; this is discussed in Subsection 2.5.2.

After describing the transmission for a given output response, I now proceed to quantify the effects of the three rounds of QE carried out by the Federal Reserve. To do so, I set three initial shocks $\varepsilon_t^x = \{2.7\%, 7.8\%, 3.9\%\}$ that match the uptakes in bond holdings that were observed in panel (b) in Figure 2.2. The shocks have persistence $\rho_x = 0.92875$

[37] Investment also responds to conventional monetary policy surprises in the data; Cloyne et al. (2018) provide evidence for the US and the UK.

[38] Output is less persistently affected than the loan due to the labor response. Adding a friction to the labor market would alter the responses, but it would do so for the two types of monetary policy shocks.



Notes: Using the benchmark parameter values of Table 2.1. Purchases amounting to 8% of the outstanding long-dated government bond stock with a persistence $\rho_x = 0.7$ as to match the output response to a standard policy rate cut. The policy rate shock has an initial shock of $\varepsilon_t^{int} = 0.0025/4$ with persistence $\rho_{int} = 0.595$.

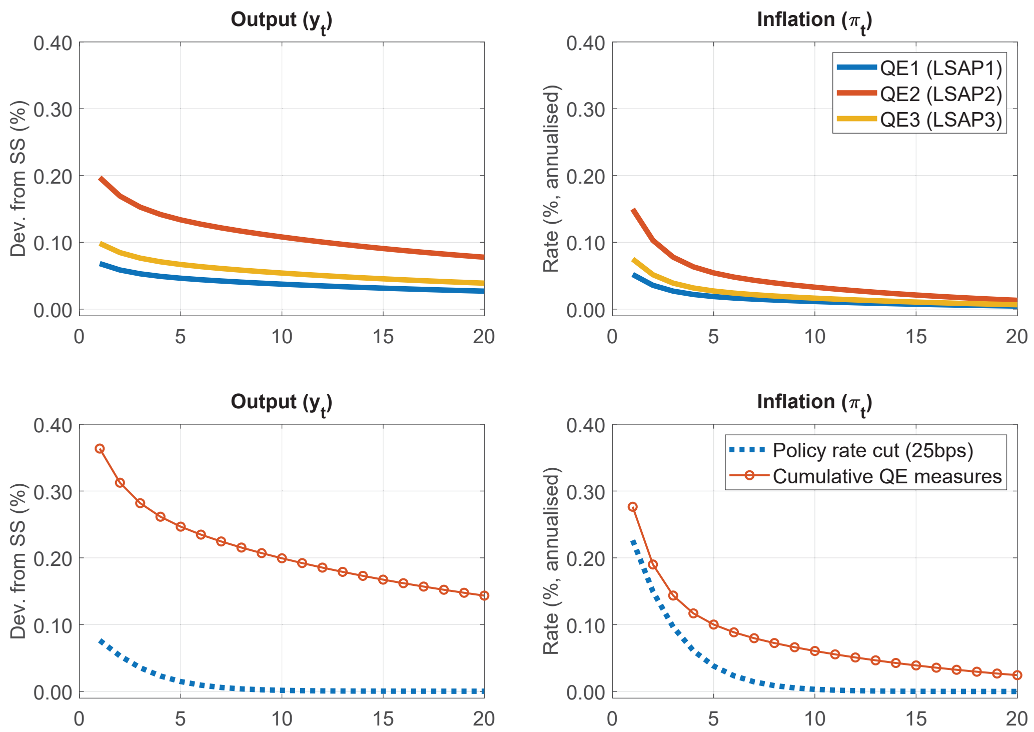
Figure 2.5: *Impulse response functions to monetary policy shocks*

as to match the cumulative central bank holdings in the simulations of Chen et al. (2012).[39]

The top panels in Figure 2.6 show the output and inflation responses to the three QE rounds outside the ZLB. The output responses are both large and persistent. The three waves of QE trigger initial output responses of 0.07%, 0.20% and 0.10%, respectively. These compare with an initial increase of 0.08% after the 25bps policy rate cut in normal times. While the effects of a policy rate cut are short-lived, the QE measures have long-lasting effects as the firm smoothes its search for corporate loans. By contrast, the inflation response is relatively muted: the *cumulative* effect of the three QE measures on inflation is similar to that of the standard policy rate cut. The bottom panels of the figure show the cumulative effects of the three QE rounds. Output initially increases by 0.36%. In normal times, the estimated unexpected policy rate cut would need to be a staggering 125bps to match this. In other words, the cumulative QE measures have a similar effect than five consecutive typical conventional accommodative shocks. Over a longer horizon, the cumulative output response is larger than the empirical effect reported by Weale and Wieladek (2016). After asset purchases that amount to 1% of GDP, they report a cumulative output response that averages 0.58% across their four

[39] After the shock, they consider a two-year holding period followed by a two-year unwinding.

VAR identifications, whereas I get a response of 2.3%. The corresponding large and sustained increase in loans implies that the share of output devoted to investment also persistently goes up in the model. This is consistent with what was observed in the US since the start of QE measures. The US investment to output ratio gradually increased since 2010, and it did so by more than after the previous recessions (see Figure 2.15 in Appendix 2.7.4).



Notes: Using the benchmark parameter values of Table 2.1. See text for the construction of the QE shocks. The policy rate shock has an initial shock of $\varepsilon_t^{int} = 0.0025/4$ with persistence $\rho_{int} = 0.595$.

Figure 2.6: *Effects of QE measures in the US*

The magnitude of the above output responses is in the upper range of previous estimates. The effects of the second round of QE (LSAP2) can be directly compared to the existing literature.[40] Table 2.2 reports the peak responses of output and inflation to LSAP2 across comparable studies. The peak output response of 0.20% is relatively large compared to the existing range of between 0.10% and 0.23%. By contrast, the peak inflation response

[40] The LSAP2 episode has been a focus of the literature for two reasons. First, empirical studies show that the LSAP2 announcement had a large effect on asset prices (see Chen et al., 2012 for a literature review), highlighting its unexpected nature. Second, the sellers of long-term government bonds were domestically based, which is in line with models of a closed economy. Indeed, Figure 2.16 in Appendix 2.7.4 shows that foreign holdings of long-dated US Treasuries did not respond to the LSAP2 episode.

of 15bps is relatively low compared to what was previously found. As discussed in the next subsection, the inflation response will however be stronger at the ZLB.

Table 2.2: *Peak responses to LSAP2*

	Peak output (y_t) response	Peak inflation (π_t) response
Falagiarda (2014)	0.23%	37bps
Baseline case	**0.20%**	**15bps**
Chung et al. (2012)	0.13%	20bps
Chen et al. (2012)	0.10%	12bps

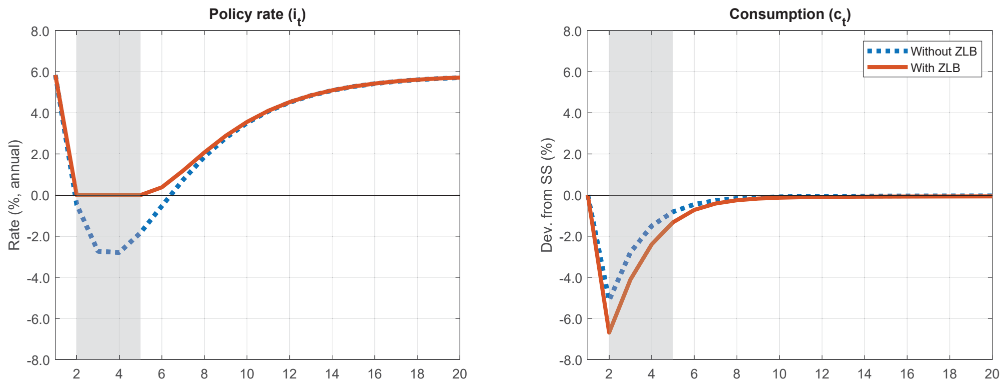
Notes: Output responses in deviations from steady-state. Annualised inflation rates. I use a LSAP2 simulation that matches the initial shock and the cumulative central bank holdings (over time) of Chen et al. (2012). The above results cannot be directly compared to Gertler and Karadi (2013) and Harrison (2012), who use QE-based rules instead of shocks.

2.5.2 Effectiveness at the ZLB

Importantly, the QE transmission described above also holds at the ZLB. Central banks have so far used unconventional policy measures due to the constraint of a lower bound on policy rates ($i_t \geq 0$). Recent research highlights that the effects of shocks are aggravated at the ZLB (Fernández-Villaverde et al., 2015, Adam and Billi, 2007 and Adam and Billi, 2006). The aggregate demand response is sharper at the ZLB (Rendahl, 2016 and Eggertsson, 2011). Ravn and Sterk (2018) confirm these non-linearities in the presence of household heterogeneity. Likewise, Guerrieri and Lorenzoni (2017) show that the adverse effects of exogenously tightening borrowing constraints are exacerbated at the ZLB. Among other effects, the ZLB acts like contractionary conventional policy. When the nominal policy rate cannot be further lowered, the real rate $r_t = i_t - \mathbb{E}_t[\pi_t]$ is also stucked at an undesirably high level, which in turn depresses current aggregate demand. The adverse effects of an occasionally binding ZLB can be seen in Figure 2.7, which shows the (perfect foresight) responses of the policy rate and consumption after a large persistent shock ϵ_t^{rp} to the deposit risk premium faced by households.[41]

The economic intuition behind an adverse policy rate shock sheds light on the transmission of QE at the ZLB. The previous subsection showed that a hypothetical QE shock increases both output and prices. In normal times, a central bank that fights inflation (via a Taylor rule in the model) would consequently simultaneously increase its policy rate. The

[41] Reaching the ZLB typically requires a large persistent adverse shock in general equilibrium models.



Notes: Impulse response functions to an 'MIT' risk premium shock $\epsilon_t^{rp} = 0.06$ with persistence $\rho_{rp} = 0.75$. Using the benchmark parameter values of Table 2.1 for the rest of the parameters and perfect foresight solutions.

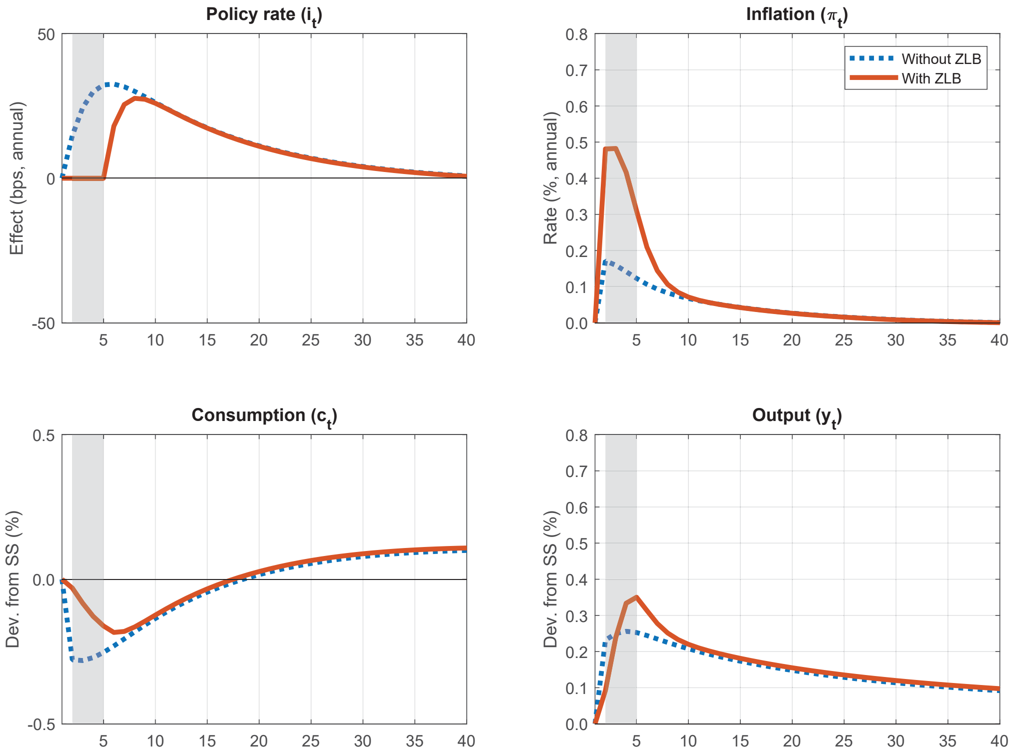
Figure 2.7: *Responses to a risk premium shock, with and without a ZLB*

resulting policy trade-off in turn dampens the response of private consumption. Of course, the policy rate does not react in parallel to a QE measure at the ZLB. Therefore, the contraction in consumption that is due to movements in the policy rate does not take place. This is seen in Figure 2.8, which compares the effects of the cumulative QE measures at and outside the ZLB. As the policy rate is not adjusted, the QE shock generates more inflation at the ZLB. Likewise, consumption does not decrease by as much at the ZLB. As a result, the output response is somewhat stronger during the ZLB spell. In the model, QE measures are accordingly also effective at stimulating both quantities and prices at the ZLB.

2.5.3 Implications for the pricing of financial instruments

The impact of QE measures on asset prices is often publically debated. Using the calibrated three rounds of central bank purchases, I discuss some of the implications of QE measures for the pricing of financial instruments. To do so, Figure 2.9 shows the pricing responses of three types of securities to the QE shock: the corporate loan, the long-dated government bond as well as a standard share (detailed below).

Corporate debt – The model was estimated using the AAA corporate bond yield as an observable for i_t^f. In the model, the transmission of QE operates by lowering the corporate loan rate i_t^f. After central bank purchases, the annualised corporate loan rate decreases by 61bps. The drop is similar at the ZLB. Thereafter, the rate remains lower than its steady-state value for up to 20 years. This is because the firm persistently accumulates loans



Notes: The charts compare the responses to the calibrated cumulative QE measures under both an (attained) occasionally binding ZLB and without a ZLB. Using the benchmark parameter values of Table 2.1 and perfect foresight solutions. The ZLB is reached by a risk premium shock $\epsilon_t^{rp} = 0.06$ with persistence $\rho_{rp} = 0.75$. For the ZLB case, the responses shown are the differences between the responses with and without the QE shock. In all cases, the QE shock takes place at the same period than the risk premium shock.

Figure 2.8: *Responses to the cumulative QE measures at and outside the ZLB (1/2)*

over time. The marginal product of loans $f_l(l_t, n_t)$ is thus kept low, which in equilibrium pushes down the rate i_t^f (see equation 2.24).

Long-dated government bonds – Bond yields marginally rise after the QE shock, and the rise decreases in the bond duration. The model does not capture the well-documented, although very short-lived, decrease in bond yields around QE announcements. Instead, the rising yields come from the increase in inflation that the central bank eventually addresses via its policy rate. This can be seen by expressing the yield-to-maturity of long-dated bonds in terms of shorter rates. One advantage of the long-term bond formulation is that the bond's yield-to-maturity i_t^b can be expressed as a weighted average of the expected future short-term rates i_t (see Appendix 2.7.1 for the derivation). Recalling that κ dictates the duration of the bond:

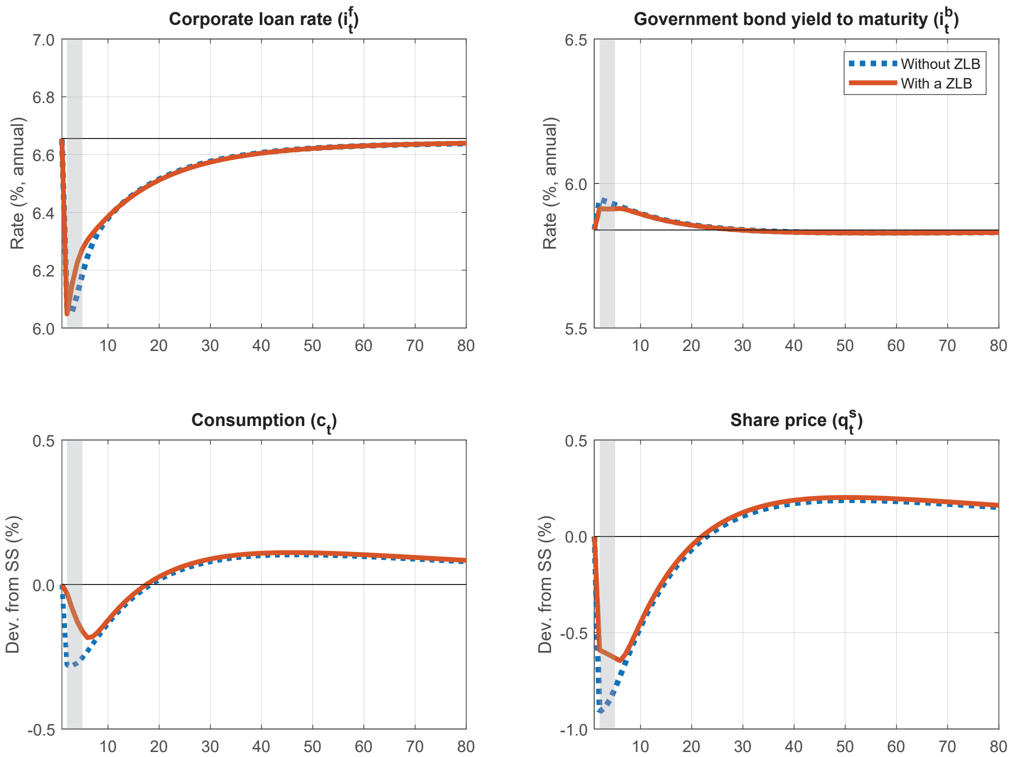
$$i_t^b \simeq (1-\kappa)i_t + \kappa \mathbb{E}_t[i_{t+1}^b] = (1-\kappa)\sum_{j=0}^{\infty} \kappa^j \mathbb{E}_t[i_{t+j}] \ .$$

Outside the ZLB, the policy rate i_t increases as to compensate the inflation generated by the QE shock. The current increase in the short-term rate only partially feeds through the long-dated yield i_t^b (via $(1-\kappa)i_t$). As a result, Figure 2.9 shows that the annualised yield of the 10-year government bond barely moves after the QE shock: it goes up by just 10bps outside the ZLB. The effect of rising yields is further dampened (to 7bps) at the ZLB as current short-term rates are temporarily stuck at zero.

Shares with pro-cyclical dividends – The QE shock has two implications for standard shares, which provide a pro-cyclical dividend: their prices initially drop, but the drop is muted at the ZLB. Share prices then gradually recover and eventually increase beyond their steady-state values for a sustained period of time.
Consider a share that trades at price q_t^s. In the next period, the share will deliver a dividend ψ_{t+1} that delivers 1% of output: $\psi_{t+1} = 0.01y_{t+1}$; the reselling price will be q_{t+1}. Using the household's stochastic discount factor Λ_{t+1}, the equilibrium share price is given by:

$$q_t^s = \mathbb{E}_t\Big[\Lambda_{t+1}\big(\psi_{t+1} + q_{t+1}^s\big)\Big] \ .$$

After a QE shock, pro-cyclical dividends mechanically increase. But like any asset price, the share price q_t^s depends on the equilibrium consumption path via the household's stochastic discount factor Λ_{t+1}. Following the QE shock, the initial decrease in consumption reduces the share price via the household stochastic discount factor. However, the initial drop is muted at the ZLB as the fall in consumption is smaller. Figure 2.9 uses an adverse shock that triggers a ZLB spell of just four quarters. The initial fall in the share price could be completely dampened for a longer spell; in the US, the recent ZLB spell lasted 24 quarters. By contrast, the subsequent sustained above-average share price happens regardless of the ZLB duration. Although consumption is temporarily muted by QE, it gradually recovers. Eventually, consumption becomes higher than its steady-state value for a prolonged period of time. This eventually increases the share price, which consequently remains above its steady-state value for several years.



Notes: The charts compares the responses to the calibrated cumulative QE measures under both an (attained) occasionally binding ZLB and without a ZLB. Using the benchmark parameter values of Table 2.1 and perfect foresight solutions. The ZLB is reached by a risk premium shock $\epsilon_t^{rp} = 0.05$ with estimated persistence $\rho_{rp} = 0.75$. For the ZLB case, the responses shown are the differences between the responses with and without the QE shock. In all cases, the QE shock takes place at the same period than the risk premium shock. The black lines show the corresponding long-run values.

Figure 2.9: *Responses to the cumulative QE measures at and outside the ZLB (2/2)*

2.5.4 Quantitative versus credit easing

In parallel to QE measures, several central banks purchased private sector debt following the great financial crisis. These *credit easing* (CE) measures, as initially coined by former Federal Reserve's Chairman Ben Bernanke, took various forms across monetary authorities. Panel (b) in Figure 2.2 showed that the Federal Reserve bought mortgage-backed securities. Under the asset purchase programme (APP), the ECB bought corporate sector bonds, covered bonds and asset-backed securities in addition to public debt. The BoE and BoJ also purchased corporate bonds via their respective asset purchase facilities.

Although the model presented here does not include asset-backed securities, it contains corporate debt. In the model, purchases of corporate debt transmit to the economy in the same way as purchases of government bonds. While the central bank cannot *issue* corporate loans (l_{t+1}), it can purchase some of the *existing* stock (l_t). This CE measure does not reduce the stock of long-term government bonds available to the bank. Nonetheless, it still increases central bank reserves. To make the CE and QE measures comparable, I consider central bank purchases of corporate loans that are of the same nominal amount than that of government bonds: $x_t^c q_t b$, with $x_t^c = x_t$. Total central bank reserves hence amount to $(x_t + x_t^c)q_t b$. The fractions x_t and x_t^c only enter the model via the probability that the bank finds a government bond (after an unsuccessful round in the corporate loan market), which is then given by:

$$\frac{(1-x_t)q_t b}{(1-x_t)q_t b + (x_t + x_t^c)q_t b} = \frac{1-x_t}{1+x_t^c} \ .$$

Clearly, purchases of government bonds have two reinforcing effects: they simultaneously decrease the government bond stock available to the bank and increase reserves (which are held by the bank in equilibrium). By contrast, purchases of corporate bonds only increase reserves (and by the same amount). Although purchases of government bonds have a slightly higher effect than those of existing coprorate loans, the difference is not perceptible up to a first-order approximation (as $\frac{1-x_t}{1+x_t^c} \simeq 1 - x_t - x_t^c$). That is, the effect of the two measures is almost identical. In the existing literature, CE is typically more effective than QE under a banking crisis as CE restores the access to credit for the private sector. Here, I do not model a financial market crisis. Consequently, the CE and QE measures are similar at times of no particular financial disruption.

2.5.5 Link to the irrelevance theorem

In the proposed model, the irrelevance result of Wallace (1981) obtains when the bank is indifferent between holding the government bond and another asset. Central bank purchases of government bonds are then ineffective. This happens when either (1) the government bond is *infinitely*-supplied or (2) excess reserves earn the same return than the bond ($i_t^m = i_t^b$).
In the model, the government issues a finite supply of the bond. Central bank bond purchases thus reduce the stock left available to the bank, in turn affecting the bank's outside investment option. By contrast, the bank would always find an infinitely-supplied bond regardless of central bank purchases.
Likewise, the bank is indifferent between holding the bond and reserves when $i_t^m = i_t^b$. This arises when the household has access to excess reserves, in which case the two assets become perfect substitutes. In contrast, the market for excess reserves is segmented in the model: they can only be held by the bank, as is the case in reality.

While market segmentation is necessary to the effectiveness of QE, it is not a sufficient condition to break the irrelevance result. Two additional conditions are required: the firm must have *some* bargaining power and excess reserves must earn a smaller return than the other assets available to the bank. As discussed below, these conditions are empirically plausible.

Firm's bargaining power – Central bank purchases affect the equilibrium corporate loan rate i_t^f by tilting the bank's outside option:

$$i_t^f = \lambda\big(p_t^f f_l(l_t, n_t) - (\delta - \gamma'(o_t)\theta_t)\big) + (1-\lambda)\big((1-x_t)i_t^b + x_t i_t^m\big) \ .$$

The bank extracts all of the net surplus of a corporate loan when the firm has no bargaining power ($\lambda \to 1$). In that case, the pricing of the corporate loan is not affected by changes in the bank's outside option $(1-x_t)i_t^b + x_t i_t^m$; the transmission channel of central bank purchases is shut down. Nonetheless, it is reasonable to think that the bank does not hold the entire bargaining power. As documented in Section 2.2, entangled lending relationships arise due to the long-term nature of corporate loan contracts. In line with this, the bank's bargaining power λ that was estimated in Section 2.4 was far from unity, and significantly so.

Differences in earned interest – Central bank purchases only lessen the bank's outside option when the return earned on excess reserves (i_t^m) is smaller than that on the other assets available to the bank, namely the corporate loan and the government bond. Suppose that $i_t^m = 0$, either because excess reserves do not earn interest (as was the case in the US and UK until 2009) or because the economy is at the ZLB and the central bank temporarily sets $i_t^m = i_t$. The corporate loan earns an excess return ($i_t^f > i_t$) due to the bank's market power. At times of central bank purchases (namely, at the ZLB), $i_t^b > i_t$ also typically holds in the data. In the model, κ dictates the duration of the government bond that is available to the bank. This corresponds to the *average* duration of outstanding government debt in reality - which is higher than one period. Because government debt is not entirely short-term (that is, $\kappa > 0$), the yield-to-maturity $i_t^b = 1/q_t + \kappa - 1$ depends on the entire expected future path of short-term rates (see Appendix 2.7.1 for the derivation):

$$i_t^b \simeq (1-\kappa)i_t + \kappa \mathbb{E}_t[i_{t+1}^b] = (1-\kappa)\sum_{j=0}^{\infty} \kappa^j \mathbb{E}_t[i_{t+j}] \ . \tag{2.25}$$

In line with the efficient market hypothesis, the yield-to-maturity i_t^b is a weighted average of the expected short-term rates.[42] Accordingly, the current value of the short-term rate i_t has little impact on the current yield i_t^b of long-dated bonds. In particular, the long-dated yield stays *strictly* positive in the event of a binding ZLB.[43]

[42]Naturally, $\lim_{\kappa \to 0} \ : \ i_t^b \to i_t$.

[43]In the deterministic steady-state, $i = 1/\beta - 1 > 0$. Because $i_t \geq 0$, the infinite sum in equation (2.25) always remains strictly positive.

2.6 Conclusion

This paper presented a novel mechanism to the transmission of central bank purchases of government bonds. Because of an imperfection in the corporate loan market, the outside option of banks matters for firms' borrowing conditions. By purchasing bonds, the monetary authority lowers the investment opportunities available to the banking sector. This increases the relative bargaining power of firms, which can then negotiate lower borrowing rates. The transmission of quantitative easing measures hence differs from that of conventional monetary policy, which instead relies on intertemporal substitution.

I nested this mechanism in a general equilibrium model that was then estimated with US data. The resulting estimates provide empirical support to the credit market imperfection on which the transmission mechanism relies. Using the model, I have shown that the three rounds of quantitative easing carried out by the Federal Reserve generate a long-lasting increase in corporate loans that in turn increases both output and inflation. In particular, the cumulative effect that the three rounds had on output matches that of a staggering 125bps policy rate cut in normal times.

Quantitative easing also persistently affects the pricing of financial instruments. Importantly, the overall transmission mechanism is effective at the zero lower bound, supporting the view that central bank asset purchase programmes can serve as an additional tool to the monetary policy mix.

2.7 Appendix

2.7.1 Long-term bond formulation

The net yield to maturity i_t^b of the long-term bond satisfies:

$$\begin{aligned} q_t &= \frac{1}{1+i_t^b} + \frac{\kappa}{(1+i_t^b)^2} + \frac{\kappa^2}{(1+i_t^b)^3} + ... \\ &= \left(\frac{1}{1+i_t^b}\right)\sum_{j=0}^{\infty}\left(\frac{\kappa}{1+i_t^b}\right)^j = \left(\frac{1}{1+i_t^b}\right)\left(\frac{1}{1-\kappa/1+i_t^b}\right) \\ \iff i_t^b &= \frac{1}{q_t} + \kappa - 1 \ . \end{aligned}$$

The second line obtains as $\frac{\kappa}{1+i_t^b} < 1$ for the maturities I consider (e.g., a maturity smaller than 20 years requires $\kappa < 1$).

The present value of the cash-flows generated by the long-term bond is equal to its current price q_t. The Macaulay duration m_t^{Dur} weighs each period by the respective contribution to the overall discounted cash-flow:

$$\begin{aligned} m_t^{Dur} &= \frac{1}{q_t}\left(\frac{1}{1+i_t^b}\right) + \frac{2}{q_t}\left(\frac{\kappa}{(1+i_t^b)^2}\right) + \frac{3}{q_t}\left(\frac{\kappa^2}{(1+i_t^b)^3}\right) + ... \\ &= \frac{1}{\kappa q_t}\sum_{j=0}^{\infty} j\left(\frac{\kappa}{1+i_t^b}\right)^j = \frac{1}{\kappa q_t}\frac{\kappa/(1+i_t^b)}{\left(1-\kappa/(1+i_t^b)\right)^2} \\ &= \frac{1+i_t^b}{q_t}\frac{1}{\left(1+i_t^{b2} + \kappa^2 - 2\kappa(1+i_t^b)\right)} \\ &= \frac{1+i_t^b}{1+i_t^b-\kappa} \ . \end{aligned}$$

The second line uses the properties of geometric series,[44] whereas the last line uses the definition of the gross yield to maturity found above ($q_t = \frac{1}{1+i_t^b-\kappa}$).

Below, I follow the steps explained in Chen et al. (2012). Because long-term bonds are decaying perpetuities, the household budget constraint contains all of the past long-term bond holdings. In the presence of a varying price index p_t, the household budget

[44] For $x < 1$, $\sum_{j=0}^{\infty} jx^j = \frac{x}{(1-x)^2}$.

constraint reads:

$$d_t(1+i_t) + \sum_{s=1}^{\infty} b^h_{t-s+1}\kappa^{s-1} + \Pi_t + p_t w_t n_t = p_t c_t + d_{t+1} + q_t b^h_{t+1} + p_t t_t \ .$$

In period t, the price of a long-term bond issued s periods before is given by:

$$q_t(s) = \kappa^s q_t \ .$$

At time $t-1$, arbitrage implies that:

$$\begin{aligned} q_t b^h_t &= \sum_{s=1}^{\infty} q_t(s) b^h_{t-s+1} \\ &= \sum_{s=1}^{\infty} q_t \kappa^{s-1} b^h_{t-s+1} \\ \Longrightarrow b^h_t &= \sum_{s=1}^{\infty} \kappa^{s-1} b^h_{t-s+1} \ . \end{aligned}$$

Because there is a secondary market, b^h_t will be worth $b^h_t(1+\kappa q_t)$ at period t. The household budget constraint conveniently reduces to:

$$d_t(1+i_t) + b^h_t(1+\kappa q_t) + \Pi_t + p_t w_t n_t = p_t c_t + d_{t+1} + q_t b^h_{t+1} + p_t t_t \ .$$

Only the long-term bond holdings of the precedent period are used by the household when taking decisions, so that the dimension of the consumer problem state-space is drastically reduced.

The steady-state price of the long-term bond is given by:

$$q = \frac{\beta}{1-\beta\kappa} \ .$$

Because $1 + i^b = \frac{1}{q} + \kappa$ (which was shown above when $\kappa < 1$ and which is not restrictive for realistic maturities), the steady-state gross yield of the long-term bond is equal to that of the short-term bond:

$$1 + i^b = \frac{\beta}{1-\beta\kappa} + \kappa = \frac{1}{\beta} = 1 + i \ ,$$

and so the steady-state Macaulay duration of the long-term bond can be set by κ:

$$m^{Dur} = \frac{1+i^b}{1+i^b-\kappa} = \frac{1}{1-\beta\kappa}$$

$$\iff \kappa = \frac{m^{Dur} - 1}{\beta m^{Dur}} \ .$$

To express the net yield to maturity i_t^b in terms of the short-term rate, I log-linearise the Euler equations of bank deposits and of the long-term bond. Starting with that of the long-term bond:

$$\begin{aligned}
q_t &= \mathbb{E}_t\left[\beta\left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}\frac{1+\kappa q_{t+1}}{1+\pi_{t+1}}\right] \\
\implies q e^{\widetilde{q}_t} &= \beta\frac{1+\kappa q}{1+\pi}\mathbb{E}_t\left[e^{-\sigma(\widetilde{c}_{t+1}-\widetilde{c}_t)}e^{\widetilde{1+\kappa q_{t+1}}}e^{-\widetilde{1+\pi_{t+1}}}\right] \\
\iff 1+\widetilde{q}_t &\simeq \mathbb{E}_t\big[(1-\sigma\widetilde{c}_{t+1})(1+\sigma\widetilde{c}_t)(1+\widetilde{1+\kappa q_{t+1}})(1-\widetilde{1+\pi_{t+1}})\big] \\
\iff 1+\widetilde{q}_t &\simeq \mathbb{E}_t\big[(1-\sigma\widetilde{c}_{t+1})(1+\sigma\widetilde{c}_t)\big(1+\kappa\beta\widetilde{q}_{t+1}\big)(1-\pi_{t+1})\big] \ , \qquad (2.26)
\end{aligned}$$

where $\widetilde{x}_t = \frac{x_t - x}{x} \simeq \log x_t - \log x$. The last line uses $\widetilde{1+\pi_{t+1}} = \pi_{t+1}$ for $\pi = 0$ and $\widetilde{1+\kappa q_{t+1}} = \frac{\kappa q}{(1+\kappa q)}\widetilde{q}_{t+1} = \beta\kappa\widetilde{q}_{t+1}$. From $i_t^b = (1+\kappa q_t)/q_t - 1$, we get:

$$\begin{aligned}
q_t &= \frac{1}{1+i_t^b-\kappa} \\
\implies q_t e^{\widetilde{q}_t} &= \frac{1}{1+i^b-\kappa}e^{-\widetilde{1+i_t^b-\kappa}} \\
\iff 1+\widetilde{q}_t &\simeq 1 - \widetilde{1+i_t^b-\kappa} \\
\implies \widetilde{q}_t &= -\left(\frac{\beta}{1-\beta\kappa}\right)(i_t^b-\rho) \ , \qquad (2.27)
\end{aligned}$$

as $\widetilde{1+i_t^b-\kappa} = \frac{i_t^b - i^b}{1+i^b-\kappa}$ and $1+i^b-\kappa = 1+\rho-\kappa = \frac{1-\beta\kappa}{\beta}$, where $\rho = 1/\beta - 1$ is the real rate prevailing in the deterministic steady-state. Inserting (2.27) into (2.26), we get:

$$1 - \left(\frac{\beta}{1-\beta\kappa}\right)(i_t^b-\rho) \simeq \mathbb{E}_t\left[(1-\sigma\widetilde{c}_{t+1})(1+\sigma\widetilde{c}_t)\left(1-\left(\frac{\beta^2\kappa}{1-\beta\kappa}\right)(i_{t+1}^b-\rho)\right)(1-\pi_{t+1})\right] \ .$$

Expanding and ignoring higher orders:

$$\widetilde{c}_t = \mathbb{E}_t[\widetilde{c}_{t+1}] - \frac{1}{\sigma}\left[\left(\frac{\beta}{1-\beta\kappa}\right)(i_t^b-\rho) - \mathbb{E}_t[\pi_{t+1}] - \left(\frac{\beta^2\kappa}{1-\beta\kappa}\right)(\mathbb{E}_t[i_{t+1}^b]-\rho)\right] \ . \qquad (2.28)$$

When the government bond has a maturity of one period (lim : $\kappa \to 0$), equation (2.28) gives the standard log-linearised Euler equation for bank deposits:

$$\widetilde{c}_t = \mathbb{E}_t[\widetilde{c}_{t+1}] - \frac{1}{\sigma}\left[\beta(i_t^b-\rho) - \mathbb{E}_t[\pi_{t+1}]\right] \ . \qquad (2.29)$$

Equation (2.29) is often encountered in the New Keynesian literature by further approximating $\beta \simeq 1$.

Equalising equations (2.28) and (2.29), we obtain:

$$\beta(i_t - \rho) = \left(\frac{\beta}{1-\beta\kappa}\right)(i_t^b - \rho) - \left(\frac{\beta^2\kappa}{1-\beta\kappa}\right)(\mathbb{E}_t[i_{t+1}^b] - \rho)$$

$$\iff i_t^b = (1-\beta\kappa)i_t + \beta\kappa\mathbb{E}_t[i_{t+1}^b] = (1-\beta\kappa)\sum_{j=0}^{\infty}\left(\beta\kappa\right)^j\mathbb{E}_t[i_{t+j}] \ ,$$

and for $\beta \simeq 1$:

$$i_t^b \simeq (1-\kappa)i_t + \kappa\mathbb{E}_t[i_{t+1}^b] = (1-\kappa)\sum_{j=0}^{\infty}\kappa^j\mathbb{E}_t[i_{t+j}] \ .$$

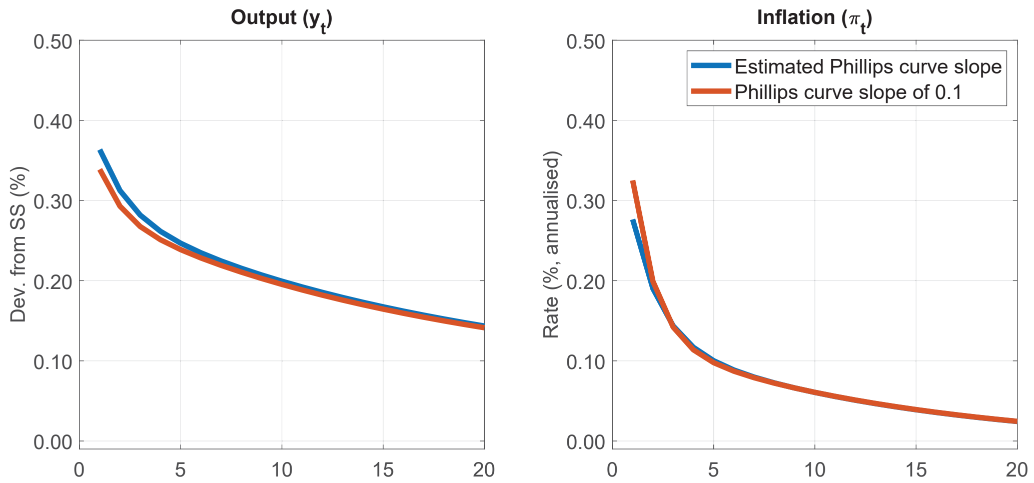
2.7.2 Alternative financial market formulation for profits

The household receives lump-sum aggregate profits Π_t in the model. An alternative formulation would be to let the household choose how much to invest in securities that deliver each of the other agents' profits. The equilibrium price q_t^s of a security s that delivers profits Π_t^s would then be given by the household's standard optimal saving decision:

$$q_t^s = \mathbb{E}_t\left[\Lambda_{t+1}\left(\Pi_{t+1}^s + q_{t+1}^s\right)\right] \ .$$

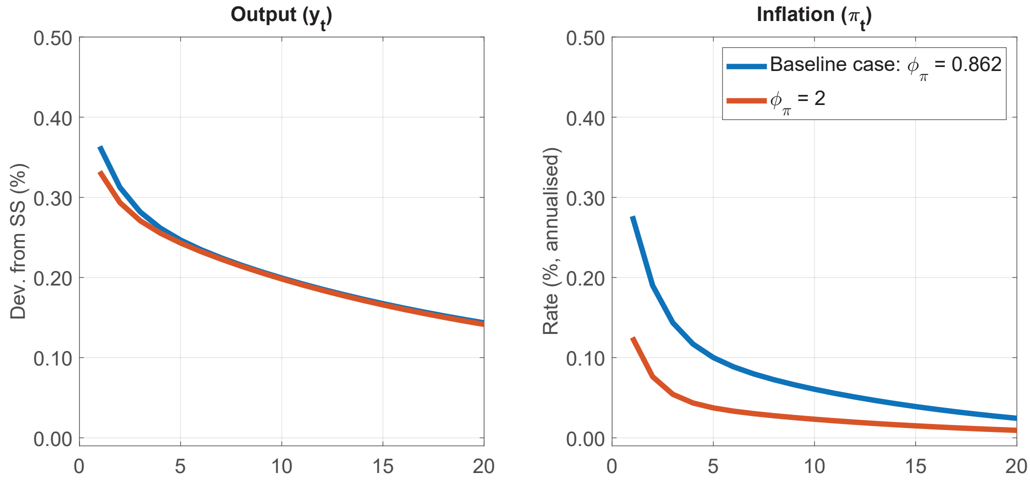
In equilibrium, the representative household owns all of the securities. Any security s is then simply priced on top of the allocation (which was given by equations 2.13 to 2.23). The allocation therefore remains unaltered.

2.7.3 Transmission of QE: sensitivity to some parameters



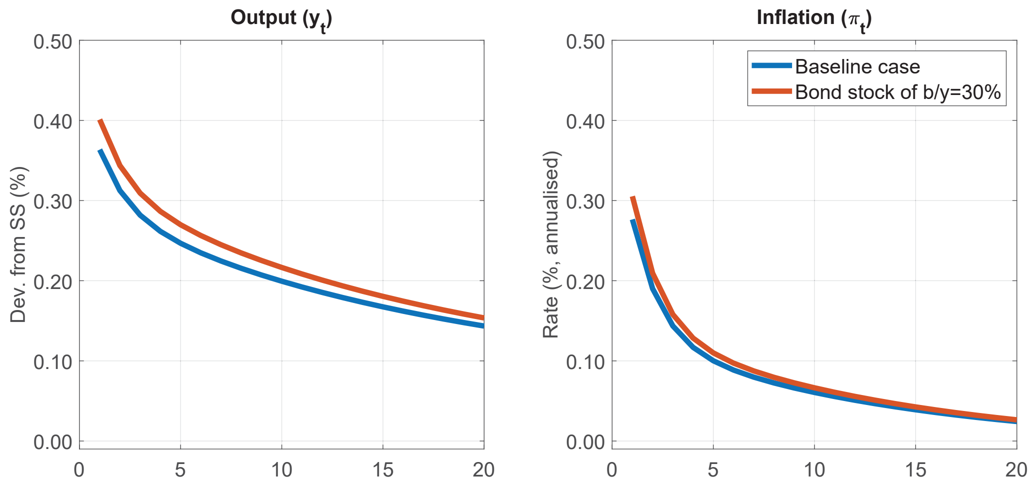
Notes: Using the benchmark parameter values of Table 2.1. Cumulative central bank purchases are 14.4% of the outstanding bond stock; see the main text in Section 2.5 for the construction of the QE shock. Estimated Phillips curve of $\varphi = 0.051$ compared to $\varphi = 0.1$.

Figure 2.10: *Effects of QE measures in the US: sensitivity to slope of Phillips curve (φ)*



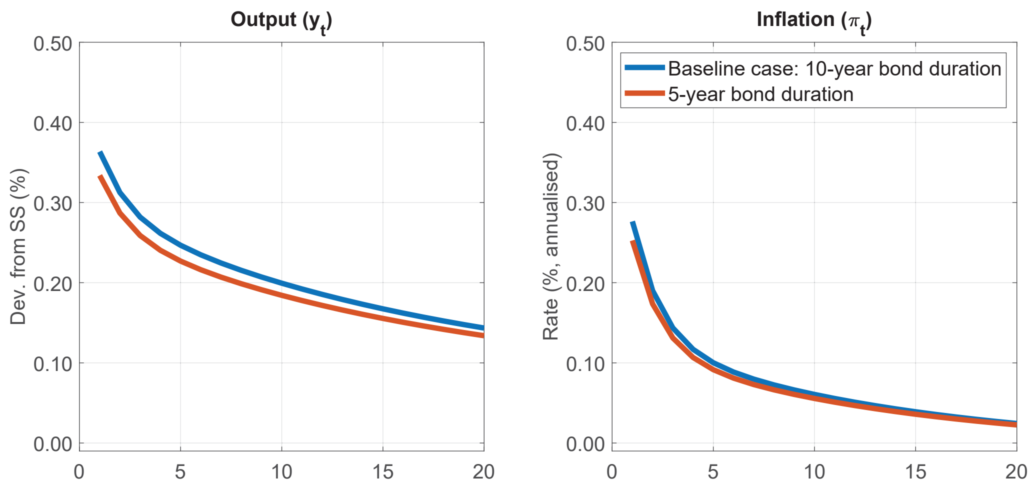
Notes: Using the benchmark parameter values of Table 2.1. Cumulative central bank purchases are 14.4% of the outstanding bond stock; see the main text in Section 2.5 for the construction of the QE shock. Estimated Taylor rule reactivity of $\phi_\pi = 0.862$ compared to $\phi_\pi = 2$.

Figure 2.11: *Effects of QE measures in the US: sensitivity to Taylor rule reactivity (ϕ_π)*



Notes: Using the benchmark parameter values of Table 2.1. Cumulative central bank purchases are 14.4% of the outstanding bond stock; see the main text in Section 2.5 for the construction of the QE shock. The outstanding bond stock is set to $b = 0.72$. This corresponds to 30% of steady-state output, which is the average long-dated Treasuries to output ratio over the sample period (1960Q1-2008Q3). The ratio was 34% in 2007Q4 (pre-crisis).

Figure 2.12: *Effects of QE measures in the US: sensitivity to bond stock (b)*



Notes: Using the benchmark parameter values of Table 2.1. Cumulative central bank purchases are 14.4% of the outstanding bond stock; see the main text in Section 2.5 for the construction of the QE shock. Macaulay durations of 10 years (baseline case, $\kappa = 0.9892$) and 5 years ($\kappa = 0.9639$) for the government bond.

Figure 2.13: *Effects of QE measures in the US: sensitivity to bond duration (κ)*

Absent the Rotemberg cost, the firm sells its output at a constant relative price $p_t^f = 1$. There is no inflation ($\pi_t = 0$) so that household deposits earn the real rate r_t. The equilibrium is then given by:

$$\frac{u_n(c_t, n_t)}{u_c(c_t, n_t)} = f_n(l_t, n_t) \tag{2.30}$$

$$f(l_t, n_t) = gf(l_t, n_t) + c_t + \gamma(o_t) + k^f(\theta_t)o_t \tag{2.31}$$

$$l_{t+1} = (1-\delta)l + k^f(\theta_t)o_t \tag{2.32}$$

$$\frac{\gamma'(o_t)}{k^f(\theta_t)} = \mathbb{E}_t\left[\beta\frac{u_c(c_{t+1}, n_{t+1})}{u_c(c_t, n_t)}\left(f_l(l_{t+1}, n_{t+1}) - (i_{t+1}^f + \delta) + \frac{(1-\delta)\gamma'(o_{t+1})}{k^f(\theta_{t+1})}\right)\right] \tag{2.33}$$

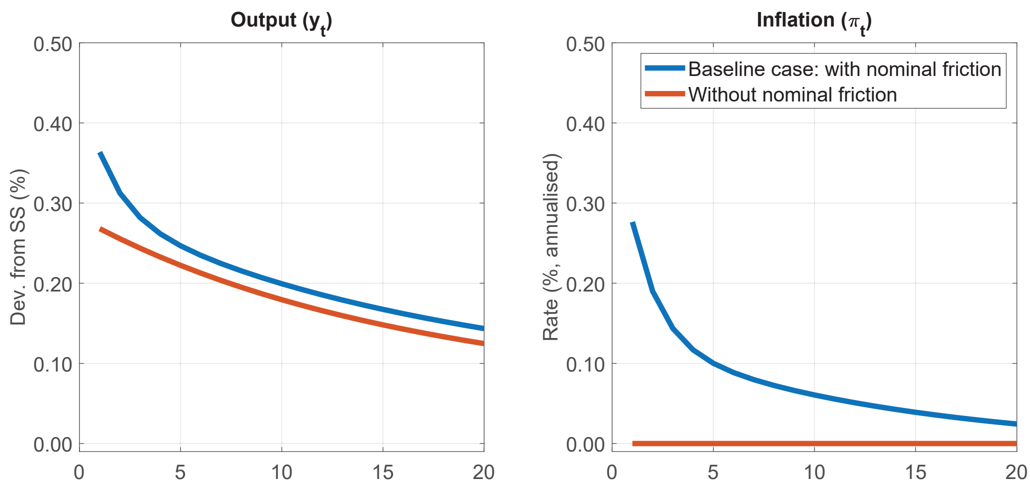
$$i_t^f = \lambda\big(f_l(l_t, n_t) - (\delta + \gamma'(o_t)\theta_t)\big) + (1-\lambda)\big((1-x_t)i_t^b + x_t i_t^m\big) \tag{2.34}$$

$$\theta_t = \frac{o_t}{l_{t+1}} \tag{2.35}$$

$$1 = \mathbb{E}_t\left[\beta\frac{u_c(c_{t+1}, n_{t+1})}{u_c(c_t, n_t)}(1+r_t)\right] \tag{2.36}$$

$$q_t = \mathbb{E}_t\left[\beta\frac{u_c(c_{t+1}, n_{t+1})}{u_c(c_t, n_t)}(1+\kappa q_{t+1})\right] \tag{2.37}$$

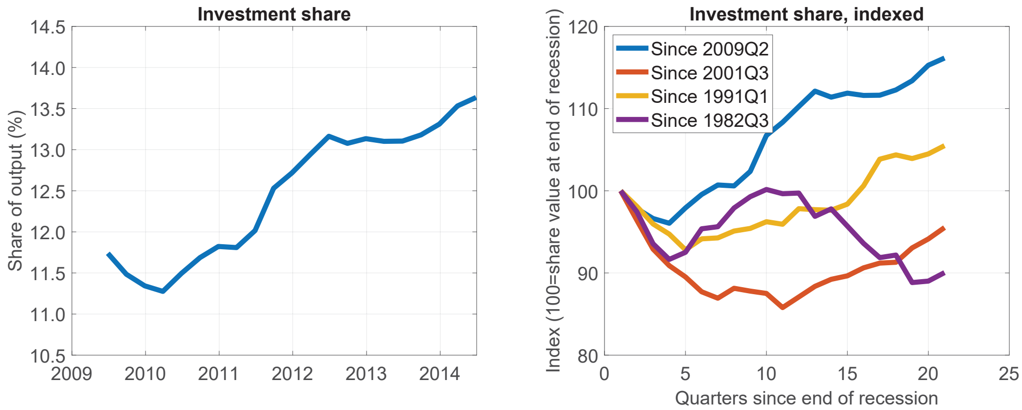
$$i_t^b = 1/q_t + \kappa - 1\ . \tag{2.38}$$



Notes: Using the benchmark parameter values of Table 2.1. Cumulative central bank purchases are 14.4% of the outstanding bond stock; see the main text in Section 2.5 for the construction of the QE shock. There is no inflation absent the nominal friction; see the text above for the corresponding equilibrium.

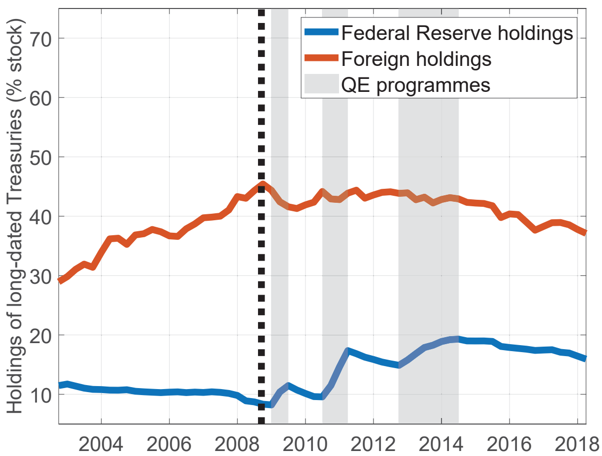
Figure 2.14: *Effects of QE measures in the US: sensitivity to the nominal friction*

2.7.4 Additional charts



Sources: FRED, NBER. *Notes:* Private non-residential fixed investment (*PNFI*) and nominal gross domestic product (*GDP*). The left panel shows the investment share (as a % of output) over time. The right panel shows the ratio, indexed at a 100 at the end of the four last recessions. End of recessions' quarters use the NBER troughs.

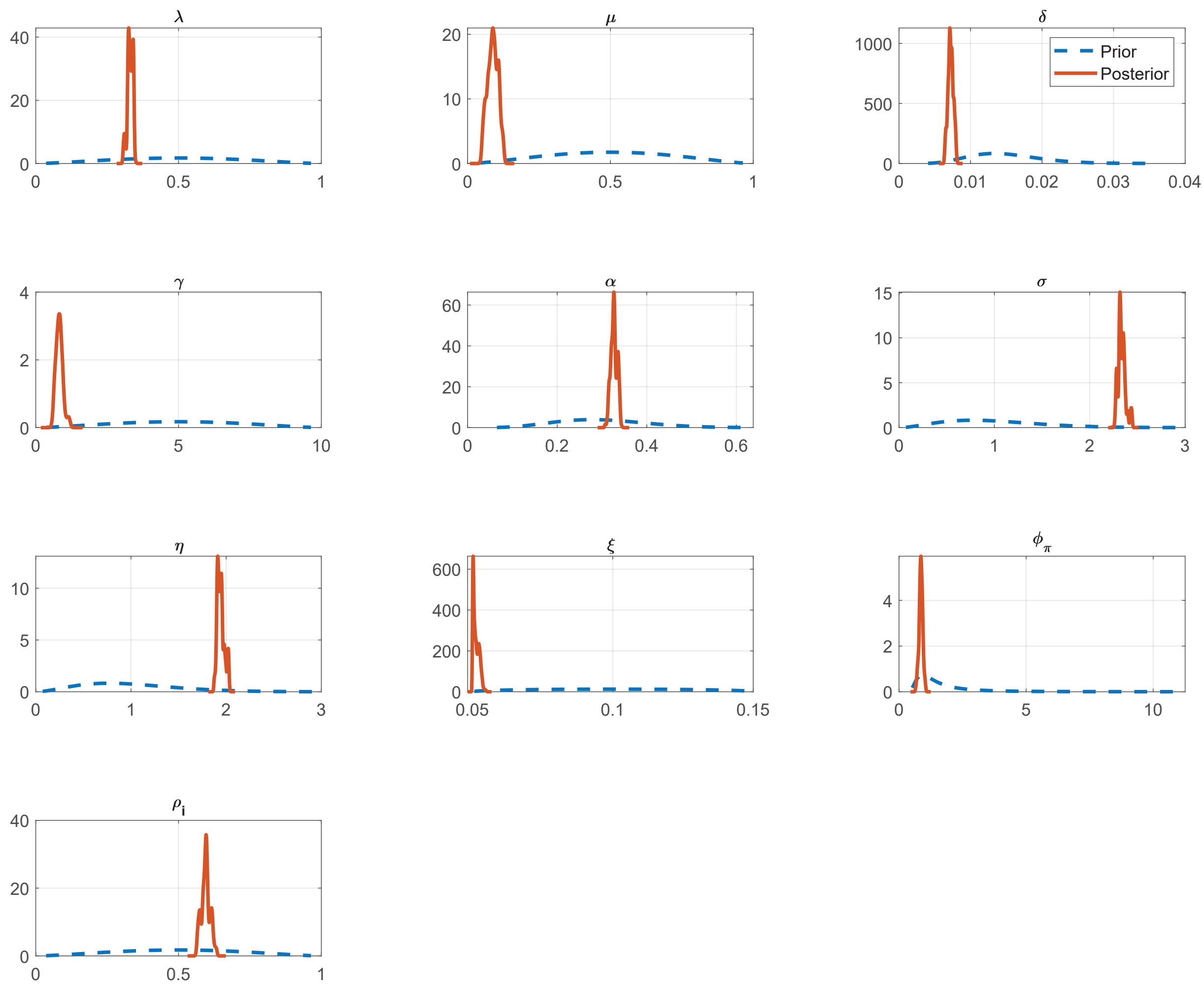
Figure 2.15: *Investment share in the US*



Sources: See note of panel (b) in Figure 2.2. Foreign holdings use the corresponding Rest of the World series (LM263061105.Q and LM263061110.Q). Holdings are shown as a (%) of the outstanding amount. Vertical line for Lehman Brother's bankruptcy (15 September 2008). Shaded areas show episodes of central bank purchase programmes.

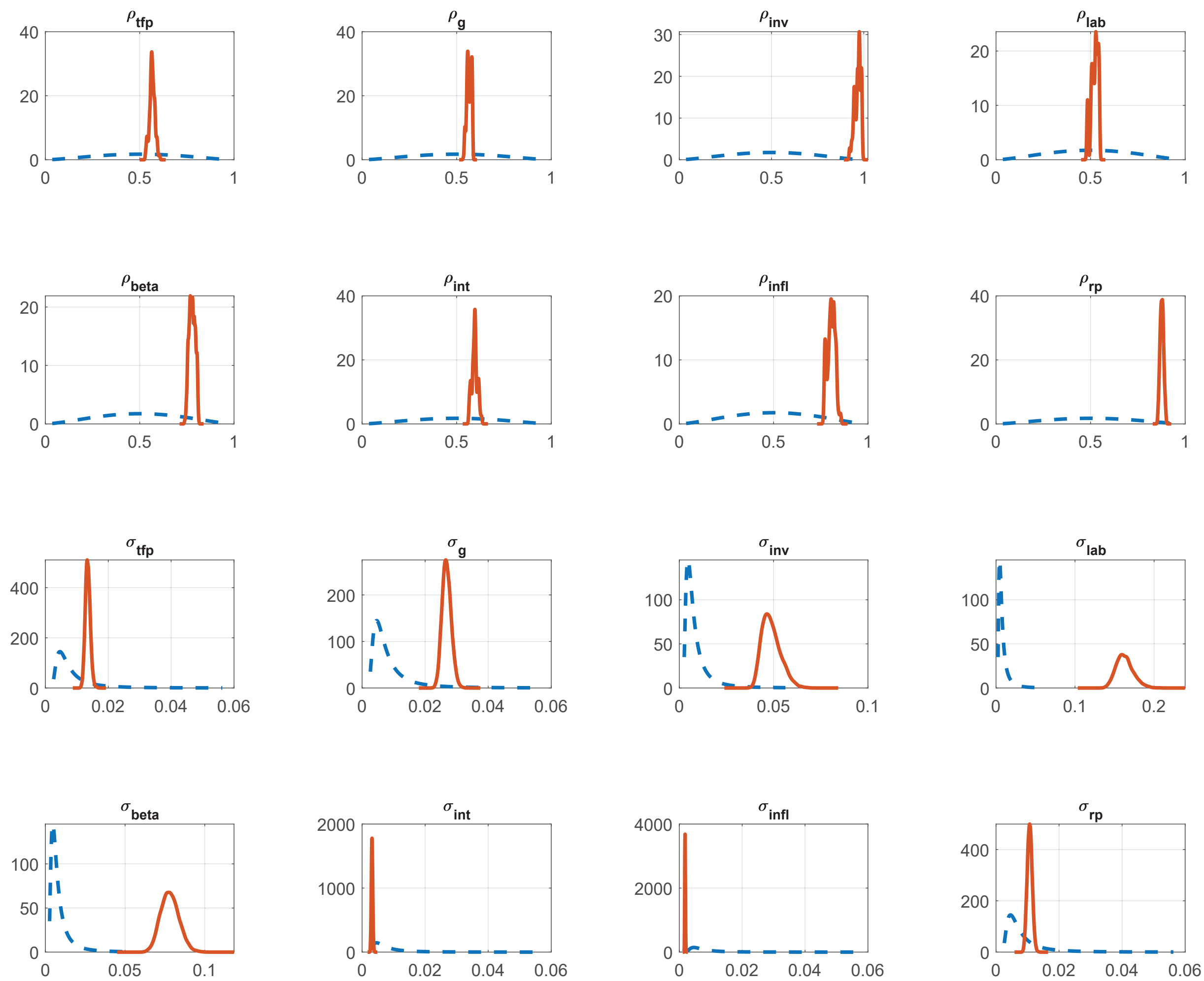
Figure 2.16: *Holdings of long-dated Treasury securities (% of outstanding stock)*

2.7.5 Estimation: priors and posteriors



Notes: Posterior densities evaluated by MCMC.

Figure 2.17: *Prior and posterior densities (1/2): behavioral parameters*



Notes: Posterior densities evaluated by MCMC.

Figure 2.18: *Prior and posterior densities (2/2): shocks' parameters*

3 On the distributional effects of central bank asset purchases

This chapter is single-authored.

Abstract:
This paper quantifies the distributional effects of central bank asset purchases that arise via the labor market. To do so, I build a model which contains rich household heterogeneity. A friction in the labor market gives rise to idiosyncratic unemployment shocks. Markets are incomplete so that wealth is heterogeneously distributed over the life cycle. An imperfection in the corporate credit market gives traction to central bank asset purchases: by holding government bonds, the central bank improves labor market conditions in general equilibrium. I show that the resulting welfare gains vary across households. Younger households benefit the most via improved employment prospects. Both the employed and the unemployed experience similar welfare gains as higher labor incomes are expected regardless of the current employment status. By contrast, the gains obtained by relatively older households are driven by the individual wealth position, which in turn summarizes past employment statuses. In particular, those who face unemployment spells closer to retirement benefit the least from central bank purchases.

Keywords: Unconventional monetary policy, Quantitative easing, Household heterogeneity, Distribution.
JEL-codes: E52, E44.

3.1 Introduction

Households differ in several dimensions that alter their exposure to changes in economic conditions. In line with the revived debate on inequality, household heterogeneity has recently taken a central stage in the study of monetary policy. The distributional effects of conventional monetary policy are by now relatively well documented. By contrast, the channels through which unconventional policy measures impact households are not fully understood.
Since the financial crisis, several new instruments were indeed introduced to the monetary policy mix. Among them, large-scale asset purchases of government bonds (so-called quantitative easing measures) have been, and remain, extensively used across advanced economies. Beyond their aggregate effects, the potential distributional consequences of central bank purchases are policy-relevant and often appear in the public debate. Such purchases are for instance notoriously believed to benefit the wealthy disproportionately via appreciating asset values. Like any other policy decision, central bank purchases nevertheless have far-reaching general equilibrium effects. In this paper, I investigate some of the distributional consequences of central bank purchases that arise via the labor market and wealth accumulation over the life cycle.

My contribution is to document the *welfare* effects across households. Nascent research has so far mostly focused on how these purchases affect income and wealth inequality as well as how this drives aggregate-level responses. I show that central bank purchases can have large distributional implications for welfare despite only modestly affecting the inequality measures that are typically reported in the literature. To my knowledge, this paper is the first to highlight the distributional welfare consequences of central bank purchases in an incomplete-markets model with endogenous unemployment. To do so, I build a closed economy general equilibrium model that assesses how purchases affect households heterogeneously depending on their individual characteristics. I consider households who not only differ in income and wealth but also in terms of their position in the life cycle. Central bank purchases are embedded via a simplified version of the corporate credit mechanism presented in the first chapter of the thesis. By purchasing government bonds, the central bank effectively lowers borrowing costs for firms in equilibrium, which in turn improves the labor market conditions faced by households. This mechanism is quantified by calibrating the model to the US economy.

While central bank purchases increase aggregate welfare, I find that welfare gains vary substantially at the individual level. In line with the empirical literature, households who become employed due to the purchases benefit the most. In addition, the model reveals that households are also unevenly affected by the purchases for a given employment path.

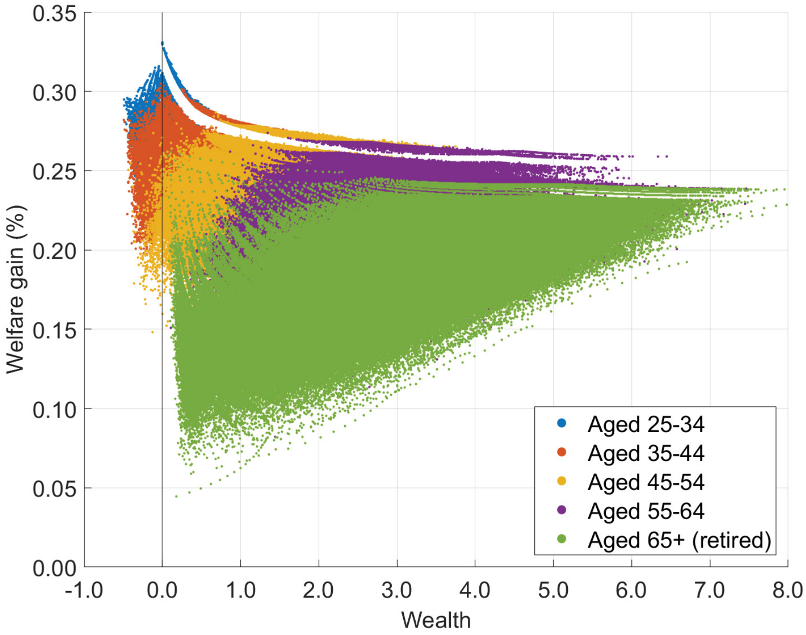
Part of my contribution is to consider the effects on unemployment, thus accounting for rich distributional effects via the labor market. In the model, involuntary unemployment arises due to a search and matching friction. This proves to play an important role in the transmission of central bank purchases to individual welfare.

Unemployment duration is on average low so that the current labor market status does not contribute much to overall income over the life cycle. In line with this, the welfare gains obtained by younger households are mostly driven by changes in expected future labor market conditions. Likewise, the employed and the unemployed benefit similarly from the purchases. By contrast, the gains of relatively older households rely on the wealth they built, which in turn depends on the individual lifetime ex-post employment path. When unemployed, households consume some of their wealth as to smooth consumption. Households who experience an unemployment spell closer to retirement hence see their wealth permanently reduced. Accordingly, they benefit markedly less from central bank purchases in the following years.

In the model, earnings inequality also arises via heterogeneous individual initial labor endowments. Although such idiosyncratic innate ability matters for welfare inequality across households, I find that it does not drive the individual welfare gains that result from central bank purchases.

The corresponding distributional consequences of central bank purchases, for given employment paths, are pictured in Figure 3.1. The figure plots the certainty-equivalent welfare gains obtained by households against their individual wealth positions, by age groups. Younger households, who are also the less wealthy, benefit the most from the improved employment prospects and hence experience the highest welfare gains. As they age, households are less dependent on labor market conditions but more so on the wealth they accumulated. In line with this, the welfare gains decrease with age. The gains also become increasingly spread out over the life cycle, reflecting the increased dispersion of individual wealth.

The next section places my contribution in the existing literature. The model is presented and calibrated in Sections 3.3 and 3.4, respectively. The equilibrium and distributional consequences of central bank purchases are then detailed in Section 3.5. Section 3.6 concludes.



Notes: Welfare gains are measured as the % difference in certainty equivalents (for given individual employment paths) obtained when the central bank holds 10% of the outstanding government bond stock (as compared to no holdings; see Section 3.5 for the details). Wealth is normalized by the equilibrium market wage.

Figure 3.1: *Individual welfare gains of central bank purchases against wealth positions*

3.2 Existing literature

It is by now established that the effects of conventional monetary policy are affected by household heterogeneity (see Ampudia et al., 2018 for a comprehensive literature review). Two-agent models continue to provide relevant intuition on the transmission and effects of monetary policy (see for instance Bilbiie and Ragot, 2017 and Iacoviello, 2005). In parallel, progress in computational power and numerical methods has allowed the incorporation of rich household heterogeneity in general equilibrium settings. In particular, research lately nested complex heterogeneity within the New Keynesian framework.
Household heterogeneity alters the transmission of conventional monetary policy (that is, interest rate targeting). Kaplan et al. (2018) show for the US that the transmission operates mostly via general equilibrium effects when households face uninsurable shocks.[1] Ravn and Sterk (2018) develop a model with incomplete asset markets to show that idiosyncratic risk also amplifies monetary policy shocks. In Auclert (2017), monetary policy affects households through individual earnings and financial positions. The role of balance sheets is further documented by Bayer et al. (2019). Because borrowing-constrained households have a high marginal propensity to consume, most of the transmission is carried through changes in aggregate demand and hence labor income in Lütticke (2018). I find that households are also mostly affected by central bank purchases via the resulting general equilibrium effects in a model with heterogeneity and one asset.

In the papers mentioned above, conventional monetary policy is also found to have distributional consequences. The importance played by labor market conditions is illustrated in Gornemann et al. (2016). Using a search and matching mechanism, they show that contractionary monetary policy decreases the income and welfare of all households except for the wealthiest. Inequality measures are accordingly increased. This is empirically confirmed by Coibion et al. (2017), who use household-level income and consumption US data from the *Consumer Expenditure Survey* (CES). A contractionary policy shock increases the constructed inequality measures, although only by a modest magnitude. Accommodative monetary policy, which is inflationary, would thus be equalizing. In line with this, Doepke and Schneider (2006) document the redistributive wealth effects of inflation in the US by using the *Survey of Consumer Finances* (SCF). In the data, young indebted households benefit the most in inflationary periods

[1]This contrasts to the representative agent case, in which households are directly affected by policy rate changes via intertemporal substitution (Galí, 2015).

whereas older asset-rich households lose out. Although not the main focus in Sterk and Tenreyro (2018), conventional monetary policy is also found to have intergenerational distributional effects. In their model, overlapping generations face a frictional labor market. Expansionary monetary policy triggers an income transfer from older to younger households.

Likewise, I find that central bank purchases have redistributional effects across generations. In my model, younger households obtain the highest welfare gains due to improved employment prospects. By contrast, retired households only benefit from the purchases via accumulated wealth (which is akin to voluntary pension in the model).[2] Such welfare distributional effects have a fiscal flavor. Figure 3.1 showed that the highest gains are obtained by less wealthy households (that is, the young). This is similar to the gains that result from changes in fiscal policy. In a model with household heterogeneity, Heathcote (2005) shows that asset-poor households display larger marginal propensities to consume out of temporary income tax changes. Likewise, Andrés et al. (2018) show that consumption responses to government spending shocks depend on individual balance sheets. Households with lower wealth levels experience the highest welfare gains after an expansionary fiscal shock in their model,[3] as is the case in my setting when the central bank holds government bonds.

The distributional consequences of unconventional monetary policy have so far mostly been investigated empirically. This recent literature finds that the asset purchase programmes carried out by several central banks have only had negligible effects on standard inequality measures. Household labor income inequality is overall modestly reduced via an increase in employment. While measuring wealth is inherently challenging, the wealth distribution seems broadly unaffected by central bank purchases.

Montecino and Epstein (2015) use the *Survey of Consumer Finances* (SCF) to compare the US household income distribution before and after quantitative easing measures. They find that an increase in individual employment decreases the dispersion of labor income, whereas the dispersion of wealth income is increased by movements in asset values.[4]

Bunn et al. (2018) provide similar findings for the UK. Using a panel of households from the *ONS Wealth and Assets Survey* and previously obtained aggregate-level estimates, they simulate the effects of the Bank of England's overall policy mix between 2008 and 2014. They document that labor income increased disproportionally for younger households. Households close to retirement instead experienced a relatively larger

[2] Equilibrium changes do not affect mandatory pension receipts (which are exogenous and net of tax) in the model.

[3] Andrés et al. (2018) use infinitely-lived households.

[4] As a result, their inequality measure of total income is modestly increased.

increase in wealth. Nevertheless, the resulting effect on standard income and wealth inequality measures remains subdued.
Modest effects on wealth inequality are likewise found for the Euro area. The effects of quantitative easing on individual households are also simulated by Lenza and Slacalek (2018), who use a four-country VAR together with the *Household Finance and Consumption Survey* (HFCS) dataset. Again, the employment channel decreases labor income dispersion. In particular, Lenza and Slacalek (2018) find a reduction in labor income inequality. This extensive margin channel is confirmed for Italian households by Casiraghi et al. (2018), who use a similar approach and the *Survey of Household Income and Wealth* (SHIW) to assess the unconventional measures carried out by the ECB between 2011 and 2012. By contrast, both studies find negligible effects on wealth inequality measures.
My structural model provides support to this nascent empirical evidence. Central bank purchases only have modest effects on standard inequality measures in the model. Likewise, the employment channel that is empirically documented for several asset purchase programmes also operates in my setting.

On the modelling side, household heterogeneity has so far mostly been analyzed in the context of another form of unconventional monetary policy, namely forward guidance (see Werning, 2015 and McKay et al., 2016). Cui and Sterk (2018) present a notable exception. They develop a tractable model that assesses the transmission of quantitative easing measures in the presence of household heterogeneity. While their focus is on the effectiveness and optimality of central bank purchases, they also discuss distributional welfare implications. Time-varying asset purchases cause fluctuations in household deposits, in turn pushing up the dispersion of individual consumption. In their model, central bank purchases can increase welfare inequality up to the point that aggregate welfare goes down.
My model departs from their setting in several ways. I endogeneize unemployment and can hence quantify the extensive margin welfare gains that result from central bank purchases. Cui and Sterk (2018) measure welfare from a timeless perspective by using unconditional expectations.[5] In contrast, my welfare measures reflect the role played by individual conditional expectations, which in turn allows to comprehensively characterize how the unemployed benefit from the purchases. By considering finitely-lived households, I can also account for the response of wealth to unemployment shocks at the individual level and hence assess welfare gains conditional on age.

[5]See Clarida et al. (1999) for an example.

3.3 Model

The model contains finitely-lived heterogeneous households who face an individual employment risk and have access to a liquid asset. A friction in the labor market gives rise to involuntary unemployment. Likewise, a strategic interaction arises between a goods' producer and a bank. There is also a government and a central bank. In equilibrium, aggregate quantities and prices are constant because there is no aggregate risk (as in Aiyagari, 1994 and Huggett, 1996).

3.3.1 Liquid versus illiquid assets

Balance sheet positions shape household consumption choices. In particular, the recent literature highlights the importance of distinguishing between liquid and illiquid wealth. Liquid wealth can be used as a cushion against shocks whereas more illiquid asset positions are not easily adjusted. Kaplan et al. (2014) show that in several advanced economies, most of the households hold little net liquid wealth,[6] even when they own illiquid assets such as housing equity. In this paper, households have access to a liquid asset: a bank deposit. The more illiquid assets consist of physical capital and shares in various institutions. These are only held indirectly by households via a mandatory pension system, which is operated by the government.[7] This modeling choice makes physical capital and securities illiquid without introducing additional frictions (as required in Kaplan et al., 2018). It also captures the fact that households do not control their (public and private) mandatory pension contributions. A large component of illiquid assets is held by pension funds in reality. This is also implicitly the case in the model as the government levies a tax on the employed and provides a retirement endowment.

3.3.2 Households

Household heterogeneity is captured via individual characteristics that are known to affect economic decisions. In the model, households age over time. They participate in the labor market until retirement; their labor earnings depend on the employment status and on hours worked. As a result, individual wealth also varies across households.

[6] The median liquid wealth position in the US mostly consists of cash-type accounts instead of directly held securities (see table 2 on page 98 in Kaplan et al., 2014).

[7] Cui and Sterk (2018) use a similar device. Households all own fixed shares in a mutual fund of illiquid assets.

In particular, there is a continuum of finitely-lived households $i \in (0,1)$ on the unit interval. The life cycle of a household consists of $j = \{1, ..., J\}$ years. There is no population growth, hence each age cohort corresponds to a fraction $1/J$ of the population. Households have access to a liquid asset that earns the net rate r but is subject to a borrowing constraint: $a_j(i) \geq -\underline{a}$. Households start with no initial asset holdings $(a_1(i) = 0)$. A household is in the workforce until age $R-1$ and is subsequently retired until it exits at age J.

Households in the workforce – Households face an idiosyncratic labor income risk while participating in the labor market. Individual labor income depends on the employment status and on a labor endowment.

As in Aiyagari (1994), labor endowments vary across households. A household i with age j has an exogenous labor endowment $l_j(i)$. The individual endowment $l_j(i)$ can be thought of as a measure of ability: it is heterogeneous at birth and grows as the household ages. The endowment consists of an initial idiosyncratic level $z(i)$, which log is normally distributed: $\ln z(i) \sim \mathcal{N}(\mu_z, \sigma_z^2)$. The individual endowment grows at a constant rate ψ over the life cycle, so that $l_j(i) = z(i)(1+\psi)^j$. This captures changes in labor efficiency as the household ages (because of e.g. learning on the job). When in the workforce, a household is either employed or unemployed. The individual employment status $e_j(i) = \{1, 0\}$ is stochastic.

An employed household earns the net wage $w(1-\tau)$, which consists of a market wage w and a tax rate τ. Its labor income is thus $l_j(i)w(1-\tau)$. When employed $(e_j(i) = 1)$, a household faces a given probability of losing the job in the next period $(e_{j+1}(i) = 0)$. The corresponding probability $\mathbb{P}(e_{j+1}(i) = 0 \mid e_j(i) = 1)$ is exogenously set to χ.[8]

An unemployed household instead receives a benefit $s_j(i)$. The benefit is proportional to the individual labor endowment: $s_j(i) = sl_j(i)$, in which $s > 0$ is a calibrated constant. This captures the fact that received unemployment benefits are proportional to the most recent earnings in reality.[9] When unemployed $(e_j(i) = 0)$, a household faces a given probability of finding a job in the next period $(e_{j+1}(i) = 1)$. This probability is given by $\mathbb{P}(e_{j+1}(i) = 1 \mid e_j(i) = 0) = h(\theta)$ and depends on a labor market tightness measure θ that is described in Subsection 3.3.3.

The consumption problem of each age cohort is detailed below. For the rest of the text, the individual household subscript i is omitted to ease notation. The value function of a household in the workforce is given by $V_j(e_j, z, a_j)$ for $j < R$. It depends

[8]The so-called job separation rate χ is relatively constant over business cycles in the US; see Shimer (2005) for empirical evidence.

[9]The unemployment benefit uses $l_j(i)$ instead of $l_{j-1}(i)$ as to simplify aggregation. Using instead the past individual labor endowment would just shift the calibrated value of s.

on the current individual state variables (e_j, z, a_j) as well as on the discounted expected value function $V_{j+1}(e_{j+1}, z, a_{j+1})$ of the household at age $j+1$ with accumulated wealth a_{j+1}. The problem of the household is hence given by:

$$\begin{aligned} V_j(e_j, z, a_j) = \max_{\{c_j\}} \ &: \ \left\{ \frac{c_j^{1-\sigma}}{1-\sigma} + \beta \mathbb{E}\left[V_{j+1}(e_{j+1}, z, a_{j+1}) \ \middle| \ e_j \right] \right\} \\ \text{s.t.} \ &: \ l_j\big(e_j w(1-\tau) + (1-e_j)s\big) + (1+r)a_j = c_j + a_{j+1} \\ & \quad a_{j+1} \geq -\underline{a} \ , \end{aligned}$$

where $\beta \in (0,1)$ is the discount factor, σ stands for the constant coefficient of risk aversion and $l_j = z(1+\psi)^j$. The derivations of the first-order conditions for the household problems are detailed in Appendix 3.7.1. Conditional on the individual state (e_j, z, a_j), the Euler equation for households aged $j < R$ is:

$$c_j^{-\sigma} = \beta(1+r)\mathbb{E}\left[{c_{j+1}}^{-\sigma} \ \middle| \ e_j \right] + \mu_j \ , \tag{3.1}$$

where $\mu_j \geq 0$ is the multiplier of the (occasionally-binding) borrowing constraint. At the optimum, households use their asset holding positions (a_{j+1}) as to equate the current marginal benefit of consumption to the discounted expected marginal benefit of consumption in the next period. The expectations formed by households in the workforce are conditional on the current employment status. Importantly, the expectations of the unemployed rely on the equilibrium probability of finding a job, $h(\theta)$. As a result, a currently unemployed household is also indirectly affected by the net wage via expectations. As detailed in Subsection 3.5.2, this will drive the response of the unemployed to central bank purchases.

Retired households – All uncertainty is revealed before entering retirement, at age $R-1$. A retired household subsequently receives a pension payment in each period. This captures mandatory pension, to which retired households contributed by paying taxes (via τ) when employed in earlier periods. The pension payment is lower than labor earnings and is given by $pz(1+\psi)^{R-1}$, in which $p > 0$. Because the payment is proportional to the individual pre-retirement labor endowment, the constant $p > 0$ can be calibrated to match a realistic mandatory pension replacement ratio.[10]

The value function of a retired household is given by $V_j(z, a_j)$ for $j \geq R$. It de-

[10] While pension is akin to a *final salary* scheme in the model, the constant p is calibrated in Section 3.4 to match typical US replacement ratios.

pends on the current individual state variables (z, a_j) as well as on the discounted[11] value function $V_{j+1}(z, a_{j+1})$ of the household when aged $j+1$ with remaining wealth a_{j+1}. The problem of the household is hence given by:

$$\begin{aligned} V_j(z, a_j) = \max_{\{c_j\}} \ &: \ \left\{ \frac{c_j^{1-\sigma}}{1-\sigma} + \beta V_{j+1}(z, a_{j+1}) \right\} \\ \text{s.t.} \ &: \ pz(1+\psi)^{R-1} + (1+r)a_j = c_j + a_{j+1} \\ &\quad a_{j+1} \geq -\underline{a} \ . \end{aligned}$$

Conditional on the individual state (z, a_j), the Euler equation for households aged $j \geq R$ is:

$$c_j^{-\sigma} = \beta(1+r){c_{j+1}}^{-\sigma} + \mu_j \ , \tag{3.2}$$

where again $\mu_j \geq 0$ is the multiplier of the (occasionally-binding) borrowing constraint. It turns out that the retired consumption problem admits an analytical solution as the borrowing constraint never binds in equilibrium (see Appendix 3.7.1). The consumption path of a household who accumulated a wealth level a_R prior to retirement is given by:

$$c_R = \left[a_R + pz(1+\psi)^{R-1} \left(\frac{1}{1+r} \right) \sum_{k=0}^{J-R} \left(\frac{1}{1+r} \right)^k \right] \left[\left(\frac{1}{1+r} \right) + \left(\frac{1}{1+r} \right) \sum_{k=1}^{J-R} \left(\frac{1}{1+r} \right)^k \left(\beta(1+r) \right)^{\frac{k}{\sigma}} \right]^{-1} \tag{3.3}$$

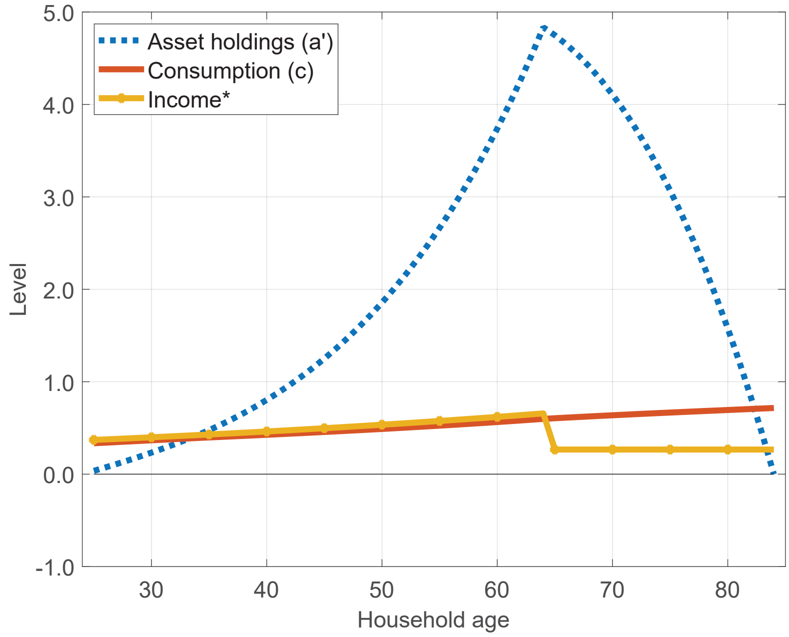
$$c_{R+k} = \left(\beta(1+r) \right)^{\frac{k}{\sigma}} c_R \quad , \quad k = \{1, ..., J-R\} \ , \tag{3.4}$$

whereas the end-of-period asset holdings a_{R+k} can be recovered from the corresponding budget constraints. Before exiting at age J, households optimally consume all of their resources so that $a_{J+1} = 0$. The analytical solution provides some intuition that will help explain how central bank purchases affect retired households. From equations (3.3) and (3.4), the only equilibrium object that directly affects the retired is the interest rate r. The other equilibrium prices and quantities only affect retired households indirectly via their effect on the wealth accumulated up to retirement (a_R).

The standard life-cycle consumption/saving behavior of a typical household is illustrated in Figure 3.2. When unemployed, the household receives a subsidy that is proportional to the labor endowment. When employed, the household instead gets the net wage. The corresponding earnings gradually increase on average until retirement. The household then receives a pension payment that is lower than pre-retirement earnings. Wealth is hence gradually accumulated over time. It is then used in later years

[11] The discount factor β would be lowered if households faced a given probability of exiting at each period. I abstract from survival risk as it would generate accidental bequests.

to compensate the permanent fall in income that takes place at retirement. In line with this, the distributional welfare effects of central bank purchases will partly operate via individual wealth accumulation.



Notes: Using the parameter values listed in Table 3.1 and the simulated averages that prevail absent central bank purchases. *The income shown uses labor income before retirement and the pension endowment thereafter.

Figure 3.2: *Illustration of the life cycle*

3.3.3 Labor market

A friction in the labor market gives rise to unemployment in equilibrium. The friction is captured by a standard search and matching mechanism in the spirit of Mortensen and Pissarides (1994) and Den Haan et al. (2000). In this subsection, I describe aggregate labor dynamics, the demand and supply sides of the labor market as well as the resulting partial equilibrium.

Labor market dynamics – The supply side in the labor market consists of all households who are not retired (that is, aged less than R). The workforce therefore totals $\frac{R-1}{J}$. The unemployment rate u, expressed as a fraction of the workforce, is assumed to be the same across age cohorts. The total amount of unemployed workers U is accordingly given by $\sum_{j=1}^{R-1} \int_i \big(1 - e_j(i)\big)\ \mathrm{d}i = \big(\frac{R-1}{J}\big)u$ and the total amount of employed workers by

$N = \left(\frac{R-1}{J}\right)(1-u)$. An employed household provides its individual labor endowment l_j. By the law of large numbers, the average initial labor endowment $\bar{z}$ is constant and I normalize it so that N equals the aggregate labor endowment in the economy.[12]

The demand side of the labor market is assumed to be a continuum of recruiters (called firms in Obiols-Homs, 2018) that search for workers. I use this modeling device to simplify the numerical implementation of the model. Recruiters play the innocuous role of an intermediary: they pass on the found workers to a good producer, which problem is detailed in the next subsection. Accordingly, recruiters have constant returns to scale with respect to the labor input.

Recruiters post vacancies in the hope of matching with a worker. A representative recruiter[13] chooses how many vacancies V to post today as to obtain the desired quantity of labor N' in the next period. Vacancies and the stock of unemployed workers do not match perfectly. Total matches are denoted by M and depend on U and V via a standard reduced-form matching function:[14]

$$M = V^{1-\mu_l} U^{\mu_l} \ ,$$

where μ_l gives the elasticity of the matching function with respect to U. Labor market tightness can be measured as $\theta = \frac{V}{U}$. As a result, the probability of filling a vacancy is $f(\theta) = \frac{M}{V} = \theta^{-\mu_l}$. Likewise, the probability that an unemployed household finds a job, denoted by $h(\theta)$ in Subsection 3.3.2, is given by $h(\theta) = \frac{M}{U} = \theta^{1-\mu_l}$. Matches break at an exogenous rate χ. The law of motion for aggregate labor N is thus:

$$N' = (1-\chi)N + f(\theta)V \ .$$

Demand side – The representative recruiter posts vacancies at cost $\gamma > 0$. When a vacancy is successfully matched, the recruiter passes on the worker to the goods' producer. The producer pays w^f to the recruiter, who in turn gives w to the worker. The recruiter's profits are thus given by $\Pi^r = (w^f - w)N - \gamma V$. Because there is no aggregate risk in the economy, it is innocuous to assume that the recruiter values future profits by a constant

[12]Appendix 3.7.2 shows that aggregate employment and aggregate labor coincide by setting $\mu_z = -\ln\left[\sum_{j=1}^{R-1}\left(\frac{1}{R-1}\right)(1+\psi)^j\right] - \frac{\sigma_z^2}{2}$.

[13]The size of recruiters does not matter due to constant returns to scale.

[14]The use of a matching function with constant returns to scale is supported by empirical evidence; see for instance Petrongolo and Pissarides (2001).

discount factor β.[15] The recursive problem of the recruiter therefore reads:

$$\begin{aligned} \widetilde{\Pi}^r = \max_{\{V,N'\}} \ &: \ \left\{ \ (w^f - w)N - \gamma V + \mathbb{E}\big[\beta \widetilde{\Pi}^{r'}\big] \ \right\} \\ \text{s.t.} \ &: \ N' = (1-\chi)N + f(\theta)V \ . \end{aligned}$$

Appendix 3.7.2 shows that the first-order condition of the recruiter satisfies:

$$\gamma = f(\theta)\mathbb{E}\Bigg[\beta\bigg(w_f' - w' + \frac{(1-\chi)\gamma}{f(\theta')}\bigg)\Bigg] \ .$$

At the optimum, the recruiter posts vacancies up to the point at which the marginal cost of posting γ equalizes the probability $f(\theta)$ of filling a vacancy times the expected marginal benefit of a successful match. The marginal benefit corresponds to the value J_m of a successful match:

$$J_m = w^f - w + \frac{(1-\chi)\gamma}{f(\theta)} \ .$$

The value of a successful match intuitively depends on the mark-up $w_f - w$ that the recruiter pockets plus the continuation value $\frac{(1-\chi)\gamma}{f(\theta)}$ of a match (that is, the future foregone vacancy posting costs). Likewise, the value J_v of posting a vacancy is:

$$J_v = -\gamma + \mathbb{E}\Bigg[\beta\bigg(f(\theta)J_m' + \big(1 - f(\theta)\big)J_v'\bigg)\Bigg]$$

as the recruiter will fill the vacancy with a probability $f(\theta)$, in which case it then receives J_m' in the next period.

Supply side – Workers are represented by a labor union. The union values the labor income of its members regardless of their individual states. This gives an analytical solution for the equilibrium wage w, in turn proving useful when solving the model numerically. Krusell et al. (2010) show that this simplification does not significantly alter the equilibrium. Using a similar setting in which households instead bargain over the wage individually, they find that the equilibrium wage curve is almost invariant with respect to the individual states.

In the model, the union accordingly assigns current flow benefits w and s to the pools of

[15] An institution values profits according to its owners' preferences, using a weighted stochastic discount factor $\beta \int_i \omega(i)\big(\frac{c(i)'}{c(i)}\big)^{-\sigma} \mathrm{d}i$, in which $\omega(i)$ denotes the share held by household i. Absent aggregate risk, the household distribution is ergodic. The term $\int_i \omega(i)\big(\frac{c(i)'}{c(i)}\big)^{-\sigma} \mathrm{d}i > 0$ is hence constant and can be normalized to one.

employed and unemployed workers.[16] The corresponding surpluses V_e and V_u consist of the current flow benefit plus a continuation value; a successful match thus generates a net surplus of $V_e - V_u$. Given the labor market dynamics described above, the surpluses are given by:

$$\begin{aligned} V_e &= w + \mathbb{E}\Big[\beta\Big(\big(1-\chi\big)V_e' + \chi V_u'\Big)\Big] \\ V_u &= s + \mathbb{E}\Big[\beta\Big(h(\theta)V_e' + \big(1-h(\theta)\big)V_u'\Big)\Big] \\ \implies V_e - V_u &= w - s + \big(1-\chi-h(\theta)\big)\mathbb{E}\big[\beta(V_e' - V_u')\big] \ , \end{aligned}$$

in which β is also the union's constant discount factor (see footnote 15).

Partial equilibrium – When they meet, the representative recruiter and the union bargain over the total net surplus of a match. A match is worth $J_m - J_v$ to the firm and $V_e - V_u$ to the union. As is common in the literature, the total net surplus S_l is shared by Nash bargaining. Denoting the bargaining power of the union by $\lambda_l \in (0,1)$, the equilibrium wage w is the result of:

$$\max_{\{w\}} \ : \ S_l = \big(V_e - V_u\big)^{\lambda_l}\big(J_m - J_v\big)^{1-\lambda_l} \ .$$

Appendix 3.7.2 contains the standard derivation that gives the equilibrium wage:

$$w = \lambda_l\big(w^f + \gamma\theta\big) + (1-\lambda_l)s \ .$$

In equilibrium, the wage depends on the benefit it brings to the recruiter as well as on the union's outside option. A successful match brings the recruiter a marginal revenue w^f. It also spares the recruiter the effective cost $\gamma\theta$ of posting a vacancy in a market with prevailing tightness θ. Likewise, a successful match spares the union to assign its (strictly dominated) outside option, namely the unemployment benefit s.

3.3.4 Corporate credit market: goods' producer and bank

Goods are produced by a representative firm with production function $Y = K^\alpha N^{1-\alpha}$. The firm hires labor N from the representative recruiter at the given wage w^f and rents capital K at the rate $r^k + \delta$, where δ is the capital depreciation rate (that is, the firm

[16] Consistent with footnote 12, the average initial labor endowment $\bar{z}$ is set such that hours worked are on average equal to one across all workers: $\mathbb{E}[l] = 1$ (see Appendix 3.7.2).

pays for capital depreciation). The firm's profits read:

$$\Pi^f = K^\alpha N^{1-\alpha} - w^f N - (r^k + \delta)K \ .$$

The firm has no market power in the goods and labor markets. The first-order condition for labor thus equates the wage w^f to the marginal product of labor:

$$w^f = (1-\alpha)\left(\frac{K}{N}\right)^\alpha .$$

Central bank purchases get traction via the corporate credit market. Building on the first chapter of the thesis, I assume that the firm has some bargaining power on the capital rental market.[17] The counter-part to the firm is a bank, who also has some bargaining power. The bank's liabilities consist of both the household liquid assets ($A^h = \sum_{j=1}^{J} \int_i a_j(i)\ \mathrm{d}i$) and the more illiquid assets (A^g) detained by the government, which all earn the net rate r. The bank can invest its liabilities in three available assets. It can invest in physical capital K, earning the net rate r^k from the firm. Alternatively, the bank can purchase government bonds B^b, earning the net rate r. Last, it can hold excess reserves M, earning the net rate r^m. The bank's balance sheet thus reads $A^h + A^g = K + B^b + M$ and its profits are given by:

$$\Pi^b = r^k K + r B^b + r^m M - r(A^h + A^g) \ .$$

Because of their respective bargaining powers, a strategic interaction arises between the firm and the bank. As in the first chapter, the capital return r^k is the result of Nash bargaining over the total net surplus S^c made when renting a unit of capital. The firm then unilaterally chooses how much capital K to rent at the negotiated rate r^k; this is akin to the *right to manage* setting often used in the presence of market power in the labor literature. It is worth noting that the resulting equilibrium rate r^k and capital level K are identical when the agents instead bargain over the total net surplus of the *entire* capital stock. This is because both the total net surplus and the production function have constant returns to scale, as shown in Appendix 3.7.3.

The net surplus to the firm is $S^f = \alpha K^{\alpha-1} N^{1-\alpha} - (r^k + \delta)$. The net surplus to the bank depends on its outside investment option. When the bank does not invest in physical capital, it faces an average return on its holdings of government bonds and reserves. The average return is given by $(1-x)r + x r^m$, where x is the fraction of bonds held by the central bank (discussed below). The net surplus to the bank is thus

[17] See Section 2.2 in the first chapter for a detailed motivation in the presence of a search cost. Here, we can think of an intermediary that negotiates on behalf of the goods' sector.

$S^b = r^k - \big((1-x)r + xr^m\big)$. Denoting the bargaining power of the bank by $\lambda_b \in (0,1)$, the total net surplus S^c is given by:

$$S^c = \left(S^b\right)^{\lambda_b} \left(S^f\right)^{1-\lambda_b} .$$

Maximizing the total net surplus S^c with respect to r^k gives the equilibrium return on capital:

$$r^k = \lambda_b\big(\alpha K^{\alpha-1}N^{1-\alpha} - \delta\big) + (1-\lambda_b)\big((1-x)r + xr^m\big) . \tag{3.5}$$

The equilibrium return r^k depends on the marginal product of capital and on the outside option of the bank; Subsection 2.3.3 in the first chapter provides more details. The firm then chooses the capital level K that optimally equalizes the marginal product of capital to the negotiated rate : $r^k = \alpha K^{\alpha-1}N^{1-\alpha} - \delta$. Re-arranging equation (3.5) then gives:

$$\alpha K^{\alpha-1}N^{1-\alpha} - \delta = r + x(r^m - r) . \tag{3.6}$$

The equilibrium rate r^k is equalized to the outside investment option of the bank. This is because the firm unilaterally decides how much capital to rent. Although the firm captures all of the total net surplus, it makes no profits in equilibrium by the Euler theorem.[18]
Equation (3.6) highlights the core transmission mechanism of central bank purchases to the real economy. By purchasing government bonds ($x > 0$) and paying a rate $r_m < r$ on the issued reserves, the central bank can lower the outside investment option of the bank. The firm accordingly negotiates a lower rate r^k, in turn pushing up its demand for capital.

3.3.5 Central bank and government

Conventional monetary policy is assumed away as there is no inflation in the model. The central bank only issues reserves M, for which it pays the gross rate $1 + r^m$, as to purchase a fraction x of the outstanding government bond stock.[19] Absent bond purchases, the central bank balance sheet is zero. By contrast, the balance sheet is $M = xB$ when the central bank holds government bonds. Central bank profits are thus given by $\Pi^{cb} = (r - r^m)xB$.

The government spends a fraction g of output and issues government bonds B',

[18] This is equivalent to the limiting case $\lambda \to 0$ in the first chapter of the thesis.
[19] Reserves hence correspond to *excess* reserves in the data.

paying the gross rate $1 + r$. Social transfers include unemployment benefit payments and retirement endowments, which total sU and $p\big(1 - \frac{R-1}{J}\big)\mathbb{E}[z](1+\psi)^{R-1}$ respectively. As explained in Subsection 3.3.1, all illiquid assets are held by the government. These consist of physical capital ($A^g = K$) and shares in the bank, the central bank and the recruiter. Overall profits $\Pi = \Pi^b + \Pi^{cb} + \Pi^r$ are hence rebated in the government budget constraint. Budget balance is achieved via the tax rate τ levied on the employed. The government budget constraint thus reads:

$$\tau w N + (1+r)K + B' + \Pi = (1+r)B + gY + sU + p\left(1 - \frac{R-1}{J}\right)\mathbb{E}[z](1+\psi)^{R-1} + K' \ . \tag{3.7}$$

3.3.6 General equilibrium

Because there is no aggregate risk, prices and *aggregate* quantities are constant over time. The law of motion for aggregate labor thus simplifies to:

$$N = \frac{f(\theta)V}{\chi} \ . \tag{3.8}$$

Using $w^f = (1-\alpha)K^\alpha N^{-\alpha}$, the first-order condition of recruiters becomes:

$$w = (1-\alpha)K^\alpha N^{-\alpha} - \frac{\gamma}{f(\theta)}\big(1/\beta - 1 + \chi\big) \ . \tag{3.9}$$

Intuitively, the cost of posting a vacancy reduces the wage below its otherwise efficient level. Nash bargaining also gave an expression for the wage:

$$w = \lambda_l\big((1-\alpha)K^\alpha N^{-\alpha} + \gamma\theta\big) + (1-\lambda_l)s \ . \tag{3.10}$$

The individual end-of-period asset holdings of age cohort j depend on the household state. The corresponding policy function is denoted by $a_{j+1}(e_j, z, a_j)$. Absent aggregate risk, total household assets A^h are constant. Market clearing for household assets is therefore given by:

$$\begin{aligned} A^h &= \sum_{j=1}^{J} \int_z \int_e \int_a a_{j+1}(e_j, z, a_j) \ \mathrm{d}a \ \mathrm{d}e \ \mathrm{d}z \\ &= (K + B^b + M) - A^g = B^b + M = (1-x)B + xB = B \ , \end{aligned}$$

where the second line uses the balance sheets of the bank and the central bank. In equilibrium, households still own the entire stock of government bonds via the bank. Equation (3.6) expressed the marginal product of capital as a function of central bank purchases:

$$\alpha K^{\alpha-1} N^{1-\alpha} - \delta = r + x(r^m - r) \ . \tag{3.11}$$

The resource constraint is then obtained by consolidating the household and government budget constraints (see Appendix 3.7.4):

$$(1-g)K^{\alpha}N^{1-\alpha} = C + \delta K + \gamma V \ ,$$

where C denotes aggregate consumption.

A general equilibrium is then defined as a collection of policy functions for the individual consumptions $c_j(e_j, z, a_j)$ and end-of-period asset holdings $a_{j+1}(e_j, z, a_j)$ that solve the age-cohort maximization problems given the equilibrium prices $\{w, r, \tau\}$ and labor market tightness θ, such that the resulting aggregate quantities $\{V, N, K, w\}$ given by equations (3.8) to (3.11) clear the markets for labor, goods and household assets:

$$\begin{aligned}
N &= \sum_{j=1}^{J} \int_i e_j(i) \ \mathrm{d}i \\
(1-g)K^{\alpha}N^{1-\alpha} &= \sum_{j=1}^{J} \int_z \int_e \int_a c_j(e_j, z, a_j) \ \mathrm{d}a \ \mathrm{d}e \ \mathrm{d}z + \delta K + \gamma V \\
B &= \sum_{j=1}^{J} \int_z \int_e \int_a a_{j+1}(e_j, z, a_j) \ \mathrm{d}a \ \mathrm{d}e \ \mathrm{d}z \ .
\end{aligned}$$

The model is solved by global methods. The age-cohort maximization problems are solved by backward induction. Market clearing is then obtained via a bisection. Appendix 3.7.5 details the solution algorithm. The model calibration is discussed in the next section.

3.4 Calibration

The model is mapped to the US economy at the annual frequency. The chosen parameter values are listed in Table 3.1 and discussed below.

The economic life of a household spans over 60 years. Households are born at age

25, retire at age $R = 65$ and exit at age $J = 85$. Parameters governing the labor market are calibrated to match established stylized facts of the US economy.[20] The typical unemployment duration averaged 20 weeks between 1980 and 2019. This is in line with a constant probability of finding a job of $h(\theta) = 0.985$ in a given year.[21] As in Shimer (2005), I calibrate the vacancy posting cost γ to achieve the constant probabilty $h(\theta)$. I then set the job separation rate χ to 0.0633 as to attain the long-run unemployment rate u of 0.0604 observed between 1980 and 2019.[22] The elasticity μ_l of the matching function with respect to the unemployed is set to 0.72, in line with the estimates of Petrongolo and Pissarides (2001). I then assume the Hosios efficiency condition by setting the unobserved labor union's bargaining power λ_l to the same value, as is typically done in the labor literature. Accordingly, and like in the heterogeneous household model of Krusell et al. (2010), I do not depart from standard labor market parameters.

Household earnings also vary via the idiosyncratic labor endowments $l_j = z(1+\psi)^j$. In a given age cohort, cross-sectional earning variations are dictated by the initial labor endowment levels z. The log of z follows a normal distribution with mean μ_z and standard deviation σ_z. I set $\sigma_z = 0.15$, which is the value reported by Aiyagari (1994) for logged annual hours worked in the *Panel Study of Income Dynamics* (PSID) data.[23] The mean μ_z is then set such that aggregate hours worked $\mathbb{E}[l]$ average to one (see Appendix 3.7.2). In the model, earnings growth over the life cycle for the employed is captured by ψ, the labor endowment annual growth rate. Using US *Census* data, Lagakos et al. (2018) document that household wages increase by a factor of around 1.8 over a 40-year life cycle. In line with this, I set $\psi = 1.8^{\frac{1}{40}} - 1 = 0.0148$.

As for fiscal policy, government spending $G = gY$ represents a typical 20% of output. Social contributions are given by the endogenous tax rate τ whereas social security takes place via the exogenous unemployment subsidy s and retirement endowment p.
A household in age cohort j with an initial endowment z receives a subsidy of $s_j = sl_j$ when unemployed, whereas its net earnings total $w(1-\tau)l_j$ when employed. I set the benefit level to $s = 0.1291$, which corresponds to 25% of the average missed net earnings $w(1-\tau)$. The chosen benefit s is in line with the related literature on monetary policy

[20] The data series used in the text come from the FRED database: unemployment duration (*UEMPMEAN*) and civilian unemployment rate (*UNRATE*).

[21] The corresponding unemployment spell is $4(20/52.1429) = 1.53$ quarters, which is achieved by a constant quarterly probability of $1/1.53 = 0.65$. The probability of *not* having found a job in a given year is thus $(1-0.65)^4 = 0.015$, in turn giving $h(\theta) = 1 - 0.015 = 0.985$.

[22] The long-run unemployment rate is obtained with a somewhat higher separation rate of 0.1 in Shimer (2005), who uses a standard search and matching model with productivity shocks.

[23] The calibrated standard deviation σ_z is not far off from that of real wages. Sonora (2010) reports a standard deviation of 0.1 for logged real wages in a given year in the US.

and household heterogeneity. Kaplan et al. (2018) set an exogenous unemployment benefit as to obtain a corresponding ratio of 50%, whereas Cui and Sterk (2018) target 25%. Both papers are calibrated at a quarterly frequency. Unemployment benefits typically stop after six months in the US. The chosen value for the subsidy s is thus closer to that of Kaplan et al. (2018).
The mandatory pension system gives a household with initial labor endowment z a pension payment of $pz(1+\psi)^{R-1}$. The payment $p = 0.2066$ is calibrated to replicate the net mandatory pension replacement rate of 40% that is observed in the US. In the model, the pre-retirement net earnings of an employed household are given by $w(1-\tau)l_{R-1}$. The pension transfer $p = 0.2066$ implies that $p = 0.40w(1-\tau)\mathbb{E}[l_{R-1}]$. This is consistent with the *Social Security* retirement benefits received in the US by a median worker (Feldstein, 2005).[24] As a result, the asset holdings a_R previously accumulated by a retired household correspond to voluntary privately provisioned pension.

Households can insure against individual unemployment shocks by accumulating asset holdings. As in Kaplan et al. (2018), I set the exogenous borrowing constraint $\underline{a}$ equal to the average annual net labor income.[25] Households can thus borrow up to their average net labor income in a given period. This borrowing channel adds to Cui and Sterk (2018), who assume a strict borrowing limit of zero as to obtain an analytical solution. As in the first chapter of the thesis, excess reserves earn a net rate of $r^m = 0$ so that $r^m < r$. The outside investment option of the bank, $(1-x)r + xr^m$, is accordingly reduced when the central bank purchases government bonds (that is, when $x > 0$).

Finally, I use standard parameter values for preferences and production. The discount factor β corresponds to an annual subjective discount rate of 4.1%, as in Cui and Sterk (2018).[26] The utility function is logarithmic ($\sigma \rightarrow 1$), in line with the estimates provided by Chetty (2006) and as is commonly assumed in the monetary policy literature. The production function uses a capital income share of $\alpha = 0.3$. Physical capital depreciates at a rate of $\delta = 0.0963$, which corresponds to a standard 2.5% at the quarterly frequency.

In the next section, I use the calibrated model to assess the consequences of central bank purchases.

[24] Likewise, the OECD uses both public and private mandatory pension to measure a total net pension replacement rate of 44.8% for an average US earner in 2015 (see OECD, 2015).

[25] While the borrowing constraint is tighter than the natural debt limit in Kaplan et al. (2018), it only binds for 0.02% of the ergodic household distribution.

[26] I obtain a capital to (annual) output ratio of 2.0 absent central bank purchases. The corresponding US ratio averaged 1.9 between 1980 and 2017 (using the net stock of private and government non-residential fixed assets and GDP; FRED series *K1YTOTL1ES000* and *GDPA*, respectively).

Table 3.1: *Parameter values*

Parameter	Value	Description
Labor market:		
γ	0.292	Cost of posting a vacancy
χ	0.0633	Job separation rate
μ_l	0.72	Elasticity of matching function with respect to unemployment
λ_l	$=\mu$	Labor union's bargaining power
Fiscal policy:		
g	0.2	Fraction of output devoted to government spending
s	0.1291	Unemployment subsidy such that $\frac{s}{w(1-\tau)} = 25\%$
p	0.2066	Retirement endowment such that $\frac{p}{w(1-\tau)\mathbb{E}[l_{R-1}]} = 40\%$
Individual labor earnings:		
σ_z	0.15	Standard deviation of the initial labor endowment $\ln(z)$
ψ	0.0148	Earnings' annual growth rate over the life cycle
Financial markets:		
$\underline{a}$	0.5165	Borrowing constraint such that $\frac{\underline{a}}{w(1-\tau)} = 100\%$
r^m	0	Return on excess reserves
Preferences and production:		
β	0.96	Household discount factor
σ	$\rightarrow 1$	Constant relative risk aversion coefficient
α	0.3	Capital income share in production function
δ	0.0963	Depreciation rate of physical capital

Notes: The model is calibrated at the annual frequency. See the main text for explanations.

3.5 Consequences of central bank purchases

I assess the consequences of central bank purchases by comparing the model outcomes for two cases. In the first case, the central bank does not purchase government bonds. The fraction of bonds held by the central bank is thus set to zero ($x = 0$). In the second case, the central bank purchases 10% of the outstanding bond stock ($x = 10\%$) by issuing the corresponding reserves. The cumulative fraction of outstanding long-dated Treasury securities purchased by the Federal Reserve reached 14.4% over its three rounds of quantitative easing (see Section 2.2 in the first chapter). I set an indicative lower $x = 10\%$ as purchases are permanent in the model.[27]

I discuss the equilibrium effects of such purchases and then detail the corresponding distributional consequences. In particular, welfare gains are measured as the difference in certainty equivalents due to the purchases. A household with value function $V_j(e_j, z, a_j)$ is made indifferent when instead receiving the certain consumption level $\bar{c}(e_j, z, a_j)$ over its remaining lifetime:[28]

$$\bar{c}(e_j, z, a_j) = \left(\frac{(1-\beta)(1-\sigma)V_j(e_j, z, a_j)}{1-\beta^{J-j+1}} \right)^{\frac{1}{1-\sigma}} .$$

The corresponding measure of aggregate welfare $\mathbb{W}$ is given by:

$$\mathbb{W} = \sum_{j=1}^{J} \int_z \int_e \int_a \bar{c}(e_j, z, a_j) \; \mathrm{d}a \; \mathrm{d}e \; \mathrm{d}z \; .$$

3.5.1 Equilibrium effects

In the model, central bank purchases generate accommodative equilibrium effects that are consistent with the nascent literature. The aggregate and price effects of the purchases are summarised in Table 3.2.

As is the case for conventional monetary policy in Kaplan et al. (2018), the transmission of central bank purchases is driven by general equilibrium effects. Aggregate demand is mostly affected by the purchases via investment (like in the first chapter of the thesis).

[27] Purchase programmes have remained long-lasting since the financial crisis. In the literature, central bank purchases are typically modelled as very persistent AR(1) processes (see for instance Chen et al., 2012 or Falagiarda, 2014).

[28] Individual certainty equivalents are recovered from the value function:
$V_j(e_j, z, a_j) = \sum_{k=0}^{J-j} \beta^k \frac{\bar{c}(e_j, z, a_j)^{1-\sigma}}{1-\sigma} = \frac{\bar{c}(e_j, z, a_j)^{1-\sigma}}{1-\sigma} \frac{1-\beta^{J-j+1}}{1-\beta} \iff \bar{c}(e_j, z, a_j) = \left(\frac{(1-\beta)(1-\sigma)V_j(e_j, z, a_j)}{1-\beta^{J-j+1}} \right)^{\frac{1}{1-\sigma}} .$

Central bank purchases reduce the outside investment option of the bank, in turn lowering the return on capital. Renting capital is cheaper for the firm and so capital K goes up in equilibrium. By complementarity, this increases the marginal product of labor. The representative firm consequently hires additional households, which lowers the equilibrium unemployment rate u by 3bps. A decrease in the unemployment rate is in line with the available empirical evidence for the US, Euro area and UK (see Montecino and Epstein, 2015, Lenza and Slacalek, 2018 and Bunn et al., 2018, respectively). For a constant separation rate (χ), the fall in unemployment implies that the probability of finding a job $h(\theta)$ increases: it goes up by 0.51 percentage points. Aggregate employment accordingly increases (by 3bps), as it does following open-market operations in Sterk and Tenreyro (2018). Output also increases (by 1.58%) as both input factors go up. Like in Cui and Sterk (2018), a permanent increase in central bank purchases pushes up the earnings of the employed. In the model, the equilibrium net wage $w(1-\tau)$ goes up by 0.31%.[29] Most of the labor market equilibrium change accordingly takes place via the wage, which is perfectly flexible in the model. Lenza and Slacalek (2018) also find empirical evidence of a wage increase after asset purchase programmes in the Euro area.

Importantly, the conditions faced by households are altered. Labor market conditions unambiguously improve: both the probability of finding a job and the net wage increase. The interest rate r modestly decreases (by a mere 0.03bps) in equilibrium. This is in line with event studies, which document that interest rates decrease after purchase programme announcements. The empirically observed fall occurs at high frequencies (see Gagnon et al., 2010) whereas the model is calibrated at the annual frequency. Although small in magnitude, the interest rate movement makes savings relatively less attractive. This effect is nonetheless dominated by the improved labor earnings. As in Cui and Sterk (2018), households hold additional bank deposits; aggregate household wealth (A^h) goes up by 0.65%. Interestingly, central bank purchases modestly encourage households to borrow. The fraction of households with negative wealth increases from 2.72% to 2.76%. As discussed in Subsection 3.5.2, the marginal increase is driven by young unemployed households, who face better employment prospects.

Overall, central bank purchases are welfare-improving in the model. The certainty equivalent measure of aggregate welfare $\mathbb{W}$ goes up by 0.14%. This nevertheless hides tremendeous variations in welfare gains across households. Households differ in several dimensions and are thus affected heterogeneously by the above equilibrium changes; this is discussed in the next subsection.

[29] The tax rate τ endogenously balances the government budget. Absent central bank purchases, the obtained equilibrium tax rate is 0.4356.

Table 3.2: *Equilibrium effects*

Aggregate quantities	$x = 0$	$x = 10\%$	*Difference (%)*
Output (Y)	0.85	0.86	1.58
Capital (K)	1.71	1.80	5.29
Unemployment rate (u, pct)	6.04	6.01	-0.03
Aggregate welfare ($\mathbb{W}$)	0.67	0.67	0.14
Market conditions faced by households			
Probability of finding a job ($h(\theta)$, pct)	98.53	99.04	0.51
Net wage ($w(1-\tau)$)	0.52	0.52	0.31
Interest rate (r, pct)	5.24	5.24	-0.03bps
Asset market			
Household wealth (A^h)	1.67	1.68	0.65
Households with negative wealth (pct)	2.72	2.76	0.04

Notes: Using the parameter values listed in Table 3.1. The table compares two equilibria: one in which the central bank does not hold government bonds ($x = 0$) and one in which it holds a fraction of the outstanding bond stock ($x = 10\%$). The last column shows the resulting differences. When the variable is already expressed as a percentage, the difference is in percentage points.

3.5.2 Distributional effects

I now assess the distributional effects of central bank purchases. In line with recent empirical evidence, the purchases only affect standard inequality measures negligibly according to the model. A different picture emerges when looking at welfare gains: households benefit heterogeneously from the purchases. Unsurprisingly, the largest gains are obtained by households who gain employment because of the purchases. The model nevertheless also reveals tremendeous variations in welfare gains for a given employment path. In particular, the gains decrease with age. Households in the workforce benefit the most via improved employment prospects. The altered equilibrium labor market conditions improve the expectations of both the employed and the unemployed, who consequently experience similar welfare gains. Although by a smaller extent, retired households also benefit from the purchases via the wealth they accumulated.

Inequality measures

Central bank purchases only have a modest effect on the inequality measures typically considered in the literature. Table 3.4 displays summary statistics for the distributions of individual labor income and wealth. The two distributions are overall shifted up as employed households earn more in equilibrium. Measures of dispersion are however little affected.

In the model, the probability of finding a job increases for all households regardless of their labor endowment and age. All of the labor income quantiles reported in Table 3.4 therefore increase by a similar percentage. The Gini coefficient accordingly decreases by a mere 0.02%. In empirical studies, the timid decrease in labor income inequality is driven by a higher proportion of lower earners who enter employment. As was discussed in Section 3.2, this extensive margin channel is documented for several countries.[30] The channel also operates in the model. Indeed, the increased net wage $w(1-\tau)$ exacerbates the dispersion of labor income as the unemployed still earn the same subsidy (conditional on age and initial labor endowment). In the table, the standard deviation of labor income accordingly goes up. Despite this, the slightly higher probability of finding a job $h(\theta)$ manages to bring down the Gini coefficient.
As seen in Table 3.4, the dispersion of individual wealth is only mildly amplified by central bank purchases. Although higher quantiles increase by relatively more, the Gini

[30] That was the case for the US (Montecino and Epstein, 2015), the Euro area (Lenza and Slacalek, 2018, and Casiraghi et al., 2018 for Italy in particular) and the UK (Bunn et al., 2018).

coefficient goes up by just 0.06%. The small increase in wealth inequality reflects the mildly widening gap between the earnings of the employed and the unemployed. That is, employed households accumulate relatively more wealth via the higher net wage.[31]
The consumption smoothing motive implies that central bank purchases have also little effect on the distribution of individual consumption. In line with this, Appendix 3.7.6 shows that the distribution shifts up and that its standard deviation remains unchanged.

While the overall dispersion of observables is only modestly affected, there is large heterogeneity in the underlying welfare gains. In the next subsections, I distinguish gains at the extensive and intensive margins.

Table 3.3: *Distributional effects: summary statistics*

Labor income	$x = 0$	$x = 10\%$	*Difference (%)*
First quantile (25pct)	0.39	0.40	0.13
Median	0.48	0.48	0.15
Mean	0.47	0.47	0.15
Third quantile (75pct)	0.57	0.57	0.17
Standard deviation	0.14	0.14	0.04
Gini coefficient	0.34	0.34	-0.02
Household wealth	$x = 0$	$x = 10\%$	*Difference (%)*
First quantile (25pct)	0.42	0.42	-0.07
Median	1.36	1.37	0.57
Mean	1.67	1.68	0.65
Third quantile (75pct)	2.77	2.78	1.30
Standard deviation	1.39	1.40	0.61
Gini coefficient*	0.94	0.94	0.06

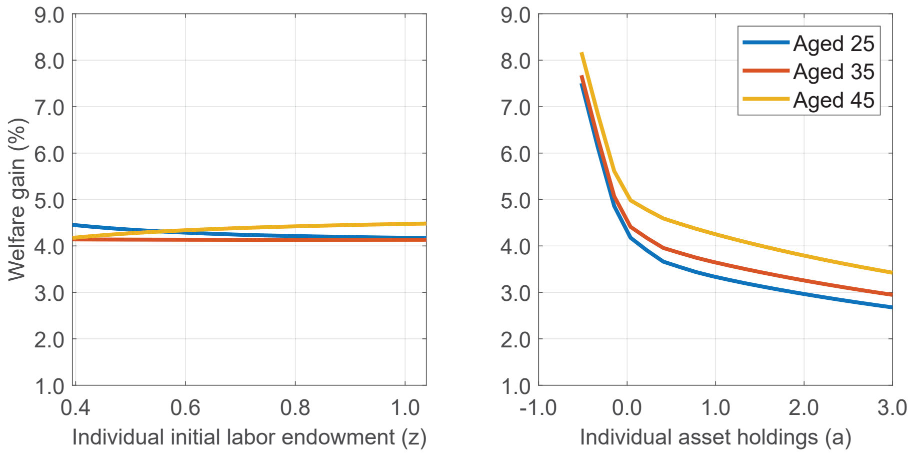
Notes: See the note in Table 3.2. Labor income measures use households in the workforce. *Gini coefficients can be larger than one for variables which admit negative values.

[31] In Lenza and Slacalek (2018), wealth inequality is somewhat reduced as central bank purchases increase the value of housing equity (which is more evenly owned by households than other assets).

Extensive margin welfare gains

The largest welfare gains are obtained by the few households who become employed as a result of central bank purchases. Table 3.2 showed that the unemployment rate decreases by 3bps when the central bank holds 10% of the bond stock. An additional 0.03% of the workforce accordingly becomes employed, in turn benefitting from higher current and expected incomes. The corresponding *extensive margin* welfare gains are shown in Figure 3.3. The figure plots the gains against individual household characteristics (namely labor endowment, age and asset holdings). Naturally, switching employment status largely improves welfare: the certainty equivalent gain obtained by a typical household is around 4%. The model thus provides support to the distributional role of the employment channel that is documented in empirical work.

Interestingly, households with different individual characteristics evenly benefit from entering employment. Because unemployment benefits are proportional to foregone earnings, labor income increases by the same proportion when becoming employed regardless of the endowment. As shown in the left panel of the figure, the gains are thus almost invariant to the individual initial labor endowment. Likewise, the gains of a given individual are similar across age groups. By contrast, the right panel of the figure shows that household wealth drives the obtained gains. Wealth is used as a cushion against individual unemployment shocks. Wealthy households are accordingly less sensitive to the employment status, whereas households with little wealth benefit the most from entering employment.



Notes: Using the parameter values listed in Table 3.1. Welfare gains are measured as certainty equivalent differences (see main text) between an unemployed household when $x = 0$ and an employed household when $x = 10\%$. The left panel uses the age's respective average asset holdings. The right panel uses the average initial labor endowment $\bar{z}$.

Figure 3.3: *Individual welfare gains obtained when becoming employed*

Intensive margin welfare gains

Because individual welfare largely depends on the employment status, the rest of the text assesses welfare changes for *given* employment paths.[32] While welfare gains differ over the life cycle, I find negligible distributional effects between the employed and the unemployed as well as across heterogeneous earnings. The dispersion in welfare gains is instead driven by the timing of unemployment shocks.

Welfare gains over the life cycle – Variations in individual welfare gains are largely determined by the life cycle. Figure 3.4 summarizes the age-dependent distributions of the gains by showing boxplots. The median gain (in red) is surrounded by the corresponding inter-quartile range (in blue) and the dotted lines stretch to the respective extrema. Welfare gains overall decrease with age. Younger households (aged 25-44) tend to get the largest gains whereas the lowest gains are obtained by retired households (aged 65 and more). Interestingly, this effect is consistent with that of conventional monetary policy. In the overlapping generations model of Sterk and Tenreyro (2018), standard monetary policy benefits the most to the young, who experience higher consumption growth.[33] Panel (a) also shows that the dispersion of the gains increases with age. The gains of the retired are the least evenly distributed. As seen in panel (b), the inter-quartile range of retired households is twice as large than that of relatively younger households. This is further discussed later in the text.

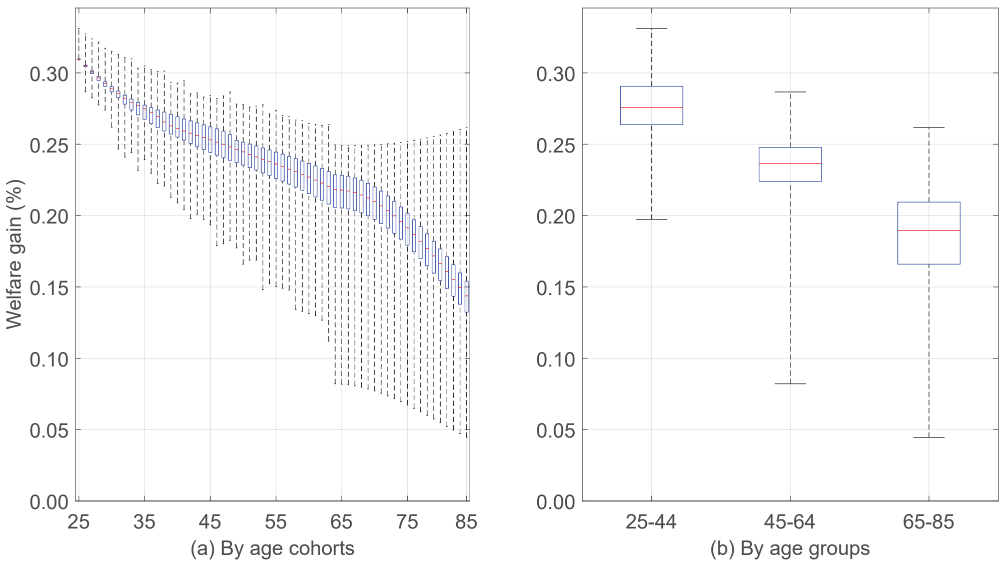
The overall decrease in gains over the life cycle is due to the exposure of households to market conditions. Younger households are part of the workforce and face an individual unemployment risk. Their welfare gains are accordingly driven by the improved labor market conditions that result from central bank purchases. By contrast, retired households rely entirely on (exogenous) mandatory and (endogenous) voluntary pension. Their welfare gains hence depend on the wealth they accumulated.

To see this, Figure 3.5 decomposes the welfare gains experienced by two given households over the life cycle. The household shown in the left panel is always employed whereas that in the right panel is unemployed in the first year of its life. The figure shows how the equilibrium changes induced by the purchases contribute to the total change in individual welfare.

In younger years, welfare gains are entirely driven by the improved labor market conditions. Most of the gains come from the higher net wage $w(1-\tau)$. The increased probability of finding a job $h(\theta)$ also improves current welfare as it makes future

[32] In particular, the figures use the simulated employment paths absent central bank purchases ($x = 0$).

[33] Like in my setting, Sterk and Tenreyro (2018) do not model inflation.

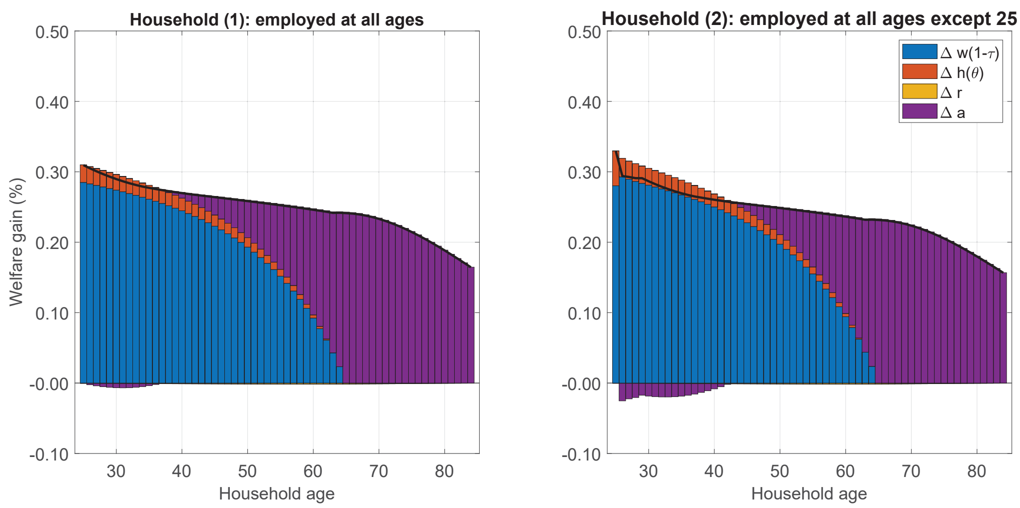


Notes: Using the parameter values listed in Table 3.1. Welfare gains are measured as the % difference in certainty equivalents obtained when the central bank holds $x = 10\%$ of the outstanding government bond stock (see main text). The charts show boxplots that summarize the welfare gains' distribution of each age cohort/group. Boxes show the interquartile ranges surrounding the corresponding medians. Dotted lines stretch to the respective extrema.

Figure 3.4: *Distributions of welfare gains over the life cycle*

unemployment spells less likely to last. Because it can be saved and thus earns interest, the higher net wage in early years is worth more than in later years. Accordingly, the contribution of improved labor market conditions to welfare gradually declines as households age; the direct beneficial effect stops when households retire (at age 65). The reduced contribution is nonetheless increasingly replaced by that of the additional accumulated wealth. Households smooth consumption over time and hence save some of the additional labor income that is due to central bank purchases. After retirement, welfare remains higher than absent central bank purchases thanks to the extra accumulated wealth, which the household then consumes until it exits.

In line with what Kaplan et al. (2018) find for conventional monetary policy, central bank purchases impact households via general equilibrium effects in the presence of heterogeneity. In my model, the welfare gains of the purchases are mostly driven via the equilibrium changes generated in the labor market. By contrast, the interest rate plays a trivial role. Although barely visible on the chart, the somewhat lower interest rate is detrimental as households are overall net savers over their lifetimes.



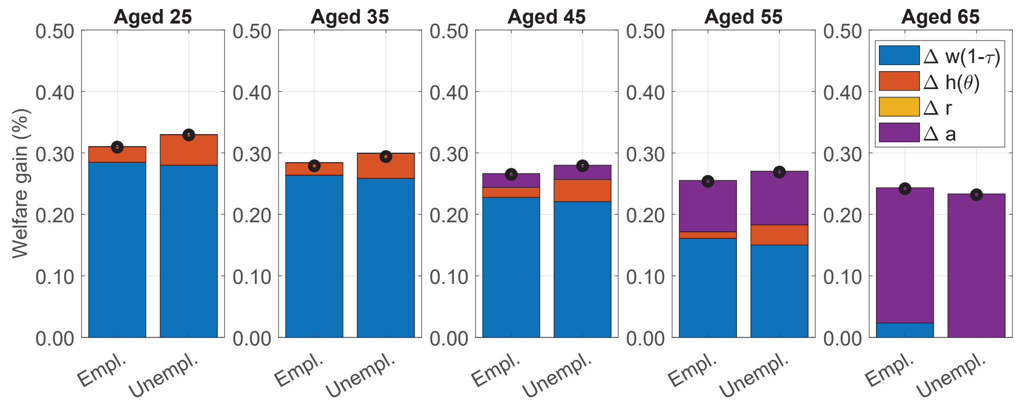
Notes: Using the parameter values listed in Table 3.1. Welfare changes are measured as the % difference in certainty equivalents obtained by a household (with average initial labor endowment $\bar{z}$) when the central bank holds $x = 10\%$ of the outstanding government bond stock (see main text). Black lines show the overall welfare gains. Household (2) is unemployed when aged 25.

Figure 3.5: *Decomposition of welfare gains over the life cycle*

Employment status channel – Importantly, the improved labor market conditions benefit to both the employed and the unemployed. The right panel in Figure 3.5 shows the gains of a particular household who only faced unemployment in one period (when aged 25). How the employment status affects welfare gains at different ages is shown in Figure 3.6. When unemployed, a household receives a (lower) subsidy instead of the market wage. Regardless of age, the contribution of the net wage to welfare remains almost as large than for an employed household. This is because future *expected* labor incomes are improved regardless of the current employment status. That is, the workforce's welfare gains are almost entirely transmitted via expectations. This conditional expectation channel is not explicit in the pioneering work of Cui and Sterk (2018), in which welfare is measured from a timeless perspective.[34]

Interestingly, the improved expectations reveal that the currently unemployed benefit relatively more from central bank purchases. The slightly lower effect of the net wage is more than compensated by the increased probability of finding a job, which matters more directly for the unemployed. The figure shows that this effect prevails at all ages until the year preceding retirement.[35]

Because of the improved job market prospects, the unemployed use relatively more of their wealth to absorb the current unemployment shock. The lessened wealth is subsequently carried on, in turn reducing welfare in the periods *following* unemployment. In the right panel in Figure 3.5, this jeopardizing persistent effect remains modest. As discussed below, this is because the unemployment spell happens at a young age.



Notes: See the note in Figure 3.5. Households are only unemployed at the age shown in the graphs. Black dots show the total welfare gains.

Figure 3.6: *Decomposition of welfare gains by employment status*

Timing of unemployment shocks – It turns out that the response of wealth to unemployment shocks has important implications for the ability of households to smooth the gains induced by central bank purchases. In contrast to younger households, the

[34]As a result, central bank purchases do not increase the dispersion of individual welfare as much as in Cui and Sterk (2018).

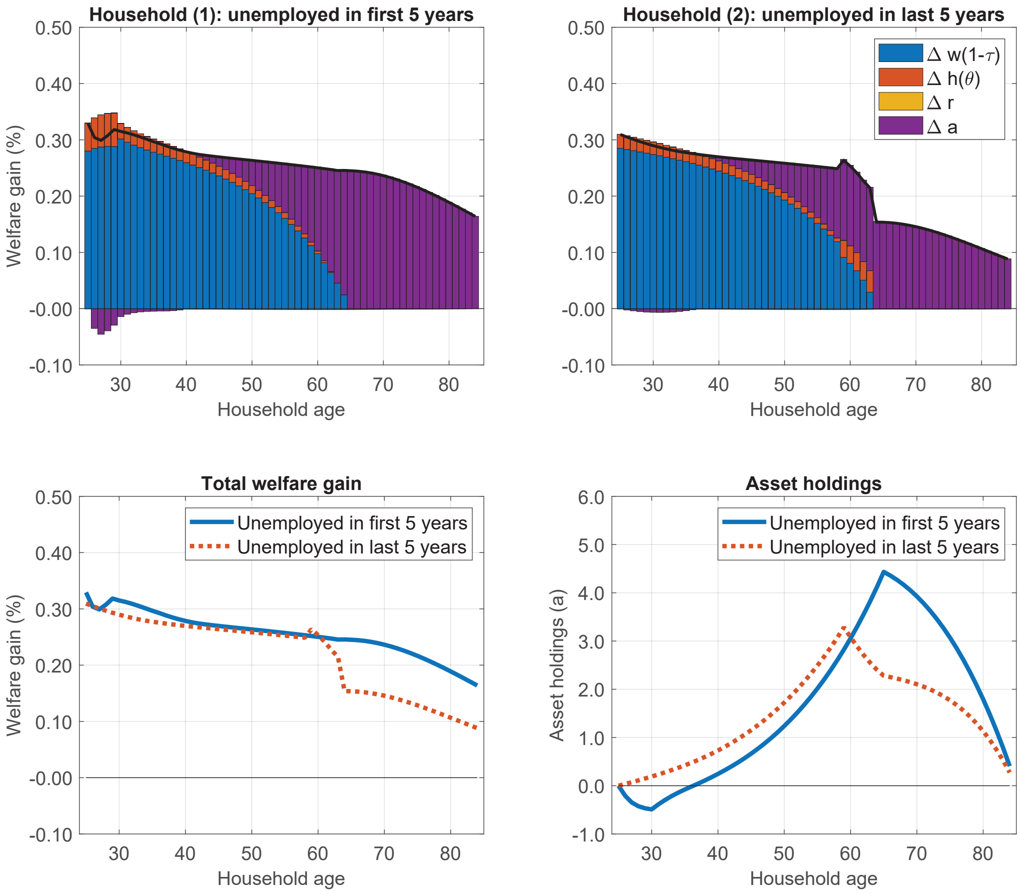
[35]Future labor market conditions become irrelevant for households aged 64 as they retire in the next period.

welfare gains of middle-aged and retired households are much more sensitive to the individual wealth position. The gains of older households rely on the wealth they accumulated, which in turn depends on *when* unemployment shocks occured in their lifetimes.
This is illustrated in Figure 3.7, which compares the welfare gains and asset holdings of two households who face an unemployment spell at different stages of the life cycle. Both households use their wealth to absorb the unemployment shock. The household who is unemployed in earlier years borrows relatively more than absent central bank purchases; this explains the higher fraction of households with negative wealth that was shown in Table 3.2. The welfare gain is somewhat dragged down by the extra borrowing, yet the household manages to rebuild wealth prior to retirement. Some of the additional labor income generated by central bank purchases can thus be transferred over time, in turn improving welfare in later years. By contrast, being unemployed closer to retirement does not leave sufficient time to re-accumulate wealth; the subsequent welfare gains are substantially reduced. In the figure, the gains obtained at retirement drop to 0.15%. This is much lower than the 0.25% achieved when unemployment happens in earlier years. The drag on welfare is then permanent; it lasts until the exit year.

The distributional welfare effects of central bank purchases are therefore increasingly driven by the individual employment path over the life cycle. The past employment statuses of a household are summarized by the individual wealth state in the model. This explains the positive correlations between welfare gains and wealth that were pictured in the introduction for given age groups. The variance of wealth is larger in older age cohorts (see Figure 3.9 in Appendix 3.7.6), whose members faced unemployment shocks at varying stages of the life cycle. The welfare gains of older households are thus less evenly distributed compared to those of the young, as was shown in Figure 3.1.

Earnings heterogeneity channel – In the model, central bank purchases benefit evenly the employed regardless of their earnings. Earnings inequality is accounted for via the initial labor endowment z, which acts like an idiosyncratic measure of innate ability.[36]
Employed households receive the same hourly net wage $w(1-\tau)$ regardless of how much labor $l_j = z(1+\psi)^j$ they provide. Central bank purchases thus increase the labor income of the employed, $l_j w(1-\tau)$, by the same proportion. Because the utility function is concave, a household with a relatively lower inital endowment obtains higher gains. Nonetheless, I find that this effect is quantitatively negligible: conditional on age, welfare gains are similar across labor endowments. This can be seen in Figure 3.8, which compares the

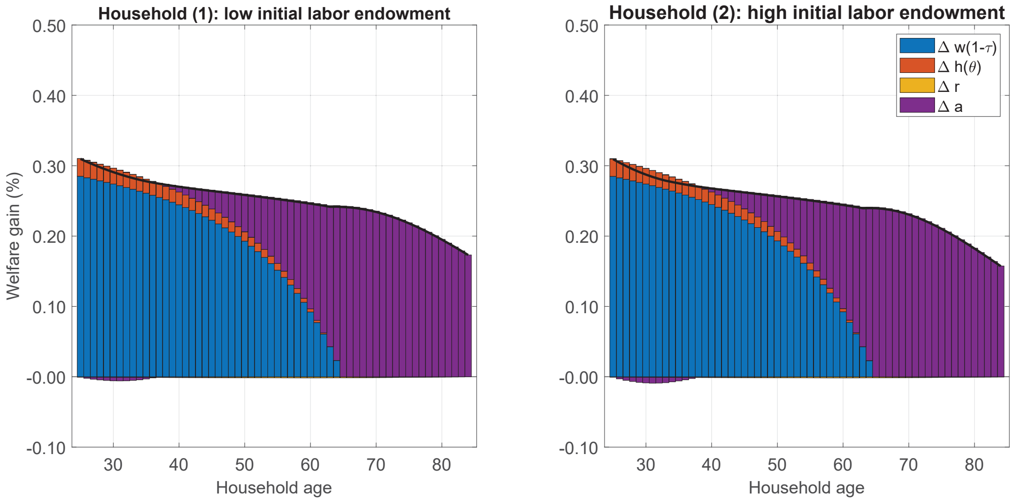
[36] Keane and Wolpin (1997) use a dynamic model to show that skill heterogeneity at schooling age contributes largely to variations in lifetime welfare across men in the US. Figure 3.10 in Appendix 3.7.6 shows that the dispersion of individual welfare *levels* likewise largely depends on the initial labor endowment z.



Notes: See the note in Figure 3.5.

Figure 3.7: *Effect of unemployment timing on welfare gains*

gains for two households with different initial labor endowments. In line with this, the simulated welfare gains and initial labor endowments display a low correlation coefficient of 0.057; the corresponding scatter plot is shown in Figure 3.11 in Appendix 3.7.6.



Notes: See the note in Figure 3.5. Households (1) and (2) are always employed and have initial endowments $z(1) = e^{\mu_z - \sigma_z}$ and $z(2) = e^{\mu_z + \sigma_z}$, respectively.

Figure 3.8: *Decomposition of welfare gains for different initial labor endowments*

3.6 Conclusion

This paper investigated the distributional consequences of central bank purchases through changes in the borrowing rate of firms, and consequently in labor market conditions, by using a general equilibrium model with heterogeneous households. Purchases generate accommodative equilibrum changes in the model. Notably, labor market conditions are improved. The unemployment rate decreases due to an increase in the probability of finding a job. Likewise, the earnings of the employed go up.

Although purchases have little effect on the inequality measures that are typically reported in the literature, the welfare gains that are correspondingly experienced by households vary considerably. The largest gains are obtained via an extensive margin channel; that is, households who become employed because of the central bank purchases. Welfare gains also differ across households for given employment paths. Overall, these intensive margin gains depend on the position in the life cycle; the gains decrease with age. Younger households benefit the most from the purchases as their expected lifetime earnings improve. In particular, these improved conditions mostly contribute to the gains via expectations. As a result, households experience similar gains regardless of their current employment status and initial ability. Households who manage to save some of the additional labor income generated by central bank purchases also benefit in later years. By contrast, those who decumulate their wealth closer to retirement cannot smooth the obtained gains going forward. This is the case for households who face unemployment spells at the end of their worklife.

These results show that central bank purchases have intricate welfare distributional consequences that are hard to observe in the data. Accordingly, the paper contributes to both the literature on unconventional monetary policy and the ongoing debate on economic redistribution.

3.7 Appendix

3.7.1 Derivations: household problems

Households in the workforce – The recursive Lagrangian of a household aged $j < R$ is:

$$\mathcal{L}_j(e_j, z, a_j) = \max_{\{a_{j+1}\}} \quad : \quad \left\{ \frac{c_j^{1-\sigma}}{1-\sigma} + \mu_j(a_{j+1} + \underline{a}) + \beta \mathbb{E}\Big[\mathcal{L}_{j+1}(e_{j+1}, z, a_{j+1}) \;\Big|\; e_j\Big] \right\}$$
$$\text{s.t.} \quad : \quad c_j = l_j\big(e_j w(1-\tau) + (1-e_j)s\big) + (1+r)a_j - a_{j+1} \; .$$

The first-order conditions are given by:

$$0 = \frac{\partial \mathcal{L}_j(e_j, z, a_j)}{\partial a_{j+1}} = -c_j^{-\sigma} + \mu_j + \beta \mathbb{E}\left[\frac{\partial \mathcal{L}_{j+1}(e_{j+1}, z, a_{j+1})}{\partial a_{j+1}} \;\middle|\; e_j\right] \tag{3.12}$$
$$a_{j+1} + \underline{a} \geq 0 \quad , \quad \mu_j \geq 0 \quad , \quad \mu_j(a_{j+1} + \underline{a}) = 0 \; ,$$

together with the budget constraint. The Envelope theorem gives:

$$\frac{\partial \mathcal{L}_{j+1}(e_{j+1}, z, a_{j+1})}{\partial a_{j+1}} = (1+r)c_{j+1}^{-\sigma} + \frac{\partial a_{j+2}}{\partial a_{j+1}}\left(\mu_{j+1} + \mathbb{E}\left[\beta \frac{\partial \mathcal{L}_{j+2}(e_{j+2}, z, a_{j+2})}{\partial a_{j+1}} \;\middle|\; e_{j+1}\right]\right) = (1+r)c_{j+1}^{-\sigma}$$
$$\implies \frac{\partial \mathcal{L}_{j+1}(e_{j+1}, z, a_{j+1})}{\partial a_{j+1}} = (1+r){c_{j+1}}^{-\sigma}. \tag{3.13}$$

Inserting equation (3.13) into equation (3.12) gives the Euler equation of a household in the workforce:

$$c_j^{-\sigma} = \beta(1+r)\mathbb{E}\big[{c_{j+1}}^{-\sigma} \;\big|\; e_j\big] + \mu_j \; .$$

Retired households – It turns out that the borrowing constraint never binds for retired households in equilibrium. This is because the pension payment is constant and the equilibrium rate r is higher than the discount rate $1/\beta - 1$. As shown below, the consumption of the retired accordingly grows by a strictly positive rate across any two adjacent periods, which is in turn only feasible when the borrowing constraint does not bind after having retired.

The Euler equation for retired households is:

$$c_j^{-\sigma} = \beta(1+r)c_{j+1}^{-\sigma} + \mu_j$$
$$\iff \left(\frac{c_{j+1}}{c_j}\right)^{-\sigma} = \frac{1}{\beta(1+r)}\left(1 - \frac{\mu_j}{c_j^{-\sigma}}\right)$$

$$\iff \frac{c_{j+1}}{c_j} = \left(\frac{\beta(1+r)}{1-\mu_j c_j^\sigma}\right)^{\frac{1}{\sigma}} .$$

It follows that $\frac{c_{j+1}}{c_j} > 1$ when $\beta(1+r) > 1 - \mu_j c_j^\sigma$. This is the case in equilibrium. Tables 3.1 and 3.2 show that $\beta(1+r) > 1$. In addition, $0 < 1 - \mu_j c_j^\sigma \leq 1$. This is because $\mu_j c_j^\sigma \geq 0$ as $\mu_j \geq 0$ and $c_j > 0$ (from the Inada conditions of the utility function). Likewise, consumption is weakly positive when $\mu_j c_j^\sigma < 1$ (otherwise the ratio $\frac{c_{j+1}}{c_j}$ would be negative). Therefore, $0 < 1 - \mu_j c_j^\sigma \leq 1$.

The growing consumption profile $\frac{c_{j+1}}{c_j} > 1$ is only consistent with never being at the borrowing constraint after having retired. This is shown by contradiction.

Suppose that a household aged $j \geq R$ and with any inherited holdings a_j chooses $a_{j+1} = -\underline{a}$. The household then consumes:

$$c_j = a_j(1+r) + pz(1+\psi)^{R-1} + \underline{a}$$
$$c_{j+1} = -\underline{a}(1+r) + pz(1+\psi)^{R-1} - a_{j+2} .$$

From above, $c_{j+1} > c_j$, so that:

$$-\underline{a}(1+r) + pz(1+\psi)^{R-1} - a_{j+2} > a_j(1+r) + pz(1+\psi)^{R-1} + \underline{a}$$
$$\iff a_{j+2} < -\underline{a}(2+r) - a_j(1+r) .$$

Now, the borrowing constraint $a_j \geq -\underline{a}$ can be rewritten as $a_j = -\underline{a} + \varepsilon$ with $\varepsilon \geq 0$. Inserting this into the above expression gives:

$$a_{j+2} < -\underline{a} - \varepsilon(1+r) ,$$

which is a contradiction as $a_{j+2} \geq -\underline{a}$ must hold. Therefore, $a_{j+1} > -\underline{a}$ and $\mu_j = 0$ for $j \geq R$. That is, the borrowing constraint never binds after having retired. This also includes the first period of retirement ($j = R$) with inherited holdings of $a_R = -\underline{a}$.

The analytical solution for the retired problem can then be derived. Re-arranging the budget constraint of a household who just retired ($j = R$) gives:

$$\begin{aligned} a_R &= \frac{c_R - pz(1+\psi)^{R-1}}{1+r} + \frac{c_{R+1} - pz(1+\psi)^{R-1}}{(1+r)^2} + \frac{c_{R+2} - pz(1+\psi)^{R-1}}{(1+r)^3} + .. \\ &= \left(\frac{1}{1+r}\right) \sum_{k=0}^{J-R} \left(\frac{1}{1+r}\right)^k \left(c_{R+k} - pz(1+\psi)^{R-1}\right) \\ \iff a_R + pz(1+\psi)^{R-1}&\left(\frac{1}{1+r}\right) \sum_{k=0}^{J-R} \left(\frac{1}{1+r}\right)^k = \left(\frac{1}{1+r}\right) \sum_{k=0}^{J-R} \left(\frac{1}{1+r}\right)^k c_{R+k} \end{aligned}$$

The first-order condition with respect to asset holdings is:

$$
\begin{aligned}
c_{R+k-1}^{-\sigma} &= \beta(1+r)c_{R+k}^{-\sigma} \\
\iff c_{R+k} &= \big(\beta(1+r)\big)^{\frac{k}{\sigma}} c_R \quad , \quad k = \big\{1, ..., J-R\big\} \ .
\end{aligned}
$$

Inserting this into the consolidated budget constraint yields:

$$
\begin{aligned}
& a_R + pz(1+\psi)^{R-1}\Big(\frac{1}{1+r}\Big)\sum_{k=0}^{J-R}\Big(\frac{1}{1+r}\Big)^k = \Big(\frac{1}{1+r}\Big)\sum_{k=1}^{J-R}\Big(\frac{1}{1+r}\Big)^k \big(\beta(1+r)\big)^{\frac{k}{\sigma}} c_R + \Big(\frac{1}{1+r}\Big)c_R \\
\iff & c_R = \Bigg[a_R + pz(1+\psi)^{R-1}\Big(\frac{1}{1+r}\Big)\sum_{k=0}^{J-R}\Big(\frac{1}{1+r}\Big)^k\Bigg]\Bigg[\Big(\frac{1}{1+r}\Big) + \Big(\frac{1}{1+r}\Big)\sum_{k=1}^{J-R}\Big(\frac{1}{1+r}\Big)^k\Big(\beta(1+r)\Big)^{\frac{k}{\sigma}}\Bigg]^{-1} \ .
\end{aligned}
$$

3.7.2 Derivations: labor market

Aggregate labor – An employed household provides its individual labor endowment $l_j = z(1+\psi)^j$. Households are randomly matched on the labor market across age cohorts. Each age cohort that works makes up a proportion $\frac{1}{R-1}$ of the workforce. The initial endowments are independent and identically distributed. By the law of large numbers, aggregate labor is thus given by:

$$
\begin{aligned}
N\mathbb{E}[l] &= N\sum_{j=1}^{R-1}\Big(\frac{1}{R-1}\Big)\mathbb{E}[l_j] \\
&= N\sum_{j=1}^{R-1}\Big(\frac{1}{R-1}\Big)(1+\psi)^j\mathbb{E}[z] \\
&= N\sum_{j=1}^{R-1}\Big(\frac{1}{R-1}\Big)(1+\psi)^j e^{\left(\mu_z+\frac{\sigma_z^2}{2}\right)} \ ,
\end{aligned}
$$

where the last line uses the properties of the log-normal distribution as $\ln(z) \sim \mathcal{N}(\mu_z, \sigma_z^2)$. Aggregate labor is equal to aggregate employment when:

$$
\begin{aligned}
\mathbb{E}[l] = \sum_{j=1}^{R-1}\Big(\frac{1}{R-1}\Big)(1+\psi)^j e^{\left(\mu_z+\frac{\sigma_z^2}{2}\right)} &= 1 \\
\iff \ln\Bigg[\sum_{j=1}^{R-1}\Big(\frac{1}{R-1}\Big)(1+\psi)^j\Bigg] + \mu_z + \frac{\sigma_z^2}{2} &= 0 \\
\iff \mu_z = -\ln\Bigg[\sum_{j=1}^{R-1}\Big(\frac{1}{R-1}\Big)(1+\psi)^j\Bigg] - \frac{\sigma_z^2}{2} & \ .
\end{aligned}
$$

The corresponding average initial labor endowment is then given by $\bar{z} = \mathbb{E}[l] = e^{\left(\mu_z + \frac{\sigma_z^2}{2}\right)}$.

Recruiters – Denote the Lagrange multiplier associated to the law of motion for aggregate labor by λ_r. The recursive Lagrangian of the representative recruiter is given by:

$$\mathcal{L}_r(N,\theta) = \max_{\{V,N'\}} \; : \; \left\{ (w^f - w)N - \gamma V + \lambda_r\big((1-\chi)N + f(\theta)V - N'\big) + \mathbb{E}\big[\beta \mathcal{L}_r(N',\theta')\big] \right\} .$$

The first-order conditions with respect to V and N' are, respectively:

$$\begin{aligned}
\lambda_r &= \frac{\gamma}{f(\theta)} \\
\lambda_r &= \mathbb{E}\left[\beta\left(w_f' - w' + \frac{(1-\chi)\gamma}{f(\theta')}\right)\right] .
\end{aligned}$$

Taken together:

$$\gamma = f(\theta)\mathbb{E}\left[\beta\left(w_f' - w' + \frac{(1-\chi)\gamma}{f(\theta')}\right)\right] .$$

Nash bargaining – The representative recruiter and the union choose the wage w that maximizes the total net surplus of a successful match:

$$\max_{\{w\}} \; : \; S_l = \big(V_e - V_u\big)^{\lambda_l}\big(J_m - J_v\big)^{1-\lambda_l} .$$

The first-order condition with respect to w gives the well-known constant sharing rule:

$$\lambda_l\big(J_m - J_v\big) = (1-\lambda_l)\big(V_e - V_u\big) .$$

Inserting it in the union's net surplus $(V_e - V_u)$ yields:

$$\begin{aligned}
V_e - V_u &= w - s + \big(1 - \chi - h(\theta)\big)\mathbb{E}\big[\beta\big(V_e' - V_u'\big)\big] \\
&= w - s + \big(1 - \chi - h(\theta)\big)\frac{\lambda_l}{1-\lambda_l}\mathbb{E}\big[\beta\big(J_m' - J_v'\big)\big] \\
&= w - s + \big(1 - \chi - h(\theta)\big)\frac{\lambda_l}{1-\lambda_l}\frac{\gamma}{f(\theta)} ,
\end{aligned}$$

where the last line uses the first-order condition of the recruiter and the fact that the union and the recruiter use the same discount factor β. Perfect competition in vacancy-posting implies that $J_v = 0$ in equilibrium. Inserting this and the definition of $J_m - J_v = J_m$ into the sharing rule then gives:

$$\begin{aligned}\lambda_l\left(w^f - w + \frac{(1-\chi)\gamma}{f(\theta)}\right) &= (1-\lambda_l)\left(w - s + \big(1-\chi-h(\theta)\big)\frac{\lambda_l}{1-\lambda_l}\frac{\gamma}{f(\theta)}\right)\\ \iff \lambda_l\big(w^f - w\big) &= (1-\lambda_l)(w-s) - \lambda_l\frac{h(\theta)\gamma}{f(\theta)}\\ \iff w &= \lambda_l\big(w^f + \gamma\theta\big) + (1-\lambda_l)s\ ,\end{aligned}$$

where the last line uses $\theta = \frac{h(\theta)}{f(\theta)}$ as the matching function has constant returns to scale.

3.7.3 Derivations: corporate credit market

Alternative bargaining – In the text, the firm and the bank bargain over the total net surplus made from renting a *unit* of capital. I show that the resulting rate r^k and capital level K are the same when the agents instead bargain over the total net surplus made from renting the *total* level of capital K.

The amount of labor N chosen by the firm affects the marginal product of capital and hence its capital rental decision. The firm's net surplus is thus given by $\widetilde{S}^f = K^\alpha N^{1-\alpha} - w^f N - (r^k+\delta)K = \alpha K^\alpha N^{1-\alpha} - (r^k+\delta)K$ as the first-order condition for labor is $w^f = (1-\alpha)K^\alpha N^{-\alpha}$. The bank net surplus is given by $\widetilde{S}^b = (r^k - \bar{x})K$. The total net surplus becomes:

$$\begin{aligned}\widetilde{S}^c &= \big(\widetilde{S}^b\big)^{\lambda_b}\big(\widetilde{S}^f\big)^{1-\lambda_b}\\ &= K\left(r^k - \bar{x}\right)^{\lambda_b}\left(\alpha K^{\alpha-1}N^{1-\alpha} - (r^k+\delta)\right)^{1-\lambda_b}\ .\end{aligned}$$

Maximizing $\widetilde{S}^c$ with respect to r^k then gives the same solution than in the text.

3.7.4 Derivations: resource constraint

The profits of the bank, the central bank and the recruiter are rebated to the government as it owns all of the respective shares. The government budget constraint is:

$$\tau w N + (1+r)K + B' + \Pi = (1+r)B + gY + sU + p\left(1 - \frac{R-1}{J}\right)\mathbb{E}[z](1+\psi)^{R-1} + K'\ ,$$

in which the profits are given by:

$$\begin{aligned}
\Pi^b &= r^k K + rB^b + r^m M - r(A^h + A^g) \\
&= (r^k - r)K + (r^m - r)xB \\
\Pi^{cb} &= rxB - r^m M \\
&= (r - r^m)xB \\
\Pi^r &= (w^f - w)N - \gamma V \\
\Longrightarrow \Pi &= \Pi^b + \Pi^{cb} + \Pi^r \\
&= (w^f - w)N - \gamma V + (r^k - r)K \ .
\end{aligned}$$

The government budget constraint thus reads:

$$\tau wN + (1 + r^k)K + B' + (w^f - w)N - \gamma V = (1 + r)B + gY + sU + p\left(1 - \frac{R-1}{J}\right)\mathbb{E}[z](1 + \psi)^{R-1} + K' \ .$$

Absent aggregate risk, it becomes:

$$\tau wN + r^k K + (w^f - w)N - \gamma V = rB + gY + sU + p\left(1 - \frac{R-1}{J}\right)\mathbb{E}[z](1 + \psi)^{R-1} \ . \tag{3.14}$$

Total household assets (A^h) are also constant over time. Aggregating the household budget constraints across age groups yields:

$$w(1 - \tau)N + sU + p\left(1 - \frac{R-1}{J}\right)\mathbb{E}[z](1 + \psi)^{R-1} + rA^h = C \ ,$$

where C denotes aggregate consumption. Using τwN to insert the government budget constraint, equation (3.14), together with the market clearing condition $A^h = B$, gives:

$$\begin{aligned}
w^f N + r^k K - \gamma V - gY &= C \\
\Longleftrightarrow (1 - g)K^\alpha N^{1-\alpha} &= C + \delta K + \gamma V \ ,
\end{aligned}$$

where the last line uses the firm's first-order conditions $r^k = \alpha K^{\alpha-1} N^{1-\alpha} - \delta$ and $w^f = (1 - \alpha)K^\alpha N^{-\alpha}$ as well as the Euler theorem.

3.7.5 Solution method

The individual household problem is solved for given prices. A bisection then updates the interest rate r, and hence the remaining equilibrium prices, until the resulting aggregate quantities coincide with those of the individual household decisions. Define initial bounds r_{low} and r_{high}, and start from an initial guess for the interest rate $r_q = \frac{r_{low}+r_{high}}{2}$, together with an initial guess for aggregate household assets A^h_q.[37] The model is solved by looping over the following steps:

(a) Set $r = r_q$ and $A^h = A^h_q$. Given r and A^h, the variables $\{\theta, N, K, w\}$ can be retrieved from the system of equations:

$$\begin{aligned} N &= \frac{f(\theta)V}{\chi} \\ w &= (1-\alpha)K^{\alpha}N^{-\alpha} - \frac{\gamma}{f(\theta)}\big(1/\beta - 1 + \chi\big) \\ w &= \lambda_l\big((1-\alpha)K^{\alpha}N^{-\alpha} + \gamma\theta\big) + (1-\lambda_l)s \\ \alpha K^{\alpha-1}N^{1-\alpha} - \delta &= r + x(r^m - r) \ . \end{aligned}$$

The corresponding tax rate τ is then recovered from the government budget constraint, equation (3.14), using $A^h_q = B$.[38]

(b) The individual household problem is solved for the given prices $\{w, \tau, r\}$ and probability $h(\theta)$. Define grids over individual labor endowments $\mathcal{Z} = \{z_1, z_2, ..., z_m\}$, asset holdings $\mathcal{A} = \{-\underline{a}, a_2, ..., a_n\}$ and employment statuses $\mathcal{E} = \{0, 1\}$, which imply a total of $\Omega = \{\mathcal{Z} \otimes \mathcal{A} \otimes \mathcal{E}\}$ collocation points.

The consumption solution in the last period is given by $c_J(e_J, z, a_J) = c_J(z, a_J) = (1+r)a_J + pz(1+\psi)^{R-1}$ as $a_{J+1} = 0$. The consumption solution for earlier years is then obtained by backward induction. Define individual net non-wealth income by y_j. A retired household has $y_j = pz(1+\psi)^{R-1}$ whereas a household in the workforce has $y_j = l_j\big(e_j w(1-\tau) + (1-e_j)s\big)$. Start with age cohort $j = J-1$. For each grid point in Ω, recover via a solver the end-of-period asset holdings $a_{j+1}(e_j, z, a_j)$ that satisfy the Euler equation:

$$\hat{c}_j^{-\sigma} = \beta(1+r)\mathbb{E}\big[c_{j+1}\big(e_{j+1}, z, a_{j+1}(e_j, z, a_j)\big)^{-\sigma} \mid e_j\big] \ ,$$

where $\hat{c}_j = y_j + (1+r)a_j - a_{j+1}(e_j, z, a_j)$. Retired households face no employment risk so that expectations are not needed and the grid only covers $\mathcal{Z} \otimes \mathcal{A}$. For households in the workforce, the expectation is calculated by using the exogenous job separation rate χ when the household is employed ($e_j = 1$) and the given job

[37] I initialize at $r_{low} = 0$ and $r_{high} = 2(1/\beta - 1)$. The initial guess for A^h_q is that of the infinitely-lived representative agent case (with $r = 1/\beta - 1$).

[38] The resource constraint $(1-g)K^{\alpha}N^{1-\alpha} = C + \delta K + \gamma V$ obtains by Walras law.

finding probability $h(\theta)$ when the household is unemployed ($e_j = 0$).

Denote the newly found holdings by $\hat{a}_{j+1}$. If $\hat{a}_{j+1} < -\underline{a}$, instead set $\hat{a}_{j+1} = -\underline{a}$ and retrieve current consumption as $\hat{c}_j = y_j + (1+r)a_j + \underline{a}$. The resulting points $\hat{c}_j$ and $\hat{a}_{j+1}$ are then used as interpolants for the policy functions $c_j(e_j, z, a_j)$ and $a_{j+1}(e_j, z, a_j)$.

Repeat the same procedure for each age cohort $j = \{J-2, ..., 1\}$.

(c) Simulate the economy with N^h households.[39] Draw initial labor endowment shocks z. Likewise, use a discrete Markov chain to draw employment statuses $e_j = \{1, 0\}$ such that $Pr[e_{j+1} = 1 \mid e_j = 1] = 1 - \chi$ and $Pr[e_{j+1} = 1 \mid e_j = 0] = h(\theta)$. Simulate the corresponding household asset holdings by using the policy functions $a_{j+1}(e_j, z, a_j)$ found in the previous step.

(d) Compute the newly found aggregate stock of assets A^h_{q+1} supplied by households:

$$A^h_{q+1} = \sum_{j=1}^{J} \int_z \int_e \int_a a_{j+1}(e_j, z, a_j) \; \mathrm{d}a \; \mathrm{d}e \; \mathrm{d}z \; ,$$

and use a bisection to update the bounds for the interest rate r. If $A^h_{q+1} > A^h_q$ there is excess asset supply for the given interest rate r_q and so update $r_{high} = \phi r_q + (1-\phi) r_{high}$ with a dampening factor $\phi \in (0, 1)$.[40] If $A^h_{q+1} < A^h_q$ then instead update $r_{low} = \phi r_q + (1-\phi) r_{low}$. Set $r_{q+1} = \frac{r_{low} + r_{high}}{2}$ and compute the aggregate convergence criterion as $\varepsilon_H = \max : \{ \mid A^h_{q+1} - A^h_q \mid , \mid r_{q+1} - r_q \mid \}$.

(e) Repeat from step (a) until $\varepsilon_H <$ 1e-6.

[39] I use $N^h = 60,000$; that is, 1,000 households per age cohort.

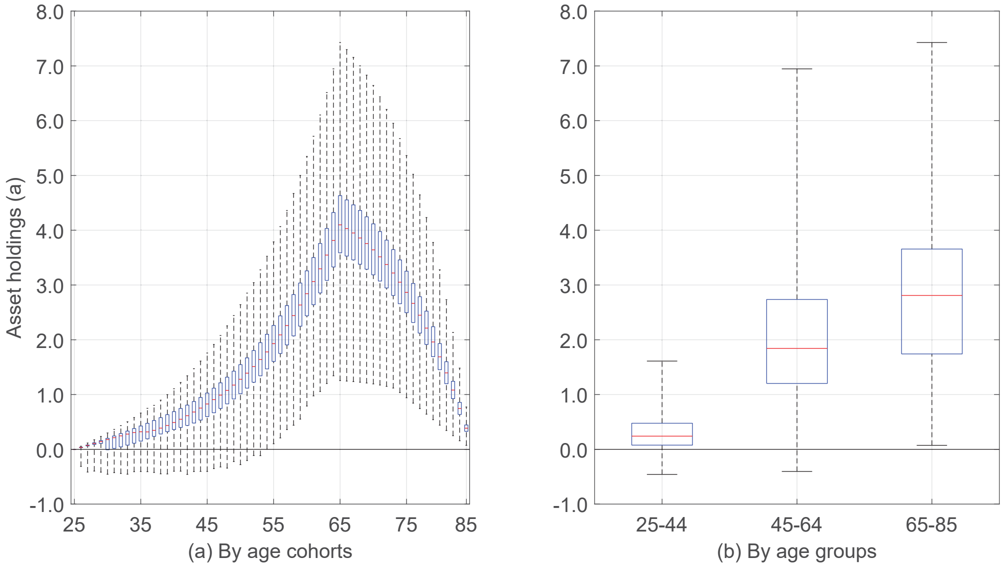
[40] Dampening helps for convergence; I use $\phi = 0.9$.

3.7.6 Additional material

Table 3.4: *Distributional effects: individual consumption*

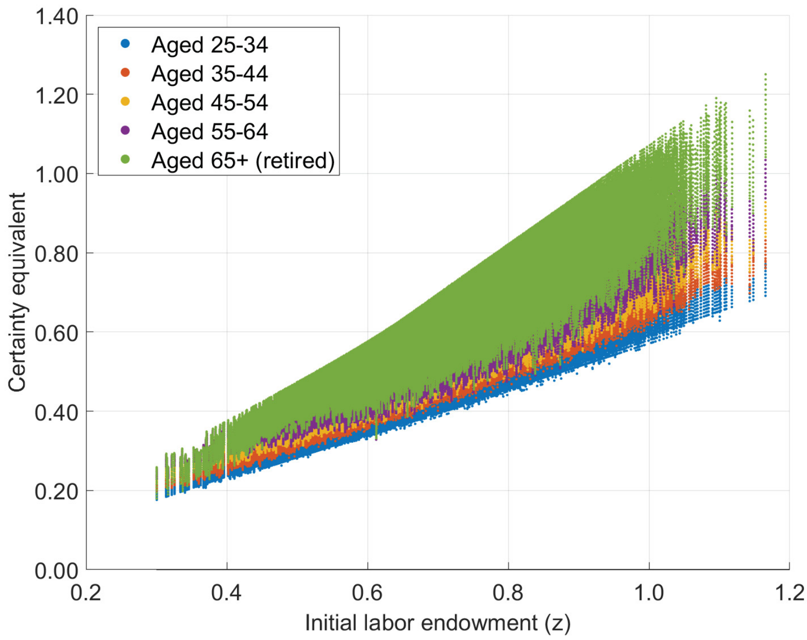
Consumption	$x = 0$	$x = 10\%$	*Difference (%)*
First quantile (25pct)	0.40	0.40	0.13
Median	0.48	0.48	0.13
Mean	0.49	0.50	0.13
Third quantile (75pct)	0.58	0.58	0.16
Standard deviation	0.13	0.13	0.00
Gini coefficient	0.29	0.29	-0.06

Notes: Using the parameter values listed in Table 3.1. The table compares two equilibria: one in which the central bank does not hold government bonds ($x = 0$) and one in which it holds a fraction of the outstanding bond stock ($x = 10\%$). The last column shows the resulting differences.



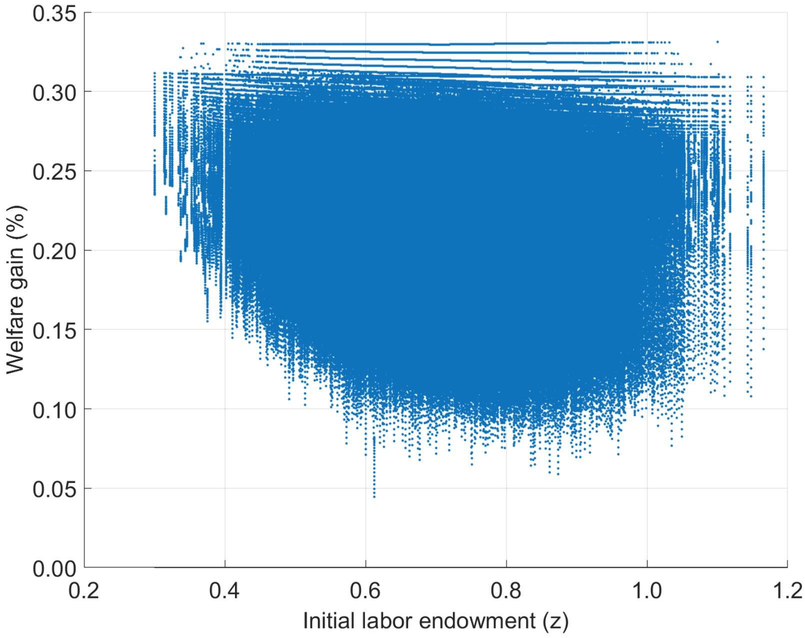
Notes: Using the parameter values listed in Table 3.1 and $x = 10\%$. The charts show boxplots that summarize the asset holdings' distribution of each age cohort/group. Boxes show the interquartile ranges surrounding the corresponding medians. Dotted lines stretch to the respective extrema.

Figure 3.9: *Distributions of asset holdings over the life cycle*



Notes: Using the parameter values listed in Table 3.1. Welfare is measured in terms of certainty equivalents, absent central bank purchases (see main text). The correlation coefficient between the welfare levels and initial labor endowments is 0.732.

Figure 3.10: *Welfare levels against initial labor endowments*



Notes: Using the parameter values listed in Table 3.1. Welfare gains are measured as the % difference in certainty equivalents (for given individual employment paths) obtained when the central bank holds $x = 10\%$ of the outstanding government bond stock (see main text). The correlation coefficient between welfare gains and initial labor endowments is 0.057.

Figure 3.11: *Welfare gains against initial labor endowments*

4 Home ownership and monetary policy transmission

This chapter was written jointly with Winfried Koeniger (University of St. Gallen).

Abstract:
We present empirical evidence on the heterogeneity in monetary policy transmission across countries with different home ownership rates. We use household-level data together with shocks to the policy rate identified from high-frequency data. We find that housing tenure reacts more strongly to unexpected changes in the policy rate in Germany and Switzerland –the OECD countries with the lowest home ownership rates– compared with existing evidence for the U.S. An unexpected decrease in the policy rate by 25 basis points increases the home ownership rate by 0.8 percentage points in Germany and by 0.6 percentage points in Switzerland. The response of non-housing consumption in Switzerland is less heterogeneous across renters and mortgagors, and has a different pattern across age groups than in the U.S. We discuss economic explanations for these findings and implications for monetary policy.

Keywords: Monetary policy transmission, Home ownership, Housing tenure, Consumption.
JEL-codes: E21, E52, R21.

4.1 Introduction

The transmission of monetary policy is at the core of the research agenda in economics. In the canonical New Keynesian model with a representative agent, intertemporal substitution of consumption determines how unexpected changes in the interest rate transmit to consumption and output (Galí, 2015). A recent literature has revived the interest in alternative transmission channels of monetary policy, for example, through direct effects on cash flows or general equilibrium effects on income, or through effects on the valuation of households' balance sheet positions (e.g., Auclert, 2017, Beraja et al., 2017, Di Maggio et al., 2017, Kaplan et al., 2018 and references therein).

Asset and liability positions in balance sheets differ across households so that consumption responses of households to unexpected changes in the monetary policy rate are heterogeneous. Cloyne et al. (2017) show that this heterogeneity matters empirically because mortgagors in the U.S. and U.K. react more strongly to changes in the policy rate than renters and Wong (2018) shows that decisions to refinance mortgages after monetary policy shocks imply much stronger consumption responses of young compared to old households in the U.S.

We contribute to this literature by providing empirical evidence at the household level which shows that the transmission of monetary policy changes across countries with different homeownership rates. Home ownership drastically changes the balance sheet of households: it adds the value of the home as asset and the value of the mortgage as liability, which are the largest items on both sides of the balance sheet for the typical homeowner. Changes in the policy rate may not only change the value of these asset and liability positions, and thus affect the housing tenure decision of households, but also directly influence the mortgage interest payments which enter the budget constraint of indebted homeowners.

We estimate the response to monetary policy shocks in Germany and Switzerland and compare these responses with existing estimates for the U.S. and U.K. We choose Germany and Switzerland because these countries have the lowest home ownership rates of roughly 40% in the OECD compared with rates of approximately two thirds in the U.S. and U.K. We show that monetary policy shocks in Germany and Switzerland trigger a stronger response in the housing market than in the U.S. and the U.K.: an unexpected decrease of the policy rate by 25 basis points increases the homeownership rate by 0.8 and 0.6 percentage points in Germany and Switzerland, respectively. We show that this net effect results from changes in housing tenure that differ across age groups. Furthermore, we find that the responses of non-housing consumption to monetary policy shocks are smaller, and more similar across mortgagors and renters, in Switzerland compared with the U.S. and the U.K.[1] An unexpected shock to the policy rate also does not impact consumption inequality in Switzerland significantly, differently to findings by Coibion et al. (2017) for the U.S.

The estimated responses are consistent with results of experiments performed in a calibrated life-cycle model with uninsurable income risk. Hintermaier and Koeniger (2018) show that an unexpected decrease in the *real* interest rate has a smaller effect on non-housing consumption if households' balance sheets are less tilted towards housing (see the top panel of table 6 in their paper). For the model calibration to Germany, they further show that the lower user cost of housing and the lower rent-to-price ratio, resulting from the fall in the real interest rate, induce a portfolio shift into owned housing for young age groups whereas the opposite is true for older age groups (see Figure 5 in Hintermaier and Koeniger, 2018).[2] We will expand on the economic intuition for these results when we discuss our empirical findings.

Our findings complement recent empirical work based on aggregate data by Calza et al. (2013) and Corsetti et al. (2018) who have shown that monetary policy transmission to aggregate consumption and house prices is heterogeneous across developed countries and within the euro area, and that this heterogeneity is associated with differences in housing markets. We analyze the transmission at the micro level using household-level data for Germany and Switzerland.[3] This allows us to uncover in more detail how differences in housing markets affect the transmission in these countries. We describe in Section 4.2 how housing markets differ between Germany and Switzerland and the U.S. and the U.K., the countries which we use to benchmark our findings.

[1] Unfortunately, no comparable household-level data on consumption are available for Germany at an annual or quarterly frequency so that we can provide a detailed analysis of consumption responses at the household level only for Switzerland.

[2] The experiments within the calibrated model focus on the part of the monetary policy transmission from changes of the *real* interest rate to the real economy. Thus, we cannot compare the results of the experiments quantitatively with our empirical estimates. To the extent that unexpected changes in the *nominal* policy rate affect the *real* interest rate, as we show below in Table 4.3, it is comforting to see that the estimated responses are qualitatively consistent with the model-based experiments. The transmission of monetary policy shocks to the real interest rate may result from nominal rigidities or from a redistribution of wealth from the private to the public sector after open market operations, as pointed out by Sterk and Tenreyro (2018).

[3] Jappelli and Scognamiglio (2018) use the quasi-experimental setting of the unexpected large drop of interest rates after the Great Recession to estimate the consumption response of mortgagors in Italy, a country with a slightly higher homeownership rate than the U.S. and the U.K. but a relatively small mortgage market. They find that the type of mortgage does not affect the consumption response significantly.

We identify monetary policy shocks using high frequency data. This approach, pioneered by Cook and Hahn (1989), Cochrane and Piazzesi (2002) and Kuttner (2001), exploits the fact that data on futures or swap contracts contain information on market expectations about monetary policy. The identification of monetary policy shocks then uses the discontinuous changes of these expectations in a short time window around the monetary policy announcements. Recent applications of this approach are in Gertler and Karadi (2015) or Nakamura and Steinsson (2018) for the U.S., Gerko and Rey (2017) for the U.K., Corsetti et al. (2018) for the euro area and Ranaldo and Rossi (2010) for Switzerland.

Our analysis proceeds in the following steps. In Section 4.2 we briefly describe important features of the housing and mortgage markets in Germany and Switzerland, and we explain why these features matter for monetary policy transmission. We then discuss in Section 4.3 how we identify exogenous movements of the policy rate. We present the household-level data for Germany and Switzerland in Section 4.4, which we then use to estimate the responses of housing tenure and consumption in Sections 4.5 and 4.6, respectively. We conclude in Section 4.7.

4.2 Housing markets and monetary policy transmission

Household portfolios, and home ownership rates in particular, differ widely across countries (see, for example, Christelis et al., 2013). Table 4.1 shows that the differences in homeownership rates, between Germany and Switzerland on the one hand and the U.S. and the U.K. on the other hand, have narrowed slightly in the 2000s but are very persistent.

Table 4.1: *Home ownership rates (%)*

	2000	2014	Change
UK	71	63	-8
US	67	65	-2
Germany	42	46	+4
Switzerland	35	38	+3

Sources: UK Ministry of Housing (English Housing Survey, Headline Report, Section 1, Figure 1.1), FRED (Economic Data, Series *RHORUSQ156N*), ECB (Statistical Data Warehouse, Dataset *SHI*, Key *SHI.A.DE.TOOT.P*), SFO (Federal Population Census, Table *09.03.02.01.01*). *Notes:* The table reports owner occupation rates. The value for 2000 in Germany is interpolated using data for 1998 and 2002.

Home ownership may modify monetary policy transmission to both nondurable and durable consumption because housing is less liquid than other assets: illiquidity increases the marginal propensity to consume out of transitory income shocks (Kaplan and Violante, 2014), which is a key determinant of the consumption response to changes in the interest rate (Auclert, 2017).

The extent of home ownership may also change the transmission of monetary policy in the housing market. We first discuss how monetary policy transmits to housing tenure choice and then mention how this transmission may be modified in countries, such as Germany and Switzerland, where the home ownership rate is low for structural reasons that are unrelated to monetary policy.

After a shock to the policy rate, households will revise their decision to consume housing services by renting or owning the accommodation in which they live. Whether households change their housing tenure after the shock depends on the size of the shock to the policy rate and its pass through to prices in the housing and mortgage market. For example, a change in the mortgage interest rate affects the user cost of owning a house and together with the response of rents and house prices may trigger changes in home ownership.[4]

As we show in Section 4.3, the pass through of policy rate shocks to long-term interest rates is sizable because markets expect monetary policy shocks to be fairly persistent in Germany and Switzerland, which is similar to the U.S. (Nakamura and Steinsson, 2018) and the U.K. (Gerko and Rey, 2017). A similar pass through of policy shocks to long-term interest rates may trigger different responses of housing tenure choices, however, if the subpopulation of (potential) marginal home buyers and sellers in Germany and Switzerland has different characteristics –for example in terms of age, income or saving behavior– and thus reacts differently to interest-rate changes compared to the marginal home buyers in the U.S. and the U.K.

The descriptive evidence in Andrews and Sánchez (2011a) and Andrews and Sánchez (2011b) suggests that the marginal home buyers and sellers in Germany and Switzerland are indeed different from those in the U.S. and the U.K. due to differences in tax incentives and regulation that are associated with differences in house prices (see also the references therein). Starting from a lower initial level of home ownership at a young age, the age

[4]The transmission of monetary policy to rents in Switzerland may be influenced by the indexation of rents to a reference mortgage rate. Until 2008, the reference rate was an average of the rates recorded by banks at the cantonal level. Since then, there is a single national reference average rate. Whether rents are indeed adjusted after a change in the mortgage interest rate depends on whether landlords and tenants agree to implement these changes. To get an indication of how the cost of renting versus owning changes with the policy rate, we estimate the response of house prices, rents and mortgage interest payments to unexpected changes in the policy rate in Sections 4.5 and 4.6.

gradient of home ownership is steeper in Germany and Switzerland until home ownership peaks at ages 55 to 64. Thus, until that peak, the net flow from rental to home ownership increases more in Germany and Switzerland than in the U.S. and the U.K. as households age. We provide further details on the flows between the types of housing tenure in Section 4.4.

The transmission of monetary policy is also influenced by characteristics of the mortgage market which differ considerably across countries (see Badarinza et al., 2018 and references therein). Shocks to the policy rate have a stronger effect on cash flows and possibly also consumption if mortgagors have an adjustable-rate mortgage, or if they can refinance a fixed-rate mortgage or release home equity at low cost (Calza et al., 2013).

Table 4.2: *Mortgage contract characteristics*

	Typical mortgage rate fixation	Equity release products	Early repayment penalties on fixed-rate mortgages
UK	Adjustable	Used	Used
US	Fixed	Used	Not used
Germany	Fixed	Not used	Used
Switzerland	Fixed	Not used	Used

Sources: Compilation of information in Lea (2010) and Calza et al. (2013) on rate fixation, equity release and early repayment penalties.

Table 4.2 shows that typical mortgage contracts are quite different in the U.S. and the U.K. compared to Germany and Switzerland. Most households in the U.K. have mortgage contracts with an adjustable rate and they can release home equity. In the U.S. most households have fixed-rate mortgages but they can refinance their mortgage at little cost (ex post, the bank bears the cost of foregone interest if a household decides to refinance). This implies that a decrease in the mortgage interest rate reduces mortgage payments and should increase the consumption of existing indebted homeowners more in the U.K. and the U.S. than in Germany and Switzerland, where most mortgage contracts have a fixed rate, refinancing is very costly and possibilities of equity release are not common.[5] Becoming a new home owner may become more attractive in all countries instead if the

[5]Using 12,700 representative mortgage transactions between 2008 and 2013 from the online platform *Comparis*, Basten and Koch (2015) show that contracts with rates fixed for four years or more accounted for around 75% of all contracts in Switzerland, where contracts with rates fixed for ten years accounted for 35% of new contracts and contracts with rates fixed for five years accounted for 26%. Only 5% of new mortgage contracts had an adjustable rate. Basten and Koch (2015) further show that changes in house prices mostly affect mortgage volumes through new mortgagors rather than through refinancing activities of existing mortgagors.

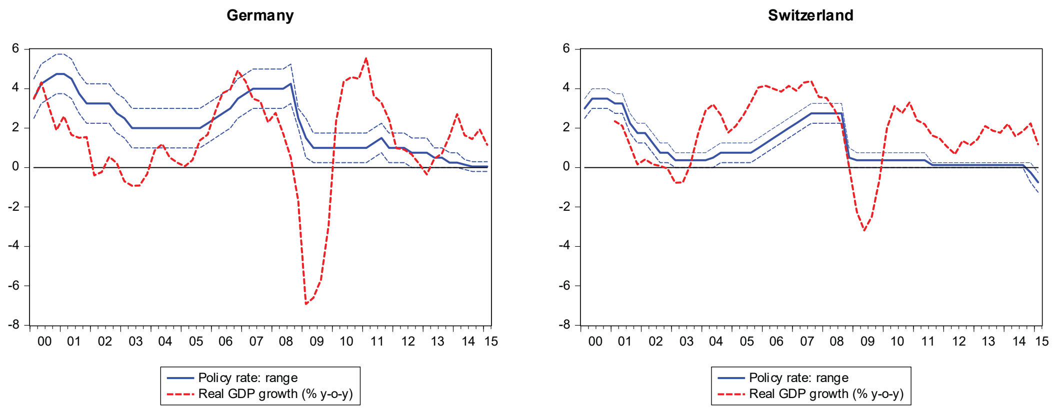
mortgage interest rate decreases unexpectedly. Whether the transmission of the policy rate shocks to home ownership is heterogeneous across countries is an empirical question which we investigate further in Section 4.5.

4.3 Identification of monetary policy shocks

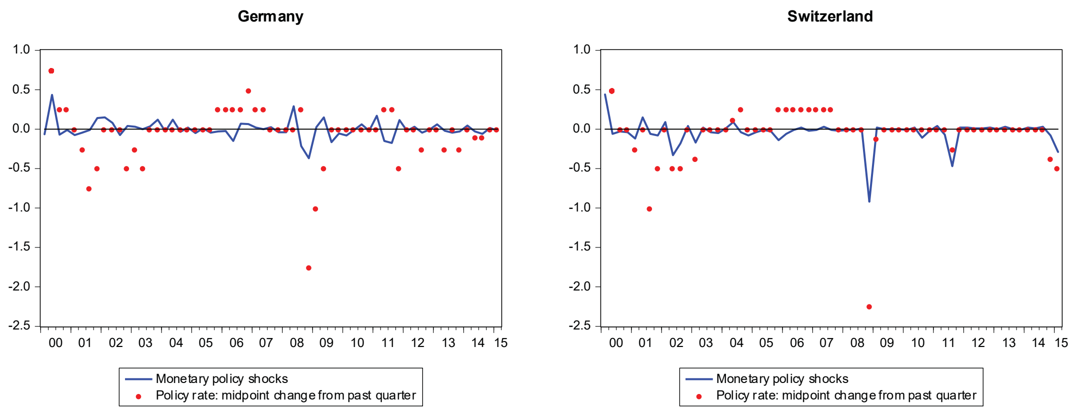
Monetary policy responds endogenously to aggregate conditions, as illustrated in panel (a) of Figure 4.1. For Germany, the figure plots the three key interest rates set by the European Central Bank (ECB). In increasing order of the value of the rates, these are the rate on the deposit facility, the rate on the main refinancing operations and the rate on the marginal lending facility. For Switzerland, the figure plots the midpoint of the target range, which is the three-month Swiss-Franc Libor, together with the range set by the Swiss National Bank (SNB). The considered time period is $2000 - 2015$, given the introduction of the euro and the targeting of the three-month Swiss-Franc Libor by the SNB since 2000. Figure 4.1 illustrates the endogeneity of monetary policy because, as expected, the policy rates in Germany and Switzerland co-move with economic conditions, represented by the growth rate of real GDP in the figure. Thus, we need to construct a measure of exogenous changes in the policy rate for the empirical analysis.

We identify monetary policy shocks by using high-frequency data on changes in financial-market expectations, which are contained in prices of futures contracts on interest rates in narrow time windows around the dates of monetary policy announcements. The identification of monetary policy shocks relies on the assumption that changes in the price of futures in these narrow time windows are due to news contained in the policy announcements and are not due to other events. For our benchmark estimates we use time windows of one day, between the end of the announcement day and the day before, and we check robustness for narrower time windows that are as short as 30 minutes.

As mentioned in the analysis of Wong (2018) for the U.S., one concern may be that policymakers have private information about the state of the economy which is correlated with economic outcomes and thus household decisions. In this case, the measured policy shock would consist of the true shock and an error which may be correlated with consumption or housing tenure. Such an error term likely would not be i.i.d. and thus would introduce some persistence into our series of the monetary policy shock. In columns 1 and 5 of Table 4.9 in Appendix 4.8.1, we check this issue by regressing the current quarterly shocks against their *past* values, with lags up to four quarters. We find no evidence of persistence for our constructed series of policy shocks for Switzerland. For the series of



(a) Policy rate range and real GDP growth (%)



(b) Monetary policy shocks and midpoint policy rate changes (%)

Sources: Short-term rates from ECB (Statistical Data Warehouse, Table *ECB/Eurosystem policy and exchange rates*, Subtable "Official interest rates") and SNB (Data Portal, Table *Official interest rates*). Futures contracts' prices from Thomson Reuters (RIC *FEIc1* and *FESc1*). German real GDP from FRED (Economic Data, Series *CLVMNACSCAB1GQDE*) and Swiss real GDP from SECO (Data, Table *qnaqcsa, ESA*, Reference *realq, B.1*b*). *Notes:* Quarterly data. In panel (a) we use the SNB target range for the Swiss policy rate. For Germany we use data for the rates on the deposit facility, the main refinancing operations (MRO) and the marginal lending operations of the ECB. The rates displayed use end of quarter values. In panel (b), the series of shocks is constructed using data of futures contracts for the 3-month Swiss-Franc Libor and the Euribor. Both the shocks and the midpoint changes are cumulated quarterly.

Figure 4.1: *Policy rates and monetary policy shocks*

policy shocks for the euro area, only the coefficient of the shock with a lag of two quarters is significant while the coefficients for all other lagged shocks in the regression are not significant. We interpret this evidence as supporting, by and large, that our constructed series of policy shocks are true shocks.[6]

The advantage of identifying monetary policy shocks, using high-frequency data on market expectations, is that one does not need to make further assumptions about the policymakers' information set or impose identifying restrictions, as in the traditional VAR-literature, to disentangle the endogenous and exogenous components of monetary policy. Such assumptions frequently result in shock series for monetary policy shocks that are not easily reconciled with data on financial market expectations (see, for example, the critique by Rudebusch, 1998).

We retrieve market expectations about the policy rates by using price data of futures contracts on the policy rate or a close counterpart. The midpoint of the policy rates in Figure 4.1 is the rate on the main refinancing operations of the ECB for Germany and the three-month Swiss-Franc Libor rate for Switzerland. Whereas futures are traded for the three-month Swiss-Franc Libor, this is not the case for the rate on the main refinancing operations so that we use futures on the three-month Euribor instead. The Euribor is highly correlated with the rate on refinancing operations, as shown in Figure 4.7 in Appendix 4.8.2.[7]

Panel (b) of Figure 4.1 plots our measure of the monetary policy shock, constructed from the unexpected price changes of the futures, together with the actual changes of midpoint policy rate changes. We cumulate the shocks, which we obtain by computing the rate changes in the narrow time window around each policy announcement, and the corresponding midpoint policy rate changes for all announcements within a quarter. As can be seen in panel (b) of Figure 4.1, changes in the policy rate are partly anticipated.

[6] In our analysis, we cumulate shocks for every year. Figure 4.6 in Appendix 4.8.1 shows the correlograms of the series with shocks cumulated over a year. Even for the cumulated series of the shocks, we do not find significant autocorrelations beyond a quarter. This is comforting because multicollinearity of the lagged shocks in the regressions is thus not a concern. In columns 2-4 and 6-8 of Table 4.9 in Appendix 4.8.1, we check whether *future* cumulated shocks can be predicted by past cumulated shocks. We find that past shocks have no predictive power for future shocks in the euro area. This is also by and large the case for the Swiss series, with the exception of past shocks with a lag of four years or more. Note that the sample size is smaller in these regressions due to the longer lags.

[7] Given that future contracts often mature around the announcement dates, we use futures contracts that deliver a specified rate in the quarter following the monetary policy announcement. These contracts mature after the announcement date so that we observe the price changes for these contracts around the announcement dates. We do not need to adjust the implied rates of the futures contracts for the number of days until expiry. In Gürkaynak et al. (2005), Nakamura and Steinsson (2018) or Wong (2018) this is necessary because they use contracts of federal funds futures in the U.S. that have a payout based on the average effective rate in a given month.

For example, only a small part of the large decrease in the policy rate in 2008 has been unexpected. On other announcement dates instead, markets expected a reduction in the policy rate while the central bank kept the rate unchanged. This resulted in an unexpected shock reflecting that the policy rate remained higher than expected.

The average of the shocks is approximately zero in the sample period for the ECB and -4 basis points for the SNB. The standard deviation of the shocks is 11 basis points for the ECB and 16 basis points for the SNB,[8] compared with the $25-35$ basis points reported in Wong (2018) for the Federal Reserve in the longer time period $1990-2007$. Given that some shocks in the sample are much larger than others, we check the robustness of our results in Appendix 4.8.3 if we split the sample in 2007, and thus before the larger policy-rate shock during the financial crisis occurred. We discuss the results of these robustness checks in Sections 4.5 and 4.6.

As mentioned above, we further check robustness by constructing the shocks using narrower time windows to measure the price changes of the future contracts based on data at minute frequency provided by *TickDataMarket*. We consider a very narrow time window of only 30 minutes around the announcement, starting 10 minutes before the announcement. This replicates the identification strategy of Gertler and Karadi (2015) and Nakamura and Steinsson (2018) for the U.S. We also consider a larger time window, which accounts for the fact that monetary policy decisions are communicated slightly differently by the ECB and SNB compared with the Federal Reserve.

The ECB typically makes an initial policy announcement at 13:45 (CET), in which the policy-rate decision is briefly stated. In a subsequent press conference at 14:30 (CET), the decision is explained further. Therefore, we also construct the shocks with a time window from 13:00 to 19:00, as in Corsetti et al. (2018). The SNB also makes an initial statement of the policy rate decision, which lasts approximately 30 minutes. Only in the quarterly meetings in June and December, this is directly followed by a press conference which lasts approximately one hour. The precise time of day of the announcement varies but is known in advance. The majority of statements started between 09:30 and 14:00 (CET) in our sample.[9] Given the similar structure of the announcements at the SNB, we also consider a time window of six hours around the announcement time, as for the ECB. Finally, we also check whether the results remain robust if we let the time window close

[8] The difference in the standard deviation may be related to the different frequency of the regular announcements. The ECB announces rate decisions every six weeks. The SNB announcements have a lower frequency of three months.

[9] The initial SNB statements started between 08:50 and 17:45 (CET) in the sample period 2000Q1-2015Q1. The June and December meetings all started in the morning. In September 2011, December 2014 and January 2015, three extraordinary announcements were followed by a press conference.

right at the end of the press conference.[10] The results for the responses of housing tenure and consumption, using these alternative time windows to measure the monetary policy shocks, are reported in Appendices 4.8.3 and 4.8.4, and discussed in Sections 4.5 and 4.6.

4.3.1 Pass through and persistent effects of shocks

Key for monetary policy transmission is the effect of the shocks on long-term interest rates. The results presented in this subsection indicate that the shocks indeed have a persistent effect on short-term rates and affect long-term interest rates, both in Germany and Switzerland.

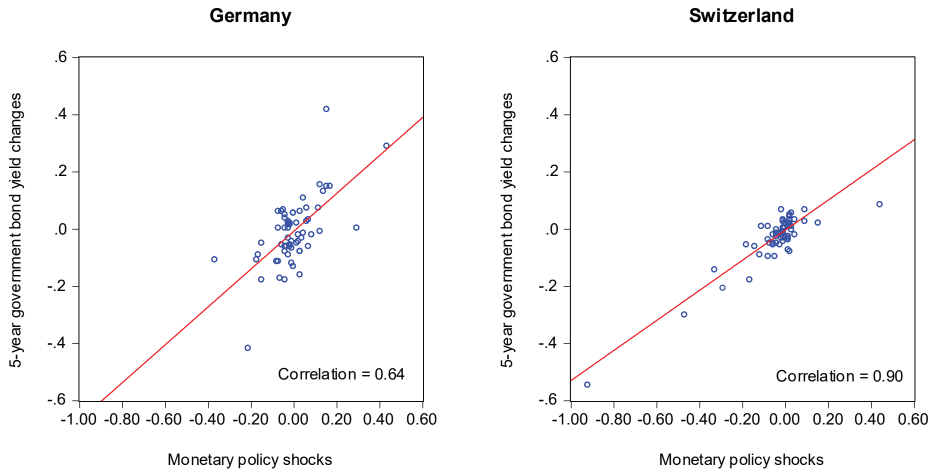
Panel (a) of Figure 4.2 shows that our measure of monetary policy shocks is highly correlated with changes in the yields of five-year government bonds in the same time window around the announcement dates, both in Germany and in Switzerland. Panel (b) of Figure 4.2 illustrates that quarterly values of interest rates for fixed-rate mortgages, which are not available at a high frequency and for the whole sample period, co-move strongly with the five-year government bond yields in both countries.

Table 4.3 provides evidence on the persistence of the monetary policy shocks. Each number reported in the table corresponds to a coefficient estimate obtained by regressing the interest rate of the respective financial instrument on a constant and the monetary policy shock. A coefficient value of 1 corresponds to a full pass through of the shock (i.e., a shock of 25 basis points translates into a change of 25 basis points in the interest rate of the respective financial instrument).

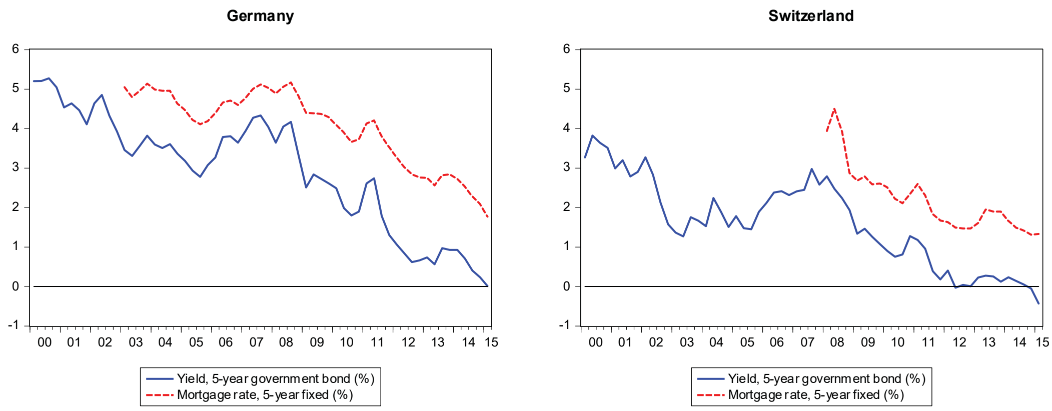
The estimated regression coefficients reveal that the shocks have persistent effects on interest rates in both countries. At the top of the table, we report the effect on the implied short-term interest rate of future contracts up to 21 months in the future. The effect on these expected short-term rates is easier to interpret than the effect on bonds with longer maturities, reported below in the same table: the effect on the rates of the long-term bonds depends on the average of the effect on short-term rates over the life of the bond and may also be affected by changes in the risk or term premium.[11] The size of the coefficients reported in Table 4.3, and hence the persistence of the effect of monetary

[10] For Switzerland, the resulting time window ends either at the end of the announcement or at the end of the press conference (when there is one). This includes the extraordinary press conferences that took place on 06.09.2011, 18.12.2014 and 15.01.2015.

[11] Nakamura and Steinsson (2018) present evidence that indicates that changes in risk premia are not the main drivers in the transmission of monetary policy shocks, identified by high-frequency variation, on long-term interest rates. The empirical analysis with daily data on yields by Söderlind (2010) suggests that an increase in expected short-term interest rates may confirm the credibility of price stability and



(a) Monetary policy shocks and long-term bond yield changes on announcement dates (%)



(b) Long-term bond yields and rates for fixed-rate mortgages (%)

Sources: Mortgage rates from Bundesbank (Statistics, Table *Effective interest rates of German banks*, Reference *BBK01.SUD118*) and SNB (Data Portal, Table *Interest rates, yields and foreign exchange market*, Subtable *Interest rates on new loan agreements, by product and maturity*, Cube ID *zikredlauf*). 5-year government bond yields from Thomson Reuters (RIC *DE5YT* and *CH5YT*). *Notes:* Panel (a) uses daily changes on announcement dates taking place between 2000Q1 and 2015Q1. Panel (b) displays end of quarter values for the mortgage rates, and quarterly averaged bond yields at the end of announcement dates.

Figure 4.2: *Monetary policy shocks and long-term interest rates*

Table 4.3: *Persistent effects of monetary policy shocks*

	Germany			Switzerland
6M Futures' implied rate	1.125***			0.945***
	(0.019)			(0.023)
9M Futures' implied rate	1.124***			0.885***
	(0.032)			(0.032)
12M Futures' implied rate	1.076***			0.830***
	(0.042)			(0.038)
15M Futures' implied rate	0.992***			0.800***
	(0.048)			(0.041)
18M Futures' implied rate	0.924***			0.769***
	(0.051)			(0.047)
21M Futures' implied rate	0.856***			0.748***
	(0.052)			(0.049)
3Y Government bond yield	0.662***			0.547***
	(0.058)			(0.042)
4Y Government bond yield	0.776***			0.453***
	(0.052)			(0.093)
5Y Government bond yield	0.639***			0.532***
	(0.052)			(0.041)
6Y Government bond yield	0.697***			0.561***
	(0.052)			(0.064)
	Nominal	*Real*	*Inflation*	
5Y Government bond yield*	0.850***	0.372***	0.478***	
	(0.109)	(0.096)	(0.091)	

Sources: Futures' implied rates from Thomson Reuters (RIC *FEIMYD* and *FESMYD*, where *MYD* denotes month, year and decade). Bond yields from Thomson Reuters (RIC *DEMYT* and *CHMYT*, where *MYT* denotes maturity, and ISDN *DE0001030526* for the *Bobl* real bond). *Notes:** Estimates for the transmission to nominal rates, real rates and break-even inflation, using the 68 monetary policy announcements since the inflation-indexed *Bobl* bond has been issued in Germany in 2006. *** p-value<0.01. Standard errors in brackets. The table reports the coefficients of separate regressions for each financial instrument against the monetary policy shocks series and a constant for Germany and Switzerland, respectively. The series are based on daily changes in the rates on the announcement dates in the period 2000Q1-2015Q1. The number of announcements in the sample period is 75 for Switzerland and 207 for Germany.

policy shocks on the nominal rates, is of similar magnitude as the estimates for the U.S. reported in table 1 of Nakamura and Steinsson (2018).

For Germany, we can provide also evidence for the effect of monetary policy shocks on real rates for a shorter sample period. Inflation-indexed bonds have been issued only since 2006. We use the available data on five-year nominal and real government bonds because no indexed bonds with shorter maturities are issued. The estimates in the last row of Table 4.3 show that nearly half (44%) of the response of the nominal rate to the monetary policy shock can be attributed to the reduction of the real rate. The effect on break-even inflation accounts for the other half, where break-even inflation is computed as the difference between the nominal and real yields. Compared with the empirical evidence of Nakamura and Steinsson (2018) for the U.S., we find a stronger, positive effect of monetary policy shocks on break-even inflation in Germany. Our results suggest that, on impact in our sample period, markets have revised their inflation expectations upward after a positive unexpected change of the policy rate.

4.4 Household data on housing tenure and consumption

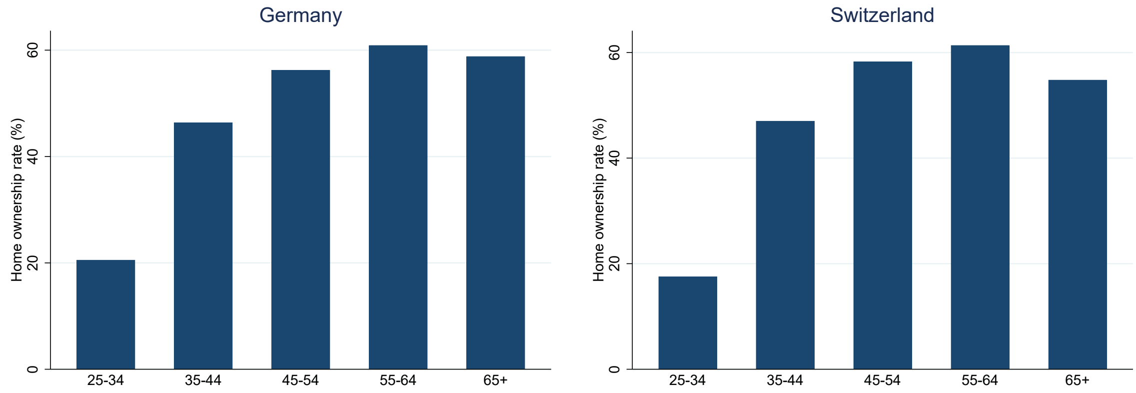
We use household-level data to analyze the transmission of monetary policy to the housing market and to consumption. Household-level data allow us to investigate the extent of heterogeneity in the transmission of monetary policy shocks across households with different ages, assets or liabilities.

We use the annual data of the German Socioeconomic Panel (GSOEP) and the Swiss Household Panel (SHP) to estimate the effect of monetary policy shocks on housing tenure choice. The data are available at an annual frequency. Since households in the surveys are interviewed across all quarters and the sample size is sufficiently large, we can use variation across quarters during the time period $2000Q1 - 2015Q1$ available in both samples. Because of the lagged independent variables in the estimations, the sample for the estimation covers the period $2003Q1 - 2015Q1$ for both countries. The sample size is $136,718$ for Germany and $40,637$ for Switzerland, where the unit of observation is a household in a given year, observed in a specific quarter for that year.

thus lead to a *de*crease in long-term rates via a reduced term premium. Without such an effect, the effect of changes in the short-term rates on the long-term rates would be even larger.

Panel (a) of Figure 4.3 shows the familiar hump shape for the age profile of home ownership in Germany and Switzerland. As mentioned in Section 4.2, the home ownership rates in Germany and Switzerland are lower at young ages than in the U.S. and the U.K. and have a steeper age gradient until they peak at ages 55-64.

Panel (b) of Figure 4.3 shows that the fraction of renters who became home owners varies over time between 3.2% and 4.6% for Germany and between 2.6% and 4.5% for Switzerland. The fraction of owners that became renters in the sample period was lower between 1.6% and 2.5% for Germany and 1.3% and 2.5% for Switzerland. We will exploit the variation of the flows between different types of housing tenure, across quarters and years, to identify the effect of the monetary policy shocks on changes in housing tenure.



(a) Home ownership by age group

(b) Flows between different types of housing tenure over time

Sources: Germany (GSOEP), Switzerland (SHP). *Notes:* Panel (a) shows averages for households in both countries. Panel (b) shows annual average flows.

Figure 4.3: *Home ownership by age groups and flows between different types of housing tenure over time*

Table 4.4: *Summary statistics for housing-tenure groups in Germany and Switzerland*

	Germany			
	Renters		Owners	
	Remained renter	Became owner	Remained owner	Became renter
Observations	63,646	2,621	69,065	1,386
Age (household head)	49.8	46.8	56.1	56.2
Household size (persons)	2.3	2.8	2.7	2.3
Number of children	0.6	0.8	0.6	0.5
In a couple (%)	56.4	77.3	79.1	59.4
Married (%)	44.3	62.3	74.7	49.9
Working (%)	63.1	73.2	61.8	56.2
Years of education	12.3	12.9	12.8	12.2
Gender (% male)	50.4	55.2	65.8	52.5
Domestic citizenship (%)	91.1	92.9	96.6	95.5
Gross household income (EUR, annual)	32,053	52,062	52,275	37,890
	Switzerland			
	Renters		**Owners**	
	Remained renter	Became owner	Remained owner	Became renter
Observations	18,750	735	20,784	368
Age (household head)	50.9	45.7	55.7	55.7
Household size (persons)	2.2	2.8	2.8	2.1
Number of children	0.4	0.8	0.6	0.4
In a couple (%)	51.8	76.3	78.7	51.6
Married (%)	41.3	61.2	74.7	42.4
Working (%)	67.4	77.6	64.8	60.6
Years of education	13.4	14.2	13.6	13.6
Gender (% male)	36.0	36.6	38.1	37.5
Domestic citizenship (%)	87.5	90.2	93.7	94.8
Gross household income (CHF, annual)	99,134	145,360	134,149	101,711

Sources: Germany (GSOEP), Switzerland (SHP). *Notes:* Averages for households interviewed between 2003Q1-2015Q1 for both data sets. Changes in tenure refer to changes since the last survey in the previous year. In 2007Q4, a euro was worth 1.45 US-$ and a Swiss Franc was worth 0.87 US-$. See Appendix 4.8.7 for further details on the construction of the variables and the sample.

Table 4.4 provides summary statistics for the different housing tenure groups in Germany and Switzerland. To learn about the characteristics of the households that changed housing tenure status, we distinguish renters that have remained renters (since the last survey in the previous year) from renters that have become home owners, and we distinguish home owners that have remained owners from those that have become renters. Table 4.4 shows that, as one would expect, renters that have become home owners tend to be younger than those who have remained renters, have a larger household size, are more likely married or live as a couple, have higher income and are more likely to work. The flow from home ownership to rental occurs at later ages, on average previous to retirement, where owners that become renters have relatively less income and are less likely to be married or live as a couple.

Table 4.5: *Summary statistics for household budget items of Swiss renters and mortgagors*

	Renters	**Mortgagors**
Observations	16,292	14,515
Age	45	52
Household labor income	64,028	69,245
Rent expenditure	11,630	-
Mortgage interest payments	-	7,056
Nondurables expenditure	31,302	36,450
Durables expenditure	4,868	7,007

Sources: Switzerland (HABE). *Notes:* Amounts are household averages in CHF over the sample period, adjusted for household size and using 2007Q4 prices. A Swiss Franc was worth 0.87 US-$ in 2007Q4. See Appendix 4.8.7 for further details on the construction of the variables and the sample.

For Switzerland we are able to complement the panel data with repeated cross-sectional data on household income, consumption, rents and mortgage interest payments contained in the Swiss household budget survey (*Haushaltsbudgeterhebung* or HABE). The data are published annually but households in the surveys are interviewed across all quarters so that we use variation across quarters during the time period 2003Q1-2014Q4.[12] The data also contain information to classify households as renters or mortgagors. Our sample consists of 16,292 renters and 14,515 mortgagors. Table 4.5 provides summary statistics

[12] As for the estimations based on the SHP and GSOEP, the estimation sample starts in 2003Q1 because of the lagged independent variables.

for these two groups. Mortgagors are older than renters on average, have more income and can afford more expenditure on durables and non-durables.[13]

Further recent descriptions of the data are provided by Wagner et al. (2007) for the GSOEP, Voorpostel et al. (2017) for the SHP and BFS (2013) for the HABE. Appendix 4.8.7 contains further information on the construction of the sample and the variables used in the regressions. In that appendix we also compare average labor income and consumption in the HABE to the corresponding measures from the national accounts, to show that the data quality is comparable to consumption surveys in other developed countries.

4.5 Response of housing tenure

We estimate the effect of monetary policy shocks on housing tenure in Germany and Switzerland. Since the shocks may induce purchases or sales of homes, we estimate the effect on both the transition from being a renter to becoming a home owner and vice versa. Home ownership refers to owner occupation of the primary residence in the data sets and does not include ownership of second homes.

We find that a monetary policy shock triggers adjustment in the housing market: some renters become home owners and, at the same time, some home owners become renters. The net effect on owner occupation is positive for an accommodative shock, suggesting that the positive demand effect resulting from such a shock does not only imply higher house prices. We now present our findings in further detail.

We can exploit variation at the quarterly frequency because we have information on the interview date of households. Given that households in the panel data are interviewed only at an annual frequency, we have to pool all the observations on renters to estimate the probability of becoming a home owner in each quarter and year, and we pool all the observations on home owners to estimate the probability of becoming a renter. Households who change housing tenure more than once are captured at each change. Age controls in the regression will account for differences in the transition probabilities across age groups.

[13] The items contained in the expenditures on non-durables and durables are listed in Appendix 4.8.7. Note that average income in Table 4.5 is adjusted for household size and thus lower than the average income of Swiss households reported in Table 4.4. Although the available income measures in the SHP and HABE data are not directly comparable, we report that the average *total* household income is CHF 117,902 in the SHP and average household labor income is CHF 99,032 in the HABE. The medians are CHF 102,000 and CHF 93,890, respectively.

We use the panel dimension of the surveys to construct a dummy variable for changes in housing tenure during the last year. For household i from region r interviewed in quarter q and year t we define

$$\text{Change}_{irqt} = \begin{cases} 1 & \text{if the housing tenure changed,} \\ 0 & \text{otherwise.} \end{cases}$$

We estimate a linear probability model and provide robustness results in non-linear probit and logit specifications in Appendix 4.8.3. The regression specification is

$$\text{Change}_{irqt} = \alpha + \beta' \mathbf{z}_{qt} + \gamma' \mathbf{x}_{irqt} + D_r + D_q + D_t + \varepsilon_{irqt},$$

where Change_{irqt} is the binary variable described above and the vector $\mathbf{z}_{qt}$ denotes the monetary policy shocks in the last three years, cumulated over quarters separately for each of the years. The vector $\mathbf{x}_{irqt}$ contains a set of control variables, which vary at the household level.[14] In all of the regression specifications we control for common effects by quarter D_q and year D_t, and thus control for common trends and seasonal effects. In some specifications we also control for common effects by region D_r.

We estimate the specification with ordinary-least squares, given that our measure of monetary policy shocks has been constructed to be an exogenous variable. The variation at the year-quarter level identifies the effect of the monetary policy shocks in our regressions. To preserve degrees of freedom, we estimate a parsimonious specification. We cumulate shocks per year and allow for lagged effects of shocks up to three years. In Appendix 4.8.3 we show that including additional lags amplifies the results that we present here, at the cost of less degrees of freedom, so that the main specification provides conservative estimates.

Table 4.6 summarizes the results for the effect of monetary policy shocks on housing tenure in Germany and Switzerland. In the benchmark specification reported in Table 4.6, we control for year and quarter dummies and add only age as additional control which is truly exogenous. The coefficients of the monetary policy shocks are thus identified by the interaction of quarter and year effects and we cluster their standard errors at quarter-of-interview level. In Appendix 4.8.3 we show that our results are robust if we add additional controls for the region and for the household characteristics listed in Table 4.4.

[14] We do not use aggregate variables as controls because this would contaminate our identification strategy. For example, unemployment and real GDP growth affect monetary policy decisions and, at the same time, are influenced by them so that these variables are endogenous. If our constructed monetary policy shocks are exogenous and thus are true surprises, which we have tried to achieve with our construction of the series, omitted variables are uncorrelated with these shocks and do not bias the coefficient estimates.

Table 4.6: *The effect of monetary policy shocks on housing tenure transitions*

	Germany		Switzerland	
	Renter to Owner	Owner to Renter	Renter to Owner	Owner to Renter
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.008	-0.037***	-0.022**
Monetary policy shock, sum Q(-5:-8)	-0.021	-0.014**	-0.020***	-0.007***
Monetary policy shock, sum Q(-9:-12)	-0.040**	0.003	-0.008***	0.001
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Age controls	Yes	Yes	Yes	Yes
Observations	66,267	70,451	19,485	21,152
R^2	0.003	0.004	0.006	0.007
Effect of unexpected 25bps policy-rate cut	+1.88pp	+0.48pp	+1.63pp	+0.70pp

Notes: * p<0.10, ** p<0.05, *** p<0.01. The dependent variable is the respective change of housing tenure status. Standard errors are clustered at the quarter of the interview because the monetary policy shock does not vary at the household level. Age controls include age and age squared and refer to the household's reference person. The cumulative effect over three years of a -25bps shock is obtained by multiplying the sum of the coefficients with -0.25.

The coefficients of the monetary policy shocks, reported in Table 4.6, are negative and highly significant. The results imply that an accommodative shock increases both the probability that renters become home owners and vice versa. As illustrated in the bottom row of the table for an unexpected fall of the policy rate by 25 basis points, the net effect on the transition probabilities is sizeable. The probability that a renter becomes an owner increases by 1.88 percentage points in Germany and 1.63 percentage points in Switzerland. Likewise, the probability that an owner becomes a renter increases by 0.48 percentage points in Germany and 0.70 percentage points in Switzerland.[15]

These results suggest that the effect of the monetary policy shocks on the relative cost of owning versus renting causes changes in housing tenure by some households. Experiments in Hintermaier and Koeniger (2018) show that the changes in housing tenure that we find are by and large consistent with a calibrated life-cycle model that features a housing tenure choice and allows agents to accumulate wealth with an illiquid housing asset and a liquid financial asset. In such a model, the lower user cost of housing and the lower rent-to-price ratio, resulting from a fall in the real interest rate after a monetary policy shock as observed empirically in Table 4.3 of Section 4.3, induce a portfolio shift into owned housing for young age groups whereas the opposite is true for older age groups. Young households are more likely to be at the home-purchase margin whereas older households are more likely to be at the selling margin because of the usual tent-shaped wealth accumulation and decumulation pattern over the life cycle. Furthermore, the fall in the interest rate

[15] These effects are obtained by adding the coefficients of the monetary policy shock reported in the table at all lags and by multiplying by -0.25, given that we consider a shock of -25 basis points.

of (mortgage) debt is less relevant for older households because they are typically less leveraged.

To provide further evidence on the mechanism through which monetary policy shocks affect housing tenure choices, we show that the shocks indeed change rents, mortgage-interest payments, house prices and thus the rent-price ratio. In Section 4.6 we will show that an accommodative monetary policy shock (an unexpected decrease in the policy-rate) reduces both mortgage-interest payments and rental payments. The reduction of the interest rate after an accommodative monetary policy shock also triggers house-price increases that may induce some existing home owners to sell their homes, as they decumulate wealth towards the end of their life cycle. Table 4.7 shows that an unexpected decrease of the policy rate by 25 basis points increases house prices in Germany and Switzerland by $1.8 - 2.8$ percentage points.[16] The regression results for the different available price indexes in the respective columns of the table show that this result is robust for prices of different types of housing units.[17]

Table 4.7: *The effect of monetary policy shocks on house price growth*

	Germany			Switzerland	
	All dwellings	New-built	Existing	Flats	One-family houses
Monetary policy shock, sum Q(-1:-4)	-2.368	-2.781	-2.293	-4.654***	-3.046***
	(1.842)	(2.255)	(2.015)	(0.800)	(0.670)
Monetary policy shock, sum Q(-5:-8)	-0.755	-4.799**	-0.030	-2.467***	-2.746***
	(1.638)	(2.006)	(1.792)	(0.835)	(0.698)
Monetary policy shock, sum Q(-9:-12)	-5.403***	-3.563*	-5.742***	-0.830	-1.342*
	(1.518)	(1.858)	(1.661)	(0.807)	(0.675)
Observations	49	49	49	49	49
R^2	0.246	0.211	0.226	0.446	0.368
Effect of unexpected 25bps policy-rate cut	+2.13pp	+2.79pp	+2.02pp	+1.99pp	+1.78pp

Sources: BIS (Statistics, Property prices statistics, references *Q:DE:0:1:0:1:6:0*, *Q:DE:0:1:1:1:6:0*, *Q:DE:0:1:2:1:6:0*, *Q:CH:0:2:0:2:0:0*, *Q:CH:0:8:0:2:0:0*). *Notes:* *** p<0.01. Standard errors are reported in brackets. The table reports the coefficients of separate regressions for house price growth against the monetary policy shocks series and a constant. The quarterly house price indexes are not seasonally-adjusted. The dependent variable is year-on-year house price growth (in %). The cumulative effect over three years of a -25bps shock is obtained by multiplying the sum of the coefficients with -0.25.

[16] These effects are again obtained by adding the coefficients of the monetary policy shock at all lags and by multiplying by -0.25, given that we consider a shock of -25 basis points.

[17] Given that our household-level data sets do not contain precise information on the location of the household, we cannot match these data with information on local house prices to investigate this transmission channel in further detail. Changes of house prices at the coarse regional level do not help to explain housing-tenure decisions because there is a lot of heterogeneity in house-price dynamics within these regions.

After presenting the main results, we now provide further discussion of the estimation results in Table 4.6 for the effect of the monetary policy shocks on housing tenure. The point estimates of the coefficients for the lagged shocks indicate that, in Switzerland, the effect of the monetary policy shocks on housing tenure is strongest in the first year after the shock and then fades away. For Germany instead the effect seems most sizable at longer lags.

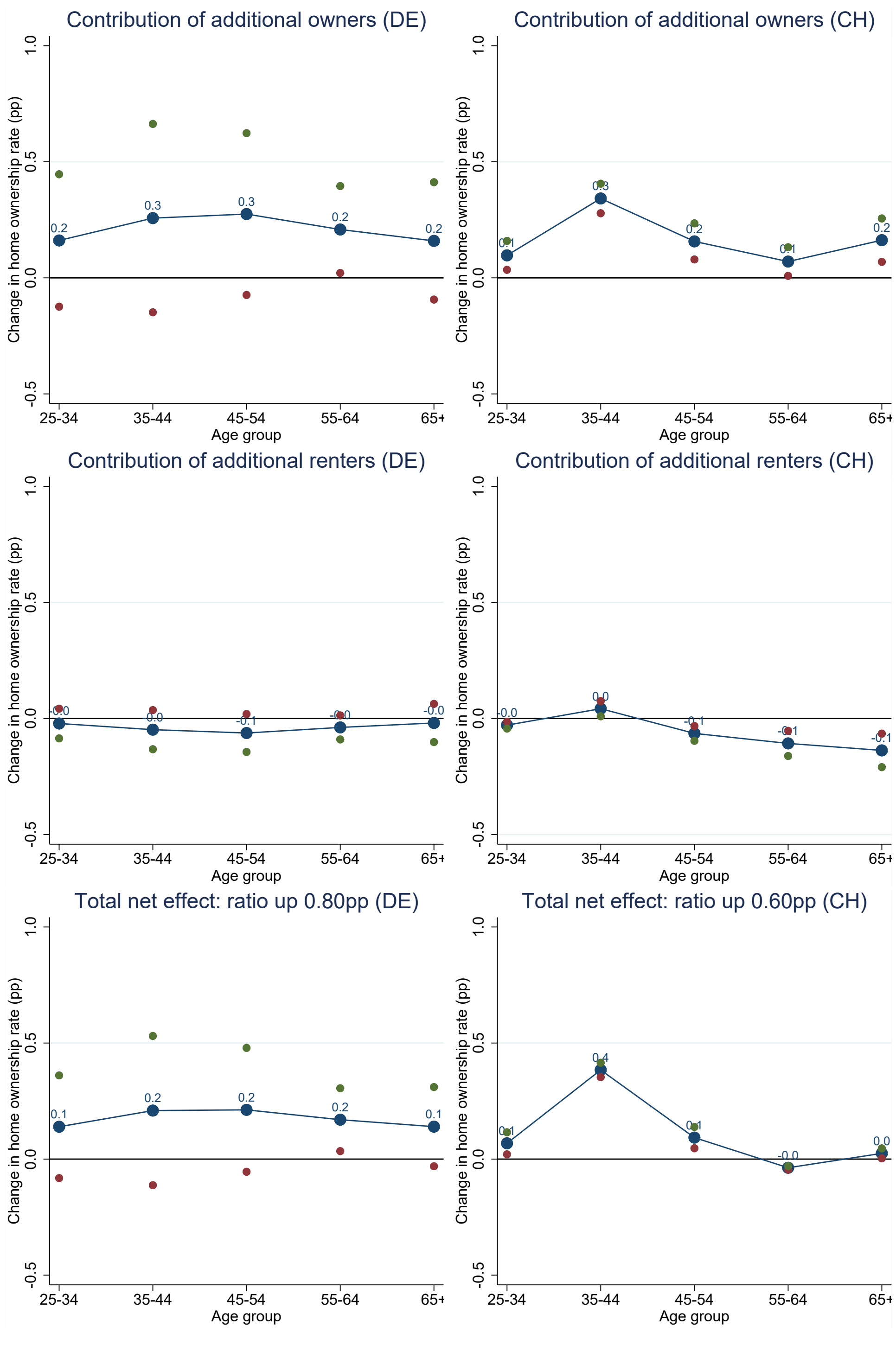
The estimates suggest that monetary policy shocks do not merely affect the timing of housing-tenure decisions over the life cycle of households but that they induce changes in housing tenure that would not have happened otherwise. If the shocks only shifted the timing, an increase in the transition probability from rental to owner occupation in the first year, for example, should be followed by a *de*crease in this transition probability at further lags. That is, some of the shocks with larger lags then should have a significant positive coefficient. Our results show that this is not the case, considering lags up to three years.[18]

We illustrate the extent to which the monetary policy shocks have heterogeneous effects across age groups. Figure 4.4 displays the unconditional effect of the monetary policy shocks on the home ownership rate by age group.[19] The figure shows that the net effect of a monetary policy shock on the home ownership rate is rather similar in both Germany and Switzerland. As shown in the bottom panel of Figure 4.4, an unexpected 25bps policy rate cut increases the home ownership rate by 0.8 and 0.6 percentage points in Germany and Switzerland, respectively. The decomposition in the top and middle panels of the figure shows how the effect of some renters becoming owners quantitatively dominates the effect of some owners becoming renters. The figure further reveals that the response of existing owners is more uniform across age groups in Germany than in Switzerland. In Switzerland, the response of the renters is offset by the response of owners for older households so that the net increase in home ownership is almost entirely driven by households with a head aged $35 - 44$.

Our findings point to substantial differences in monetary policy transmission in Germany and Switzerland compared with the U.S. and the U.K. Figure E.1 in Cloyne et al. (2017)

[18] Given our short sample period, we have checked robustness for specifications with lags up to six years. The results reported in Tables 4.18 and 4.19 in Appendix 4.8.3 show the robustness, in particular for the probability of becoming an owner which drives the net effect on home ownership in our results.

[19] The effects reported are obtained with the regression specifications reported in Table 4.6, augmented by interactions of the monetary policy shocks with dummies for each age group. Since the estimated changes in probabilities are conditional on housing-tenure status, we have to weigh the estimates for the respective age group with the fraction of renters or home owners in that age group. These weights are based on the distribution of 2014 which is representative for the whole sample period. The weights would be similar if we used the distribution for all sample years.



Notes: The results are based on the regression specification in Table 4.6, adding interaction dummies for age groups. The graphs show the cumulative effect (over three years) of a 25bps shock on the housing tenure choice (as in Table 4.6), using the age distribution for the representative year 2014 in the SOEP and SHP samples, respectively, together with the fractions of owners and renters in 2014. The top charts show the effect of additional owners on the home ownership rate and the middle charts show the effect of the additional renters. The bottom charts show the net effect, obtained by combining the two effects which are estimated independently. All charts show 95% confidence intervals, with the respective upper and lower bound depicted by the green and red dots.

Figure 4.4: *Effect of a -25bps shock on the home ownership rate*

shows that housing tenure does not respond significantly to monetary policy shocks in the U.S. and the U.K. Figure 5 in Wong (2018) displays that the adjustment of loans in the U.S. housing market, due to refinancing of mortgages and new purchases of homes, is larger for young households. We find instead that there is a significant response of housing tenure in Germany and Switzerland, that the response is rather homogenous across age groups in Germany, and that the response is stronger in Switzerland at the later ages $35 - 44$ than in Wong (2018). One reason for these differences may be that refinancing is much more costly and thus less common in Germany and Switzerland than in the U.S., as described in Section 4.2. Furthermore, differences in mortgage markets, tax incentives for home ownership, housing regulation and the resulting feedback to house prices imply differences in the characteristics of marginal home buyers and sellers in Germany and Switzerland compared with the U.S. and the U.K., as suggested by the evidence in Andrews and Sánchez (2011b) discussed in Section 4.2.

Our results indicate that monetary policy shocks also transmit to household debt in Germany and Switzerland, given that new home owners typically finance their housing purchases with a mortgage and new home owners tend to be more leveraged than existing home owners who have partly amortized their mortgage. Although highly policy relevant, lack of data unfortunately does not allow us to investigate whether monetary policy shocks have a quantitatively sizeable effect on household debt in Germany or Switzerland. If leverage affects the marginal propensity to consume, we will capture part of this transmission channel of monetary policy in our analysis of the consumption responses to the shocks that we perform in Section 4.6.

4.5.1 Robustness

Appendix 4.8.3 contains all the robustness checks for the main regression specification reported in Table 4.6.

Further control variables. – Tables 4.10 and 4.11 report results if we add further control variables where we repeat the results for the benchmark specification at the beginning of each subtable for convenience. The additional control variables increase the explained variation in terms of the R^2-statistic without substantially affecting the coefficient estimates. This result is to be expected if our constructed monetary policy shocks are exogenous and thus are true surprises. In this case, omitted variables are uncorrelated with the shocks and do not bias the coefficient estimates. We thus prefer the parsimonious specification reported in Table 4.6, in which we reduce the risk of possible biases resulting from adding possibly endogenous variables to a minimum, because our goal is not to maximize the explained variation to forecast housing tenure changes.

Non-linear probit and logit specifications. – Tables 4.12 and 4.13 show that the marginal effects of the monetary policy shocks are very similar in the non-linear probit and logit specifications compared with the benchmark OLS specification, which supports the linearity assumption in our benchmark specification.

Sample split into years before and after the financial crisis. – In Tables 4.14 and 4.15 we check the robustness if we split the sample in 2007 and thus before the large policy-rate shock which occurred during the financial crisis. The coefficient estimates are remarkably robust given the much smaller number of quarter-year observations which identify the coefficient estimates for the monetary policy shocks in the respective subsamples. The results suggest that the effect of monetary policy shocks on housing tenure are somewhat stronger before 2007.

Asymmetric effects of positive and negative monetary policy shocks? – Tables 4.16 and 4.17 provide some evidence that the effect of positive and negative monetary policy shocks is asymmetric in Germany but less so in Switzerland. The results also suggest, however, that the limited variation in the data makes it difficult to identify such possible differences.

More lags of the shocks and estimation of separate coefficients for lagged shocks in each quarter. – Tables 4.18 and 4.19 show that the estimated effect on housing tenure is qualitatively robust to adding lags for the shock up to six years. The effect on the probability of becoming an owner, which is the driver of the total effect of the shocks on housing tenure, becomes a bit larger.[20] Tables 4.20 and 4.21 show that separately estimating the coefficients of lagged monetary policy shocks for each quarter provides similar insights as the benchmark specification in which we cumulate the shocks by year. We thus prefer the more parsimonious specification as benchmark.

Higher-frequency shocks. – In Tables 4.22 and 4.23 we show that our findings are robust if we allow for different time windows around the monetary policy announcements to measure the shocks. Figures 4.8 to 4.10 show that also the age patterns of the effects are robust. As explained in more detail Section 4.3, we consider a six-hour time window around the announcements as in Corsetti et al. (2018), a time window that closes right at the end of the press conference, and a 30-minute time window starting 10 minutes before

[20]Note that in the second column of each subtable we report the results of the benchmark specification, estimated on the smaller sample required for the specification with more lags. The estimated coefficients for the benchmark specification are very similar for this smaller sample that starts in the year 2006Q1, given that the sample is constructed to estimate the effect of lagged shocks up to six years.

the announcement as in the analysis of Gertler and Karadi (2015) and Nakamura and Steinsson (2018) for the U.S. We find that the size of the shocks becomes smaller as we shorten the time window, and more so for Germany than for Switzerland. The monetary policy announcements seem to need some time to be reflected in prices of the futures so that the series of the shocks to the policy rate for shorter time windows resembles a scaled-down version of the shock series measured over longer time windows. As a result, the size of the coefficient estimates reported in Tables 4.22 and 4.23 increases in absolute size for the shorter time windows. This is particularly visible for the effects of the shocks on the probability that renters become owners. We view the benchmark time window of one day, between the end of the announcement day and the day before, as a reasonable compromise between capturing the full effect of the monetary policy announcement on the prices of futures and avoiding that other changes in that time window confound results.

Shocks conditional on stock market movements. – In Tables 4.24 and 4.25 we consider only monetary policy shocks that are negatively correlated with changes in the valuation of the stock market, as measured by the DAX and SMI, respectively. Jarociński and Karadi (2018) have argued that this reduces the bias resulting from confounding news shocks that may be associated with monetary policy announcements. We thus require that, for example, an accommodative shock, which unexpectedly lowers the interest rates, at the same time increases the stock-market valuation, as predicted by standard asset-pricing theory. If such a shock is associated with a decrease in stock-market valuation instead, we take this as a sign that the monetary policy announcement revealed also news about a worse economic outlook.

Given the possibility of such confounding news effects, we check the robustness of our results by discarding those shocks for which interest rate movements are positively correlated with the stock market. The results reported in Tables 4.24 and 4.25 show that, while some point estimates become larger in absolute terms in Switzerland, the overall pattern of the estimates remains unchanged both in Germany and Switzerland. The point estimates for the effect of policy rate shocks during the previous year increase by $30 - 50\%$, in absolute terms, for Switzerland. These larger estimates are consistent with the interpretation that confounding news shocks imply a downward bias for the housing tenure response to policy rate shocks.

4.6 Response of non-housing consumption

We use the HABE dataset, available for the time period 2001-2014 in Switzerland, to investigate the effect of the monetary policy shocks on consumption and other budget items that enter the budget constraint of households. This generates further insights into the transmission of monetary policy in countries with low home ownership rates.

We find that the transmission of shocks to consumption and labor income is rather similar across mortgagors and renters.[21] This differs from findings by Cloyne et al. (2017) and Wong (2018) for the U.S. and the U.K. that mortgagors react more strongly to monetary policy shocks than renters because mortgagors are more leveraged and thus have a higher marginal propensity to consume. The suggestive evidence in Appendix 4.8.5, further discussed below, suggests that, differently to the U.S. and the U.K., the financial situation and saving patterns of mortgagors and renters are very similar in Switzerland, consistent with a more similar marginal propensity to consume.

We now present the analysis in detail. The HABE contains information on durable and non-durable consumption, rental expenditures, mortgage interest payments and labor income. We construct a sample at the quarterly frequency using the information about the time of the interview of households. Appendix 4.8.7 contains further information on the sample and the variables.

Denoting membership in the group of mortgagors or renters with index g, we estimate the specification

$$\mathrm{y}_{igrqt} = \alpha + \left(\beta_0' + \beta_1' D_g\right)\mathbf{z}_{qt} + \gamma'\mathbf{x}_{igrqt} + D_g + D_r + D_q + D_t + \varepsilon_{igrqt},$$

where y_{igrqt} is the respective outcome variable of interest and, as before, the vector $\mathbf{z}_{qt}$ denotes the monetary policy shocks in the last three years, cumulated over quarters separately for each of the years. The vector $\mathbf{x}_{igrqt}$ contains control variables, which vary at the household level. In all of the regression specifications we control for effects by group D_g, quarter D_q and year D_t, and in robustness checks discussed below we also control for effects by region D_r.

We interact the monetary policy shocks with a group dummy D_g, which denotes whether a household has a mortgage on the primary residence, and also add the dummy for

[21] We eliminate outright home owners from our sample because this group is too small in Switzerland. Renters and mortgagors account for 52.5% and 44.1% of the sample, respectively, whereas outright owners only account for the remaining 3.4%.

mortgagors D_g separately in the specification to capture possible permanent differences across renters and mortgagors.[22] This specification allows us to investigate whether the transmission of monetary policy in Switzerland differs across mortgagors and renters in a similar way as reported in Cloyne et al. (2017) and Wong (2018) for the U.S. and the U.K.

In the benchmark specification reported in Table 4.8, we control for group, year and quarter dummies, and age. The coefficients of the monetary policy shocks are thus identified by the interaction of quarter and year effects and we cluster their standard errors at quarter-of-interview level. Although most of the responses to the shocks reported in Table 4.8 are not estimated precisely enough to be significant at the 10 percent level, the sign of the coefficients is as predicted by standard models: an accommodative monetary policy shock, i.e., a policy-rate cut, increases labor income and expenditure on non-durables and durables.

Table 4.8, column 3, further shows that an accommodative monetary policy shock lowers mortgage-interest payments. This confirms that a lower policy rate is passed through to the mortgage interest rate, as illustrated in Subsection 4.3.1.[23] The results in column 2 show that rental payments also decrease after a policy-rate cut, and significantly so. This is different than in the U.S. and the U.K. (see figure 9 in Cloyne et al., 2017), and is likely related to the explicit indexation of rents to the mortgage-interest rate in Switzerland (see the discussion in footnote 4, Section 4.2).

The size of the responses to labor income and consumption for an unexpected policy-rate cut of 25 basis points, reported in the last row of Table 4.8, is of the same order of magnitude as in the U.S. and the U.K. reported in Cloyne et al. (2017), where the noise in the estimation does not allow for more precise comparisons. Although our estimations do not reveal any significant differences between mortgagors and renters for the responses of labor income and consumption, Figure 4.5 shows that there are significant differences in the responses across age groups. The results in the figure reveal that the response of consumption and labor income is stronger and significant at the 5%-level for households with a head aged $55 - 64$. Furthermore, the response of durable consumption is significantly stronger, at the 1% level, than the response of non-durables for that age group. Figure

[22] In the regressions for rental payments and mortgage-interest payments, the sample contains only renters or mortgagors, respectively, so that no explicit control for group D_g is included in the regression specification.

[23] The coefficient estimates imply that the pass-through is less than full. The sum of the coefficients for the shocks at the lags up to three years is 0.14 whereas a full pass through would imply a total response of approximately 0.5. To see this, note that the unit of the shocks is in percent. Denoting the interest rate with r and debt with D, the derivative of $ln(rD)$ with respect to r then equals $1/(r \times 100)$, which, for $r = 0.02$, is equal to 0.5.

Table 4.8: *The effect of monetary policy shocks on income and expenditures*

	Labor income (logarithm)	Rental payments (logarithm)	Mortgage interest payments (logarithm)	Non-durable consumption (logarithm)	Durable consumption (logarithm)
Futures shock (3M): sum Q(-1:-4)	-0.051	0.092***	0.059	-0.033	-0.027
	(0.043)	(0.024)	(0.049)	(0.023)	(0.110)
Futures shock (3M): sum Q(-5:-8)	-0.021	0.030	0.068	-0.021	-0.013
	(0.037)	(0.018)	(0.043)	(0.025)	(0.096)
Futures shock (3M): sum Q(-9:-12)	-0.001	-0.005	0.013	-0.001	0.016
	(0.033)	(0.012)	(0.033)	(0.021)	(0.071)
Interaction mortgagors:					
Futures shock (3M): sum Q(-1:-4)	-0.000			0.018	-0.017
	(0.046)			(0.027)	(0.098)
Futures shock (3M): sum Q(-5:-8)	0.030			0.052*	-0.011
	(0.040)			(0.030)	(0.076)
Futures shock (3M): sum Q(-9:-12)	-0.044			-0.012	-0.146
	(0.033)			(0.030)	(0.097)
Age	8.954***	-0.474**	5.285***	1.715***	2.430***
	(0.662)	(0.191)	(0.693)	(0.163)	(0.480)
Age: squared	-10.990***	0.586***	-6.169***	-1.416***	-3.510***
	(0.780)	(0.196)	(0.663)	(0.165)	(0.477)
Dummy: mortgagors	0.087***			0.128***	0.474***
	(0.020)			(0.016)	(0.039)
Quarter dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	25630	16292	14515	30807	30807
R^2	0.046	0.018	0.051	0.047	0.051
Effect of unexpected 25bps policy-rate cut	1.8%	-2.9%	-3.5%	1.4%	0.6%

Notes: * p<0.10, ** p<0.05, *** p<0.01. Standard errors are reported in brackets. The dependent variables are expressed in units of prices in 2007Q4, adjusted for household size and in logarithms. Standard errors are clustered at the quarter of the interview because the monetary policy shock does not vary at the household level. Labor income regressions are based on a sample of households aged less than 65 years, the retirement age. Age is divided by 100. The effect of a policy-rate cut of 25bps, displayed in the last row of the table, is obtained by first cumulating the coefficients of the monetary policy shock for the lags of three years, without considering the interaction terms for mortgagors, and then multiplying by -0.25.

4.5 also shows that these effects are mitigated at the aggregate level by the responses of households with a head aged $35-44$ which are of opposite sign.

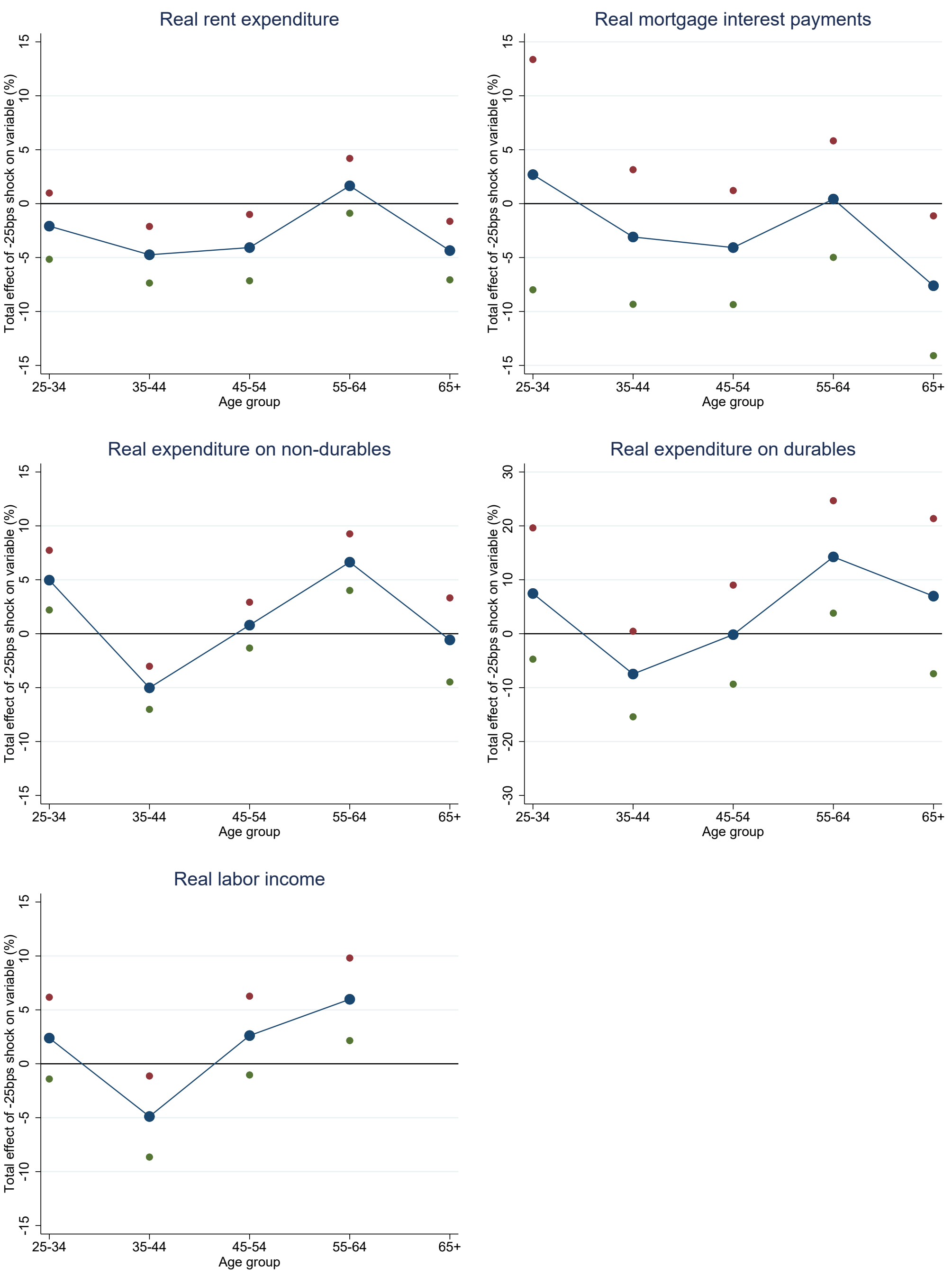
The finding that the responses of consumption and income are strongest at ages 55-64 in Switzerland differs from findings for the U.S. where young households respond most strongly to monetary policy shocks (Wong, 2018). The results in Figure 4.5 further show that the responses of rental expenditure and mortgage-interest payments in Switzerland are rather similar across age groups, and that the differences in the consumption responses across age groups seem to be driven by the differences in the responses of labor income. Thus, the effect of monetary policy shocks on labor income, emphasized in the literature (e.g., Cloyne et al., 2017 and Kaplan et al., 2018), also shapes monetary policy transmission in countries with low home ownership rates such as Switzerland.

In order to further understand why the responses of mortgagors and renters are more similar in Switzerland than in the U.S. and the U.K., we compare the saving rates and the financial situation of these groups. Figure 4.15 in Appendix 4.8.5 shows that the distribution of saving rates (abstracting from mortgage amortization) is very similar for renters and mortgagors, independent of whether they are younger than age 40 or not. Including amortization would imply that the saving rates are even larger for mortgagors than for renters. Le Blanc and Schmidt (2017) report similar results for Germany. This suggests that the marginal propensity to consume of mortgagors is not higher than for renters in Germany and Switzerland, which is an important difference to the U.S. or the U.K. where mortgagors are more likely to be wealthy hand-to-mouth households with a relatively higher marginal propensity to consume. This seems different in Germany and Switzerland. Indeed, as shown in Table 4.30 in Appendix 4.8.5, mortgagors and renters give very similar answers when asked about their financial situation in the HABE dataset.[24]

Given the recent interest in the effect of monetary policy shocks on inequality (e.g., Coibion et al., 2017), we report the response of consumption inequality to monetary policy shocks in Appendix 4.8.6. Figure 4.16 shows that consumption inequality has been quite stable during the sample period in Switzerland. For all three measure of consumption inequality reported in the appendix, we find that the consumption inequality observed in Switzerland is lower than in the U.S. but of similar size as in Germany.[25] Table 4.31 shows

[24]The HABE data do not contain further information on the balance sheets of mortgagors and renters.

[25]See Coibion et al. (2017), figure 1, for the U.S. and Fuchs-Schuendeln et al. (2010), figure 15, for Germany. Note that in Figure 4.16 in the appendix we report the differences in the logarithm of consumption at the 90th and 10th percentile for comparison with Coibion et al. (2017). And we report the ratio of consumption levels at the 50th and 10th percentile for comparison with Fuchs-Schuendeln et al. (2010). The ratio of consumption levels at the 90th percentile and 50th percentile can be obtained by applying the exponential operator to the values of the log differences.



Notes: The results are based on the regression specification in Table 4.8 without the dummy for mortgagors and its interactions with the shocks, adding interaction dummies for age groups. The graphs show the cumulative effect over three years (in %) of an unexpected 25bps policy-rate cut. All charts show 95% confidence intervals, with the respective upper and lower bound depicted by the green and red dots.

Figure 4.5: *Effect of a -25bps shock on expenditures and income*

that, differently to the U.S., monetary policy shocks in Switzerland do not significantly affect consumption inequality and there is no clear pattern in the point estimates of the responses across the specifications with the different considered measures of consumption inequality. Further research is needed to determine whether this is due to the relatively small sample size or because of the smaller heterogeneity in the financial situation of households in Switzerland compared with the U.S., as discussed above.

4.6.1 Robustness

Appendix 4.8.4 contains robustness checks for the main regression specification reported in Table 4.8. We performed a similar set of robustness checks as for the housing-tenure regression. Given that these checks did not yield any further substantial insights, beyond of what we stated for the robustness checks for the housing-tenure regression in Subsection 4.5.1, we only report results for a subset of these checks. Tables 4.26 to 4.29 show that the coefficient estimates are robust if we control for region effects and if we allow for additional interactions with the group dummy D_g for mortgagors. The coefficient estimates for the responses of labor income and non-durable consumption keep the same sign but decrease in size if the interactions are added.

Higher-frequency shocks. – Figures 4.11 to 4.13 show that the responses by age groups are robust if we allow for different time windows around the monetary policy announcements to measure the policy-rate shocks. As discussed in Subsection 4.5.1, the series of the shocks to the policy rate for shorter time windows resembles a scaled-down version of the shock series measured over longer time windows. Thus, the size of the effect of a 25 basis point cut of the policy rate tends to become larger across Figures 4.11 to 4.13 if the policy-rate shocks are measured for shorter time intervals.

Shocks conditional on stock market movements. – In Figure 4.14 we show that the results of our benchmark estimation, particularly the described patterns across age groups, remain robust if we consider only monetary policy shocks that are negatively correlated with movements in stock-market valuations, as suggested by Jarociński and Karadi (2018).

4.7 Conclusion

Our analysis has shown that monetary policy transmission differs across countries with different home ownership rates. Monetary policy shocks cause more adjustment in the housing market in Germany and Switzerland than in the U.S. and the U.K. We find that an accommodative shock of 25 basis points increases the home ownership rate by 0.8 and 0.6 percentage points in Germany and Switzerland, respectively. Furthermore, we find that consumption responses to monetary policy shocks are more homogenous across mortgagors and renters, and that the responses have a different pattern across age groups in Germany and Switzerland compared with the U.S. and the U.K.

Our empirical evidence shows that the effectiveness of monetary policy in stimulating consumption in Germany and Switzerland depends less on housing tenure because the financial situation is less heterogenous across mortgagors and renters than in the U.S. or the U.K. Responses to monetary policy shocks in the housing market itself are more relevant in Germany and Switzerland instead, suggesting that unintended effects of monetary policy on housing tenure choices are more important in countries with low home ownership.

Our results point to trade-offs caused by differences in home ownership within a currency union, given that monetary policy is then common across member countries or regions in which the policy transmission differs. For further analysis of these trade-offs, more quantitative work is needed at the micro level to better understand the mechanisms through which monetary policy affects the housing market and consumption. Our findings suggest that such work has to consider that insights about the transmission of monetary policy obtained for a certain country are not easily transferrable to another country if household balance sheets differ, for example due to differences in home ownership rates.

4.8 Appendix

4.8.1 Correlation of monetary policy shocks over time

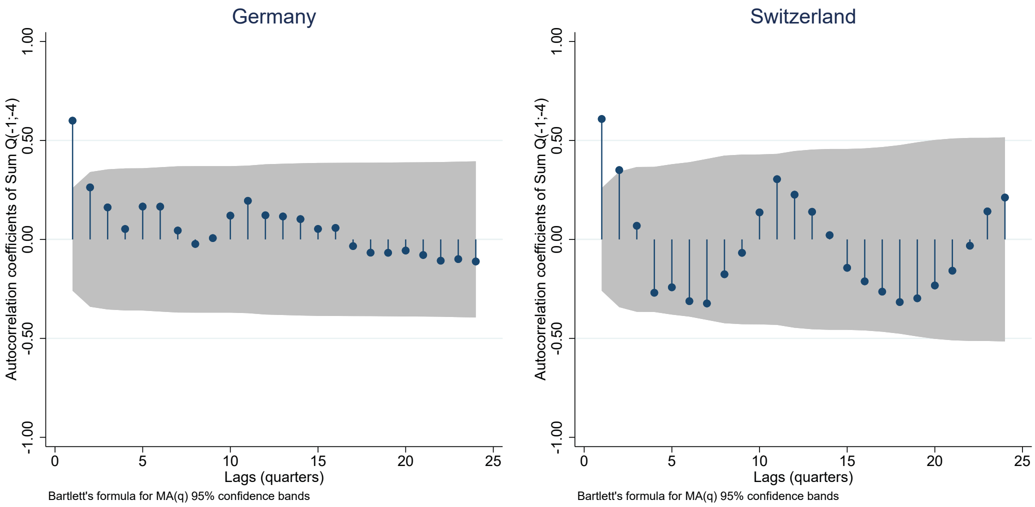
In this appendix we check whether the constructed monetary policy shocks are true shocks and thus not predictable by past values of the shocks. As mentioned in Section 4.3, private information of the monetary policy maker may introduce some persistence in our constructed series of shocks. Table 4.9 reports results of regressions of the monetary policy shocks on their lagged values. Columns 1 and 5 show results for regressions of the current quarterly shock on its past values for Germany and Switzerland, respectively. Columns 2-4 and columns 6-8 show regression results for the cumulated shock series where we check whether future shocks can be predicted by past values at different horizons. As mentioned in the main text in Section 4.3, the results by and large support that our constructed series of the shocks are not predictable by past values and thus are true shocks.

In our main regression specifications, we cumulate shocks for every year. Figure 4.6 shows that for these moving sums of the shocks, the autocorrelations are not significant beyond a quarter. Hence, multicollinearity of the lagged shocks in the regressions is not a concern.

Table 4.9: *Regressions of current and future monetary policy shocks on past shocks*

	Germany				**Switzerland**			
	Current shock	Sum Q(+1,+4)	Sum Q(+5,+8)	Sum Q(+9,+12)	Current shock	Sum Q(+1,+4)	Sum Q(+5,+8)	Sum Q(+9,+12)
Monetary policy shock, Q(-1)	-0.055				-0.093			
	(0.137)				(0.141)			
Monetary policy shock, Q(-2)	-0.339**				-0.128			
	(0.137)				(0.141)			
Monetary policy shock, Q(-3)	-0.019				-0.015			
	(0.120)				(0.142)			
Monetary policy shock, Q(-4)	-0.014				-0.110			
	(0.119)				(0.130)			
Monetary policy shock, sum Q(-1:-4)		0.044	-0.177	0.149		-0.343*	-0.096	-0.151
		(0.145)	(0.135)	(0.148)		(0.172)	(0.186)	(0.179)
Monetary policy shock, sum Q(-5:-8)		0.010	0.125	-0.079		-0.131	0.003	-0.618***
		(0.129)	(0.123)	(0.136)		(0.182)	(0.196)	(0.187)
Monetary policy shock, sum Q(-9:-12)		0.134	-0.041	-0.033		0.060	-0.355*	-0.462**
		(0.122)	(0.116)	(0.130)		(0.172)	(0.179)	(0.171)
Observations	57	45	41	37	57	45	41	37
R^2	0.113	0.031	0.063	0.039	0.033	0.122	0.123	0.295

Notes: * p<0.10, ** p<0.05, *** p<0.01. Standard errors in brackets. Dependent variables are indicated at the top of the respective columns. All regressions include a constant. *Current shock* refers to the sum of the shocks that take place in a given quarter. *Sum Q(+1,+4)* denotes shocks cumulated over the next four quarters.

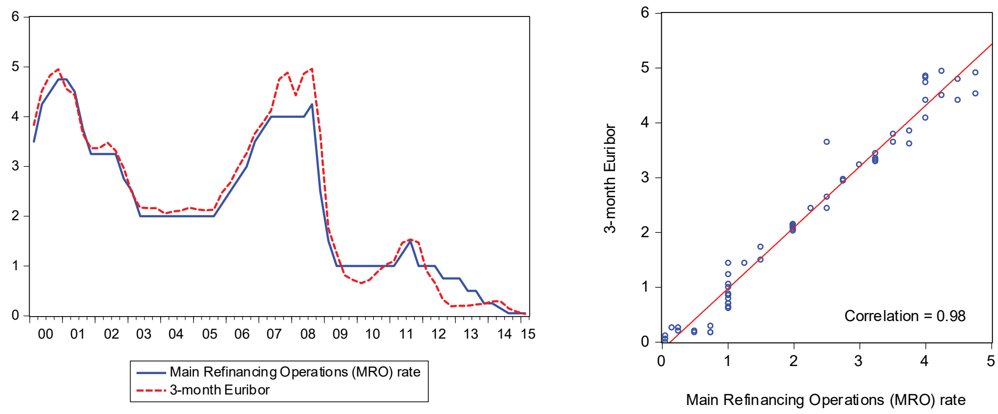


Notes: Correlograms of the moving sum of the quarterly shocks cumulated over a year.

Figure 4.6: *Correlograms of the cumulated shock series*

4.8.2 Correlation of Euribor with rate on main refinancing operations

This appendix provides evidence in Figure 4.7 that the three-month Euribor is highly correlated with the midpoint of the ECB policy rates, the rate on the main refinancing operations. This correlation is of interest, as mentioned in Section 4.3, because futures, which we use to identify monetary policy shocks, are not available for the ECB policy rates but are available for the Euribor.



Sources: Short-term rates from ECB (Statistical Data Warehouse, Table *ECB/Eurosystem policy and exchange rates*, Subtable *Official interest rates*). Both series contain end of quarter values.

Figure 4.7: *Euribor and MRO rates*

4.8.3 Robustness results for housing tenure

More control variables

Table 4.10: *Regression output: housing tenure status changes in Germany*

	Probability in Germany: from renting to owning			**Probability in Germany: from owning to renting**		
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.012	-0.012	-0.008	-0.008	-0.007
Monetary policy shock, sum Q(-5:-8)	-0.021	-0.018	-0.019	-0.014**	-0.013**	-0.012*
Monetary policy shock, sum Q(-9:-12)	-0.040**	-0.037**	-0.033**	0.003	0.003	0.003
Age (reference person)	-0.000	-0.000	-0.002***	-0.004***	-0.004***	-0.004***
Age squared	-0.005	-0.009	0.175***	0.364***	0.374***	0.306***
Household size (persons)			-0.001			-0.002***
Number of children			0.007***			-0.001*
Married			0.012***			-0.016***
In a couple			0.014***			-0.003
Working			0.003			-0.000
Years of education			0.001***			-0.001***
Gender			-0.004**			-0.002*
German citizenship			0.016***			-0.007**
Gross income (household)			0.463***			-0.014
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Region dummies	No	Yes	Yes	No	Yes	Yes
Observations	66267	66267	66267	70451	70451	70451
R^2	0.003	0.006	0.021	0.004	0.004	0.011

Notes: * p<0.10, ** p<0.05, *** p<0.01. The dependent variables are the probabilities of switching housing tenure status. Standard errors are clustered at quarter-of-interview. Individual characteristics refer to the household's reference person. Age is divided by 100 and household gross income by one million to display their coefficients conveniently in the table.

Table 4.11: *Regression output: housing tenure status changes in Switzerland*

	Probability in Switzerland: from renting to owning			Probability in Switzerland: from owning to renting		
Monetary policy shock, sum Q(-1:-4)	-0.037***	-0.037***	-0.033***	-0.022***	-0.022***	-0.024***
Monetary policy shock, sum Q(-5:-8)	-0.020***	-0.019***	-0.017***	-0.007**	-0.007***	-0.012***
Monetary policy shock, sum Q(-9:-12)	-0.008***	-0.008***	-0.006**	0.001	0.001	-0.001
Age (reference person)	0.119**	0.128**	0.051	-0.526***	-0.523***	-0.559***
Age squared	-0.174***	-0.181***	-0.069	0.461***	0.458***	0.439***
Household size (persons)			0.005			-0.002*
Number of children			0.002			-0.006***
Married			0.007			-0.017***
In a couple			0.011**			-0.006
Working			-0.006			-0.001
Years of education			0.002***			0.000
Received a wealth transfer			0.058***			0.013**
Gender			-0.004			-0.000
Swiss citizenship			0.009**			0.002
Gross income (household)			0.190***			-0.019***
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Region dummies	No	Yes	Yes	No	Yes	Yes
Observations	19485	19485	19485	21152	21152	21152
R^2	0.006	0.009	0.027	0.007	0.007	0.018

Notes: See Table 4.10.

Probit and Logit specifications

Table 4.12: *Marginal effects: housing tenure status changes in Germany*

	Probability in Germany: from renting to owning			**Probability in Germany: from owning to renting**		
	OLS	Probit	Logit	OLS	Probit	Logit
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.010	-0.011	-0.008	-0.006	-0.007
Monetary policy shock, sum Q(-5:-8)	-0.021	-0.013	-0.013	-0.014**	-0.011**	-0.011**
Monetary policy shock, sum Q(-9:-12)	-0.040**	-0.031***	-0.030***	0.003	0.004	0.004
Observations	66267	66267	66267	70451	70451	70451

Notes: * p<0.10, ** p<0.05, *** p<0.01. The dependent variables are the probabilities of switching housing tenure status. Standard errors are clustered at quarter-of-interview. The marginal effects are computed at the mean based on the benchmark regression specification in Table 4.6, which includes quarter and year dummies as well as controls for age and age squared. For the computation of the marginal effects in the logit and probit specifications, we set monetary policy shocks to zero which is the approximate value of the shocks' mean.

Table 4.13: *Marginal effects: housing tenure status changes in Switzerland*

	Probability in Switzerland: from renting to owning			**Probability in Switzerland: from owning to renting**		
	OLS	Probit	Logit	OLS	Probit	Logit
Monetary policy shock, sum Q(-1:-4)	-0.037***	-0.032***	-0.030***	-0.022***	-0.020***	-0.018***
Monetary policy shock, sum Q(-5:-8)	-0.020***	-0.016***	-0.015***	-0.007**	-0.004	-0.003
Monetary policy shock, sum Q(-9:-12)	-0.008***	-0.005**	-0.004	0.001	0.002	0.003
Observations	19485	19472	19472	21152	21145	21145

Notes: See Table 4.12. For Switzerland, the probit and logit models are estimated without observations for households interviewed in 2015Q1. Only a few households have been interviewed in this last quarter of our sample and none of them switched tenure. Thus, including households interviewed in 2015Q1 would create identification problems in the probit and logit models for a binary outcome variable, given that our estimated specification includes dummies for each quarter. The results of the OLS regressions with a continuous outcome variable are robust to including households in quarter 2015Q1.

Sample splits into years before and after the financial crisis

Table 4.14: *Regression output: housing tenure status changes in Germany*

	Probability in Germany: from renting to owning			Probability in Germany: from owning to renting		
	Full sample	Year < 2007	Year ≥ 2007	Full sample	Year < 2007	Year ≥ 2007
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.122***	-0.018	-0.008	-0.008	-0.008
Monetary policy shock, sum Q(-5:-8)	-0.021	0.020	-0.047**	-0.014**	-0.021***	-0.012
Monetary policy shock, sum Q(-9:-12)	-0.040**	-0.026	-0.045***	0.003	0.015***	-0.005
Age (reference person)	-0.000	-0.001	-0.000	-0.004***	-0.005***	-0.004***
Age squared	-0.005	0.051	-0.029	0.364***	0.445***	0.337***
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	66267	19046	47221	70451	20184	50267
R^2	0.003	0.003	0.003	0.004	0.005	0.003

Notes: * p<0.10, ** p<0.05, *** p<0.01. The dependent variables are the probabilities of switching housing tenure status. Standard errors are clustered at quarter-of-interview. Age is divided by 100.

Table 4.15: *Regression output: housing tenure status changes in Switzerland*

	Probability in Switzerland: from renting to owning			Probability in Switzerland: from owning to renting		
	Full sample	Year < 2007	Year ≥ 2007	Full sample	Year < 2007	Year ≥ 2007
Monetary policy shock, sum Q(-1:-4)	-0.037***	-0.323**	-0.038***	-0.022***	-0.097	-0.020***
Monetary policy shock, sum Q(-5:-8)	-0.020***	-0.150*	-0.023***	-0.007**	-0.040	-0.006**
Monetary policy shock, sum Q(-9:-12)	-0.008***	-0.098***	-0.006**	0.001	0.007	-0.001
Age (reference person)	0.119**	0.196	0.092*	-0.526***	-0.607***	-0.511***
Age squared	-0.174***	-0.245*	-0.151***	0.461***	0.553***	0.441***
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19485	5662	13823	21152	5207	15945
R^2	0.006	0.005	0.006	0.007	0.007	0.008

Notes: See Table 4.14.

Allowing for asymmetric effects of positive and negative shocks

Table 4.16: *Regression output: housing tenure status changes in Germany*

	Probability in Germany: from renting to owning		**Probability in Germany: from owning to renting**	
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.066**	-0.008	0.005
Monetary policy shock, sum Q(-5:-8)	-0.021	0.009	-0.014**	-0.016***
Monetary policy shock, sum Q(-9:-12)	-0.040**	-0.056**	0.003	0.014***
Interaction Q(-1;-4): negative shocks		0.104***		-0.025**
Interaction Q(-5;-8): negative shocks		-0.046		-0.003
Interaction Q(-9;-12): negative shocks		0.048		-0.032***
Age (reference person)	-0.000	-0.000	-0.004***	-0.004***
Age squared	-0.005	-0.005	0.364***	0.363***
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Observations	66267	66267	70451	70451
R^2	0.003	0.003	0.004	0.004

Notes: * p<0.10, ** p<0.05, *** p<0.01. The dependent variables are the probabilities of switching housing tenure status. Standard errors are clustered at quarter-of-interview. Age is divided by 100. For the effect of negative monetary policy shocks, the coefficient of the respective interaction terms has to be added to the base coefficient to obtain the total effect.

Table 4.17: *Regression output: housing tenure status changes in Switzerland*

	Probability in Switzerland: from renting to owning		**Probability in Switzerland: from owning to renting**	
Monetary policy shock, sum Q(-1:-4)	-0.037***	0.169	-0.022***	-0.016
Monetary policy shock, sum Q(-5:-8)	-0.020***	-0.111	-0.007**	0.176
Monetary policy shock, sum Q(-9:-12)	-0.008***	-0.039	0.001	-0.202*
Interaction Q(-1;-4): negative shocks		-0.216		-0.008
Interaction Q(-5;-8): negative shocks		0.109		-0.184
Interaction Q(-9;-12): negative shocks		0.024		0.234*
Age (reference person)	0.118**	0.118**	-0.526***	-0.526***
Age squared	-0.174***	-0.174***	0.461***	0.461***
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Observations	19485	19485	21152	21152
R^2	0.006	0.006	0.007	0.007

Notes: See Table 4.16.

Allowing for more lags of the shocks

Table 4.18: *Regression output: housing tenure status changes in Germany*

	Probability in Germany: from renting to owning			Probability in Germany: from owning to renting		
	Full sample	2006Q1+	2006Q1+	Full sample	2006Q1+	2006Q1+
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.019	-0.033	-0.008	-0.008	0.001
Monetary policy shock, sum Q(-5:-8)	-0.021	-0.047**	-0.083***	-0.014**	-0.011	0.009
Monetary policy shock, sum Q(-9:-12)	-0.040**	-0.044***	-0.080***	0.003	-0.004	0.020*
Monetary policy shock, sum Q(-13:-16)			-0.031			0.025***
Monetary policy shock, sum Q(-17:-20)			-0.045**			0.021***
Monetary policy shock, sum Q(-21:-24)			-0.015			0.008*
Age (reference person)	-0.000	0.000	0.000	-0.004***	-0.004***	-0.004***
Age squared	-0.005	-0.038	-0.037	0.364***	0.342***	0.341***
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	66267	51641	51641	70451	55102	55102
R^2	0.003	0.003	0.003	0.004	0.003	0.003

Notes: See Table 4.16.

Table 4.19: *Regression output: housing tenure status changes in Switzerland*

	Probability in Switzerland: from renting to owning			Probability in Switzerland: from owning to renting		
	Full sample	2006Q1+	2006Q1+	Full sample	2006Q1+	2006Q1+
Monetary policy shock, sum Q(-1:-4)	-0.037***	-0.038***	-0.045***	-0.022***	-0.021***	-0.020***
Monetary policy shock, sum Q(-5:-8)	-0.020***	-0.023***	-0.037***	-0.007**	-0.007**	-0.000
Monetary policy shock, sum Q(-9:-12)	-0.008***	-0.007**	-0.030***	0.001	-0.001	0.009
Monetary policy shock, sum Q(-13:-16)			-0.026***			0.019*
Monetary policy shock, sum Q(-17:-20)			-0.048**			0.002
Monetary policy shock, sum Q(-21:-24)			0.010			-0.041
Age (reference person)	0.119**	0.104**	0.103**	-0.526***	-0.511***	-0.511***
Age squared	-0.174***	-0.158***	-0.157***	0.461***	0.444***	0.444***
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19485	15411	15411	21152	17470	17470
R^2	0.006	0.006	0.006	0.007	0.007	0.007

Notes: See Table 4.16.

Allowing for separate coefficients of lagged shocks in each quarter

Table 4.20: *Regression output: housing tenure status changes in Germany, using quarterly shocks*

	Probability in Germany: from renting to owning		Probability in Germany: from owning to renting	
Monetary policy shock, sum Q(-1:-4)	-0.014		-0.008	
Monetary policy shock, sum Q(-5:-8)	-0.021		-0.014**	
Monetary policy shock, sum Q(-9:-12)	-0.040**		0.003	
Monetary policy shock, Q(-1)		-0.054*		0.002
Monetary policy shock, Q(-2)		-0.075		-0.003
Monetary policy shock, Q(-3)		-0.063		0.003
Monetary policy shock, Q(-4)		-0.054		-0.012
Monetary policy shock, Q(-5)		-0.049		-0.009
Monetary policy shock, Q(-6)		-0.010		-0.012
Monetary policy shock, Q(-7)		-0.029		-0.014
Monetary policy shock, Q(-8)		-0.012		-0.013
Monetary policy shock, Q(-9)		-0.038		0.018
Monetary policy shock, Q(-10)		-0.052		0.027**
Monetary policy shock, Q(-11)		-0.055*		0.006
Monetary policy shock, Q(-12)		-0.035		0.006
Age (reference person)	-0.000	-0.000	-0.004***	-0.004***
Age squared	-0.005	-0.006	0.364***	0.361***
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Observations	66267	66267	70451	70451
R^2	0.003	0.003	0.004	0.004

Notes: See Table 4.14.

Table 4.21: *Regression output: housing tenure status changes in Switzerland, using quarterly shocks*

	Probability in Switzerland: from renting to owning		**Probability in Switzerland: from owning to renting**	
Monetary policy shock, sum Q(-1:-4)	-0.037***		-0.022***	
Monetary policy shock, sum Q(-5:-8)	-0.020***		-0.007**	
Monetary policy shock, sum Q(-9:-12)	-0.008***		0.001	
Monetary policy shock, Q(-1)		-0.084**		-0.117
Monetary policy shock, Q(-2)		0.060		-0.142
Monetary policy shock, Q(-3)		-0.008		-0.064
Monetary policy shock, Q(-4)		-0.006		-0.054
Monetary policy shock, Q(-5)		-0.018		-0.044
Monetary policy shock, Q(-6)		0.026		-0.035
Monetary policy shock, Q(-7)		-0.010		-0.239
Monetary policy shock, Q(-8)		-0.018		-0.238
Monetary policy shock, Q(-9)		-0.013		-0.260
Monetary policy shock, Q(-10)		0.003		-0.106
Monetary policy shock, Q(-11)		0.005		-0.066
Monetary policy shock, Q(-12)		0.011		-0.007
Age (reference person)	0.118**	0.119**	-0.526***	-0.524***
Age squared	-0.174***	-0.175***	0.461***	0.459***
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Observations	19485	19485	21152	21152
R^2	0.006	0.006	0.007	0.008

Notes: See Table 4.14.

Robustness results for narrower time windows around monetary policy announcements

Table 4.22: *Regression output: housing tenure status changes in Germany*

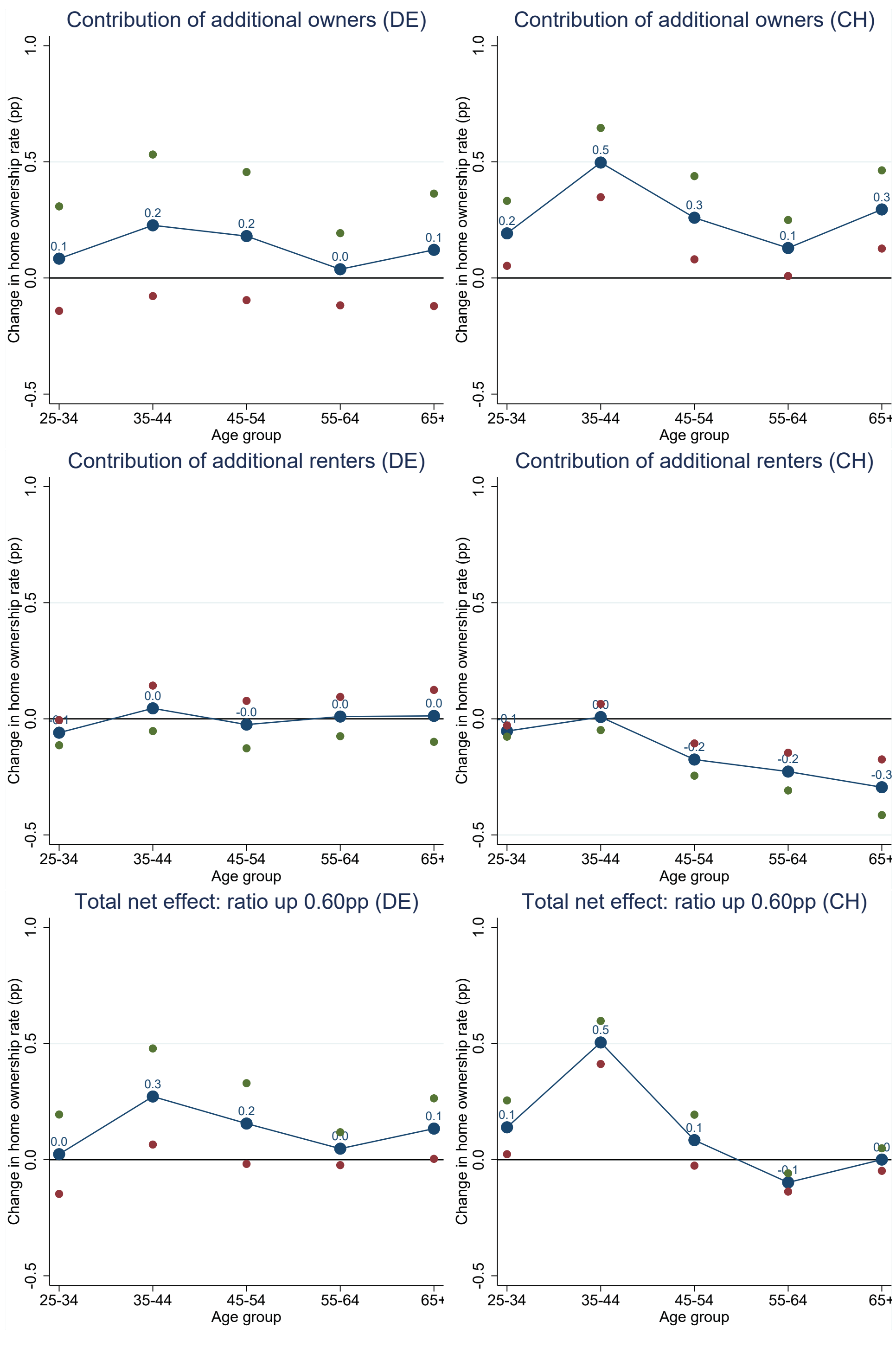
	Probability in Germany: from renting to owning				Probability in Germany: from owning to renting			
	Benchmark window	Six-hour window	Press conference window	30-minute window	Benchmark window	Six-hour window	Press conference window	30-minute window
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.014	-0.008	-0.091	-0.008	-0.001	-0.002	-0.008
Monetary policy shock, sum Q(-5:-8)	-0.021	-0.019	-0.007	-0.188***	-0.014**	-0.003	0.001	0.029
Monetary policy shock, sum Q(-9:-12)	-0.040**	-0.015	-0.013	-0.122	0.003	0.000	0.003	0.036
Age (reference person)	-0.000	-0.000	-0.000	-0.000	-0.004***	-0.004***	-0.004***	-0.004***
Age squared	-0.005	-0.004	-0.004	-0.005	0.364***	0.365***	0.365***	0.365***
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	66267	66267	66267	66267	70451	70451	70451	70451
R^2	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004

Notes: See Table 4.14. The six-hour window starts 45 minutes before the announcement and stops 6 hours later. The press conference window starts 45 minutes before the announcement and stops at the end of the press conference. The 30-minute window starts 10 minutes before the announcement and stops 20 minutes after.

Table 4.23: *Regression output: housing tenure status changes in Switzerland*

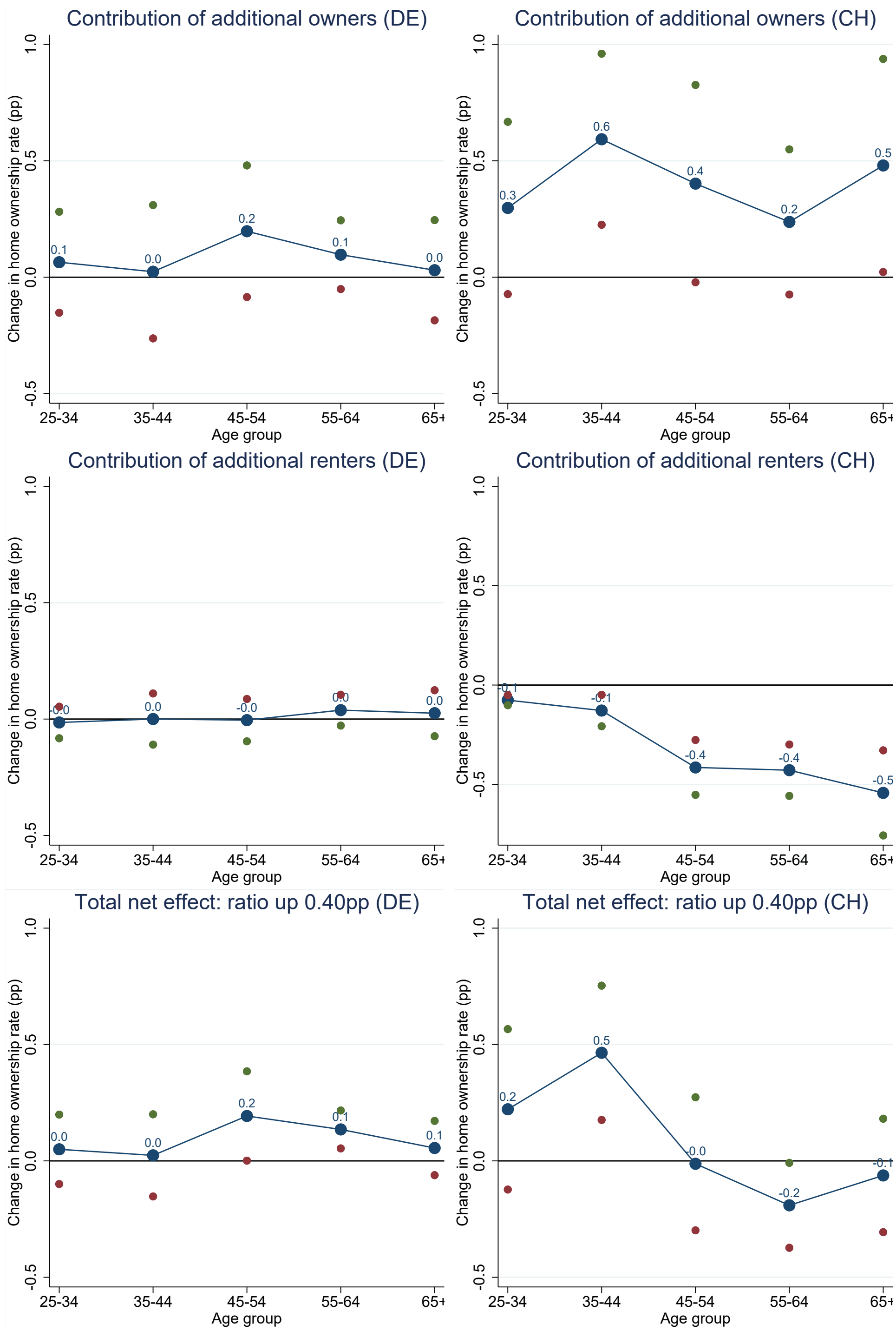
	Probability in Switzerland: from renting to owning				Probability in Switzerland: from owning to renting			
	Benchmark window	Six-hour window	Press conference window	30-minute window	Benchmark window	Six-hour window	Press conference window	30-minute window
Monetary policy shock, sum Q(-1:-4)	-0.037***	-0.056***	-0.097***	-0.110***	-0.022***	-0.041***	-0.079***	-0.104***
Monetary policy shock, sum Q(-5:-8)	-0.020***	-0.040***	-0.036	-0.062	-0.007**	-0.028***	-0.064***	-0.049***
Monetary policy shock, sum Q(-9:-12)	-0.008***	-0.011	-0.029	-0.031	0.001	-0.002	-0.011	-0.011
Age (reference person)	0.119**	0.119**	0.120**	0.119**	-0.526***	-0.526***	-0.525***	-0.525***
Age squared	-0.174***	-0.174***	-0.175***	-0.175***	0.461***	0.461***	0.460***	0.460***
Quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19485	19485	19485	19485	21152	21152	21152	21152
R^2	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.007

Notes: See Table 4.14. The six-hour window starts 45 minutes before the announcement and stops 6 hours later. The press conference window starts 45 minutes before the announcement and stops either at the end of the announcement or at the end of the press conference (when there is one). The 30-minute window starts 10 minutes before the announcement and stops 20 minutes after.



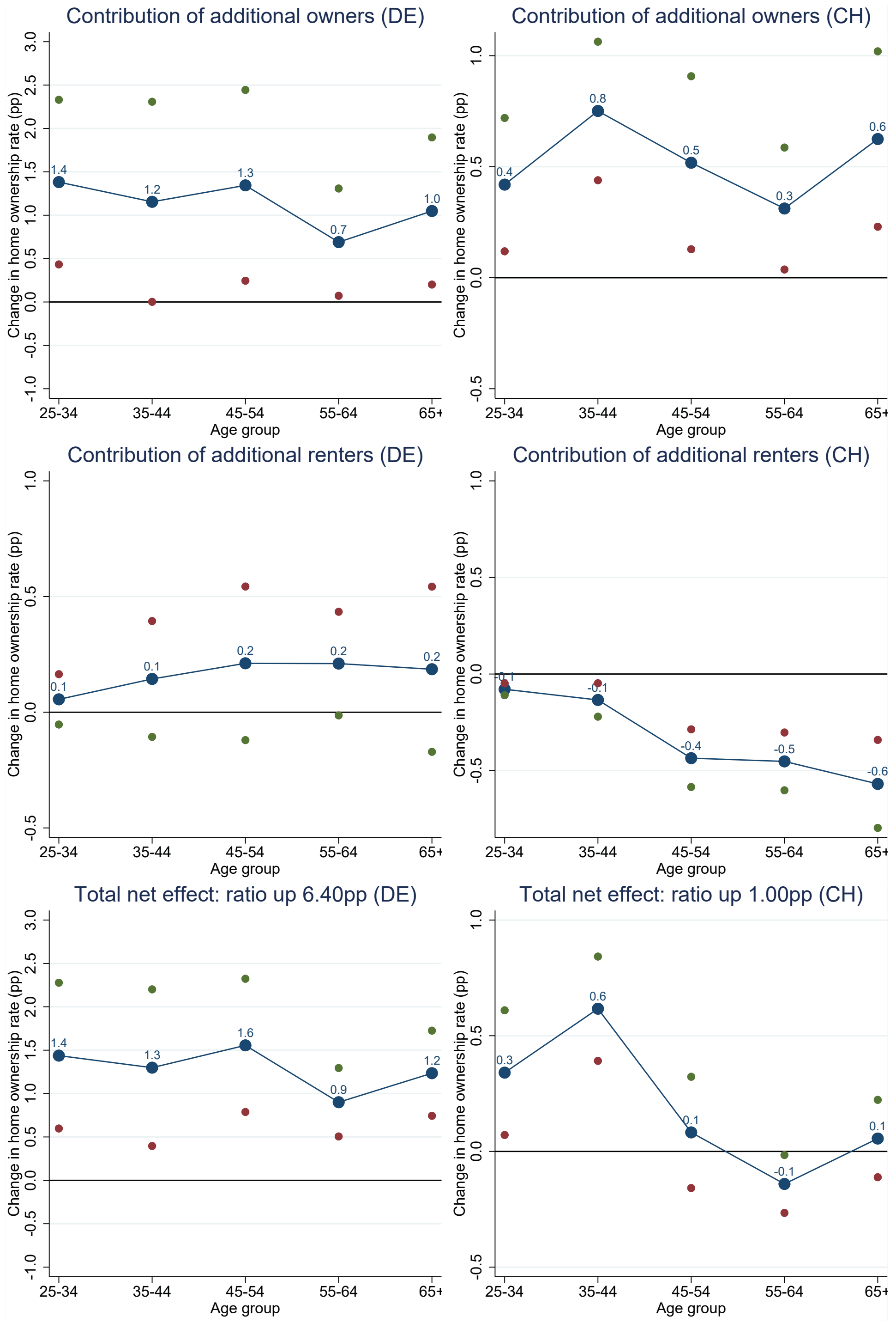
Notes: The results are based on the regression specification in Tables 4.22 and 4.23 using the six-hour window shocks, adding interaction dummies for age groups. The graphs show the cumulative effect (over three years) of a 25bps shock on the housing tenure choice (as computed in Table 4.6), using the age distribution for the representative year 2014 in the SOEP and SHP samples, respectively, together with the fractions of owners and renters in 2014. The top charts show the effect of additional owners on the home ownership rate and the middle charts show the effect of the additional renters. The bottom charts show the net effect, obtained by combining the two effects which are estimated independently. All charts show 95% confidence intervals, with the respective upper and lower bound depicted by the green and red dots.

Figure 4.8: *Six-hour window: effect of a -25bps shock on the home ownership rate*



Notes: The results are based on the regression specification in Tables 4.22 and 4.23 using the press-conference window shocks, adding interaction dummies for age groups. See also the further notes to Figure 4.8.

Figure 4.9: *Press-conference window: effect of a -25bps shock on the home ownership rate*



Notes: The results are based on the regression specification in Table 4.6 using the 30-minute window shocks, adding interaction dummies for age groups. See also the further notes to Figure 4.8.

Figure 4.10: *30-minute window: effect of a -25bps shock on the home ownership rate*

Robustness results for shocks that are negatively correlated with the response of the stock market

Table 4.24: *Regression output: housing tenure status changes in Germany*

	Probability in Germany: from renting to owning		**Probability in Germany: from owning to renting**	
	Benchmark	Conditional on changes of stock market	Benchmark	Conditional on changes of stock market
Monetary policy shock, sum Q(-1:-4)	-0.014	-0.022	-0.008	-0.010*
Monetary policy shock, sum Q(-5:-8)	-0.021	-0.011	-0.014**	-0.021***
Monetary policy shock, sum Q(-9:-12)	-0.040**	-0.033*	0.003	-0.009*
Age (reference person)	-0.000	-0.000	-0.004***	-0.004***
Age squared	-0.005	-0.005	0.364***	0.363***
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Observations	66267	66267	70451	70451
R^2	0.003	0.003	0.004	0.004

Notes: See Table 4.14. The shocks conditional on stock market movements only consider announcements days on which the changes of the policy rate and the valuation of the stock market are negatively correlated. For Germany, this decreases the number of announcements from 207 to 98.

Table 4.25: *Regression output: housing tenure status changes in Switzerland*

	Probability in Switzerland: from renting to owning		**Probability in Switzerland: from owning to renting**	
	Benchmark	Conditional on changes of stock market	Benchmark	Conditional on changes of stock market
Monetary policy shock, sum Q(-1:-4)	-0.037***	-0.049***	-0.022***	-0.033***
Monetary policy shock, sum Q(-5:-8)	-0.020***	-0.021***	-0.007**	-0.010**
Monetary policy shock, sum Q(-9:-12)	-0.008***	-0.007	0.001	0.001
Age (reference person)	0.119**	0.118**	-0.526***	-0.526***
Age squared	-0.174***	-0.174***	0.461***	0.461***
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Observations	19485	19485	21152	21152
R^2	0.006	0.006	0.007	0.007

Notes: See Table 4.14. The shocks conditional on stock market movements only consider announcements days on which the changes of the policy rate and the valuation of the stock market are negatively correlated. For Switzerland, this decreases the number of announcements from 75 to 30.

4.8.4 Robustness results for regressions based on the HABE dataset

More control variables

Table 4.26: *Regression output: labor income*

	Labor income (logarithm)		
	(1)	(2)	(3)
Futures shock (3M): sum Q(-1:-4)	-0.051	-0.042	-0.007
Futures shock (3M): sum Q(-5:-8)	-0.021	-0.015	-0.012
Futures shock (3M): sum Q(-9:-12)	-0.001	0.003	0.019
Interaction mortgagors:			
Futures shock (3M): sum Q(-1:-4)	-0.000	0.001	-0.069
Futures shock (3M): sum Q(-5:-8)	0.030	0.040	0.035
Futures shock (3M): sum Q(-9:-12)	-0.044	-0.041	-0.068
Age	8.954***	9.021***	9.056***
Age: squared	-10.990***	-11.082***	-11.127***
Dummy: mortgagors	0.087***	0.108***	0.105
Quarter dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Regional dummies	No	Yes	Yes
Year dummies, interacted with mortgagors	No	No	Yes
Quarter dummies, interacted with mortgagors	No	No	Yes
Regional dummies, interacted with mortgagors	No	No	Yes
Observations	25630	25630	25630
R^2	0.046	0.056	0.057

Notes: See Table 4.8. Regional dummies control for location in the seven Swiss regions.

Table 4.27: *Regression output: housing expenditure*

	Rent payments (logarithm)		Mortgage interest payments (logarithm)	
	(1)	(2)	(3)	(4)
Futures shock (3M): sum Q(-1:-4)	0.092***	0.098***	0.059	0.078
Futures shock (3M): sum Q(-5:-8)	0.030	0.034*	0.068	0.087**
Futures shock (3M): sum Q(-9:-12)	-0.005	-0.002	0.013	0.025
Age	-0.474**	-0.466**	5.285***	5.199***
Age: squared	0.586***	0.576***	-6.169***	-6.131***
Dummy: mortgagors				
Quarter dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Regional dummies	No	Yes	No	Yes
Observations	16292	16292	14515	14515
R^2	0.018	0.086	0.051	0.070

Notes: See Table 4.26.

Table 4.28: *Regression output: non-durables expenditure*

	Expenditure on non-durables (logarithm)		
	(1)	(2)	(3)
Futures shock (3M): sum Q(-1:-4)	-0.033	-0.028	-0.005
Futures shock (3M): sum Q(-5:-8)	-0.021	-0.019	-0.000
Futures shock (3M): sum Q(-9:-12)	-0.001	0.001	0.012
Interaction mortgagors:			
Futures shock (3M): sum Q(-1:-4)	0.018	0.019	-0.028
Futures shock (3M): sum Q(-5:-8)	0.052*	0.059*	0.018
Futures shock (3M): sum Q(-9:-12)	-0.012	-0.007	-0.023
Age	1.715***	1.704***	1.739***
Age: squared	-1.416***	-1.422***	-1.458***
Dummy: mortgagors	0.128***	0.147***	0.171***
Quarter dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Regional dummies	No	Yes	Yes
Year dummies, interacted with mortgagors	No	No	Yes
Quarter dummies, interacted with mortgagors	No	No	Yes
Regional dummies, interacted with mortgagors	No	No	Yes
Observations	30807	30807	30807
R^2	0.047	0.065	0.069

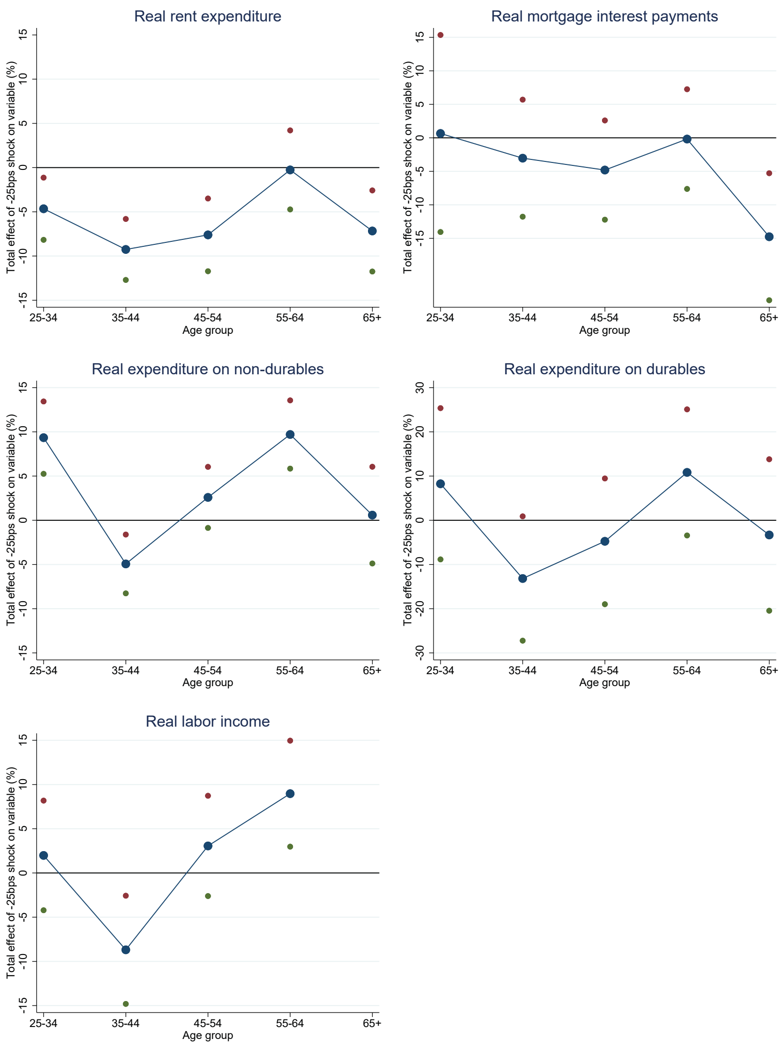
Notes: See Table 4.26.

Table 4.29: *Regression output: durables expenditure*

	Expenditure on durables (logarithm)		
	(1)	(2)	(3)
Futures shock (3M): sum Q(-1:-4)	-0.027	-0.015	-0.032
Futures shock (3M): sum Q(-5:-8)	-0.013	-0.006	-0.007
Futures shock (3M): sum Q(-9:-12)	0.016	0.022	-0.020
Interaction mortgagors:			
Futures shock (3M): sum Q(-1:-4)	-0.017	-0.015	0.013
Futures shock (3M): sum Q(-5:-8)	-0.011	-0.004	-0.004
Futures shock (3M): sum Q(-9:-12)	-0.146	-0.144	-0.048
Age	2.430***	2.479***	2.515***
Age: squared	-3.510***	-3.569***	-3.612***
Dummy: mortgagors	0.474***	0.493***	0.495***
Quarter dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Regional dummies	No	Yes	Yes
Year dummies, interacted with mortgagors	No	No	Yes
Quarter dummies, interacted with mortgagors	No	No	Yes
Regional dummies, interacted with mortgagors	No	No	Yes
Observations	30807	30807	30807
R^2	0.051	0.055	0.057

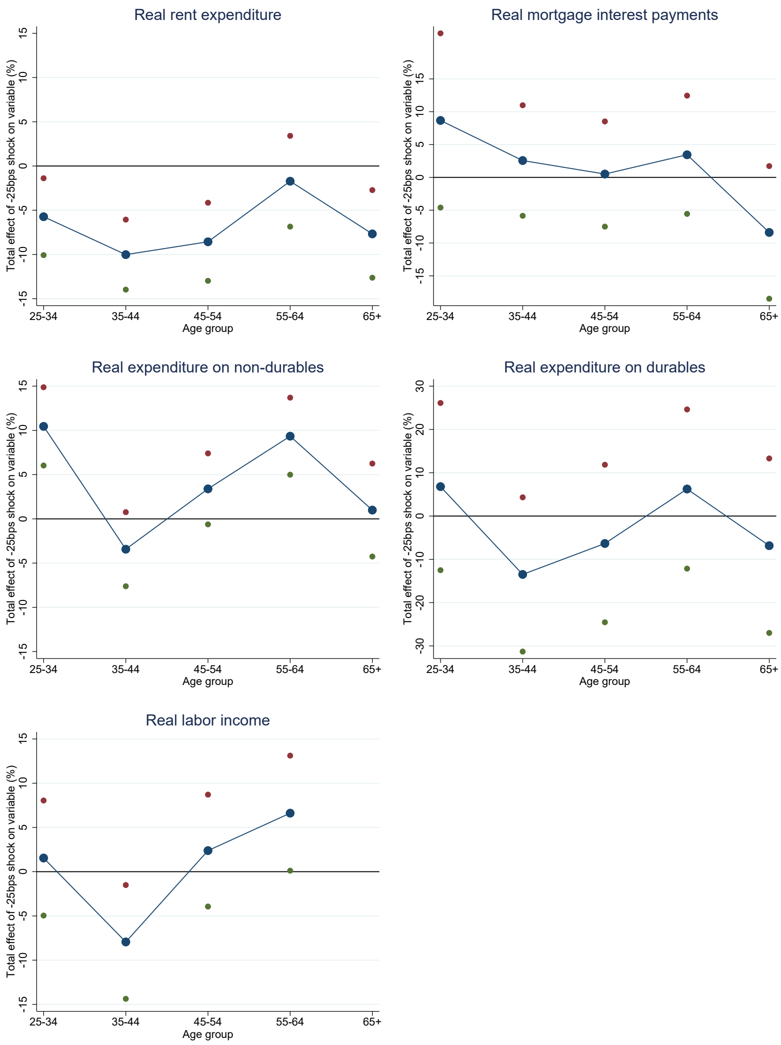
Notes: See Table 4.26.

Robustness results for narrower time windows around monetary policy announcements



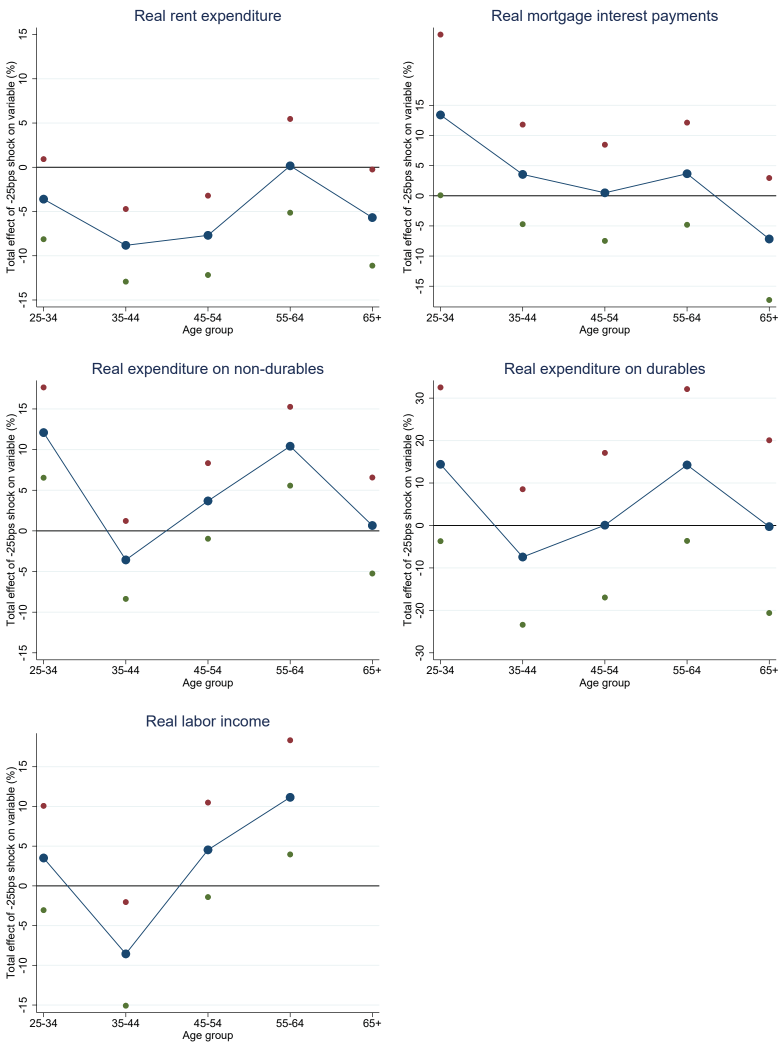
Notes: The results are based on the regression specification in Table 4.8 without the dummy for mortgagors and its interactions with the shocks, using the six-hour window shocks and adding interaction dummies for age groups. The graphs show the cumulative effect over three years (in %) of an unexpected 25bps policy-rate cut. All charts show 95% confidence intervals, with the respective upper and lower bound depicted by the green and red dots.

Figure 4.11: *Six-hour window: effect of a -25bps shock on expenditures and income*



Notes: The results are based on the regression specification in Table 4.8 without the dummy for mortgagors and its interactions with the shocks, using the press-conference window shocks and adding interaction dummies for age groups. See also the further notes to Figure 4.11.

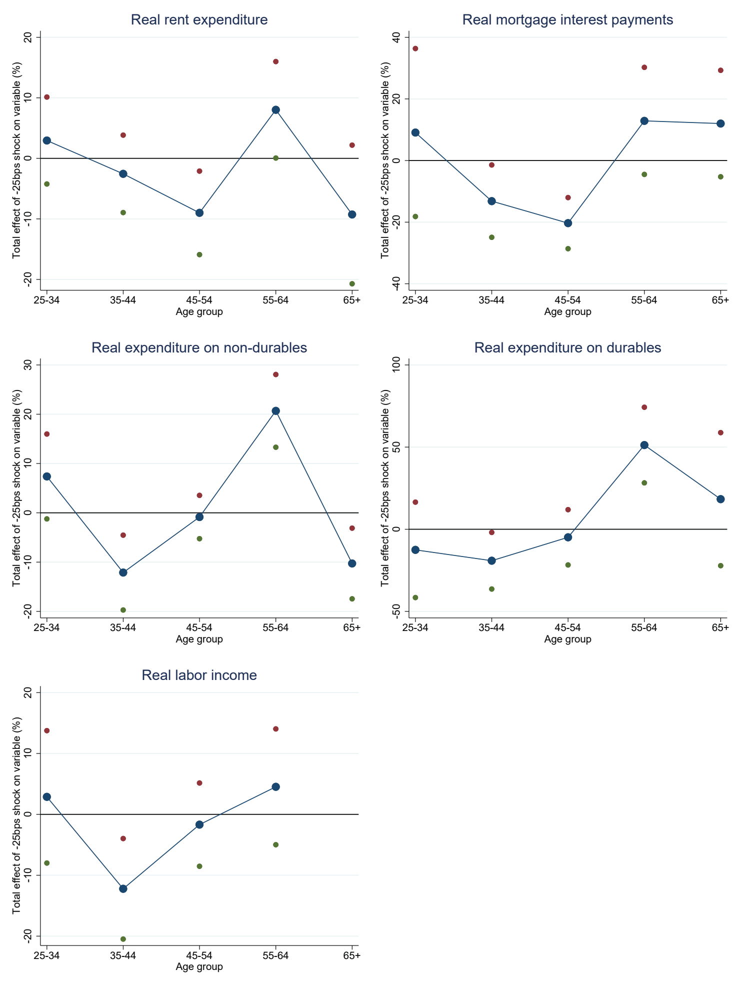
Figure 4.12: *Press conference window: effect of a -25bps shock on expenditures and income*



Notes: The results are based on the regression specification in Table 4.8 without the dummy for mortgagors and its interactions with the shocks, using the 30-minute window shocks and adding interaction dummies for age groups. See also the further notes to Figure 4.11.

Figure 4.13: *30-minute window: effect of a -25bps shock on expenditures and income*

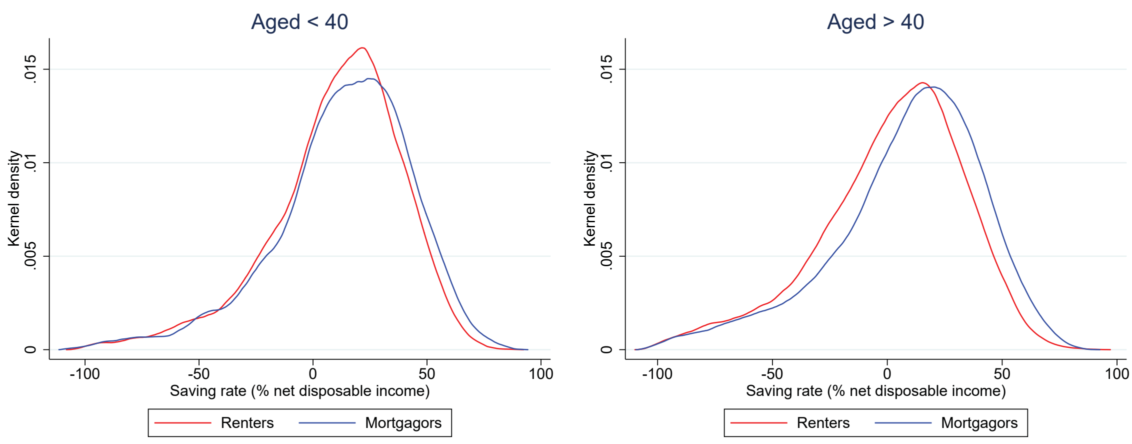
Robustness results for shocks that are negatively correlated with the response of the stock market



Notes: The results are based on the regression specification in Table 4.8 without the dummy for mortgagors and its interactions with the shocks, adding interaction dummies for age groups. The graphs show the cumulative effect over three years (in %) of an unexpected 25bps policy-rate cut. For constructing the shocks conditional on stock-market movements, we only consider announcements days on which the changes of the policy rate and the valuation of the stock market are negatively correlated. For Switzerland, this decreases the number of announcements from 75 to 30. All charts show 95% confidence intervals, with the respective upper and lower bound depicted by the green and red dots.

Figure 4.14: *Effect of a -25bps shock on expenditures and income for an alternative identification of policy-rate shocks using stock-market movements*

4.8.5 Saving rates and the financial situation of mortgagors and renters



Sources: HABE (SFSO). *Notes:* Net disposable income is the sum of labor income, wealth income and transfer income, minus social security contributions and taxes. Kernel density estimates with optimal bandwidth using data for 2006Q1-2014Q4. Wealth and transfer incomes, and social security contributions are not available for the previous years.

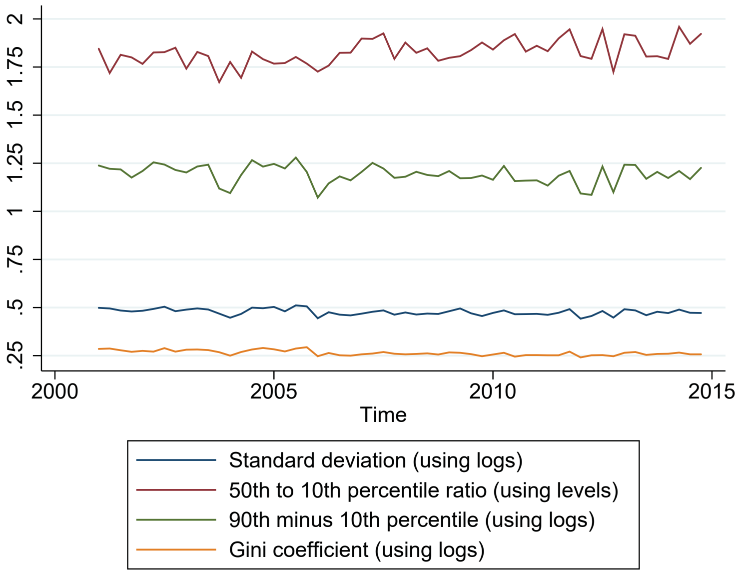
Figure 4.15: *Distribution of saving rates, by housing tenure*

Table 4.30: *Household financial situation*

	Age < 40		Age ≥ 40	
	Renters	Mortgagors	Renters	Mortgagors
Strong improvement	21%	19%	9%	9%
Weak improvement	31%	31%	21%	26%
Stagnation	23%	25%	35%	36%
Weak deterioration	16%	18%	23%	22%
Strong deterioration	9%	8%	13%	8%

Sources: HABE (SFSO). *Notes:* Answers to the question about the financial situation in the HABE are available for 7,328 renters and 5,865 mortgagors between 2001Q1 and 2005Q4. The interviewee is asked how the financial situation of the household is compared to last year. The reported numbers may not add up to 100 due to rounding errors.

4.8.6 Responses of inequality



Notes: We plot three measures for the inequality of households' non-durable consumption expenditure by quarter. Consumption is expressed in units of prices in 2007Q4 and adjusted for household size. We use the logarithms of consumption to compute the standard deviation and the 90th-10th percentile difference; and we use consumption levels to compute the Gini coefficients and the 90th-50th percentile ratios. These different measures allow easy comparison with the literature mentioned in the main text.

Figure 4.16: *Inequality of non-durable consumption in Switzerland over time*

Table 4.31: *Regression output: non-durable consumption inequality*

	(1) Std. deviation	(2) P(50)-P(10)	(3) P(90)-P(10)	(4) Gini coefficient
Futures shock (3M): sum Q(-1:-4)	-0.00069	-0.00106	0.02828	0.00294
	(0.00984)	(0.04060)	(0.02928)	(0.00760)
Futures shock (3M): sum Q(-5:-8)	0.00309	-0.01878	0.01743	0.00584
	(0.01036)	(0.04275)	(0.03083)	(0.00800)
Futures shock (3M): sum Q(-9:-12)	-0.00817	-0.05153	-0.00054	-0.00091
	(0.01004)	(0.04141)	(0.02986)	(0.00775)
Constant	0.47375***	1.81478***	1.19608***	0.26394***
	(0.00532)	(0.02197)	(0.01584)	(0.00411)
Observations	48	48	48	48
R^2	0.028	0.039	0.027	0.019

Notes: * p<0.10, ** p<0.05, *** p<0.01. The dependent variables are the measures for the inequality of household-level non-durable consumption, computed per quarter in the time period 2003Q1-2014Q4. Consumption is expressed in units of prices in 2007Q4 and adjusted for household size. We use the logarithms of consumption to compute the standard deviation and the 90th-10th percentile difference, and we use consumption levels to compute the Gini coefficients and the 90th-50th percentile ratios. This is to make our numbers comparable to the literature. Standard errors are reported in brackets.

4.8.7 Data appendix

The German Socioeconomic Panel (GSOEP) and the Swiss Household Panel (SHP) are unbalanced household panels. Households are interviewed once a year. The GSOEP covers all German households since 1990 whereas the SHP starts in 1999. We use the data on households since 2000, the time period for which we have constructed the series of monetary policy shocks.

For both the GSOEP and the SHP, our constructed sample consists of households for which the following variables were recorded: housing tenure, age, household size, number of children, income, education years, civil status and region. We keep households whose interviewee is the household head (or partner), and drop duplicates (i.e., when the partner also answered separately). We only consider household heads with an age of 24 and older, an age at which most households have finished full-time education and have entered the labor market. We thus drop 9.6% and 13.9% of the observations in the initial data sets for the GSOEP and SHP, respectively. The constructed sample contains $159,079$ and $46,498$ households for the GSOEP and the SHP. The samples reported in the text and used for the regressions are smaller: $136,718$ and $40,637$ respectively. This is because of the lagged values of the shocks, which are not available for households at the beginning of the sample period.

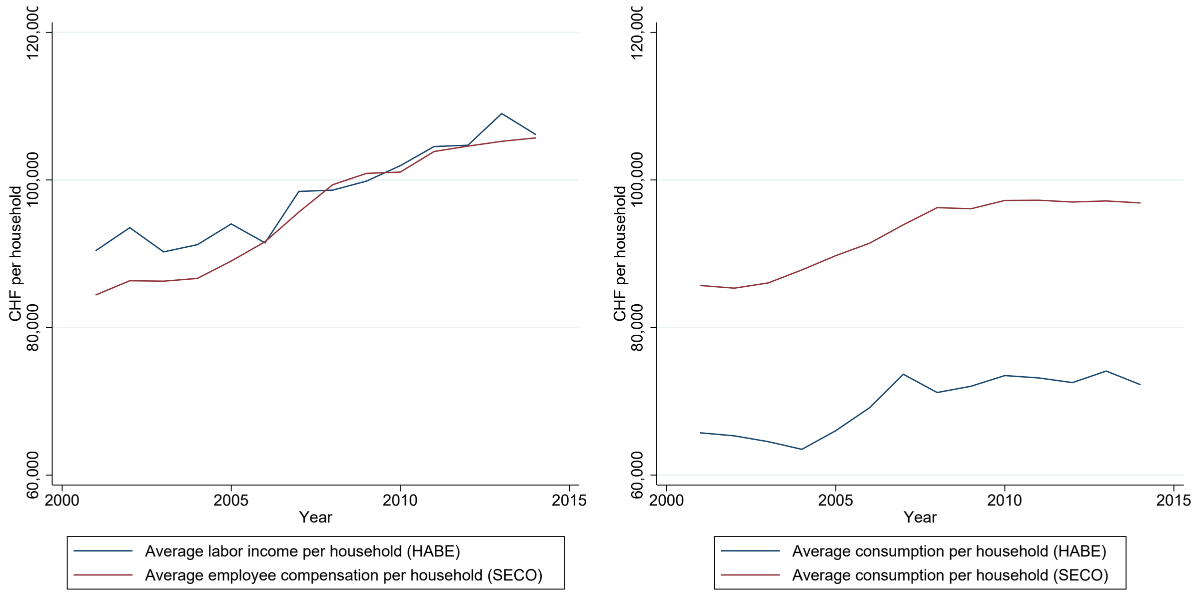
The Swiss household budget survey (*Haushaltsbudgeterhebung* or HABE) is a repeated cross-sectional data set that interviews households since 2001. It contains data on detailed household income and expenditure items between 2001Q1 and 2014Q1 and is used for the national CPI calculations. We construct the variables based on the HABE as follows.

Labor income contains both salary payments for the employed and income for the self-employed.[26] Our measures of nondurable and durable expenditures follow closely that of Cloyne et al. (2017). *Non-durables* include the following categories: food and non-alcoholic drinks, tobacco and alcoholic drinks, food and accommodation services, clothes and shoes, nondurable household goods, utilities, health services, motoring nondurable expenditure and gas, communication services, nondurable leisure items and services, culture services, other nondurable goods and services. *Durables* include the following categories: cars, bikes, motorised bikes, durable household goods (fridges, furniture, electric appar-els), eletronic durables (IT, photo and audio-visual equipments), durable leisure goods,

[26] Income for the self-employed consists of the sum of all transfers from the owned firm to the household. For limited and partly limited companies, this takes the form of an individual declared salary. For firms with full liability, all private transfers are included (this includes personal invoices paid via the firm).

jewellery and watches. We define a household as a *mortgagor* when the household owns the primary home and pays mortgage interest for it.

We adjust the budget items for household size, using the equivalent scale of Fernandez-Villaverde and Krueger (2007) in Table 1, column 7 (p. 554). For households with more than five persons, the scale is increased by 0.3 per additional person which equals the increment for the fifth person in Fernandez-Villaverde and Krueger (2007). In the HABE dataset only 1% of households contain more than five persons. The monetary variables are then expressed in units of prices in 2007Q4, using the final consumption expenditure deflator from the SECO (Data, Table *qnaqcsa, ESA*, Reference *deflq, P.3*).



Sources: HABE, SECO, SFSO. *Notes:* Data from the national accounts are converted into averages using the SFSO household count which we linearly interpolate for missing years. The consumption data from the SECO contain expenditure of households and non-profit institutions serving households (NPISHs).

Figure 4.17: *Comparison of labor income and consumption in the HABE dataset with aggregates from the national accounts*

The constructed sample consists of households for which the following variables are recorded: housing tenure (renting or owning the primary home), age, expenditure on both nondurables and durables, rent/mortgage interest payments and net income. Net income is the sum of labor income, wealth income and transfers (social transfers and pensions) net of taxes. We keep households with a positive net income, i.e., households who have *some* resources available (only 390 households are thus dropped). Analogously to the construction of the GSOEP and SHP samples, we keep households whose interviewee is the household head (or partner) and drop duplicates (i.e., when the partner also answered separately). We consider household heads aged between 24 and 75 years, as in Cloyne et al. (2017), and we keep those households who report some durables' expenditure and housing expenditure (all households report some expenditure on non-durables). We are thus left with 75.6% of the observations in the initial data set and our constructed sample contains $36,785$ households, of which $30,807$ are used in the benchmark specification due to the use of lagged shocks that are not available for households at the beginning of the sample period.

In Figure 4.17, we compare the average labor income and consumption in the HABE with the respective averages obtained by dividing employee compensation and consumption from the national accounts, available from the SECO, by the number of households based on the SFSO's household count. The series for average labor income are remarkably similar for the two datasets. Average consumption in the HABE is not comparable with the series based on the national accounts because the final consumption expenditure reported by the SECO includes expenditure by non-profit institutions serving households (NPISH) such as sports clubs or churches. Although the level of average consumption is thus smaller in the HABE dataset, Figure 4.17 shows that the behavior of consumption over time is very similar for both data series. Overall, this comparison suggests that the survey data in the HABE is meaningful so that we use it in our regression analysis in Section 4.6.

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6 Curriculum vitae

Education

2018 – 2019	**London School of Economics** (United Kingdom) Visiting doctoral student, SNF Doc.Mobility fellowship
2014 – 2019	**University of St. Gallen** (Switzerland) Doctoral student, Programme in Economics and Finance Advisor: Prof. Dr. Winfried Koeniger
2014 – 2015	**Gerzensee Study Center** (Switzerland) Swiss Program for Doctoral Students in Economics
2011 – 2012	**University of Cambridge** (United Kingdom) MPhil. in Economics
2010 – 2011	**Birkbeck College, University of London** (United Kingdom) Graduate Diploma in Economics
2006 – 2010	**Ecole Hôtelière de Lausanne** (Switzerland) BSc. in Management

Professional experience

2014 – 2018	**University of St. Gallen** (Switzerland) Research and Teaching Assistant, SEW Institute
2017 – 2018	**European Central Bank** (Germany) Consultant, Directorate General Research
2012 – 2014	**Grosvenor** (United Kingdom) Economist, UK and Global research teams
2010 – 2011	**LaSalle Investment Management** (United Kingdom) Strategy Analyst, real estate research EMEA team
2009	**HVS Global Hospitality Services** (United Kingdom) Six-month internship in hotel valuations and feasibility studies
2007	**Nestlé World** (Switzerland) Six-month internship in fine dining kitchen and service