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MoNK: Mortgages in a New-Keynesian Model*

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Abstract

There has been much interest recently in the role of household long-term, mortgage, debt in the transmission of monetary policy. This paper offers a tractable framework that integrates the long-term debt channel with the standard New-Keynesian channel, providing a tool for monetary policy analysis that reflects the recent debates in the literature. As the model includes both short- and long-term debt, it provides a useful laboratory for the analysis of monetary policy operating not only through short-term actions, as has been done traditionally in the literature, but also through expected, persistent, changes in its stance.

JEL Classification Codes: E52, G21, R21.

Keywords: Long-term mortgage debt, household balance sheets, cash-flow effects, sticky prices, monetary policy transmission.

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1 Introduction

When a central bank decides on the next course of monetary policy, the whole machinery of the monetary transmission mechanism sets in motion (e.g., Bernanke and Gertler, 1995; Mishkin, 1995). The main lever of the mechanism in the current go-to models for monetary policy analysis is the presence of nominal price rigidities (sticky prices) in product markets as embedded in the New-Keynesian Phillips curve. Recently, however, the literature started to pay increasing attention to the part of the mechanism that works through the exposure of households to long-term debt, typically mortgage debt (among others, Doepke and Schneider, 2006; Di Magio, Kermani, Keys, Piskorski, Ramcharan, Seru and Yao, 2017; Auclert, 2019; Cloyne, Ferreira and Surico, 2020).[1]

This paper integrates both channels—the New-Keynesian and the long-term debt channel– in a tractable analytical framework to provide a tool for monetary policy analysis that reflects the recent debate in the literature. While such endeavor may be interesting in its own right, it gains particular usefulness in light of other recent developments in macroeconomics and finance. A stream of research documents that monetary policy surprises are more complex than traditional analysis suggested, consisting of not only central bank actions but also of statements and signals about the likely future course of monetary policy (e.g., Gürkaynak, Sack and Swanson, 2005a; Campbell, Evans, Fisher and Justiniano, 2012; Nakamura and Steinsson, 2018).[2] Furthermore, a large body of work in finance, starting with Ang and Piazzesi (2003), suggests that monetary policy contains an important component that persistently affects expectations of future policy rates over time. Both streams of research thus point to the expectations of future monetary policy as an integral part of the transmission mechanism. While the current policy rate determines the cost of short-term

[1] We use the term "long-term debt exposure" or "long-term debt channel" to simply mean that households hold long-term debt either as a liability or an asset, which can potentially transmit monetary policy. Sometimes the literature refers to this channel as the "household balance sheet channel".

[2] As an example, in December 2019, the Riksbank surprised markets by both lifting its policy rate and announcing that the policy rate is likely to remain at the new level for years (a surprise by both action and statement). In June 2019, after a sequence of policy rate hikes, the Fed surprised markets by a statement hinting at no further increases in the policy rate, while keeping the current rate, in line with expectations, unchanged (a surprise only by statement).

debt, expectations about future monetary policy affect the cost of long-term financing (see, e.g., Hamilton, 2008, for an empirical analysis in the case of mortgages).[3]

Figure 1 illustrates, with the help of an episode, the basic concepts that the model intends to capture. The figure plots movements of the ECB policy rate, together with movements of nominal mortgage interest rates, in a number of euro area countries around the time of the ECB monetary policy easing in 2008. Since in the case of long-term debt one needs to distinguish between new loans (flow) and outstanding debt (stock), each with potentially different interest rates, we separate the two. Furthermore, the countries are divided into two groups, those with fixed-rate mortgages (FRM) and those with adjustable-rate mortgages (ARM), based on the typical contract used. The two basic contracts are characterized by different pass throughs of the policy rate.[4]

Without doubt, the cut in the ECB rate was partly transmitted into the economy through the standard New-Keynesian channel. The figure, however, shows that the ECB decision also affected households directly through their exposure to mortgage debt. Furthermore, the effects were not uniform across mortgage types and across new loans and outstanding debt. In the case of ARM countries, the interest rate on both new and outstanding debt declined more or less immediately and nearly by the full amount of the ECB rate cut. In FRM countries, however, while the interest rate on new loans also declined—though less then the ECB rate—the interest rate on outstanding debt remained essentially unchanged.[5] Furthermore, the decline in the FRM rates on new loans was not only due to the cut in the ECB rate itself, but reflected, at least partially, expectations of its persistence. With the benefit of

[3]The long-term debt channel is therefore also likely to be important for full assessment of Neo-Fisherian policies arguing for persistent changes in the policy rate as a tool to affect inflation (e.g., Uribe, 2018; Williamson, 2018).

[4]In broad sense, FRM has a constant nominal interest rate set at origination, whereas the interest rate of ARM is linked to a short-term nominal interest rate and can change during the life of the loan whenever the underlying interest rate changes. Typically, one of the two contracts dominates a country's mortgage market (Scanlon and Whitehead, 2004; European Mortgage Federation, 2012; Badarinza, Campbell and Ramadorai, 2016).

[5]In principle, mortgages can be pre-paid or refinanced. The extent to which this is legally or economically feasible, however, varies across countries (Scanlon and Whitehead, 2004; Green and Wachter, 2005; European Mortgage Federation, 2012; Badarinza et al., 2016). The lack of responses of the interest rates on FRM outstanding debt in Figure 1 suggests that in the FRM euro area countries little refinancing took place.

historical hindsight, we know the reduction in the ECB rate was very persistent indeed. Given that mortgage debt is on average around 70% of annual GDP in developed economies (International Monetary Fund, 2011), just how important is the long-term debt channel, when compared with the standard New-Keynesian channel, in transmitting monetary policy?

In the model, long-term debt plays a role by facilitating purchases of housing.[6] Specifically, a fraction of new housing is financed through new *long-term nominal* mortgages (either FRM or ARM), which are amortized over time in a way that mimics the payment schedule of a typical mortgage. There are two types of representative agents: “homeowners”, representing middle-class households, and “capital owners”, representing the top quintile of the wealth distribution (Campbell and Cocco, 2003). Both agent types supply labor. Capital owners can invest in capital used in production, whereas homeowners cannot. Capital owners also finance mortgages used by homeowners to purchase housing. Furthermore, the two agent types trade a noncontingent one-period nominal bond (unsecured credit), albeit homeowners only at a cost. The key distinction between the two agents is thus their access to capital and bond markets.[7] This has consequences for their valuation of mortgage payments (cash flows) over the life of a loan and for their marginal propensities to consume. Due to the limited ability of homeowners to smooth out fluctuations in disposable income, they can be thought of as the “rich hand-to-mouth” consumers in the spirit of Kaplan and Violante (2014). A calibrated parameter determines how close to hand-to-mouth consumers they are. The rest of the model has the standard New-Keynesian features: nominal price rigidities in product markets and a Taylor rule. The Taylor rule, however, includes shocks affecting expected future interest rates, in addition to standard policy shocks.[8]

[6] The literature typically explores the role of housing debt in New-Keynesian settings by considering only one-period loans (see Iacoviello, 2010); Calza, Monacelli and Stracca (2013) consider two-period loans. In Rubio (2011), mortgage interest rates are sticky but the debt itself is still a one-period loan. Ghent (2012) considers a flexible-price model with multi-period FRMs denominated in real terms.

[7] This structure has flavor of Guvenen (2009).

[8] Our focus on expected interest rates, rather than term premia, is grounded in practical considerations. Despite a large body of work, the economic drivers behind movements of term premia are still not well understood (e.g., a survey chapter by Duffee, 2012). Unsurprisingly, generating sufficiently large and time-varying term premia within structural general equilibrium models has so far proved unsuccessful (e.g., Rudebusch and Swanson, 2008; van Binsbergen, Fernandez-Villaverde, Koijen and Rubio-Ramirez, 2012).

When the measure of homeowners is zero, the model boils down to a representative agent New-Keynesian (RANK) model with capital. When mortgages are removed, the model becomes akin to a two-agent New-Keynesian (TANK) model, e.g., Debortoli and Galí (2018), with one-period debt. Introducing richer household-level heterogeneity would transform the model, at a significant computational cost, to a heterogenous-agent (HANK) model, e.g., Kaplan, Moll and Violante (2018), with mortgages.[9]

In relation to our previous work (Garriga, Kydland and Šustek, 2017), we extend the model of that paper to the conventional New-Keynesian setting. At the same time, however, we simplify the more general mortgage market structure of that paper by abstracting from optimal refinancing/prepayment and the choice between FRM and ARM. As we have shown in that paper, if FRM is refinanced every period when interest rates decline (which would be optimal in the absence of refinancing costs), FRM becomes equivalent to ARM along such an interest rate path. However, for calibration replicating the frequency of refinancing observed in US data, it turned out that the equilibrium dynamics of an economy with refi-FRM were still closer to that with pure FRM than ARM.[10] If refinancing also involves costlessly changing the debt outstanding (cash-in/cash-out), both FRM and ARM boil down to one-period loans. Again, for realistic calibration, we have shown this is not the case.

In terms of analysis, we add to our previous work in three ways. First, given the growing interest in the long-term debt channel, we compare its importance, in a common setting, to the New-Keynesian channel and explore any potential interactions between the two channels (e.g., do changes in disposable income, due to changes in mortgage payments, transmit through sticky prices to output?). This question is partially related to the ongoing debate on the channels of monetary policy transmission: intertemporal substitution vs. household

[9] In a RANK model, long-term household debt is a redundant asset. That is, it is priced but does not affect equilibrium outcomes (among others, Hördahl, Tristani and Vestin, 2008; Bekaert, Cho and Moreno, 2010; Rudebusch and Swanson, 2012). Sheedy (2014) considers a TANK model while Hedlund, Karahan, Mitman and Ozkan (2017) a HANK model with long-term debt.

[10] Berger, Milbradt, Tourre and Vavra (2018) make the point that the fraction of US mortgage debt that is refinanced depends on the historical path of interest rates, while Wong (2018) argues the fraction depends on demographics. Refinancing is still more frequent in the United States than in many other developed economies.

disposable income (e.g., Kaplan et al., 2018).[11] Second, we clarify and contrast the following concepts employed in the debt channel literature, discussed in the next section: (i) monetary policy operating through current cash flows vs. the present value of the long-term debt position and (ii) the interest rate exposure vs. the Fisher revaluation channel. In the case of ARM these concepts are subtle and are not well understood, despite being increasingly used. Our model encompasses all four cases and we explain how they are underpinned by asset market incompleteness. Finally, we relate the policy shocks in the model closely to the yield curve concepts of slope vs. level factors and, in the Supplementary material, further to action vs. statement policy shocks (Gürkaynak et al., 2005a; Nakamura and Steinsson, 2018). These mappings help both with the interpretation of the shocks and calibration of their persistence, which turned out to be key for the workings of the two channels.[12]

The paper proceeds as follows. Section 2 reviews the streams of research that motivate some of our assumptions and computational experiments. Section 3 develops the model, section 4 describes its calibration, and section 5 reports the findings. Section 6 then explains the mechanism and connects it with the concepts in the literature. Section 7 summarizes the main lessons and concludes. A supplementary material contains details of the equilibrium, secondary derivations, and examples of two rotations of the policy shocks, which offer their alternative interpretations.

[11]The two-agent setting makes the analysis of the transmission mechanism transparent. However, we expect the key insights to carry over to New-Keynesian models with mortgage debt and rich household heterogeneity. Obviously, the current model cannot address questions related to the details of observed heterogeneity. While such an extension is straightforward in principle, it carries an enormous computational burden.

[12]In Garriga et al. (2017) we have cross-validated the model (containing a larger set of shocks than the two considered here) against various empirical studies and business cycle regularities. Here we therefore do not repeat such tests.

2 Related literature

2.1 The long-term household debt channel

The literature on the long-term household debt channel of monetary policy transmission can be split into two main categories, depending on whether the debt channel works through the present value of the outstanding debt position or the timing of the cash flows. Broadly speaking, in the first category households maximize their utility subject to their life-time budget constraint, whereas in the second category they do not. In the most extreme case, they only face their flow budget constraints (i.e., they are hand-to-mouth consumers).

The first category includes Doepke and Schneider (2006) and their follow-up papers[13], Meh, Rios-Rull and Terajima (2010), Meh and Terajima (2011), Adam and Zhu (2016), and Auclert (2019). The last two papers focus on changes in the present value of the debt position brought about by temporary (one-off) changes in inflation and the real interest rate, as would occur in response to a standard monetary policy shock, whereas the rest consider effects of persistent shifts in the inflation rate. Auclert (2019) refers to the impact of the real interest rate as the "interest rate exposure channel" and to the impact of the inflation rate as the "Fisher revaluation channel".[14] The second category, highlighting the role of cash flows, includes, for instance, Cava, Hughson and Kaplan (2016), Flodén, Kilström, Sigurdsson and Vestman (2018), Di Magio et al. (2017), and Cloyne et al. (2020). The main contribution of these papers is to show that, empirically, the timing of mortgage cash flows affects household spending decisions, in particular in the case of ARMs.[15]

[13] Doepke and Schneider (2006b), Doepke and Schneider (2006c), and Doepke, Schneider and Selezneva (2018).

[14] The interest rate exposure channel is different from the standard intertemporal substitution channel. The latter shows up as the substitution effect in the Euler equation for a one-period bond, whereas the former is a wealth effect in the life-time budget constraint. A household wealth effect, albeit due to revaluation of government debt, is also at the center of the mechanism explored by Sterk and Tenreyro (2018).

[15] The quantitative model of Hedlund (2019) and the empirical framework of Slacalek, Tristani and Violante (2020) include both the present value and the cash flow channel.

2.2 Monetary policy and nominal interest rates

Incorporating long-term household debt into a model for monetary policy analysis is particularly pertinent if monetary policy can, in some way, affect the cost of long-term financing. Two lines of research, while working with data at different frequencies, suggest that this is the case. Furthermore, that this occurs, at least partially, through expected future policy rates (see footnote 8 regarding our focus on expected interest rates).

The first literature concerns the nature of monetary policy surprises. The traditional analysis, based on structural VARs, e.g., Christiano, Eichenbaum and Evans (1999), identifies policy surprises as unexpected changes in the current policy rate. A limitation of this analysis is that it focuses on the *actions* of the central bank, relative to what the empirical model or the agents in its theoretical counterpart expected. Such shocks are empirically found to have a temporary effect on short rates and almost no effect on long-term interest rates (e.g., Evans and Marshall, 1998). The private sector, however, pays attention not only to what the central bank does but also to what it says, or signals, it may do in the future. Unexpected changes in policy *statements* therefore lead to substantial movements of the entire yield curve.[16] This dimension of policy surprises has been established in high-frequency studies, using daily or intra-day data, around policy meetings (Gürkaynak et al., 2005a; Campbell et al., 2012).[17]

The second literature concerns the behavior of nominal interest rates over time, rather than at a point in time. A large body of work uses yield curve data to extract factors driving nominal interest rates at monthly or quarterly frequencies (e.g., Ang and Piazzesi, 2003; Diebold, Rudebusch and Aruoba, 2006; Rudebusch and Wu, 2008). A robust finding

[16] During the recent Great Recession such communication became known as "forward guidance". However, policy communication had been used, and affected financial markets, long before this period.

[17] Related studies include Cieslak and Schrimpf (2018), Jarocinski and Karadi (2018), and Nakamura and Steinsson (2018). Responses of long-term interest rates to policy surprises can occur also due to changes in term premia (e.g., Gertler and Karadi, 2015). Unfortunately, empirical decompositions into expected interest rates and term premia generally suffer from weak identification, large standard errors, and a small sample bias (e.g., Joslin, Singleton and Zhu, 2011; Bauer, Rudebusch and Wu, 2012; Hamilton and Wu, 2012; Kim and Orphanides, 2012). We proceed under the assumption that monetary policy statements at least partially affect expectations of future interest rates, as suggested by the studies cited.

in this literature is that interest rates contain a highly persistent, latent, stochastic factor, with autocorrelation near the unit root, which has an approximately equal effect on both short and long rates. Importantly, the presence and dynamic properties of this factor are essentially unaffected by the change of measure from risk-neutral to physical, meaning that the factor drives predominantly expected future interest rates, as opposed to term premia (e.g., Cochrane and Piazzesi, 2008; Duffee, 2012; Bauer, 2018).[18] While a consensus on the origins of this factor is yet to be reached, a long list of studies prescribe a chunk of its movements to persistence in monetary policy, due to the factor's strong positive correlation with inflation (e.g., Kozicki and Tinsley, 2001; Atkeson and Kehoe, 2009; Bekaert et al., 2010).[19]

3 The model

The model intends to capture, in a parsimonious way, the pass-through effects illustrated in Figure 1, in addition to the standard New-Keynesian transmission of monetary policy. The model environment is motivated by some U.S. observations, with the hope that these apply more broadly, at least in the context of developed economies. In order to present the framework and its properties in the clearest possible way, we abstract from various features (habits, labor market frictions, backward indexation of prices, etc.) that are often required in the New-Keynesian literature to obtain a good fit to the data. Such extensions are left for future work.

[18]While the risk of the factor is priced–i.e., there is a risk premium attached to this factor—the risk premium does not vary with the factor itself and neither do risk premia attached to other factors. For instance, in a tightly identified decomposition by Cochrane and Piazzesi (2008), movements in term premia are set off by an almost hidden (unspanned by yields) factor, as in Duffee (2011) and Joslin, Priebsch and Singleton (2014), which is dynamically correlated with a factor driving the slope of the yield curve.

[19]See also Ang and Piazzesi (2003), Diebold et al. (2006), Dewachter and Lyrio (2006), Hördahl, Tristani and Vestin (2006), Ang, Bekaert and Wei (2008), Rudebusch and Wu (2008), Duffee (2012), and Haubrich, Pennacchi and Ritchken (2012).

3.1 Environment

There are two types of representative households, "homeowners" and "capital owners", with measures Ψ and $(1-\Psi)$, respectively. Both agent types supply labor. Homeowners invest in housing whereas capital owners invest in productive capital. Capital owners also finance mortgages used by homeowners to purchase housing and the two agents trade a noncontingent one-period nominal bond, although homeowners only at a cost.[20] The economy is studied under either only FRM or ARM, the two opposing cases of policy rate pass-through. For the reasons explained in the Introduction, the loans are held until maturity.

The production side of the economy has the standard New-Keynesian features and monetary policy follows a Taylor rule. To achieve sensible calibration, labor supply by the two agent types differs in efficiency units and the model also includes constant tax rates and government expenditures (and transfers that ensure the government budget constraint holds). While these features have some quantitative implications, they are unimportant for understanding the qualitative properties of the model.

3.2 Capital owners

The capital owner (indexed by "1") chooses contingency plans for c_{1t}, n_{1t}, x_{Kt}, k_{t+1}, $b_{1,t+1}$, and l_{1t} to maximize expected life-time utility

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_{1t}, n_{1t}), \quad \beta \in (0,1),$$

[20] This abstraction is motivated by the cross-sectional observations by, e.g., Campbell and Cocco (2003): the typical homeowner is a middle class household (in the third and fourth quintiles of the wealth distribution), with housing their main asset and mortgages their main liability and almost no corporate equity; in contrast, households in the top quintile of the wealth distribution own the entire corporate equity in the economy and housing makes up a small fraction of their assets. The lowest two quintiles in the data are renters with little assets and little debt and are not included in the model. Our abstraction is also consistent with Doepke and Schneider (2006) and Meh et al. (2010) who document that the middle classes are the largest borrowers in nominal debt whereas the top quintile are the biggest holders of nominal debt.

where $u(.,.)$ has the standard properties guaranteeing a unique interior solution, subject to a sequence of budget constraints and laws of motion for capital

$$c_{1t}+q_{Kt}x_{Kt}+\frac{b_{1,t+1}}{p_t}+\frac{l_{1t}}{p_t}=\left[(1-\tau_K)r_t+\tau_K\delta_K\right]k_t+(1+i_{t-1})\frac{b_{1t}}{p_t}+\frac{m_{1t}}{p_t}+(1-\tau_N)\epsilon_w w_t n_{1t}+\tau_{1t}+\Pi_t, \tag{1}$$

$$k_{t+1}=(1-\delta_K)k_t+x_{Kt}.$$

We index by "1" only those variables of the capital owner that pertain to both agent types. Here, c_{1t} is consumption, n_{1t} is labor, x_{Kt} is investment in capital, q_{Kt} is its relative price, $b_{1,t+1}$ is holdings of the one-period nominal bond between periods t and $t+1$, p_t is the nominal price level, l_{1t} is new nominal mortgage lending, $\tau_K \in (0,1)$ is a capital income tax rate, r_t is a real capital rental rate, $\delta_K \in (0,1)$ is a capital depreciation rate, k_t is capital, i_{t-1} is the nominal interest rate on the one-period bond bought in the previous period, m_{1t} is receipts of nominal payments from outstanding mortgages, $\tau_N \in (0,1)$ is a labor income tax rate, $\epsilon_w > 0$ is the relative productivity of capital owners, w_t is the aggregate real wage rate, τ_{1t} is government transfers, and Π_t is profits of monopolistically competitive producers, assumed to be owned by the capital owner. The capital owner's endogenous state variables are k_t, b_{1t}, and m_{1t}. The determination of mortgage payments, m_{1t}, is described after introducing the homeowner.[21]

3.3 Homeowners

A representative homeowner (indexed by "2") chooses contingency plans for c_{2t}, n_{2t}, x_{Ht}, h_{t+1}, $b_{2,t+1}$, and l_{2t} to maximize expected life-time utility

$$E_0\sum_{t=0}^{\infty}\beta^t v(c_{2t},h_t,n_{2t}),$$

[21] As capital owners are the sole holders of mortgage debt in the economy, and given that they are identical, outstanding mortgage debt is not traded in equilibrium. We therefore do not include adjustments in an individual capital owner's holdings of outstanding mortgage debt in the budget constraint, as doing so would have no equilibrium consequences.

where $v(.,.,.)$ also has the standard properties guaranteeing a unique interior solution, subject to a sequence of budget and financing constraints and laws of motion for housing

$$c_{2t} + q_{Ht}x_{Ht} + \frac{b_{2,t+1}}{p_t} = (1-\tau_N)w_t n_{2t} + (1 + i_{t-1} + \Upsilon_{t-1})\frac{b_{2t}}{p_t} + \frac{l_{2t}}{p_t} - \frac{m_{2t}}{p_t} + \tau_{2t}, \tag{2}$$

$$\frac{l_{2t}}{p_t} = \theta q_{Ht} x_{Ht}, \tag{3}$$

$$h_{t+1} = (1-\delta_H)h_t + x_{Ht}.$$

The homeowner has the same time discount factor β as the capital owner. We index by "2" only those variables of the homeowner that pertain to both agent types. Here, c_{2t} is consumption, h_t is the existing stock of housing, n_{2t} is labor, x_{Ht} is purchases of new housing, q_{Ht} is the relative price of housing, $b_{2,t+1}$ is holdings of the one-period nominal bond between periods t and $t+1$, l_{2t} is new nominal mortgage borrowing, m_{2t} is nominal mortgage payments on outstanding debt, τ_{2t} is transfers, $\theta \in [0,1)$ is a loan-to-value ratio, and $\delta_H \in (0,1)$ is a housing depreciation rate. Υ_{t-1} is described below. The homeowner's endogenous state variables are h_t, b_{2t}, and m_{2t}.

Observe that the financing constraint (3) applies to new housing, which is purchased with new mortgages. That is, the homeowner purchases new housing with a new mortgage, at the loan-to-value ratio θ, and then repays the loan over time according to a given amortization schedule, described below. In this sense, mortgages in the model are first mortgages, as opposed to home equity loans, which allow homeowners to draw new credit against the value of their existing housing stock.[22,23]

Unlike mortgages, the one-period bond is not tied to housing. However, it entails a

[22] While widespread in the United States, home equity loans are less common in other countries and, to keep the model simple, are therefore abstracted from.

[23] The financing constraint (3) is assumed to hold with equality. This assumption, which simplifies the model, has some empirical support at both aggregate and micro levels. First, over time there has been little variation in the aggregate loan-to-value ratio for newly built home first mortgages, despite large changes in interest rates and other macroeconomic conditions (Federal Housing Finance Agency, Monthly Interest Rate Survey, Table 10). Second, at the micro level, Greenwald (2018) documents that most newly originated mortgages are taken out at the maximum loan-to-value ratios. Micro-founded justifications for such findings may include life-cycle and tax considerations that our model abstracts from.

participation cost Υ_{t-1}, taking the form of a spread over the short rate. The cost is governed by a function $\Upsilon(-\widetilde{b}_{2t})$, where $\widetilde{b}_{2t} \equiv b_{2t}/p_{t-1}$. The function $\Upsilon(.)$ is assumed to be increasing and convex and satisfy the following additional properties: $\Upsilon(.) = 0$ when $\widetilde{b}_{2t} = 0$, $\Upsilon(.) > 0$ when $\widetilde{b}_{2t} < 0$ (the homeowner is borrowing), and $\Upsilon(.) < 0$ when $\widetilde{b}_{2t} > 0$ (the homeowner is saving). We think of $\Upsilon(.) > 0$ as capturing a premium for unsecured consumer credit, which is increasing in the amount borrowed; $\Upsilon(.) < 0$ can be interpreted as intermediation costs that reduce the homeowner's returns on savings below those of the capital owner. At a technical level, the function $\Upsilon(.)$ controls the extent to which the homeowner can use the bond market to smooth out fluctuations in income. In equilibrium, however, the function also affects the extent to which the capital owner can use the bond market to keep consumption smooth, as the two agent types are counterparties in bond trades. If Υ_{t-1} was equal to zero for all $\widetilde{b}_{2t}$, the homeowner would be a permanent income hypothesis consumer. If $\Upsilon_{t-1} = \infty$ for all $\widetilde{b}_{2t}$, the homeowner would be a complete hand-to-mouth consumer. Our case lies in-between these two extremes.

3.4 Mortgages

We adopt the representation of mortgages proposed by Kydland, Rupert and Šustek (2016), which has a recursive form that is convenient in models with infinitely lived agents. Under this representation, mortgage loans—like the agents—live forever, but their amortization rates are chosen so as to approximate the amortization schedule, and thus the mortgage payments, of standard 30-year mortgages. A key characteristic of standard mortgage contracts is that, unless the mortgage rate changes, nominal payments are constant.

Denoting by d_{2t} the outstanding nominal mortgage debt of the homeowner in period t, the nominal mortgage payments the homeowner has to make in period t are

$$m_{2t} = (R_{2t} + \gamma_{2t})d_{2t}. \tag{4}$$

Here, R_{2t} and γ_{2t} are, respectively, the interest and amortization rates of outstanding debt.

The variables determining m_{2t} are state variables evolving as

$$d_{2,t+1} = (1 - \gamma_{2t})d_{2t} + l_{2t}, \tag{5}$$

$$\gamma_{2,t+1} = (1 - \phi_{2t})\left(\gamma_{2t}\right)^{\alpha} + \phi_{2t}\kappa, \tag{6}$$

$$R_{2,t+1} = \begin{cases} (1 - \phi_{2t})R_{2t} + \phi_{2t}i_t^F, & \text{if FRM,} \\ i_t, & \text{if ARM,} \end{cases} \tag{7}$$

where i_t^F is the interest rate on new FRM loans and $\phi_{2t} \equiv l_{2t}/d_{2,t+1}$ is the fraction of new loans in outstanding debt next period. The parameters $\kappa, \alpha \in (0, 1)$ define the amortization schedule. Specifically, κ is the initial amortization rate of a new loan and α governs the evolution of the amortization rate of outstanding debt. The amortization rate $\gamma_{2,t+1}$ thus evolves as a weighted average of the amortization rates of outstanding and new debt. The parameters κ and α are chosen so that equation (6) satisfies the restriction that a single loan (i.e., no previous debt and no further loans in the future) gets effectively repaid in 30 years (120 periods in a quarterly model) and its nominal payments stay approximately constant during this period, provided the loan's interest rate does not change (see Kydland et al., 2016, for details).[24] The interest rate $R_{2,t+1}$ evolves in a similar way, as a weighted average of interest rates on outstanding and new debt. In the FRM case, the interest rates on the stock and flow are potentially different, whereas in the ARM case they are the same, equal to the short rate. An ARM, however, is still a long-term loan—the evolution of the amortization rate is still dictated by the law of motion (6).[25]

Notice that as long as x_{Ht} is positive, l_{2t} will also be positive due to the financing constraint (3). As we do not observe negative housing investment in aggregate data, the

[24]Essentially, the amortization rate needs to increase at a speed that just compensates for the fact that outstanding debt declines over the life of the loan, thus keeping mortgage payments roughly constant until the loan if effectively repaid.

[25]One period loans result under $\kappa = 1$ and $\alpha = 0$. The system (5)-(7) has a well-defined steady state given by: $l_2 = \gamma_2 d_2$, $(1 - \kappa) = (1 - \gamma_2)\gamma_2^{\alpha-1}$, and $R_2 = i^F$ or $R_2 = i$. It is straightforward to show that the steady-state non-linear equation in γ_2 has a unique solution in $[0, 1]$. It is also straightforward to show that when linearized around the steady state, the highest eigenvalue of the system is less than one in absolute value, rendering the system stationary.

model will be calibrated so that x_{Ht}, and thus l_{2t}, are always positive. This, however, does not mean that there cannot be deleveraging in the model. Such situation occurs when $0 < l_{2t} < \gamma_t d_{2t}$.

The receipts of mortgage payments by the capital owner are determined analogously

$$m_{1t} = (R_{1t} + \gamma_{1t}) d_{1t}, \tag{8}$$

$$d_{1,t+1} = (1 - \gamma_{1t}) d_{1t} + l_{1t}, \tag{9}$$

$$\gamma_{1,t+1} = (1 - \phi_{1t}) (\gamma_{1t})^{\alpha} + \phi_{1t} \kappa, \tag{10}$$

$$R_{1,t+1} = \begin{cases} (1 - \phi_{1t}) R_{1t} + \phi_{1t} i_t^F, & \text{if FRM,} \\ i_t, & \text{if ARM,} \end{cases} \tag{11}$$

where $\phi_{1t} \equiv l_{1t}/d_{1,t+1}$. Aggregate consistency requires: $(1 - \Psi) d_{1t} = \Psi d_{2t} \equiv D_t$, $\gamma_{1t} = \gamma_{2t} \equiv \gamma_t$, and $R_{1t} = R_{2t} \equiv R_t$. As a consequence, $(1 - \Psi) m_{1t} = \Psi m_{2t}$.

Why not simply assume a constant amortization rate, $\gamma_{jt} = \gamma \ \forall t$, $j \in \{1, 2\}$, as in, for instance, Woodford (2001)? This is because a constant amortization rate implies geometrically declining mortgage payments, thus (unlike in standard mortgage contracts) concentrating the nominal payments at the beginning of the life of the loan.

3.5 Production

The production side of the economy has the standard New-Keynesian features resulting in the prototypical New-Keynesian Phillips Curve. Identical perfectly competitive final good producers, of which there is a measure one, produce output Y_t, using as inputs a continuum of intermediate goods $y_t(j)$, $j \in [0, 1]$. The representative final good producer solves a static profit maximization problem

$$\max_{Y_t, \{y_t(j)\}_0^1} p_t Y_t - \int_0^1 p_t(j) y_t(j) dj \quad \text{subject to} \quad Y_t = \left[\int_0^1 y_t(j)^{\varepsilon} dj \right]^{1/\varepsilon},$$

where $p_t(j)$ is the nominal price of an intermediate good j and $\varepsilon \in (0, 1]$. As the measure of the producers is equal to one, Y_t represents also aggregate output. A first-order condition of this problem gives a demand function for good j

$$y_t(j) = \left[\frac{p_t}{p_t(j)}\right]^{\frac{1}{1-\varepsilon}} Y_t. \tag{12}$$

The producer of the intermediate good j is a monopolist in market j. It faces the Calvo price stickiness, which stipulates that with probability $\psi \in [0, 1]$ the producer cannot change its price in a given period. If allowed to change its price in period t, the producer j chooses $p_t(j)$, understanding it may not change the price in the future, to solve

$$\max_{p_t(j)} E_t \sum_{s=0}^{\infty} \psi^s Q_{1,t+s} \left[\frac{p_t(j)}{p_{t+s}} y_{t+s}(j) - \chi_{t+s} y_{t+s}(j) - \Delta\right], \quad j \in [0, 1], \tag{13}$$

where $Q_{1,t+s} \equiv \beta u_{c,t+s}/u_{ct}$ is the stochastic discount factor of the capital owner, χ_{t+s} is the real marginal cost, the expression in the square brackets is the real per-period profit, and $y_{t+s}(j)$ is given by the demand function (12), with $p_{t+s}(j) = p_t(j)\ \forall s$.[26] Further, Δ is a fixed cost, measured in terms of the final good, which is a common feature of New-Keynesian models with capital, ensuring that profits in steady state are equal to zero.[27] The discounted sum thus pertains to profits in all individual future states in which the producer cannot change its price.

The real marginal cost χ_t is given by a linear cost function derived from a static cost minimization problem of producer j

$$\chi_t y_t(j) = \min_{k_t(j), n_t(j)} r_t k_t(j) + w_t n_t(j) \quad \text{subject to} \quad A k_t(j)^{\varsigma} n_t(j)^{1-\varsigma} = y_t(j).$$

Here, A is total factor productivity, $\varsigma \in (0, 1)$, and $k_t(j)$ and $n_t(j)$ are capital and labor,

[26]Notation such as u_{ct} means the first derivative of the function u with respect to argument c, evaluated in period t.

[27]This is relevant only for mapping the parameter ς to capital share in National Income and Product Accounts in a straightforward way.

respectively, rented by producer j in spot markets. The first-order condition is

$$\frac{w_t}{r_t} = \left(\frac{1-\varsigma}{\varsigma}\right)\frac{k_t(j)}{n_t(j)}. \tag{14}$$

The value function of the cost minimization problem then yields $\chi_t \equiv A^{-1}(r_t/\varsigma)^{\varsigma}[w_t/(1-\varsigma)]^{1-\varsigma}$, which is independent of j, as already anticipated in the profit function (13).

3.6 Aggregate expenditures

Aggregate output Y_t, less the fixed costs incurred by the intermediate good producers, has four uses

$$C_t + q_{Kt}X_{Kt} + q_{Ht}X_{Ht} + G = Y_t - \Delta, \tag{15}$$

where $C_t \equiv (1-\Psi)c_{1t} + \Psi c_{2t}$, $X_{Kt} \equiv (1-\Psi)x_{Kt}$, $X_{Ht} \equiv \Psi x_{Ht}$, and G is (constant) government expenditures.[28] Further, q_{Kt} is the marginal rate of transformation between consumption and capital investment and q_{Ht} is the marginal rate of transformation between consumption and housing investment. The rates of transformation are given by strictly increasing convex functions $q^K(X_{Kt})$ and $q^H(X_H)$, which make the economy's production possibilities frontier (PPF) concave. A normalization restriction is imposed on these functions so that the rates of transformation are equal to one in steady state. This specification of the PPF is akin to that of Fisher (1997) and Huffman and Wynne (1999). Such a concave PPF could be derived from, for instance, a multisectoral input-output environment (e.g., construction, manufacturing, services) with different factor shares or imperfect factor mobility, as in, e.g., Davis and Heathcote (2005). If the transformation of output into the respective uses is carried out by perfectly competitive firms, the rates of transformation are equal to the relative prices of capital and housing investment, as already anticipated in the budget constraints.[29]

[28]When we map the model into data, we take $Y_t - \Delta$ as the model counterpart to aggregate output in the data.

[29]Since old and new housing are perfect substitutes, q_t^H represents a house price. As we are not interested in house prices per se, we abstract from the fact that a house consists of both a structure and a land; a house in the model is just a structure. It is well known that a fixed plot of land works like an additional adjustment cost.

At a technical level, the nonlinear PPF plays a role similar to that of capital adjustment costs, controlling the size of the responses of X_{Kt} and X_{Ht} to shocks (to a first-order approximation, the two specifications are equivalent). The more curvature the PPF has, the more of the aggregate adjustment to shocks occurs through changes in relative prices, and the less through investment in capital or housing. The curvature of the PPF thus has implications for the ability of the agents to use capital and housing to keep consumption smooth in response to shocks.

3.7 Equilibrium

Let us define the following aggregates, in addition to those already defined: $K_t \equiv (1-\Psi)k_t$, $H_t \equiv \Psi h_t$, and $B_t \equiv \Psi b_{2t} = -(1-\Psi)b_{1t}$. The aggregate state of the economy in period t is characterized by the following endogenous state variables: K_t, H_t, B_t, D_t, γ_t, R_t, i_{t-1}, p_{t-1}, and the shocks introduced below.[30] A (Markov) stochastic process for the shocks is known to all agents. The capital owner comes into period t with the following individual endogenous state variables, summarizing his balance sheet: k_t, b_{1t}, d_{1t}, γ_{1t}, and R_{1t}. The homeowner comes into the period with these individual endogenous state variables, summarizing her balance sheet: h_t, b_{2t}, d_{2t}, γ_{2t}, and R_{2t}. The economy operates under either FRM or ARM.

In equilibrium, the following conditions hold: (i) the capital owner and the homeowner solve their respective maximization problems, choosing contingency plans for c_{1t}, n_{1t}, x_{Kt}, $b_{1,t+1}$, and l_{1t} (capital owner) and c_{2t}, n_{2t}, x_{Ht}, $b_{2,t+1}$, and l_{2t} (homeowner); (ii) the intermediate good producers choose $k_t(j)$ and $n_t(j)$ to solve their cost minimization problem and, if allowed, choose $p_t(j)$ to maximize the discounted profits, subject to their demand function; (iii) the relative prices q_{Kt} and q_{Ht} are given by the respective marginal rates of transformation; (iv) monetary policy follows a Taylor rule, specified in the next section; and (v) the

[30] The variables i_{t-1} and p_{t-1} can be eliminated from the set of endogenous state variables if the budget constraints are written in terms of the price of the one-period bond, rather than its interest rate, and the model is rewritten in terms of the inflation rate, rather than the price level.

mortgage, bond, labor, capital, and goods markets clear

$$(1-\Psi)l_{1t} = \Psi l_{2t},$$

$$-(1-\Psi)b_{1,t+1} = \Psi b_{2,t+1},$$

$$\int_0^1 n_t(j) = \epsilon_w N_{1t} + N_{2t},$$

$$\int_0^1 k_t(j) = K_t,$$

$$C_t + q_{Kt}X_{Kt} + q_{Ht}X_{Ht} + G = Y_t - \Delta,$$

where $N_{1t} \equiv (1-\Psi)n_{1t}$, $N_{2t} \equiv \Psi n_{2t}$, and $Y_t = \left[\int_0^1 y_t(j)^{\varepsilon} dj\right]^{1/\varepsilon}$. As capital owners' and homeowners' labor inputs are perfect substitutes, capital owners' wage rate is $\epsilon_w w_t$, whereas homeowners' wage rate is w_t, as already anticipated in the respective budget constraints.

In the FRM case, the stochastic sequences of prices clearing these five markets are for i_t^F, i_t, w_t, r_t, and p_t. In the ARM case, as discussed below, the capital owner is indifferent between the one-period bond and a new ARM loan at any sequence for i_t and supplies mortgages in the amount demanded by the homeowner. Under ARM, therefore, any sequence of i_t that clears the bond market also clears the mortgage market. A complete list of the equations characterizing the equilibrium is contained in the supplementary material. For the reasons explained in the Introduction, we are not concerned with risk premia. The model is therefore solved under certainty equivalence, in its log-linear form.[31]

[31] The government budget constraint holds by Walras' law and is given by $G + (1-\Psi)\tau_{1t} + \Psi\overline{\tau}_2 = \tau_K(r_t - \delta_K)K_t + \tau_N w_t(\epsilon_w N_{1t} + N_{2t})$. In the government budget constraint, τ_{1t} adjusts so as to ensure that the budget constraint is satisfied state-by-state. The transfer to the homeowner, τ_{2t}, is given by $\tau_{2t} = \overline{\tau}_2 - (b_{2t}/p_{t-1})\Upsilon_{t-1}$, where $\overline{\tau}_2$, the 'genuine' transfer, is constant. The bond market participation cost is rebated back to the homeowner as a part of τ_{2t} in order not to affect the definition of aggregate output. In steady state, $b_{2t} = 0$ and the participation cost is equal to zero.

3.8 Policy shocks and the Taylor rule

The motivation for the specification of the shocks and the policy rule requires some discussion. The two strands of research reviewed in Section 2.2 suggest monetary policy has a dimension affecting expected future interest rates. Our specification of the Taylor rule therefore reflects the lessons from that literature.

In broad sense, the short-term nominal interest rate i_t is typically considered in these lines of research to (linearly) depend on a number of factors, which can be both latent and observable. A standard formulation is

$$i_t = i + f_{1t} + \ldots + f_{Jt},$$

where (without the loss of generality) the 'loadings' of all the factors on the short-term interest rate are normalized to equal to one and i is the unconditional mean of the short rate (the factors are normalized to have an unconditional mean equal to zero). While the factors can be mutually correlated, a natural restriction typically imposed in the literature is that they are orthogonal to each other. Interest rates on bonds of longer maturities also depend on the J factors, though potentially with different loadings. For a bond of maturity s

$$i_t^{(s)} = i^{(s)} + A_1^{(s)} f_{1t} + \ldots + A_J^{(s)} f_{Jt},$$

where $i^{(s)}$ is the unconditional mean. The loadings, $A_1^{(s)}, \ldots, A_J^{(s)}$, can come from a purely statistical relationship, such as a principal component decomposition of the yield curve, or from no-arbitrage restrictions on bond prices. Duffee (2012) and Diebold, Piazzesi and Rudebusch (2005) provide brief overviews.[32]

Given the factor loadings, the S yields can be used at any point in time to back out the J

[32] In the case of the popular no-arbitrage affine term structure models, a given coefficient $A_j^{(s)}$ is a sum of two parts. One captures the effect of the factor j on yield s working through expected future short rates and is purely determined by the factor's persistence. The other captures the effect of the factor working through a term premium. For the reasons stated in the Introduction and Section 2.2, we are only concerned with the expectations part.

factors ($J \leq S$). The high-frequency studies carry this out using data from a window around monetary policy meetings. The lower-frequency studies do so using monthly or quarterly data. A robust finding from both literatures is that two factors alone capture about 95% of the movements of yields across maturities. A parsimonious representation of nominal interest rates is thus: $i_t = i + f_{1t} + f_{2t}$ and $i_t^{(s)} = i^{(s)} + A_1^{(s)} f_{1t} + A_2^{(s)} f_{2t}$. The first factor turns out to affect all yields more or less equally (the loadings are close to one for all maturities) and is therefore commonly referred to as the 'level' factor. Its time series has high persistence, close to random walk, implying near one-for-one effects on expected future interest rates. The second factor affects the long-short spread and is therefore generally referred to as the 'slope' factor. Its time series is also less persistent, implying a small effect on expected future interest rates at the long end.[33] While various macroeconomic shocks affect interest rates, the yield curve decomposition suggests that by far and large these shocks manifest themselves in the term structure by moving only its slope and/or its level. Monetary policy shocks that affect expected future interest rates at the long end are therefore reflected in the level factor (the studies reviewed in Section 2.2), whereas temporary policy shocks show up in the slope factor (Wu, 2001; Piazzesi, 2005; Diebold et al., 2006).

The two policy shocks are modeled here as independent AR(1) processes. One shock is temporary and the other close to random walk. Following much of both macro and macro-finance literatures, the highly persistent shock is modeled as a shock to an inflation target (the central bank's tolerance for inflation).[34] The benchmark Taylor rule, which closes the

[33]As noted in Section 2.2, the level factor is largely unrelated to *movements* in term premia (Cochrane and Piazzesi, 2008; Duffee, 2012; Bauer, 2018), whereas the slope factor and term premia are strongly correlated (a long list of studies, starting with Fama and Bliss, 1987).

[34]Technically, the inflation target shock is just a label for a 'standard' but very persistent policy shock, as the Taylor rule can always be rewritten in such a way. Specifying the shock as an inflation target shock leads to a convenient characterization of equilibrium interest and inflation rates derived in the next section. Gürkaynak, Sack and Swanson (2005b) provide reasons why a central bank's tolerance for inflation may be time-varying. Ireland (2007) contains a long list of references in the macro literature, including the celebrated Smets and Wouters (2003) model, that employ Taylor rules with inflation target shocks. A number of the studies listed in Section 2.2 employ inflation target shocks in the macro-finance literature.

model, is therefore specified as

$$i_t = i + \mu_t - \pi + \nu_\pi(\pi_t - \mu_t) + \eta_t, \quad \nu_\pi > 1. \tag{16}$$

Here, $\pi_t \equiv p_t/p_{t-1} - 1$ is the inflation rate between periods t and $t-1$, π is its steady-state value, and ν_π is a weight on deviations of the inflation rate from a stochastic inflation target μ_t. The inflation target has an unconditional mean equal to π and follows a stationary, though highly persistent, process $\mu_{t+1} = (1-\rho_\mu)\pi + \rho_\mu \mu_t + \xi_{\mu,t+1}$, where $\xi_{\mu,t+1}$ is a mean-zero innovation and ρ_μ is close to but less than one. The other shock, η_t, is a temporary shock. It has an unconditional mean equal to zero and follows a less persistent process $\eta_{t+1} = \rho_\eta \eta_t + \xi_{\eta,t+1}$, where $\xi_{\eta,t+1}$ is a mean-zero innovation. The two innovations, $\xi_{\mu t}$ and $\xi_{\eta t}$, are assumed to be orthogonal to each other. Observe that when μ_t is equal to its unconditional mean π, the Taylor rule is standard.

The present assumption of modeling the shocks as two independent AR(1) processes has two useful implications. First, as shown in the next section, it allows a straightforward mapping from the equilibrium effects of the two shocks on interest rates into the orthogonal level and slope factors, thus connecting the model to the lessons from the aforementioned literatures. Second, as shown in Section 6, it allows a simple exposition of the inner workings of the model. As demonstrated by Gürkaynak et al. (2005a), and as we also show in the Supplementary material, various rotations of these basic shocks provide different economic interpretations of the shocks, including as action shocks vs. statement shocks about the expected future path of policy rates.[35]

As a final remark, one may think that including interest rate smoothing into the Taylor rule (dependence on i_{t-1}), as is common in the macro literature, may affect the equilibrium persistence of nominal interest rates. While this is true to some extent, a number of studies demonstrate that without highly persistent policy shocks, Taylor rules are unable to generate

[35]Statement shocks can be both pure statements shocks (Gürkaynak et al., 2005a) as well as information shocks about the future state of the economy (Nakamura and Steinsson, 2018). In the Supplementary material we consider both cases.

in equilibrium as persistent nominal interest rates as in the data.[36] Another common element of Taylor rules, the output gap, is dropped from our specification for an easier exposition of the transmission mechanism in the model. Experimentation with an output gap did not change the main findings in any significant way.

3.9 Equilibrium interest, mortgage, and inflation rates

This section prepares the ground for our discussion of the inner workings of the model later on by explaining how the short- and long-term nominal interest rates, and the inflation rate, are determined in equilibrium.

The capital owner invests in all three assets in the economy. His optimality conditions thus have to exclude arbitrage opportunities across capital, the nominal one-period bond, and the nominal long-term mortgage (without the loss of generality, it is useful in the following discussion to abstract from the capital income tax to simplify notation). His Euler equation for the one-period nominal bond, together with the Euler equation for capital and the Taylor rule, provide a convenient characterization of the equilibrium short rate. The first-order conditions for $b_{1,t+1}$ and x_{Kt}, respectively, are

$$1 = E_t \left(Q_{1,t+1} \frac{1+i_t}{1+\pi_{t+1}} \right) \quad \text{and} \quad 1 = E_t \left[Q_{1,t+1} \left(\frac{r_{t+1}}{q_{Kt}} + \frac{q_{K,t+1}(1-\delta_K)}{q_{Kt}} \right) \right],$$

where $Q_{1,t+s} \equiv \beta u_{c,t+s}/u_{ct}$ is the real pricing kernel of the capital owner. Once log-linearized around a deterministic steady state (for convenience of the exposition), the two equations yield the Fisher equation

$$i_t - E_t \pi_{t+1} \approx E_t \left[r_{t+1} + (1-\delta_K) q_{K,t+1} - q_{Kt} \right] \equiv r_t^*, \tag{17}$$

where r_t^* is the ex-ante real interest rate and (abusing notation) all variables are in percentage

[36] E.g., Gürkaynak et al. (2005b), Hördahl et al. (2006), Rudebusch and Wu (2008), and Bekaert et al. (2010).

point deviations from steady state.[37] Combining equation (17) with the policy rule (16), assuming ρ_μ is close to one and excluding explosive paths for inflation, yields

$$i_t \approx \mu_t + \left[\sum_{s=0}^{\infty} \left(\frac{1}{\nu_\pi} \right)^s E_t r^*_{t+s} - \frac{\rho_\eta}{\nu_\pi - \rho_\eta} \eta_t \right], \tag{18}$$

where μ_t is the effect of monetary policy on the level factor and the expression inside the square brackets is the effect on the slope factor. In the notation of the conceptual framework of the preceding section, equation (18) can be written as $i_t \approx f_{1t} + f_{2t}$.[38] This is how it works: Observe that unless the effect of μ_t is sufficiently offset by an endogenous response of the expected future path of the real rate, the μ_t shock generates highly persistent, one-for-one, changes in i_t. It thus affects not only the short rate but also the long rate (the FRM rate derived below) and, thus, works like a level factor. The η_t shock represents the standard temporary monetary policy shock, calibrated to generate the standard New-Keynesian responses. That is, through the New-Keynesian channel (discussed in Section 6), a positive η_t shock increases the ex-ante real interest rate to the extent that i_t increases as well. Because the η_t shock and this New-Keynesian effect are only temporary, i_t responds only temporarily, leaving the long rate unaffected.[39] The η_t shock thus triggers a movement in the slope factor. Furthermore, as long as the persistent shock μ_t leaves the real rate relatively unaffected, the movements in the level and slope factors due to the two monetary policy shocks are approximately orthogonal to each other. The numerical findings in Section 5 confirm this to be the case.

The capital owner's first-order condition for l_{1t} in the FRM case determines the long-term nominal interest rate on a new FRM loan. Recall that according to equation (8) mortgage payments are determined by three state variables as $m_{1t} = (R_{1t} + \gamma_{1t})d_{1t}$, where the state

[37] As we are not concerned with term premia, we can work with log-linear expressions, in which certainty equivalence holds.

[38] As noted earlier, other shocks can affect the level and slope factors but our focus is only on monetary policy shocks.

[39] In principle, in a richer model, the η_t shock could affect the long rate by generating an increase or a decline in the risk premium. In the conceptual framework of the preceding section, the risk premium effect on yield s would show up as the part of the loading A^s_j, $j = \eta$, that is not purely due to the shock's persistence.

variables follow the laws of motion (9)-(11). In this representation, the first-order condition for l_{1t} consists of the marginal effects of l_{1t} on the capital owner's expected life-time utility, working through the three state variables

$$1 = E_t \left[\beta \frac{U_{d,t+1}}{u_{ct}} + \beta \frac{U_{\gamma,t+1}}{u_{ct}} \zeta_{1t} \left(\kappa - \gamma_{1t}^{\alpha} \right) + \beta \frac{U_{R,t+1}}{u_{ct}} \zeta_{1t} (i_t^F - R_{1t}) \right].$$

Here, $U_{d,t+1}$, $U_{\gamma,t+1}$, and $U_{R,t+1}$ are the derivatives of the capital owner's value function U in a recursive formulation of the problem and

$$\zeta_{1t} \equiv \frac{\frac{1-\gamma_{1t}}{1+\pi_t} \widetilde{d}_{1t}}{\left(\frac{1-\gamma_{1t}}{1+\pi_t} \widetilde{d}_{1t} + \widetilde{l}_{1t} \right)^2} \in (0,1), \tag{19}$$

where $\widetilde{d}_{1t} \equiv d_{t1}/p_{t-1}$ and $\widetilde{l}_{1t} \equiv l_{1t}/p_t$. The Supplementary material provides the recursive formulation of the capital owner's problem.

An insight into the first-order condition is gained when there is no previous debt and no further loans beyond period t. In this case $\zeta_{1t} = 0$ and the first-order condition simplifies to

$$1 = E_t \beta \frac{U_{d,t+1}}{u_{ct}}, \quad \text{where} \quad U_{dt} = u_{ct} \frac{i_t^F + \gamma_{1t}}{1+\pi_t} + \beta \frac{1-\gamma_{1t}}{1+\pi_t} E_t U_{d,t+1}$$

is obtained by the Benveniste-Scheinkman condition. Successive substitutions then yield an intuitive expression

$$1 = E_t \left[Q_{1,t+1} \frac{i_t^F + \gamma_{1,t+1}}{1+\pi_{t+1}} + Q_{1,t+2} (1-\gamma_{1,t+1}) \frac{i_t^F + \gamma_{1,t+2}}{(1+\pi_{t+1})(1+\pi_{t+2})} + \ldots \right], \tag{20}$$

where γ_{1t} evolves in a deterministic way according to the law of motion (10); specifically, as $\gamma_{1,t+s+1} = \gamma_{1,t+s}^{\alpha}$, starting with $\gamma_{1,t+1} = \kappa$. According to condition (20), the real mortgage payments on a loan of one unit of consumption have to be worth in present value terms one unit of consumption, when discounted by the capital owner's pricing kernel. The FRM interest rate i_t^F has to be such that condition (20) holds. Using the first-order condition for the one-period nominal bond, and the law of iterated expectations, the FRM pricing equation (20) can also be written in terms of future short-term nominal interest rates as

$$1 = E_t \left[\frac{i_t^F + \gamma_{1,t+1}}{1+i_t} + (1-\gamma_{1,t+1}) \frac{i_t^F + \gamma_{1,t+2}}{(1+i_t)(1+i_{t+1})} + ... \right] + \Psi_t, \tag{21}$$

where Ψ_t soaks up all the covariance terms between the pricing kernel and interest rates, and thus term premia. Using the property of the amortization rate that $\lim_{s\to\infty} \gamma_{1,t+s} = 1$ (i.e., the loan is eventually repaid), it is then straightforward to show that to a first-order effect, if all future short rates, i_t, i_{t+1},..., increase by λ percentage points, due to an increase of the μ_t shock by λ, the FRM rate also increases by λ percentage points.[40] The persistent policy shock thus affects the short and long rates equally, as claimed above. In terms of the conceptual framework of the preceding section, μ_t has loadings close to one on both the short and long rates. Changes in the short rate that are less persistent are also priced in i_t^F, but their impact is smaller.

In the ARM case, again using the property $\lim_{s\to\infty} \gamma_{1,t+s} = 1$, it is straightforward to verify that the discounted mortgage payment condition (again derived from the first-order condition for l_{1t}) always holds. That is,

$$1 = E_t \left[\frac{i_t + \gamma_{1,t+1}}{1+i_t} + (1-\gamma_{1,t+1}) \frac{i_{t+1} + \gamma_{1,t+2}}{(1+i_t)(1+i_{t+1})} + ... \right]$$

for any sequence of nominal interest rates. The capital owner is thus indifferent between the one period bond and a new ARM loan at any sequence for i_t, as claimed earlier.

Finally, substituting the expression for the short rate (18) into the policy rule (16) gives

[40] A first-order Taylor-series expansion of equation (21) with respect to interest rates around a deterministic steady state yields $0 = \frac{1}{1+i}(i_t^F - E_t i_{t+1}) + \frac{1-\gamma}{(1+i)^2}(i_t^F - E_t i_{t+2}) + ...$, where variables without a time subscript represent steady state and (abusing notation) variables with time subscript are in percentage point deviations from steady state (the first-order approximation essentially gets rid off nonlinearities arising due to Jensen's inequality).

an expression for the equilibrium inflation rate

$$\pi_t \approx \mu_t + \left[\frac{1}{\nu_\pi} \sum_{s=0}^{\infty} \left(\frac{1}{\nu_\pi} \right)^s E_t r^*_{t+s} - \frac{1}{\nu_\pi - \rho_\eta} \eta_t \right]. \tag{22}$$

As long as μ_t leaves the real rate more or less unaffected and η_t has only a temporary effect on the real rate, the inflation rate (22) is a sum of a near random walk and a temporary component, as in the model of inflation studied by Stock and Watson (2007). Furthermore, observe that μ_t moves the inflation rate approximately one-for-one with the short and long rates. The persistent shock thus makes the level factor positively correlated with inflation, as documented by the studies in the macro-finance literature noted in Section 2.2.

3.10 Demand for new mortgage loans

The preceding section explained how new mortgages are priced by no-arbitrage. Demand for new mortgages, l_{2t}, is determined by demand for new housing, x_{ht}, through the financing constraint (3). In our representation of mortgages, a new mortgage affects the homeowner's expected life-time utility through the three state variables that make up mortgage payments. The first-order condition for x_{ht} thus takes the form

$$(1-\theta)q_{Ht} + \theta q_{Ht} \beta E_t \left[-\frac{V_{d,t+1}}{v_{ct}} - \frac{V_{\gamma,t+1}}{v_{ct}} \zeta_{2t}(\kappa - \gamma^\alpha_{2t}) - \frac{V_{R,t+1}}{v_{ct}} \zeta_{2t}(i^M_{t+1} - R_{2t}) \right] = \beta E_t \frac{V_{h,t+1}}{v_{ct}},$$

where $V_{d,t+1}$, $V_{\gamma,t+1}$, $V_{R,t+1}$, and $V_{h,t+1}$ are the derivatives of the homeowner's value function V in a recursive formulation of the problem (the first three have a negative sign) and i^M_{t+1} is equal to either i^F_t or i_t, depending on whether the contract is FRM or ARM, respectively. Further, ζ_{2t} has the same form as in (19), except that the variables pertain to the homeowner. The first-order condition for x_{ht} states that the marginal cost of new housing has to be equal to its marginal benefit. Further, the marginal cost on the left-hand side is a sum of the current marginal cost of downpayment, the first expression, and the expected life-time marginal cost of debt financing, the second expression. The first-order condition can be conveniently rewritten in terms of an implicit wedge τ_{Ht} between the relative price of new housing and the marginal rate of substitution between housing and non-housing consumption

$$q_{Ht}(1+\tau_{Ht}) = \beta E_t \frac{V_{h,t+1}}{v_{ct}}.$$

The wedge works like a tax/subsidy on new housing and the product $q_{Ht}(1+\tau_{Ht})$ represents the effective price of new housing from the perspective of the homeowner.

An insight into the wedge is gained when, again, there is no previous debt and no further loans beyond period t. In this case $\zeta_{2t} = 0$ and the wedge becomes

$$\tau_{Ht} = -\theta \left\{ 1 - E_t \left[Q_{2,t+1} \frac{i^M_{t+1} + \gamma_{2,t+1}}{1+\pi_{t+1}} + Q_{2,t+2} \frac{(i^M_{t+2} + \gamma_{2,t+2})(1-\gamma_{2,t+1})}{(1+\pi_{t+1})(1+\pi_{t+2})} + ... \right] \right\},$$

where $Q_{2,t+s} \equiv \beta v_{c,t+s}/v_{ct}$ is the stochastic discount factor of the homeowner and γ_{2t} evolves in a deterministic way according to the law of motion (6). Observe that the expression inside the square brackets is the present value of future real mortgage payments, either on FRM or ARM, when discounted with the homeowner's stochastic discount factor. If the stochastic discount factor of the homeowner is different from that of the capital owner (i.e., $Q_{2,t+s} \neq Q_{1,t+s}$), then the present value is in general different from one and the wedge is nonzero, its value being determined by the cash-flows of mortgage payments over the life of the loan. For instance, redistributing real cash flows from periods/states with low $Q_{2,t+s}$ to those with high $Q_{2,t+s}$ increases the wedge. Holding income of the homeowner constant, when the wedge increases (declines), demand for mortgages declines (increases). In Garriga et al. (2017) we refer to this effect as the *price effect* of long-term mortgage debt, as it affects the effective price of new mortgages and, thus, housing investment.[41]

[41] In the ARM case, the wedge would always be equal to zero if the homeowner, like the capital owner, could trade the one-period nominal bond at zero cost. In the FRM case, the wedge would always be equal to zero if the agents could trade zero coupon bonds of all maturities at no cost. Under both contracts, a complete set of Arrow securities ensures a zero wedge. In these cases, mortgage finance would have no effect on the price of housing investment. Our assumption that the homeowner can trade the nominal bond only at a cost guarantees that the wedge is in general nonzero, except in the deterministic steady state (in which the bond market participation cost is equal to zero).

4 Calibration

While the goal of the paper is to propose a framework for monetary policy analysis, without any specific country in mind, to demonstrate the quantitative properties of the model, we rely on U.S. calibration. Most of the parameter values are based on the New-Keynesian literature (e.g., Galí, 2015) and U.S. calibration targets described in detail in Garriga et al. (2017). One period in the model corresponds to one quarter. Given that the model has cross-sectional implications (even though the split of the population is coarse), the calibration of the model deserves some detailed discussion.

4.1 Functional forms

We consider utility functions that are standard in the New-Keynesian literature: $u(c_1, n_1) = \log c_1 - [\omega_1/(1+\sigma)]n_1^{(1+\sigma)}$ and $u(c_2, h, n_2) = \varrho \log c_2 + (1-\varrho)\log h - [\omega_2/(1+\sigma)]n_2^{(1+\sigma)}$, where $\omega_1 > 0$, $\omega_2 > 0$, $\sigma \geq 0$, and $\varrho \in (0, 1)$. The production function has already been specified as Cobb-Douglas, with technology level A and capital share ς. The functions governing the curvature of PPF are $q_H(X_{Ht}) = \exp(\zeta(X_{Ht} - X_H))$ and $q_K(X_{Kt}) = \exp(\zeta(X_{Kt} - X_K))$, where $\zeta > 0$ and X_H and X_K are, respectively, the steady-state ratios of housing and capital investment to output (output, $Y - \Delta$, is normalized to be equal to one in steady state).[42] Finally, $\Upsilon(-B_t) = \exp(-\vartheta B_t) - 1$, where $\vartheta > 0$ and in steady state $B = 0$ (p is normalized to be equal to one, so there is no need to distinguish between real and nominal quantities in steady state). All functional forms conform to the assumptions made in the description of the model.

4.2 Parameter values

The parameter values are listed in Table 1, organized into eight categories. Population: Ψ. Preferences: β, σ, ω_1, ω_2, ϱ. Technology: Δ, ς, δ_K, δ_H, ϵ_w, ζ. Fiscal: G, τ_N, τ_K, $\overline{\tau}_2$. Price setting: ε, ψ. Mortgages: θ, κ, α. Bond market: ϑ. And monetary policy: π, ν_π, ρ_μ, ρ_η.

[42] For our calibration, $A = 1.3712$ ensures $Y - \Delta = 1$ in steady state.

Most parameters can be assigned values independently, without solving a system of steady-state equations. Six parameters (ω_1, ω_2, ϱ, ϵ_w, τ_K, $\overline{\tau}_2$) have to be obtained jointly from such steady-state relations. The parameters ζ and ϑ are calibrated on the basis of the dynamic properties of the model, given all other parameter values.

We start by describing, in the order of the above categories, those parameters that are calibrated individually. The population parameter Ψ is set equal to 2/3, so that homeowners correspond to the 3rd and 4th quintiles of the wealth distribution and capital owners to the 5th quintile. As is typical in the New-Keynesian literature, $\sigma = 1$. The discount factor is constrained by Euler equations. Data averages for the FRM and inflation rates imply $\beta = 0.9883$.[43] Setting $\Delta = 0.2048$ implies zero steady-state profits, for the value of ε noted below. The parameter ς then corresponds to the NIPA share of capital and is set equal to 0.283. The depreciation rates δ_K and δ_H are set equal to 0.02225 and 0.01021, respectively, on the basis of the average flow-stock ratios for capital and housing. Based on NIPA, G is set equal to 0.138 and τ_N to 0.235. The price-setting parameters take on uncontroversial values, $\varepsilon = 0.83$ and $\psi = 0.75$.[44] The loan-to-value ratio for new loans θ is set equal to 0.6, the long-run cross-sectional average for conventional newly-built home mortgages. The amortization parameters are taken from Kydland et al. (2016): $\kappa = 0.00162$ and $\alpha = 0.9946$.[45] In the Taylor rule, $\pi = 0.0113$, the same value used in the calibration of β and $\nu_\pi = 1.5$, a typical value in the New-Keynesian literature. Finally, $\rho_\mu = 0.99$ and $\rho_\eta = 0.3$. The persistent shock is thus close to random walk and the temporary shock has autocorrelation in the range of values typically found in the literature.

Given the above parameter values, six parameters $(\omega_1, \omega_2, \varrho, \epsilon_w, \tau_K, \overline{\tau}_2)$ are calibrated jointly by minimizing, in steady state, equally weighted distance between six targets in the

[43]In a deterministic steady state, FRM and ARM rates are equal. As a consequence, the steady-state ARM rate implied by the above value of β is somewhat higher than its data average. The model dynamics, however, are quantitatively almost the same regardless of whether FRM or ARM rate (or return on capital) is used to calibrate β.

[44]The average price duration is thus $(1-\psi)^{-1} = 4$ quarters.

[45]These parameters, together with the loan-to-value ratio, the depreciation rate for housing, and the steady-state housing stock imply a steady-state mortgage debt to quarterly GDP ratio equal to 1.61. This is somewhat lower than in the data, likely due to the fact that the model speaks only to first mortgages and does not include second mortgages and other forms of housing credit.

data and the model: the observed average capital-to-output ratio (K); the housing stock-to-output ratio (H); the aggregate hours worked (N); the ratio of mortgage payments to homeowner's income ($m_2/income_2$); homeowner's income share from transfers ($\bar{\tau}_2/income_2$); and capital owner's income share from labor ($\epsilon_w w n_1/income_1$). Here, $income_1 = (rk + m_1) + \epsilon_w w n_1 + \tau_1$ and $income_2 = wn_2 + \overline{\tau}_2$, which are constructed to be consistent with the way income is defined in the Survey of Consumer Finances (SCF). In particular, the capital owner's income includes income from all assets, including those backed by mortgage payments. The steady-state relations between the six parameters and targets consist of four optimality conditions (for capital, housing, and labor supply by the two agents) and the model counterparts to individual incomes (the above variables $income_1$ and $income_2$). While the six parameters and targets are interdependent, they are loosely related as follows. K identifies τ_K, H identifies ϱ, and the homeowner's income share from transfers identifies $\overline{\tau}_2$. Further, the labor supply parameters ω_1, ϵ_w, and ω_2 are identified from the three labor-related variables: aggregate hours worked, capital owner's income share from labor, and the ratio of mortgage payments to homeowner's income, most of which is labor income. The values of the six targets are provided in Table 2 and the resulting parameter values in Table 1. Table 2 also reports the model's implications for steady-state moments of the two agents not targeted in calibration, as well as some additional aggregate ratios. Although the model's cross-section is coarse, we see that the model is consistent with the corresponding cross-sectional facts, alongside the standard aggregate ratios.

Given all other parameter values, the PPF curvature parameter ζ and the parameter ϑ governing the bond market participation cost are calibrated on the basis of dynamics. In particular, the model is required to generate the standard New-Keynesian responses to the temporary policy shock.[46] The logic behind this calibration is that there is much more information in the literature on the responses of key variables to temporary than persistent

[46] As noted earlier, we prefer to keep the model relatively simple to highlight its mechanism. As a result, the model does not reproduce the exact timing and shape of the New-Keynesian responses, for which various additional frictions are necessary. We simply aim to achieve the right direction and magnitude of the responses. Further research can fine tune their shape and timing.

policy shocks (e.g., Christiano, Eichenbaum and Evans, 2005, among many others). Thus, ζ is calibrated so that in response to the temporary policy shock the model generates an increase in the short-term nominal interest rate, accompanied by a decline in both output and inflation of a smaller magnitude in absolute value than the increase in the short rate. Setting $\zeta = 3.2$ achieves this outcome.[47] Further, ϑ, which controls consumption smoothing by homeowners, is set equal to 0.15 so that, as in the data, aggregate consumption declines in response to the temporary shock by a little over half as much as output. Observed consumption smoothing in response to the temporary policy shock thus dictates the value of this parameter. (Essentially the same values of ζ and ϑ are obtained regardless of which mortgage contract is used in the model to calibrate these parameters.)

As a final remark, we explain the role of the fiscal parameters (G, τ_N, τ_K, $\overline{\tau}_2$). Government expenditures ensure that tax revenues can be sensibly distributed across the agents, without counterfactually distorting the composition of their incomes. The tax on capital ensures that, given the calibrated β, the observed capital-to-output ratio is consistent with the Euler equation for k. The transfer represents a fixed part of homeowners' income and thus determines the extent to which their income is subject to fluctuations in labor income. The labor income tax achieves realistic net income and thus a realistic ratio of mortgage payments to *net* income.

5 Findings

In this section we simply report the findings, highlighting the main lessons, and defer the explanation of the mechanism to the next section. Figure 2 demonstrates the presence of the debt channel in the model. This is the model counterpart to Figure 1, conditional on shock persistence (here we consider an increase, rather than a cut, in the policy rate). The figure shows the differences in the pass through of the policy rate to mortgage interest rates across

[47] Rupert and Šustek (2019) discuss why a parameter restricting capital adjustment is critical, in models with capital, for generating the standard New-Keynesian impulse responses.

the two mortgage contracts and across new and outstanding debt, for a given persistence of the policy shock, with the two calibrated values 0.3 and 0.99.

5.1 The experiments

The next four figures, Figures 3-6, present the findings for some key variables, distinguishing between the two shocks (temporary and persistent) and contracts (ARM and FRM). Each figure contains responses of three versions of the model: with both mortgages and sticky prices (MoNK), with mortgages only (Mo), and with sticky prices only (NK). Specifically, Mo has $\psi = 0$ whereas NK has $\theta = 0$, implying D_t=0 and $m_{jt} = 0$. All other parameter values are kept as in Table 1 (setting $\theta = 0$ affects the steady state, but the differences in all variables except debt are minuscule). The purpose of the alternative specifications is to isolate the effects of the two frictions, as well as their interaction.[48]

For both contracts and shock types, the size of the shock is normalized such that on impact, in MoNK, the short-term nominal interest rate increases by one percentage point (annualized). The same shock size is then used in the decomposition into Mo and NK. In the figures, the inflation rate is expressed as annualized percentage point deviations; quantities are expressed as percentage deviations.

5.2 Temporary policy shock

Figures 3 and 4 pertain to the temporary policy shock. Recall that the responses of the nominal interest rate, inflation, output, and aggregate consumption are engineered by the parameterization of ζ and ϑ to be consistent with the standard responses of the New-Keynesian channel.

There are two main, related, takeaways from Figures 3 and 4. First, the responses of all variables in MoNK (with the trivial exception of mortgage payments) are almost the same regardless of the contract used. Second, the responses of MoNK are similar to those of NK,

[48]Because the equilibrium needs to be recomputed when the specification changes, the below impulse responses from Mo and NK do not necessarily sum up to the one in MoNK.

with the exception of consumption of homeowners and, to a lesser extent, consumption of capital owners. Thus, except individual consumption, the debt channel is largely irrelevant for the transmission of the temporary shock and this shock transmits mainly through sticky prices.

With regard to individual consumption, there are two features to note: (i) the differences in the responses across the agents and (ii) between MoNK and NK. Regarding the first feature, the model possesses the attractive property that consumption of homeowners declines more than consumption of capital owners. In MoNK, about twice as much under ARM and by two thirds more under FRM. The decline in homeowners' consumption is also substantially more persistent. These properties of the model are consistent with empirical evidence that homeowners are constrained in their ability to smooth out fluctuations in income (e.g., Kaplan and Violante, 2014). Regarding the second point, individual consumption is visibly sensitive to the presence of the debt channel. This is particularly the case under ARM, where the decline in homeowners' consumption in MoNK is by a third as large as in NK, due to the temporary sharp increase in real mortgage payments, which provides an additional channel of monetary policy transmission interacting with sticky prices. The decline in homeowners' consumption under ARM is also clearly more persistent in MoNK than in NK.

In sum, while the theory is consistent with the lessons of the empirical studies noted in Section 2.1 that consumption expenditures of indebted homeowners (especially those with ARM) are highly sensitive to monetary policy shocks, it also cautions against extrapolating this lesson to the effect of mortgage debt on the economy as a whole, at least if the New-Keynesian channel is the dominating channel of monetary policy transmission: in Figures 3-4, the responses of aggregate output are effectively the same across the two contracts, as well as across MoNK and NK, despite differences in the response of individual consumption.

5.3 Persistent policy shock

Figures 5 and 6 pertain to the persistent policy shock. Due to higher persistence, the responses are plotted for 40 periods, instead of 20 as in the case of the temporary shock. Observe that in line with equations (18) and (22) the short rate and the inflation rate both increase by the same magnitude, leaving the ex-ante real interest rate essentially unaffected. Furthermore, as already observed in Figure 2, and in line with our earlier discussion, the FRM interest rate on new loans also increases by about the same magnitude as the short rate. The persistent shock thus manifests itself in the level factor.

There are four main takeaways from Figures 5 and 6. First, the differences between MoNK and Mo are small, meaning that most of the transmission of the shock works through the debt channel, with sticky prices playing secondary role. Second, most of the effects are redistributive, between consumption of the two agents and the two types of investment, with only small effects on aggregates. The lack of sizable aggregate responses occurs despite the fact that there are technological costs (nonlinear PPF) of changing the composition of aggregate expenditures, affected by the redistribution. Third, there are marked differences between ARM and FRM, with the responses quantitatively larger under ARM. And fourth, the real effects of monetary policy are present despite the fact that the real interest rate is essentially unaffected. In particular, the responses of individual consumption are not resulting from intertemporal substitution, a channel of monetary policy transmission critiqued by Kaplan et al. (2018) and other studies cited therein.

As in the case of the temporary shock, there are significant differences in the magnitude of the responses of consumption of the two agents. Here again, in absolute value, consumption of homeowners responds more than consumption of capital owners. This is particularly visible under ARM, where the decline in consumption of homeowners is immediate, due to the sharp persistent increase in real mortgage payments, which is costly to smooth out. Instead, under FRM, consumption of homeowners increases, due to the gradual decline in real mortgage payments. But in contrast to the immediate decline of their consumption under ARM, the increase under FRM is gradual. This again reflects the costly consumption smoothing of homeowners. Homeowners would like to increase consumption immediately by borrowing against the future savings on their mortgage payments on outstanding debt (deflated by persistent inflation), but this is costly due to the bond market participation cost. As a result, consumption under FRM increases only gradually and homeowners substitute on impact towards housing consumption, which can be financed through mortgages without incurring the participation cost. This substitution occurs even though the FRM rate on new loans increases, as we have seen in Figure 2.

While there is ample evidence on the responses of macro variables to temporary policy shocks (which the model is designed to replicate), information on responses to persistent policy shocks is so far, at best, scattered, due to difficulties with identification. Nonetheless, a couple of studies that attempted such analysis give some support to the responses generated by the model. Diebold et al. (2006) estimate a bi-directional (macro to yields, yields to macro) term structure model. A level factor shock in their model increases the short and long rates, inflation, and to a smaller extent aggregate economic activity. A similar result is obtained also by Rudebusch and Wu (2008). Using a standard VAR empirical framework, but with novel identification, Uribe (2018) finds that a permanent nominal interest rate shock increases inflation nearly one-for-one, accompanied by a modest increase in output. The responses of interest rates, inflation, and output from these studies are consistent with the properties of the model.

As in the case of the temporary shock, the theory again cautiones against drawing conclusions for the economy as a whole from strong responses of indebted homeowners to monetary policy shocks. Here, under ARM, aggregate output increases despite the sharp and sizable decline in homeowners consumption. And to the extent that the model is consistent with the empirical findings noted in the preceding paragraph, an increase in output and a decline in homeowners consumption (resulting from an increase in ARM payments) can coincide, if the policy shock hitting the economy resembles our persistent shock.

6 The mechanism

This section explains the mechanism behind the findings reported above. Specifically, it explains why in the above experiments the temporary shock in MoNK propagates mainly through the New-Keynesian channel, whereas the persistent shock propagates mainly through the long-term debt channel. This is again done by considering each channel in isolation. We subsequently discuss their (limited) interaction. Further, we connect the long-term debt channel in the model with the following concepts in the literature: (i) cash flow effects vs. the present value effects and (ii) the interest rate exposure channel vs. the Fisher revaluation channel.

6.1 New-Keynesian channel

While the New-Keynesian monetary transmission mechanism may be well understood, for completeness we briefly explain how it operates in our two-agent setting with capital and housing. As in the above experiments, when considering the role of the New-Keynesian mechanism in MoNK, we remove mortgages from the model (the NK specification: $\theta = 0$, implying $D_t = 0$ and $m_{jt} = 0$). In this case, the two agents still trade the one-period bond, with homeowners at a cost, but there is no long-term debt in the economy. The model is thus akin to a TANK model, albeit with capital and housing, two assets that can be used to smooth out consumption in the aggregate.

The nominal rigidity in the New-Keynesian mechanism is the price stickiness contained in the optimization problem (13). As demonstrated by numerous texts (e.g., Galí, 2015), the log-linearized version of the first-order condition for this problem, once aggregation is imposed, yields the New-Keynesian Phillips curve (NKPC)

$$\pi_t = \frac{(1-\psi)(1-\beta\psi)}{\psi}\widehat{\chi}_t + \beta E_t \pi_{t+1}, \tag{23}$$

where $\widehat{\chi}_t$ is a deviation of the real marginal cost from steady state, or equivalently from the flexible-price level (like in steady-state, under flexible prices the marginal cost is constant).[49] For β close to one, the NKPC provides a negative relationship between an expected change in the inflation rate, $E_t\pi_{t+1} - \pi_t$, and the real marginal cost, $\widehat{\chi}_t$. For a highly persistent inflation rate, $E_t\pi_{t+1} - \pi_t$ is close to zero, implying $\widehat{\chi}_t \approx 0$. This results in the case of the persistent policy shock and monetary policy has almost no real effects (in the quantitative experiment the expected change in inflation is slightly negative, as inflation declines slowly back to its steady state following the shock, leading to small positive real effects). If, in contrast, the inflation rate is not very persistent, then $E_t\pi_{t+1} - \pi_t \neq 0$ and $\widehat{\chi}_t \neq 0$. This results under the temporary policy shock, in which case monetary policy has real effects.

In the supplementary material we establish that percentage deviations in the real marginal cost are positively related to percentage deviations in aggregate output, $\widehat{Y}_t$.[50] Equation (23) thus provides a negative relationship between $E_t\pi_{t+1} - \pi_t$ and $\widehat{Y}_t$. As a result, the policy shock that temporarily reduces inflation, thus generating $E_t\pi_{t+1} - \pi_t > 0$, produces a decline in output, $\widehat{Y}_t < 0$. As both agents' incomes represent a claim on aggregate output (in the form of labor and capital income), the temporary decline in output translates into a temporary decline in income, which the agents would like to smooth out. As a result, both capital and housing investment drop. However, as investment is costly to adjust, due to the nonlinear PPF, full consumption smoothing cannot be achieved and the declines in incomes must be partly reflected also in temporary declines in consumption.

Further, because consumption smoothing is costlier for the homeowner than the capital owner, C_{2t} declines by more than C_{1t}. There are two reasons for this. First, housing is costlier to adjust than capital as it involves a direct utility loss, in addition to the nonlinear PPF. And second, the homeowner cannot easily tap (indirectly) into using capital to keep consumption smooth as borrowing from the capital owner through the bond market involves a

[49]Equation (23) is derived under the common assumption that the steady-state inflation rate is equal to zero, which leads to a more elegant expression for the linearized NKPC than would otherwise be the case. The model is computed under the calibrated non-zero steady-state inflation rate.

[50]A positive relationship between $\widehat{\chi}_t$ and $\widehat{Y}_t$ is easier to establish in the textbook New-Keynesian model, in which $\widehat{C}_t = \widehat{Y}_t$.

cost in the form of the premium over the short rate.[51] Homeowners nonetheless use the bond market to some extent, which explains the persistence in the decline in their consumption, as borrowing to mitigate the impact of the shock results in debt repayments, and thus lower consumption, over time. Finally, the fall in capital investment leads to a decline in q_{Kt} and thus positive expected capital gains, $E_t(1-\delta_K)q_{K,t+1} - q_t > 0$, generating the typical New-Keynesian temporary increase in the ex-ante real interest rate r_t^* (see equation (17)), following a monetary tightening. Effectively, the increase in the real interest rate ensures that, in equilibrium, capital owners are content with the temporary decline in their consumption, as required by their Euler equation.

In sum, the New-Keynesian channel is the strongest for temporary policy shocks and its power declines with the persistence of the shock. In the limit, as the shock persistence approaches random walk, the New-Keynesian channel shuts down completely. A temporary shock temporarily reduces the inflation rate, output and all its expenditure components, and temporarily increases the real interest rate.

6.2 Long-term debt channel

Next, consider the case when housing is financed by mortgages but there are no New-Keynesian frictions (the Mo specification: $\psi = 0$, meaning flexible prices). In this case, the NKPC (23) implies $\widehat{\chi}_t = 0$. The marginal cost is constant and r_t and w_t are equal to their respective marginal products, subject to a constant markup. Section 3.10 explained how demand for new mortgages is determined and that it depends on the distribution of real mortgage payments over the life of the loan, showing up as a wedge in the first-order condition for housing. We referred to that effect as the price effect. In this section we focus on how the equilibrium is affected by the outstanding stock of mortgage debt, referring to

[51] An additional reasons for a stronger response of homeowners' consumption is that capital owners are partially hedged against the drop in aggregate output by an increase in monopoly profits, which are well known to be counter-cyclical in New-Keynesian models. This partially compensates them for the decline in labor and capital income. On the other hand, in our calibration, a larger fraction of homeowners' income, than capital owners' income, is derived from fixed transfers, which provide a buffer against fluctuations in income from production factors.

this effect as the *income effect*, as it affects disposable income. Outstanding debt is the focus of the literature reviewed in Section 2.1

In the case of outstanding debt, what matters are the payments over the remaining term of existing loans. It is convenient to write these payments in real terms: $\widetilde{m}_{j,t+s} \equiv m_{j,t+s}/p_{t+s}$, with $j \in \{1, 2\}$ denoting the agent and $s = 0, 1, 2, ...$ denoting the time period ahead. To focus squarely on outstanding debt, let us assume that $l_{j,t+s} = 0$, for $s = 0, 1, 2, \ldots$. That is, there are no new loans originated after and including the current period t. The sequence of real payments on outstanding debt, following and including period t, is thus

$$\widetilde{m}_{jt} = \frac{R_{jt} + \gamma_{jt}}{1 + \pi_t} \widetilde{d}_{jt} \tag{24}$$

$$\widetilde{m}_{j,t+1} = \frac{R_{j,t+1} + \gamma_{j,t+1}}{(1 + \pi_{t+1})(1 + \pi_t)} (1 - \gamma_{jt}) \widetilde{d}_{jt}, \tag{25}$$

$$\widetilde{m}_{j,t+2} = \frac{R_{j,t+2} + \gamma_{j,t+2}}{(1 + \pi_{t+2})(1 + \pi_{t+1})(1 + \pi_t)} (1 - \gamma_{j,t+1})(1 - \gamma_{jt}) \widetilde{d}_{jt}, \quad \text{etc.} \tag{26}$$

Here, $\widetilde{d}_{jt} \equiv d_{jt}/p_{t-1}$ is the stock of outstanding debt, as of period t, in real terms. Recall that in period t the variables R_{jt}, γ_{jt}, and d_{jt} are pre-determined state variables, which in subsequent periods evolve according to the laws of motion (5)-(7), for the homeowner, and (9)-(11), for the capital owner (p_{t-1} is also pre-determined). Further, the evolution of the interest rate $R_{j,t+s}$ depends on whether loans are FRM or ARM.

In the following subsections, we specialize the general expressions for mortgage payments (24)-(26) to FRM and ARM contracts. After describing the payments in each case, we explain their impact on households in two extreme cases: a hand-to-mouth consumer and a permanent income hypothesis consumer. The quantitative findings reported above lie in-between these two boundaries. Recall that the position between the two boundaries was calibrated on the basis of replicating the response of consumption, relative to output, to the standard temporary policy shock. Finally, we discuss how the effects of the inflation rate and the real interest rate on mortgage payments in the model are related to the Fisher revaluation channel and the interest rate exposure channel noted in Section 2.1.

6.2.1 FRM

Under FRM, $R_{j,t+s}$ is constant for all $s = 0, 1, 2, ...$ As a result, monetary policy affects the remaining sequence of real mortgage payments on outstanding debt only through inflation. An increase in inflation reduces the real value of the payments. What matters quantitatively, however, is the accumulated effect of the inflation rate. As is apparent from equations (24)-(26), the size of the real effects on the payments gradually increases over time in line with inflation persistence: a temporary change in inflation has a much smaller effect on the real value of mortgage payments in the later periods of the remaining term than a persistent change.[52]

Hand-to-mouth homeowner

A hand-to-mouth homeowner, which in our setup results if the cost of adjusting the one-period bond is infinite, takes the real payments as they come and, in the absence of new loans and housing investment (and the labor supply margin), adjusts consumption one-for-one with the real payments, $\widetilde{m}_{2,t+s}$, $s = 0, 1, 2, ...$ This effect is in the literature (see Section 2.1) generally referred to as the *cash flow effect*, since it is the period payments—cash flows—that determine consumption through a sequence of independent period budget constraints (i.e., constraint (2) with $b_{2,t+1} = b_{2t} = 0$ for all t, in addition to the absence of l_{2t} and x_{Ht}).[53] Due to the accumulated effect of inflation in equations (24)-(26), the cash flow effects under FRM get stronger over time with inflation persistence.

Permanent income hypothesis homeowner

A permanent income hypothesis homeowner, which results in our setup if the cost of adjusting the one-period bond is zero, faces a life-time budget constraint, rather then a sequence of independent period constraints. The life-time budget constraint can be derived from equation

[52] Observe from equations (24)-(26) that if mortgages were one-period loans ($\gamma_{jt} = 1$), the inflation effect would occur only in period t and inflation persistence would be irrelevant.

[53] In the full model, homeowners can use the housing investment margin, x_{Ht}, and the labor supply margin, n_{2t}, to mitigate the cash flow effects, even if the cost of accessing the bond market is infinite.

(2) by forward substitution for $b_{2,t+s}$, $s = 1, 2, ...$, with $\Upsilon_t = 0$ for all t. Putting again aside new loans and housing investment, the life-time budget constraint is

$$\mathcal{C}_t = \mathcal{W}_t + \frac{1 + i_{t-1}}{1 + \pi_t}\widetilde{b}_{2t} - \left[\widetilde{m}_{2t} + \sum_{s=1}^{T}\prod_{i=0}^{s-1}\frac{1}{1 + r_{t+i}}\widetilde{m}_{2,t+s}\right], \tag{27}$$

where $\mathcal{C}_t \equiv c_{2t} + \sum_{s=1}^{T}\prod_{i=0}^{s-1}\frac{1}{1+r_{t+i}}c_{2,t+s}$ and $\mathcal{W}_t \equiv w^*_{2t} + \sum_{s=1}^{T}\prod_{i=0}^{s-1}\frac{1}{1+r_{t+i}}w^*_{2,t+s}$, with $w^*_{2,t+s}$ denoting post-tax labor income plus transfers, and where the real mortgage payments are given by equations (24)-(26) for FRM. To simplify exposition, we have abstracted from uncertainty in deriving the life-time budget constraint and use r_t here for the real interest rate, between t and $t + 1$, in the Fisher equation: $1 + r_t = (1 + i_t)/(1 + \pi_{t+1})$. With infinite horizon, $T = \infty$. As is apparent from equation (27), in the case of a permanent income hypothesis homeowner, consumption depends only on the present value of the long-term debt position—the term in the square brackets—not individual cash flows.

Inflation affects the present value of the long-term debt position by determining the sequence of real mortgage payments, as described above. The inflation effect on the present value is in the literature referred to as the *Fisher revaluation channel*. In Doepke and Schneider (2006), and their follow-up papers, as well as in Meh et al. (2010) and Meh and Terajima (2011), changes in inflation are persistent, similar to those resulting from our persistent shock. In contrast, in Adam and Zhu (2016), and Auclert (2019) changes in inflation are only temporary (these authors only consider changes in the current π_t), similar to those resulting from our temporary shock. Given the above discussion on the determination of real mortgage payments, persistent changes in inflation have clearly a stronger effect on the present value of the debt position than temporary changes.[54]

Changes in the real interest rate also affect the present value of the long-term debt position. Auclert (2019) refers to this effect as the *interest rate exposure channel*. As is apparent from equation (27), persistent changes in the real interest rate have a stronger

[54]Campbell and Cocco (2003) refer to the Fisher revaluation channel as "the real capital value risk of FRM".

effect on the present value than temporary changes. As we have seen in the computational experiments, and as explained in Section 3.9, the shocks and frictions in the model generate in equilibrium only short-lived changes in the real rate: the temporary shock has a sort-lived effect on the real rate, in the presence of sticky prices, while the persistent shock leaves the real rate unaffected, both with and without sticky prices. The short-lived changes in the real rate in the model are close to a scenario considered by Auclert (2019), who shows that in the case of a change only in the current r_t, the present value of total wealth (net financial wealth plus discounted future earnings) changes by the amount equal to, using our notation, $w^*_{2t} + \frac{1+i_{t-1}}{1+\pi_t}\widetilde{b}_{2t} - \widetilde{m}_{2t} - c_{2t}$, where $\widetilde{m}_{2t}$ is given by (24). He refers to this expression as the "unhedged interest rate exposure". Clearly, this concept, increasingly used in empirical studies (see, e.g., Tzamourani, 2019; Slacalek et al., 2020), rests on the presence of the life-time budget constraint and thus applies only in cases in which households have sufficiently unconstrained access to financial markets.

The calibrated homeowner

As noted above, in our model, homeowners are in-between the two extreme cases, hand-to-mouth and permanent income hypothesis households. Which of the two types they resemble more can be inferred from how closely their consumption tracks real mortgage payments. The comovement between these two variables can be easily read off Figure 6, which considers the persistent shock, resulting in a persistent increase in inflation, with sizable gradual effects on real mortgage payments. As consumption of homeowners grows gradually in line with the gradual decline in real mortgage payments, the cash flow effects in the model are fairly strong (recall the real rate in this experiment is approximately constant and so the increase in consumption does not result from an intertemporal substitution effect). On this basis, the homeowners in the model are closer to hand-to-mouth households than permanent income hypothesis households. The *calibrated* model is thus closer to the world of, e.g., Di Magio et al. (2017) than that of Doepke and Schneider (2006) or Auclert (2019). This can also be observed from the left panel of Figure 11, which compares the model responses under the three versions of the homeowner.[55, 56]

6.2.2 ARM

Under ARM, the income effect is dramatically different. In this case, the interest rate in the current period t, R_{jt}, is predetermined, equal to i_{t-1}, but subsequent interest rates are reset in line with the short rate: $R_{j,t+1} = i_t$, $R_{j,t+2} = i_{t+1}$, etc. (recall from Section 3.9 that this guarantees the absence of arbitrage on the part of capital owners between ARM and rolling over the one-period bond). After the current period t, monetary policy thus affects both the denominator and the numerator in the expressions for real mortgage payments (24)-(26). To highlight the combined effect, let us focus on the first period in which a re-set applies (i.e., period $t+1$). The ratio in equation (25) can be approximately written as[57]

$$\frac{i_t + \gamma_{j,t+1}}{(1+\pi_{t+1})(1+\pi_t)} \approx \frac{i_t + \gamma_{j,t+1}}{1+\pi_{t+1}+\pi_t} \approx i_t + \gamma_{j,t+1} = r_t + \pi_{t+1} + \gamma_{j,t+1}.$$

Similar expressions can be derived for real payments in other periods, at least as long as the effect of accumulated inflation in the denominator can be safely ignored (discussed below).

The key insight here is that an increase in the short-term nominal interest rate has the same effect on real mortgage payments regardless of whether the increase is due to an

[55] The shock has the opposite effect on capital owners, leaving aggregate consumption fairly unaffected. This is despite the fact that homeowners are more constrained in consumption smoothing, as reflected in the stronger responses of their consumption, than capital owners. The reason for the lack of a quantitatively interesting response of aggregate consumption is that the steady-state consumption of capital owners is higher than that of homeowners.

[56] Observe that consumption of capital owners also follows the path of the cash flows, even though less strongly than consumption of homeowners. This is because, as discussed earlier, if homeowners are constrained in the use of the bond market, in equilibrium, so are capital owners, as they are the only counterparty to bond trades. And while capital owners can use capital investment to achieve consumption smoothing, this involves a cost in the form of the nonlinear PPF. A factor that also somewhat insulates their consumption from fluctuations in mortgage payments is that relative to their income, the receipts from mortgage payments are small (see Table 2).

[57] In this derivation, the first approximation step holds for sufficiently small inflation rates and the second step holds again for sufficiently small inflation rates and for $\gamma_{j,t+1}$ sufficiently smaller than one, which is generally the case, unless the stock is close to maturity. Further, in the final step, we have utilized the Fisher equation, assuming perfect foresight for easier exposition.

increase in the real rate, r_t, or the inflation rate, π_{t+1}. Thus, in contrast to the FRM case, an increase in π_{t+1} under ARM *increases* the real value of mortgage payments. Monetary policy can thus engineer the same effect on real payments regardless of whether the effect comes from its ability to increase the real rate or expected inflation. All that matters is the increase in the short-term nominal interest rate. But while its ability to affect the real rate is only temporary (under sticky prices and the temporary shock), expected inflation can be increased persistently in line with the persistent policy shock. After sufficiently long time, however, the effect of accumulated inflation in the denominator starts to dominate the inflation effect in the numerator and the overall effect of the persistent shock on real mortgage payments under ARM starts to resemble that under FRM. This is why, in Figure 5, after period 30 (7.5 years), the real value of mortgage payments falls below the initial level.

Hand-to-mouth homeowner

A hand-to-mouth homeowner takes the mortgage payments (cash flows) as they come. Thus, in the first period in which the mortgage rate is reset upwards, his consumption sharply drops in line with the increase in real mortgage payments. Clearly, from equation (25), if mortgage loans were one-period loans ($\gamma_{2t} = 1$), the cash-flow effects coming from the reset of the mortgage rate would be absent.

Permanent income hypothesis homeowner

A permanent income hypothesis homeowner faces again the life-time budget constraint (27)—recall this constraint holds for a generic sequence of $\widetilde{m}_{2,t+s}$—but now with the mortgage payments (24)-(26) applicable to ARM. In particular, the present value of the long-term debt position in the life-time budget constraint becomes

$$\widetilde{m}_{2t} + \sum_{s=1}^{T} \prod_{i=0}^{s-1} \frac{1}{1+r_{t+i}} \widetilde{m}_{2,t+s}$$

$$= \frac{(i_{t-1}+\gamma_{2t})\widetilde{d}_{2t}}{1+\pi_t} + \left[\frac{i_t+\gamma_{2,t+1}}{(1+r_t)(1+\pi_{t+1})} + \frac{(i_{t+1}+\gamma_{2,t+2})(1-\gamma_{2,t+1})}{(1+r_t)(1+\pi_{t+1})(1+r_{t+1})(1+\pi_{t+2})} + \ldots \right] \frac{(1-\gamma_{2t})\widetilde{d}_{2t}}{1+\pi_t},$$

where the last term is the unamortized real debt at the end of period t. Without loss of generality consider $T = 2$. That is, there are mortgage payments in the current period t and two further periods, $t+1$ and $t+2$. In this case, $\gamma_{2,t+2} = 1$, as $t+2$ is the final period of the life of the loan. Then, working backwards from period $t+2$, using the Fisher equation $1 + i_{t+s} = (1 + r_{t+s})(1 + \pi_{t+s+1})$, the expression in the square brackets becomes equal to one and the present value of the long-term debt position becomes $[(1 + i_{t-1})/(1 + \pi_t)]\widetilde{d}_{2t}$. This is equivalent to a one-period debt position.

Effectively, the ability to costlessly trade the one-period bond, which is used to price ARM by capital owners, allows the homeowner to offset any changes in the real mortgage payments resulting from changes in the short-term nominal interest rate. In other words, the one-period nominal bond completes the market in the dimension of nominal interest rate re-sets under ARM.[58] The important point here is that under ARM and the assumption of a permanent income hypothesis homeowner, the Fisher revaluation channel matters only to the extent that it works through current inflation, π_t, while the interest rate exposure channel is absent.

The calibrated homeowner

Again, the position of homeowners in the model between the two extremes can be inferred from the comovement between their consumption and real mortgage payments. It is apparent from Figure 5 that, although there is some consumption smoothing around the sharp increase

[58] While, for easy exposition, we have abstracted from considering uncertainty explicitly, the above derivation holds also with uncertainty. In that case, all that is needed is to replace the simple Fisher equation with its general form, $(1+i_t)^{-1} = E_t[Q_{2,t+1}/(1+\pi_{t+1})]$, and to replace the real rate in the discounted sums with the inverse of the homeowner's pricing kernel $Q_{2,t+s}$. Working backwards, exploiting the law of iterated expectations, gives the discounted sum in the square brackets again equal to one.

in real mortgage payments at the time of the first re-set (consumption is smoother than real mortgage payments at that point and falls ahead of the re-set), overall, homeowners consumption tracks real mortgage payments fairly closely (in the opposite direction); again recall there is no change in the real rate and thus no intertemporal substitution effect. Homeowners in the model are thus closer to hand-to-mouth homeowners than permanent income hypothesis homeowners. This can also be observed from the right panel of Figure 11, which compares the model responses under the three versions of the homeowner. For the same reasons discussed in the FRM case, consumption of capital owners responds less (and in the same direction as the re-sets), but still tracks the real mortgage payments over time.

Finally, compare the real mortgage payments in Figures 3 and 5 (under MoNK). In both figures, at the time of the first re-set (period 2), real mortgage payments increase by 6 percent. This is because the short-term nominal interest rate in both cases increases by the same magnitude. In Figure 3, the increase in the nominal rate is due to an increase in the real rate, whereas in Figure 5 it is due to an increase in expected inflation. This confirms the point made above that all that matters for real mortgage payments under ARM (at least in short to medium run) is the nominal rate.

6.3 Interactions under ARM and the temporary shock

Although there is much separation between the potency of the two channels to transmit monetary policy, one place where they interact in a quantitatively nontrivial way is in the response of homeowners consumption under the temporary shock, especially under ARM (Figure 3). In the Mo case, there is almost no response of C_{2t} on the impact of the shock but this variable responds substantially more strongly in MoNK than in NK. The combination of the two nominal rigidities thus has a bigger impact than the sum of their individual effects.

The reason for this outcome is the following. Under both MoNK and NK, the temporary monetary policy tightening leads to a temporary decline in output, resulting in a decline in income of both agents and an increase in the ex-ante real rate. Both agents are trying to borrow in order to smooth out the temporary decline in income, driving the real rate up. Under MoNK, in addition, homeowners face a temporary increase in real mortgage payments, which they would also like to smooth out. However, they find it very costly to do so when all agents are trying to borrow. Effectively, in MoNK, homeowners are hit by a double whammy: an increase in real mortgage payments at the time of an aggregate decline in output. Or in other words, their mortgage payments go up at the time when the cost of unsecured credit also goes up. Therefore, their consumption under MoNK has to adjust more than under NK.

7 Conclusions

In recent years, there has been much interest in the role of household long-term, mortgage, debt in the transmission mechanism of monetary policy. This paper offers a tractable framework that integrates the long-term debt channel with the standard New-Keynesian channel, providing a tool for monetary policy analysis that reflects the recent debates in the literature. In line with much empirical evidence, an important feature of the model is a limited ability of homeowners to smooth out fluctuations in disposable income. We have shown how the model can be calibrated to be consistent with both basic aggregate and cross-sectional moments and carried out computational experiments to get a sense of the relative importance of the two channels, as well as of their interaction. The nature of the computational experiments was guided by recent lessons from both the macroeconomic and finance literatures regarding the effects of monetary policy on nominal interest rates. We have explained at length the inner workings of the model and related it to key concepts employed in the literature on the long-term debt channel.

The key findings from our computational experiments can be summarized as follows. First, there is much decoupling between the two channels. The New-Keynesian channel transmits temporary deviations from the Taylor rule, whereas the long-term debt channel transmits persistent changes in the course of monetary policy. Put differently, for most key variables, mortgage debt is largely irrelevant for the transmission of temporary policy shocks, while sticky prices are largely irrelevant for the transmission of persistent policy shocks. The New-Keynesian channel generates short-lived aggregate effects whereas the long-term debt channel generates persistent distributional effects. The distributional effects are quantitatively comparable with the aggregate effects, holding the initial change in the policy rate the same. Second, under both channels, consumption of homeowners is more sensitive to monetary policy than consumption of capital owners, who represent in the model the richest quintile of the population. Furthermore, consumption of homeowners is the only variable significantly affected by the presence of long-term debt in the New-Keynesian channel, especially under ARM. Monetary tightening in this case is a double whammy for homeowners: their real mortgage payments increase at the time when the cost of unsecured credit also goes up. Third, although the effect of mortgage debt on homeowners consumption in the model is consistent with empirical evidence on the strong effects of monetary policy on this segment of the population, the model calls for caution when extrapolating from such observations to the economy as a whole.

There are two extreme cases of the debt channel considered in the literature: one based on the present value of the debt position and the other on the timing of cash flows. The homeowners in the model operate in-between these boundaries, but our calibration based on VAR evidence implies that they are closer to the cash flow channel. This is crucial for the debt channel in the case of ARM. We have shown that if only the present value of the debt position mattered, then only surprises in current inflation (not its persistence) would matter for the workings of the long-term debt channel while changes in the real interest rate would be irrelevant. This is because frictionless trade in a one-period nominal bond, which underpins the present value of the debt position as the relevant variable, effectively completes the market in the dimension of ARM re-sets.

For analytical purposes, we have imposed orthogonality on the two types of shocks. In practice both policy shocks likely occur at the same time, making the two channels operate concurrently. Furthermore, the two basic shocks can be intertwined by various rotations, forming shocks with interesting economic interpretations, such as statement and action shocks.

There are various ways in which the present model could be extended in future work. First, a natural extension is to incorporate various bells and whistles in order to obtain a closer fit to the data along the dimensions well established in empirical studies, such as the responses to the temporary shock. Next, while we have listed a few reduced-form studies that give some support to the responses in the model to the persistent shock, this area clearly requires further empirical research. In some sense, the theory is ahead of measurement and more empirical work is needed to establish widely accepted 'facts'. Third, long-term nominal debt adds an extra nominal rigidity to the standard sticky-price framework, with nontrivial implications for optimal monetary policy. What makes the design of optimal policy even more interesting is that both ARM and FRM loans may exist in different parts of a single monetary area, such as the eurozone. Finally, the big open question regards the role of term premia in the transmission mechanism. Existing research suggests that the persistent shock, as reflected in the level factor, is an unlikely source of time variation in term premia. It is, however, feasible that the present framework underestimates the role of the temporary shock if temporary shocks cause movements in term premia, and thus in the cost of long-term loans.

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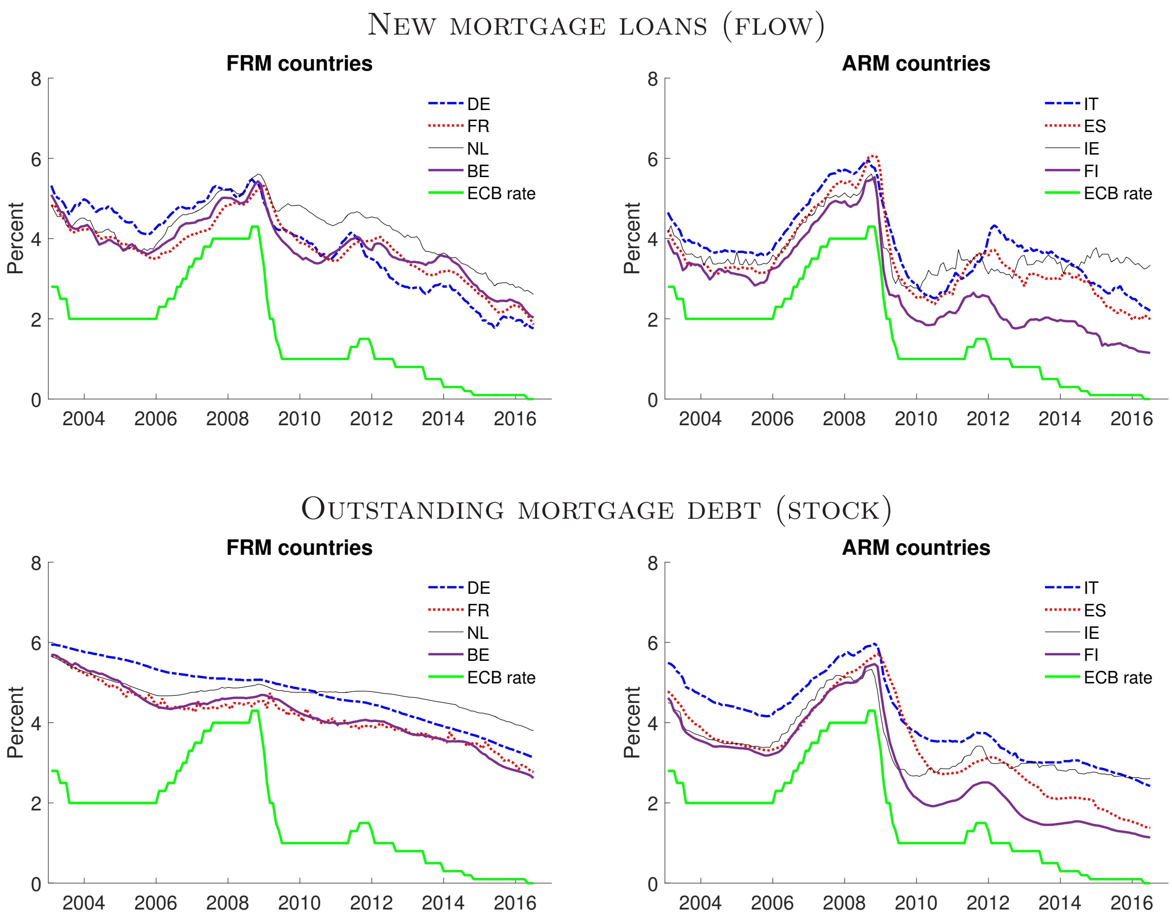

Figure 1: Illustration of the debt channel. ECB policy rate and nominal interest rates on mortgages in the euro area (aggregate averages for each country). Data source: European Central Bank.

Table 1: Parameter values

Symbol	Value	Description
Population		
Ψ	2/3	Share of homeowners
Preferences		
β	0.9883	Discount factor
σ	1.0	Frisch elasticity
ω_1	8.4226	Disutility from labor (capital owner)
ω_2	12.818	Disutility from labor (homeowner)
ϱ	0.6258	Weight on consumption (homeowner)
Technology		
Δ	0.2048	Fixed cost
ς	0.283	Capital share of output
δ_K	0.02225	Depreciation rate of capital
δ_H	0.01021	Depreciation rate of housing
ϵ_w	2.3564	Rel. productivity of cap. owners
ζ	3.2	Curvature of PPF
Fiscal		
G	0.138	Government expenditures
τ_N	0.235	Labor income tax rate
τ_K	0.3361	Capital income tax rate
$\overline{\tau}_2$	0.05853	Transfer to homeowner
Price setting		
ε	0.83	Elasticity of substitution
ψ	0.75	Fraction not adjusting prices
Mortgages		
θ	0.6	Loan-to-value ratio
κ	0.00162	Initial amortization rate
α	0.9946	Amortization adjustment factor
Bond market		
ϑ	0.15	Participation cost function
Monetary policy		
π	0.0113	Steady-state inflation rate
ν_π	1.5	Weight on inflation
ρ_μ	0.99	Autocorr. of persistent shock
ρ_η	0.3	Autocorr. of temporary shock

Table 2: Nonstochastic steady state vs. long-run averages of U.S. data

Symbol	Model	Data	Description
Targeted in calibration:			
K	7.06	7.06	Capital stock
H	5.28	5.28	Housing stock
N	0.255	0.255	Aggregate hours worked
$m_2/(wn_2+\overline{\tau}_2)$	0.15	0.15	Mortgage payments to income
$\overline{\tau}_2/(wn_2+\overline{\tau}_2)$	0.12	0.12	Transfers in homeowner's income
$\epsilon_w wn_1/income_1$	0.53	0.53	Labor income in cap. owner's income
Not targeted:			
A. Capital owner's variables			
$(rk+m_1)/income_1$	0.42	0.39§	Income from assets in total income
$\tau_1/income_1$	0.05	0.08	Transfers in total income
$m_1/netincome_1$	0.07	N/A	Mortg. income to post-tax income
B. Homeowner's variables			
$wn_2/(wn_2+\tau_2)$	0.88	0.82	Labor income in total income
$m_2/[(1-\tau_N)wn_2+\tau_2]$	0.18	N/A	Mortgage payments to post-tax income
C. Earnings distribution			
$\epsilon_w wN_1/(\epsilon_w wN_1+wN_2)$	0.59	0.54	Capital owners' share
$wN_2/(\epsilon_w wN_1+wN_2)$	0.41	0.46	Homeowners' share
D. Income distribution			
$Income_1/[Income_1+(wN_2+\Psi\tau_2)]$	0.70	0.61	Capital owners' share
$(wN_2+\Psi\tau_2)/[Income_1+(wN_2+\Psi\tau_2)]$	0.30	0.39	Homeowners' share
E. Aggregate housing consumption			
$(r_H+\delta_H)H/[C1+C2+(r_H+\delta_H)H]$	0.15	0.17§§	Housing services in aggr. consumption

Notes

Normalizations in steady state: $Y-\Delta=1$ and $p=1$.

Income and earnings data come from SCF. The model counterparts are constructed to be consistent with SEF definitions.

$income_1=(rk+m_1)+\epsilon_w wn_1+\tau_1$ (capital owner's income).

$Income_1=(1-\Psi)income_1$ (aggregate income of capital owners).

$netincome_1=[(1-\tau_K)rk+\tau_K\delta_K k+m_1]+(1-\tau_N)\epsilon_w wn_1+\tau_1$ (after tax income of capital owners).

§ The sum of capital and business income in SCF, where capital income is income from all financial assets.

§§ NIPA-based estimate; the model counterpart is defined in line with NIPA (the numerator = imputed rents, where $r_H=1/\beta-1$ is the net rate of return on housing).

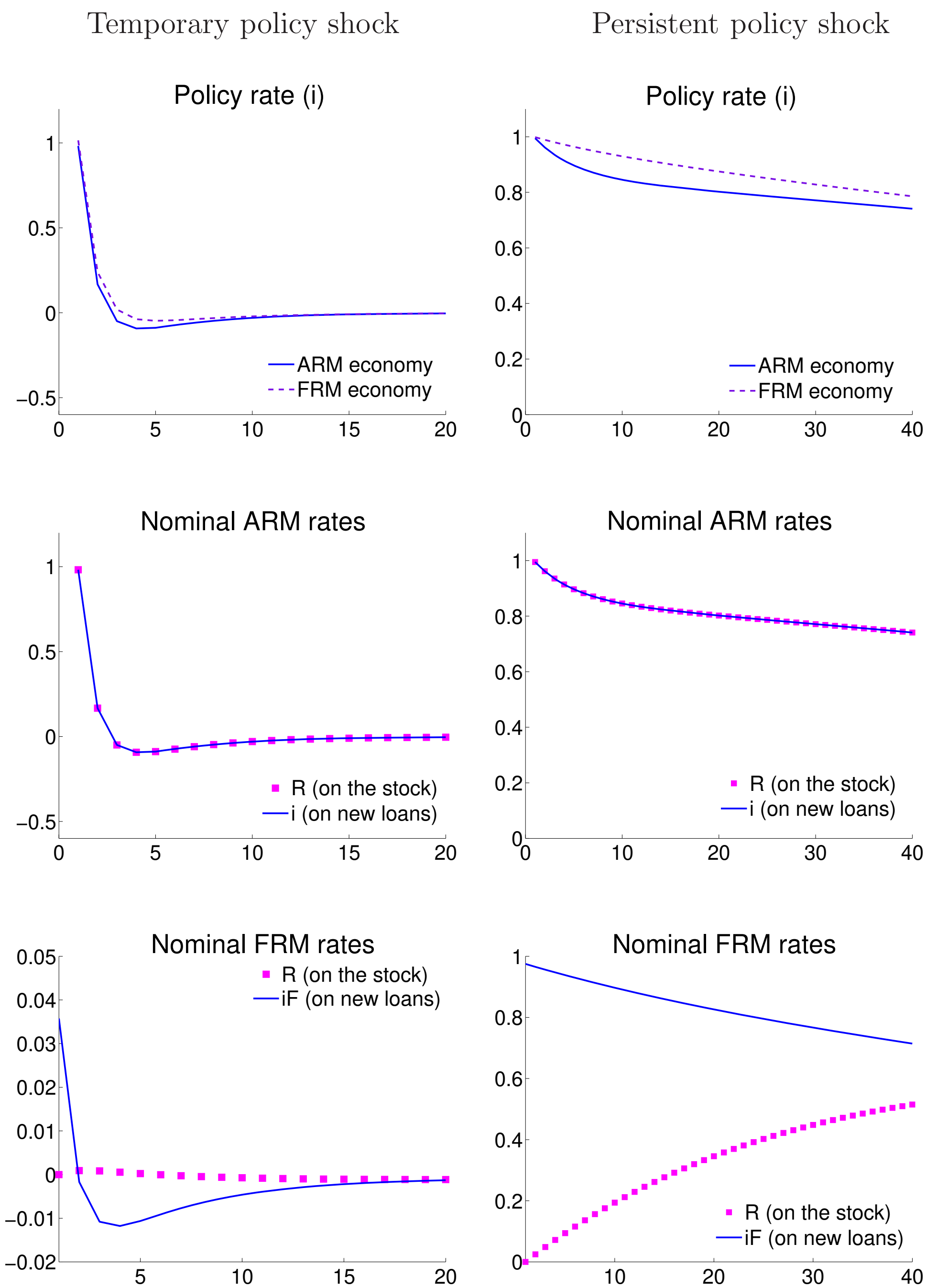

Figure 2: The debt channel in the model. Policy and mortgage interest rates, expressed as percentage point (annualized) deviations from steady state.

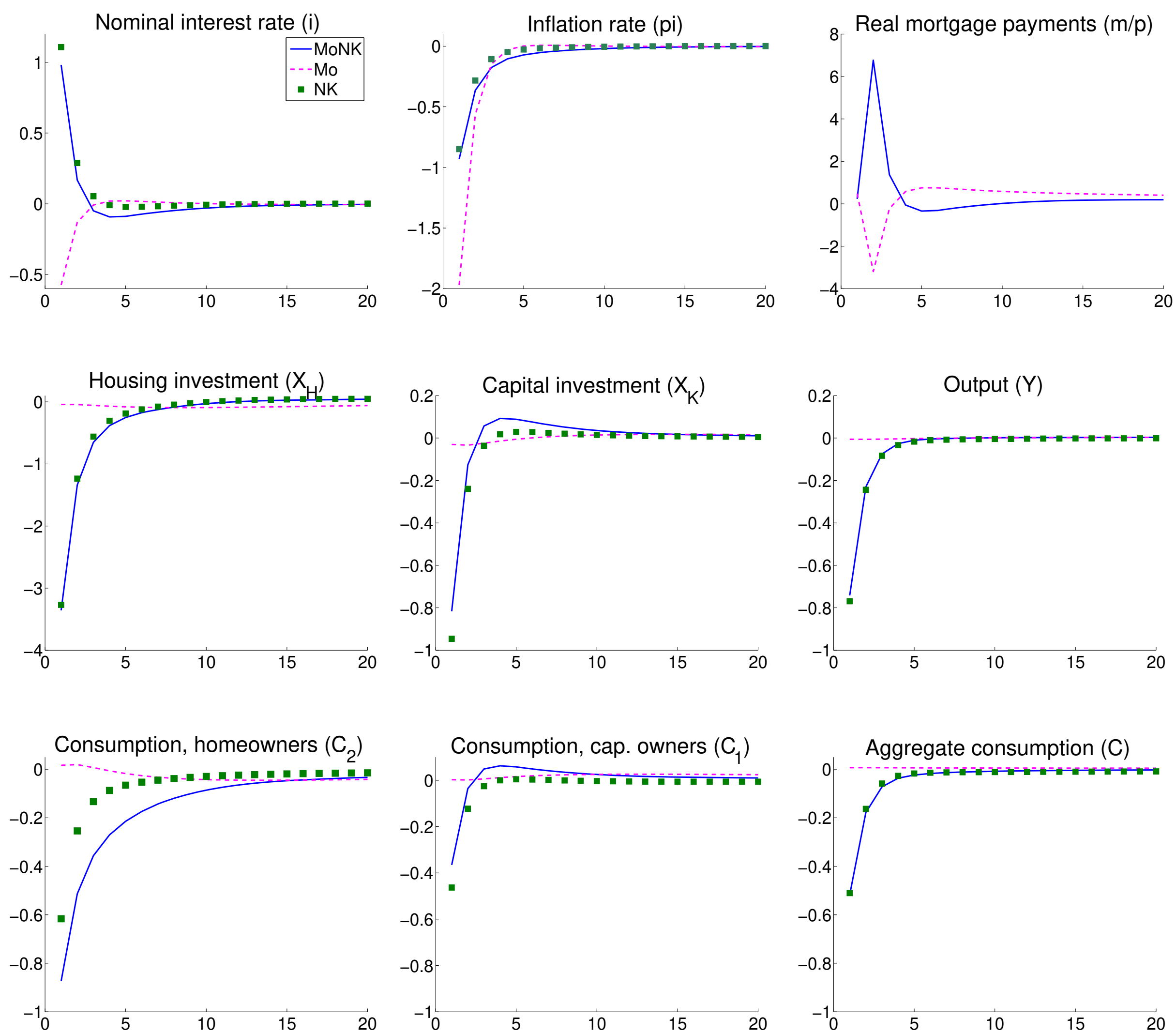

Figure 3: Temporary monetary policy shock: ARM. Interest rates and the inflation rate are expressed as percentage point (annualized) deviations from steady state, quantities are in percentage deviations. One period = one quarter. Output is $Y - \Delta$.

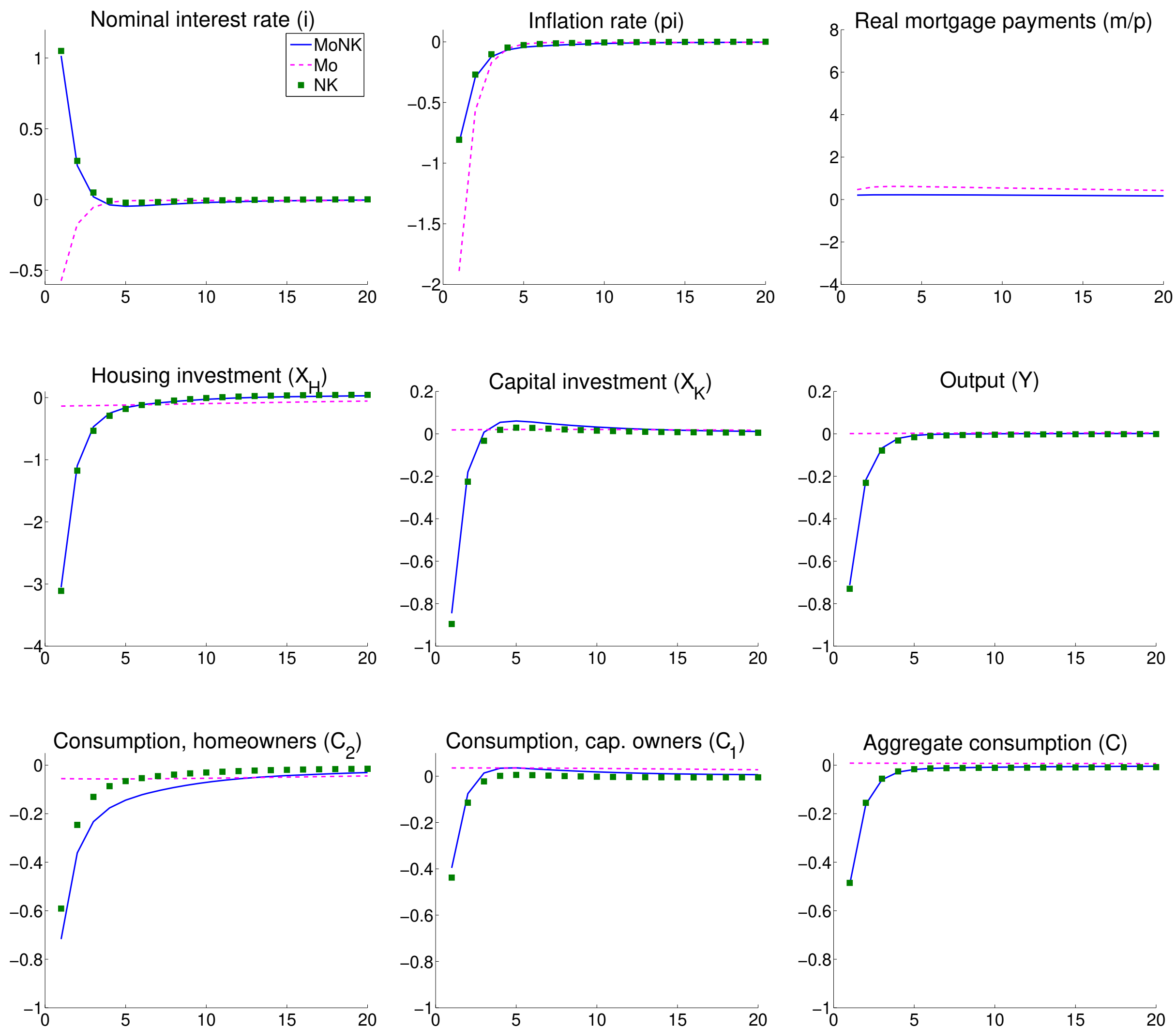

Figure 4: Temporary monetary policy shock: FRM. Interest rates and the inflation rate are expressed as percentage point (annualized) deviations from steady state, quantities are in percentage deviations. One period = one quarter. Output is $Y - \Delta$.

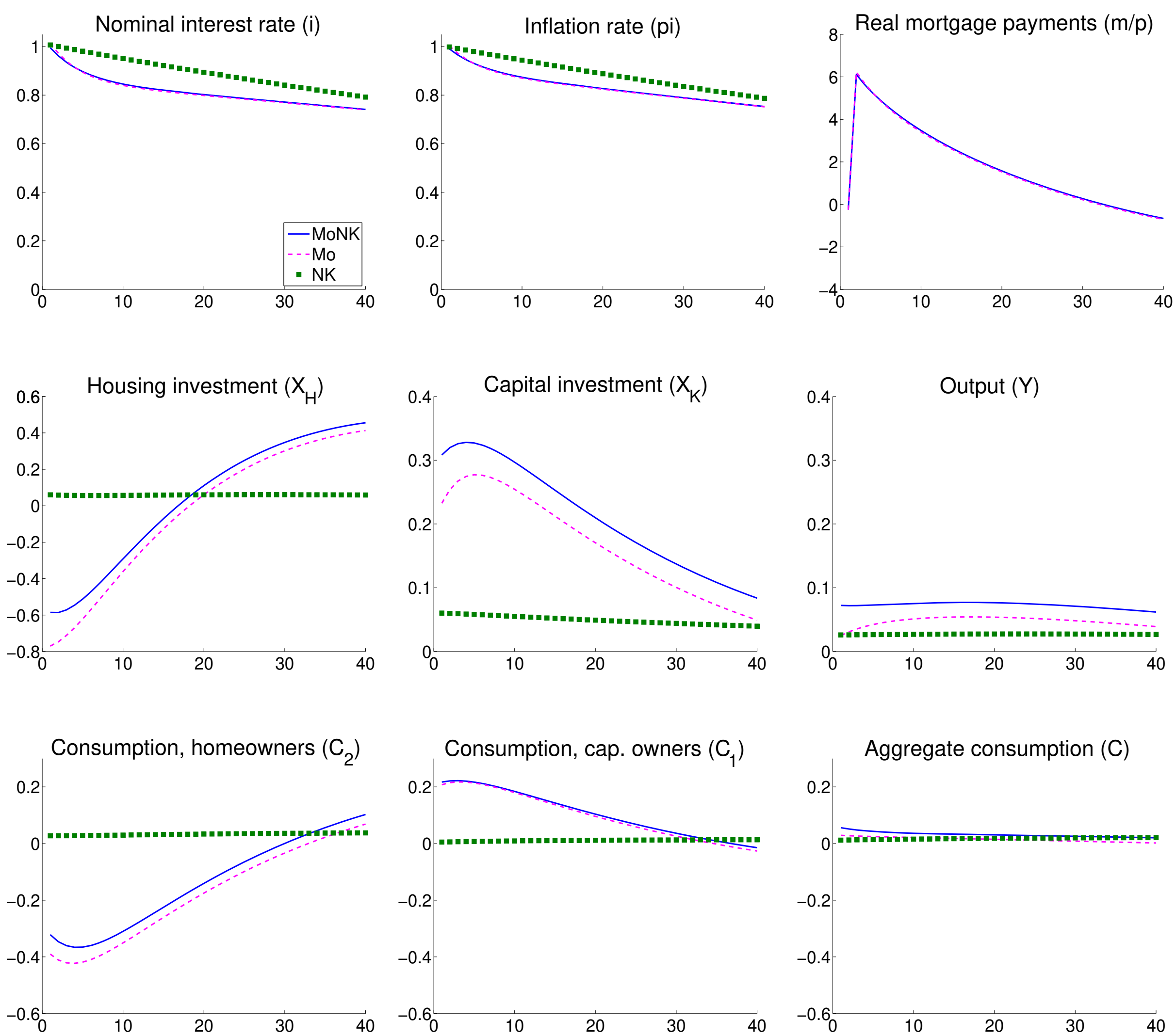

Figure 5: Persistent monetary policy shock: ARM. Interest rates and the inflation rate are expressed as percentage point (annualized) deviations from steady state, quantities are in percentage deviations. One period = one quarter. Output is $Y - \Delta$. All responses eventually converge back to zero.

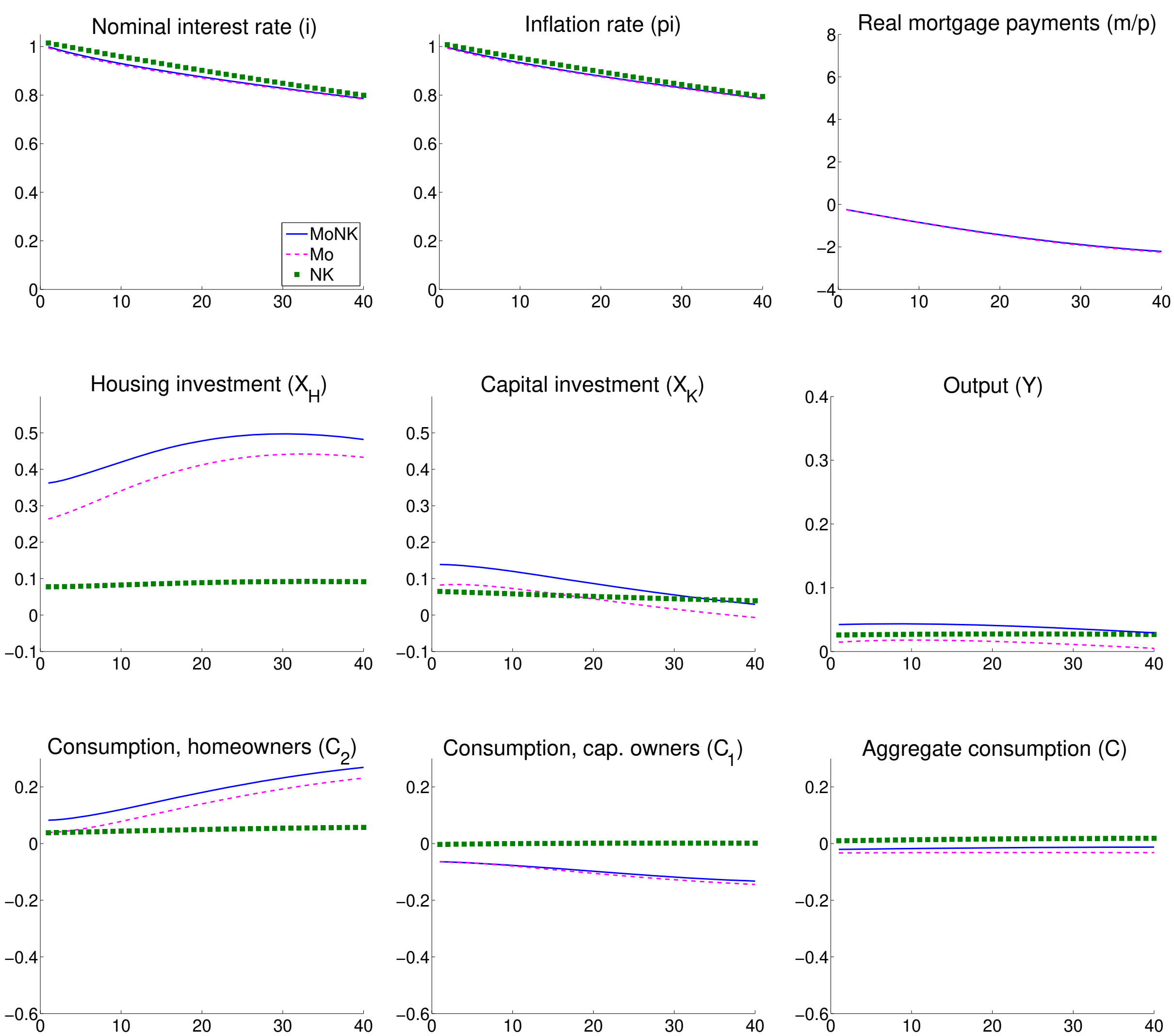

Figure 6: Persistent monetary policy shock: FRM. Interest rates and the inflation rate are expressed as percentage point (annualized) deviations from steady state, quantities are in percentage deviations. One period = one quarter. Output is $Y - \Delta$. All responses eventually converge back to zero.

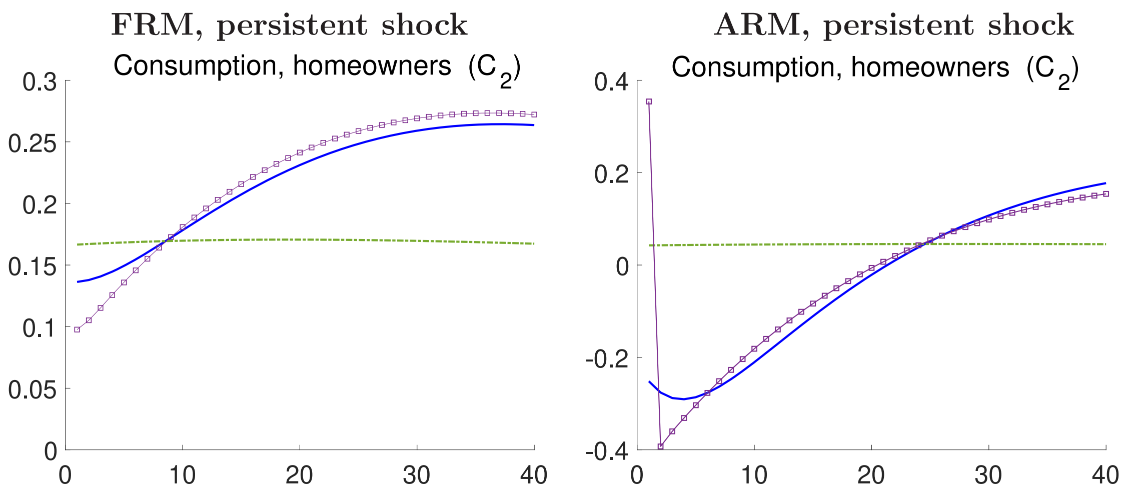

Figure 7: Debt channel, comparison across homeowner types: model-calibrated homeowner (solid line), permanent income hypothesis homeowner (dash-dotted line), and hand-to-mouth homeowner (line with markers).