Monetary Policy Transmission Through Adjustable-Rate Mortgages in the Euro Area*

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Abstract

This paper studies the role of adjustable-rate mortgages (ARMs) in monetary policy transmission within the Euro Area. Conventional wisdom holds that ARMs are relevant *per se*. This study finds that the presence of liquidity-constrained households strongly influences their impact. Using Euro Area survey data, I document that transmission is stronger in countries that exhibit both high ARM shares *and* sizable shares of liquidity-constrained households. Using Italian time series data, I show that ARMs are key for transmission only when a high fraction of households are liquidity-constrained. To explain these findings, I develop a heterogeneous-agent model featuring (i) heterogeneity in marginal propensities to consume (MPCs), (ii) agents making both housing and mortgage choices, and (iii) a fraction of households with ARMs. In the model, MPCs determine the extent to which changes in mortgage payments translate into changes in consumption, making ARMs an important transmission vehicle only when paired with high MPCs. These results underscore the importance of accounting for household heterogeneity when evaluating monetary policy transmission through adjustable-rate mortgages.

JEL classification: D14, E21, E52, E58

Keywords: Adjustable-rate mortgages, Euro Area, household heterogeneity, marginal propensity to consume, monetary policy

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1 Introduction

The transmission of monetary policy varies considerably across Euro Area economies (Calza et al.; 2013; Slacalek et al.; 2020; Corsetti et al.; 2022; Almgren et al.; 2022; Pica; 2023; Lenza and Slacalek; 2024). Spanish consumption, for instance, is three times more responsive to monetary policy shocks than German consumption. The disparity is even more pronounced between Ireland and France, where Irish consumption reacts up to ten times more than French consumption.[1] These differences pose a challenge to the European Central Bank, as the effects of its policy measures differ widely among member states. To address these challenges effectively, it is critical to understand the underlying reasons driving this heterogeneity.

This paper studies the transmission of monetary policy through mortgages in the Euro Area, focusing on the role played by the share of adjustable-rate mortgages (ARMs). Mortgages are a crucial component of household balance sheets, accounting for approximately 75% of total household debt in the Euro Area.[2] Moreover, ARMs account for approximately 48% of total mortgages in the Euro Area, making mortgage interest payments very sensitive to changes in monetary policy.[3] Consequently, differences in mortgage characteristics across Euro Area economies are likely to explain a significant fraction of the observed heterogeneity in transmission.

The existing literature has explored how variations in the prevalence of ARMs influence monetary pass-through, emphasizing that higher ARM shares lead to stronger transmission in the Euro Area (Calza, Monacelli and Stracca; 2013; Corsetti, Duarte and Mann; 2022; Pica; 2023). The contribution of this paper is twofold. First, I document empirically that the presence of liquidity-constrained households strongly influences the strength of transmission through ARMs. Using Euro Area survey data and Italian time series data, I show that ARMs are important for transmission primarily when matched with a high fraction of liquidity-constrained households. Second, I develop a quantitative heterogeneous-agent model to rationalize this finding and to quantify how much of the empirical differences in transmission are driven by differences in transmission through ARMs. In the model, a larger fraction of liquidity-constrained households im-

[1]Figure 1 shows the estimated peak consumption effects of a contractionary monetary policy shock. Complete IRFs estimated using equation (1) are displayed in Appendix B.1.

[2]This figure uses data from the ECB Distributional Wealth Accounts, and it refers to the average ratio of mortgages over total liabilities of Euro Area households during the period 2012-2018.

[3]This figure uses data from the second wave of the ECB Household Finance and Consumption Survey, computing the fraction of ARMs within outstanding mortgages in the Euro Area.

plies a higher marginal propensity to consume (MPC) in the economy. After a recessionary monetary policy shock, households with ARMs experience increased mortgage payments. The impact that these have on consumption critically depends on the MPC of the affected households, with higher MPC households adjusting their consumption more sharply. As a result, ARMs substantially amplify monetary transmission only when paired with high marginal propensities to consume (MPCs), consistent with the empirical evidence. By calibrating the model to Euro Area economies, I show that 46% of the empirical differences in transmission across these countries are due to variations in transmission through ARMs.

In the first part of the paper, I analyze the empirical relationship between the strength of monetary pass-through and the share of ARMs, investigating the influence that MPCs have on this relationship. Due to the lack of MPC estimates for individual Euro Area countries, I proxy each economy's MPC with its fraction of households that are hand-to-mouth (HtM).[4] The proxy is constructed using data from the ECB Household Finance and Consumption Survey, where households are classified as HtM following the methodology introduced by Kaplan, Violante and Weidner (2014). Since HtM households are characterized by limited liquid savings relative to their income, HtM shares measure the fraction of liquidity-constrained households in each economy.

The empirical analysis is conducted through three exercises. First, I use local projections to estimate the response of individual countries to a contractionary monetary policy shock. I proxy the strength of transmission in each country with their peak consumption responses, and then correlate these with (i) the share of ARMs, and (ii) the share of agents that are both HtM and have ARMs.[5] Two key findings emerge. First, consistent with findings in Pica (2023), transmission is stronger in countries with higher ARMs. Second, the correlation is stronger where the prevalence of agents that are both HtM and have ARMs is larger, providing *prima facie* evidence that ARMs are a more effective transmission vehicle when paired with liquidity-constrained households.

Second, I directly incorporate ARMs and their interaction with HtM shares into a regression to estimate their correlations with the strength of monetary transmission. Using panel local projections, I find that transmission is particularly strong when a high share of ARMs is matched with a high share of HtM agents: the interaction effect is as large

[4] Kaplan, Violante and Weidner (2014) show that HtM households have significantly larger MPCs than non-HtM households, making HtM shares a good proxy for MPCs.

[5] While my baseline results proxy the strength of transmission with the peak consumption response, I show that the results are robust to using average responses as proxies in Appendix B.3.

as the individual effect of ARMs and statistically significant. This result suggests that in Euro Area economies with a large share of liquidity-constrained households, the impact of ARMs on transmission is twice as strong as in those with low shares of constrained households. This finding highlights that HtM households significantly influence the impact of ARMs on transmission, and that a high share of liquidity-constrained households is essential for ARMs to effectively amplify monetary pass-through.

Third, I complement these exercises with an analysis of Italian data. While the first two exercises exploit heterogeneity across countries in their shares of ARMs and HtM households, this analysis leverages within-country time variation in these variables. Consistent with the previous exercises, I find that transmission is particularly pronounced when the economy has both a high share of ARMs and a significant fraction of liquidity-constrained households.

Overall, the empirical analyses establish that the interaction between the shares of ARMs and HtM households is positively correlated with the strength of monetary policy transmission in the Euro Area. Motivated by this empirical fact, the second part of the paper develops a quantitative heterogeneous-agent model that accommodates different levels of ARMs and MPCs. The model is used to (i) rationalize the empirical finding, (ii) study the mechanism through which ARMs and MPCs shape the transmission of monetary policy through mortgages, and (iii) quantify how differences in transmission through ARMs across Euro Area economies contribute to the observed heterogeneity in transmission.

The model has three key features. First, households face idiosyncratic uncertainty, leading to income heterogeneity. This results in a distribution of MPCs across households, which allows me to study monetary transmission in economies with different MPC levels. Second, households make decisions regarding the size of their housing stock and the amount of mortgage they want to take on. This allows the model to accommodate transmission through the mortgage channel. Third, the model distinguishes between households with ARMs and households with fixed-rate mortgages (FRMs). The former see their mortgage payments fluctuate following changes in monetary policy, while the latter do not experience payment fluctuations. This distinction allows me to use the model to analyze how different ARM shares influence the strength of monetary policy transmission.

The core intuition from the model on how ARMs and MPCs interact to shape monetary policy transmission through mortgages is as follows. Households experience idiosyncratic productivity shocks, leading to income heterogeneity that affects both their MPCs and their mortgage choices: poorer households have higher MPCs and tend to opt for mortgages with higher loan-to-value ratios. When a monetary policy shock occurs, the mortgage payments of households with ARMs are immediately impacted due to the swift pass-through of short-term interest rates to mortgage rates, affecting their available resources for consumption. Wealthier households, whose mortgage payments constitute a small fraction of their overall income, hardly change their consumption choices. Poorer households, in contrast, with higher MPCs and more burdensome mortgage payments, need to make significant adjustments. As a result, powerful transmission through mortgages requires (i) a high fraction of households with ARMs, as they experience changes in mortgage payments, and (ii) a high prevalence of high-MPC households, as they make larger consumption adjustments. This mechanism rationalizes the empirical relation between the strength of monetary transmission and the interaction between ARMs and liquidity-constrained households highlighted in the first part of the paper.

I calibrate the model to the Spanish economy, which I choose to ease comparability with other studies that have analyzed monetary policy transmission through mortgages in the Euro Area (Corsetti, Duarte and Mann; 2022; Pica; 2023). The model accurately mirrors the distributions of liquid assets and housing wealth in the population. It also reproduces the empirical hump-shaped profile of the distribution of mortgage debt, where the bottom and top quartiles of the liquid asset distribution hold less mortgage debt than the middle quartiles. Importantly, in the model as in the data, lower-income households carry higher levels of debt relative to their resources: the ratio between mortgage debt and total wealth displays a decreasing pattern along the liquid asset distribution.

Starting with the Spanish calibration, I assess the impact of ARMs and MPCs on monetary policy transmission through counterfactual exercises. I calibrate a counterfactual economy with an MPC half that of Spain and compare transmission under two different ARM rates: 20% and 80%. Following an expansionary monetary policy shock, the peak consumption response increases by 5.6% in the low-MPC economy as the ARM share rises from 20% to 80%. In the Spanish economy, the response increases by 39%. Consistent with the empirical evidence, these findings suggest the presence of a significant interaction between ARMs and MPCs: as the MPC level increases, the effect of increasing the share of ARMs on monetary policy transmission becomes higher.

I use the model to investigate how the distribution of ARMs across the population affects the strength of monetary policy transmission. Using the baseline Spanish calibration, I keep the economy-wide MPC level and ARM share constant but modify the distribution of ARMs: in one scenario, ARMs are concentrated among lower-income (high-MPC) households, while in the other, they are concentrated among higher-income (low-MPC) households. The results show that monetary policy transmission is significantly stronger when ARMs are concentrated among lower-income households, suggesting that the distribution of ARMs across income levels is an important variable to take into account in order to anticipate the effects of monetary policy interventions.

By calibrating counterfactual ARMs and MPCs to reflect Euro Area data, I use the model to quantify the extent to which differences in transmission across these countries are driven by differences in transmission through ARMs. The results show that 46% of the overall empirical differences in transmission relative to the baseline economy, Spain, can be attributed to this channel. Specifically, 9% of these differences are due to differences in ARMs, 26% to differences in MPCs, and 11% to the interaction between ARMs and MPCs. Given the substantial role played by differences in MPCs, these findings underscore the critical importance of accounting for household income heterogeneity to accurately capture transmission through ARMs in the Euro Area.

Finally, I use the model to evaluate the welfare effects of contractionary monetary policy shocks on the economy as a whole and across different income groups. My results indicate that welfare declines are more severe in economies with higher ARM shares and greater MPC levels, as these conditions lead to larger consumption drops. Moreover, the adverse effects are disproportionately felt by households at the lower end of the income distribution, who experience larger welfare losses compared to higher-income households due to their high MPCs. These findings suggest that, during periods of prolonged interest rate hikes, policies that alleviate the burden of mortgage payments for lower-income families can be particularly effective in mitigating welfare losses.

Related literature This study contributes to the literature studying how the efficacy of monetary policy is influenced by mortgage market characteristics by showing, both empirically and quantitatively, that the interaction between ARMs and MPCs is an important amplifier of monetary transmission.

From an empirical standpoint, the significance of housing institutions for monetary policy transmission has been investigated by studies such as Slacalek, Tristani and Violante (2020), Cloyne, Ferreira and Surico (2020), Flodén et al. (2021), Battistini et al. (2022), and Corsetti, Duarte and Mann (2022). The findings in Di Maggio et al. (2017)

are particularly relevant for this study: in the United States, interest rate transmission to consumption is more pronounced in areas with a higher proportion of ARMs and low-income households. Caspi, Eshel and Segev (2024) exploit an exogenous variation in the exposure to ARMs due to a regulatory shift in Israel and unveil a similar pattern: households with a higher fraction of their mortgage being subject to adjustable-rates decrease their consumption after a monetary policy tightening, with this effect being predominant across lower-income households.[6] For the Euro Area, similar findings are documented in Pica (2023) and Almgren et al. (2022). Pica (2023) shows stronger monetary policy transmission in those Euro Area countries where ARMs are more widespread, while Almgren et al. (2022) find that the impact of monetary policy shocks is positively correlated with the proportion of HtM households in the economy. This paper contributes to this literature by showing that the interaction between the share of ARMs and the fraction of HtM households matters for the strength of monetary pass-through in the Euro Area, with transmission being particularly pronounced when both variables are elevated.

From a theoretical standpoint, monetary policy transmission through housing and mortgage markets has been explored extensively. Important contributions include Iacoviello (2005), Calza, Monacelli and Stracca (2013), Hedlund et al. (2016), Garriga, Kydland and Šustek (2017, 2021), and Greenwald (2018). Among these contributions, Corsetti, Duarte and Mann (2022) and Pica (2023) develop representative-agent open-economy New-Keynesian models to show that, within the Euro Area, stronger transmission takes place where home-ownership rates and ARM shares are higher. This paper contributes to this literature by developing a heterogeneous-agent model that allows to explore the role of MPCs for transmission through ARMs. Consistent with the empirical evidence, the model predicts that the ability of ARMs to amplify transmission depends on the level of the MPC in the economy, with these being particularly effective when MPCs are high.

The model developed in this paper builds on studies that incorporate heterogeneous agents, arising from the presence of idiosyncratic uncertainty, into housing models, such as Beraja et al. (2019), Wong (2020), McKay and Wieland (2021), Eichenbaum, Rebelo and Wong (2022), and Berger et al. (2023).[7] In particular, the household block of the model used in this paper is based on Wong (2020), with two important distinctions. First, given

[6] Note that mortgage features in Israel are such that households have a *fraction* of their overall mortgage debt which is subject to adjustable rates.

[7] Other important studies with heterogeneous agents investigating housing and mortgage institutions, albeit with lower emphasis on monetary policy transmission, are: Kaplan, Mitman and Violante (2020), Berger et al. (2018), and Guerrieri, Lorenzoni and Prato (2020).

the prominent role of ARMs in the Euro Area, the model incorporates this mortgage feature and disregards the refinancing option, much more widespread in the United States. Second, unlike Wong (2020), which uses an overlapping generations (OLG) model, this paper adopts a more conventional infinitely-lived household framework.

Structure of the paper The rest of the paper is organized as follows. Section 2 presents the empirical findings on the effects of ARMs and HtM households on monetary policy transmission. Section 3 describes the model, its calibration and empirical fit. Section 4 presents the quantitative results and analyzes the mechanism by which ARMs and MPCs shape the transmission of monetary policy through mortgages. Finally, section 5 concludes.

2 Motivating facts

This section studies the empirical relationship between the strength of monetary pass-through and the share of ARMs across Euro Area countries, with a focus on how MPCs influence this relationship. Since MPC estimates for individual countries are unavailable, these are proxied by the share of HtM households in each Euro Area economy.[8] I construct the proxy classifying households as HtM following the methodology introduced by Kaplan, Violante and Weidner (2014), as detailed in Appendix B.2. HtM households are characterized by having low liquid savings relative to their income, so that the share of HtM households provides a measure of the fraction of liquidity-constrained households in each economy. Importantly, Kaplan, Violante and Weidner (2014) show that HtM households have MPCs more than double those of non-HtM households, making HtM shares a suitable proxy for MPCs in this analysis.

The analysis is conducted through three different exercises. The first two exercises use data from the second wave of the ECB Household Finance and Consumption Survey (HFCS), where I compute the share of ARMs as the fraction of outstanding mortgages

[8]Figure B.2 in appendix B.2 shows the different HtM shares across Euro Area economies.

with an adjustable rate.[9,10] The advantage of this dataset is to provide harmonized information on the share of ARMs and HtM households across several European economies. This allows me to leverage cross-country variation in these two variables to estimate their relationship with the potency of monetary pass-through. The disadvantage of this dataset is that, given its low frequency, it lacks a time-series dimension that can be exploited in the analysis. To overcome this issue, I conduct a third exercise using data from Italy, where time-series of the shares of ARMs and HtM households are available.

In the first analysis, following the approach in Almgren et al. (2022) and Pica (2023), I estimate the strength of monetary policy transmission in each Euro Area country independently, and then correlate it with the share of ARMs and the share of households that are both HtM and have ARMs. The results show that the strength of transmission is strongly correlated with the share of households that are both HtM and have ARMs.

The second analysis refines the first investigation by directly incorporating ARMs and their interaction with HtM shares into a panel local projection regression. By leveraging the varying levels of exposure to monetary policy shocks across countries based on their ARM and HtM shares, I find that the interaction between ARMs and HtM households matters for the strength of transmission: monetary pass-through is substantially increased in economies displaying high shares of both ARMs and HtM households.

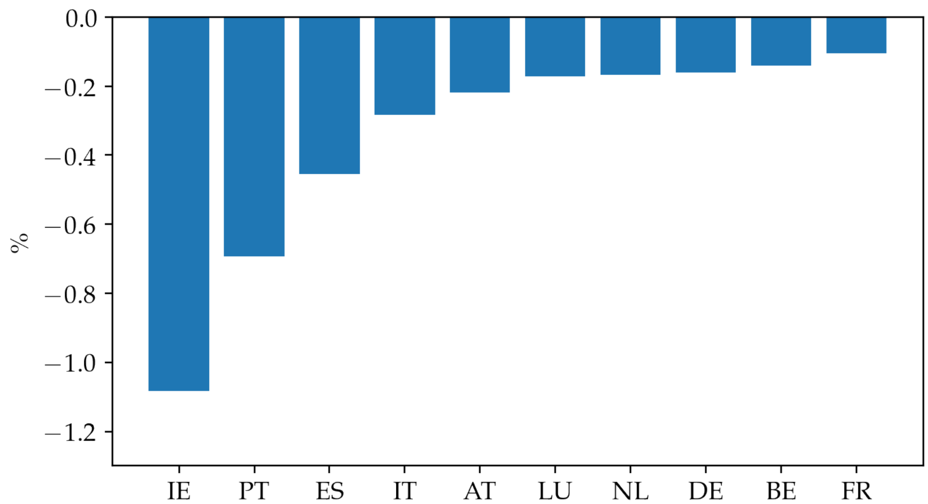
Finally, I study the importance of the interaction between ARMs and HtM households using Italian time-series data. Rather than exploiting cross-country variation in ARMs and HtM shares, this analysis leverages the time variation of these variables within a single country, Italy. Consistent with the cross-country evidence, I find that transmission is stronger when high shares of ARMs are matched with high shares of HtM households.

The following sections detail each exercise in turn. Overall, the empirical evidence

[9] While my baseline results use data from the second wave of the HFCS, appendices B.3 and B.5 contain robustness exercises using data from alternative waves. The HFCS is conducted by the ECB, national central banks of the Eurosystem and national statistical agencies. The survey collects household-level data on household finances and consumption, similarly to the Survey of Consumer Finances conducted by the Federal Reserve Board for families in the United States. Four waves of the survey have been carried out with an approximate triennial frequency: in 2010, in 2014, in 2017 and in 2021. Additional information on the dataset can be found here.

[10] While my baseline results use the share of ARMs in total outstanding mortgages as the main variable of interest, appendices B.3 and B.5 present robustness results where I replace this variable with (i) the share of households with an ARM in the population of each economy and (ii) the product between the share of ARMs in total outstanding mortgages and the fraction of households with mortgages in the population of each economy.

Figure 1: Maximum effect of a contractionary monetary policy shock on consumption



Notes: Responses to a one standard deviation contractionary monetary policy shock. Each bar represents the maximum response of consumption within a 12-quarter period after the shock estimated using equation (1).

consistently points to a positive correlation between the interaction of ARMs and HtM households and the strength of monetary policy transmission across Euro Area countries.

2.1 Simple correlations

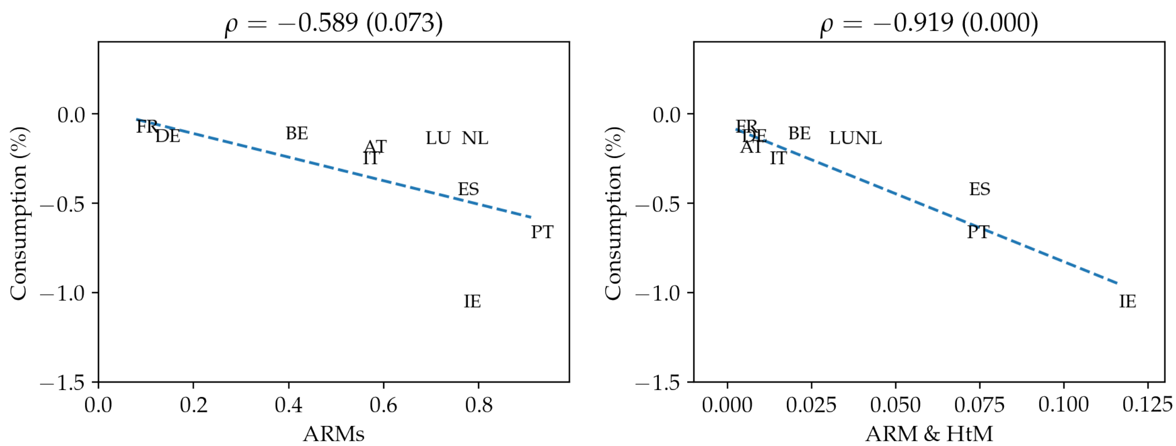
My analysis uses data from the following Euro Area countries: Austria, Belgium, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain.[11] The sample covers the period 1999Q1-2019Q4, ending before the beginning of the Covid-19 pandemic. For each country in the sample, my goal is to estimate the strength of monetary policy pass-through across Euro Area countries. To do so, I estimate the response of consumption to monetary policy shocks using local projections (Jordà; 2005). In particular, for each country c, I estimate the following regression:

$$y^c_{t+h} = \alpha^{h,c} + \beta^{h,c}\epsilon^{MP}_t + \sum_{j=1}^{p} \Gamma^{h,c}_j X_{t-j} + u^c_{t+h}, \qquad h = 0, 1, 2, \ldots \tag{1}$$

where y^c is the logarithm of consumption in country c and X is a set of lagged control variables. Importantly, to measure the monetary policy shock, ϵ^{MP}, I use the series con-

[11]These represent ten of the eleven early adopters of the Euro. Finland, the eleventh early adopter, is excluded from the main analysis due to the lack of data availability for its share of ARMs in the HFCS.

Figure 2: Correlation between the response of consumption, ARMs, and the share of HtM households with ARMs



Notes: The y-axes show the peak responses of consumption to a one standard deviation contractionary monetary policy shock in each Euro Area country, estimated using equation (1). The x-axis of the left panel is the share of outstanding ARMs in each Euro Area country in the HFCS; the x-axis is the share of households in the population who are both HtM and have an ARM in the HFCS. On top of each chart I show ρ, the correlation coefficient, together with its p-value in parenthesis.

structed by Jarociński and Karadi (2020). In the baseline regressions, I set the number of lags to $p = 2$. The variables included as lagged controls in X are the left-hand-side variable, the monetary policy shock, GDP and CPI in country c, and Euro Area GDP, CPI and short-term interest rate.[12] The coefficient of interest is $\beta^{h,c}$, which captures the effects of a monetary policy shock on consumption in each country at different horizons.[13]

Figure 1 shows the maximum effect of a recessionary monetary policy shock on consumption over a 12-quarter period, which I use as a proxy for the strength of monetary policy transmission in each country in the sample. In line with previous findings in the literature, the figure shows that transmission is very heterogeneous in the Euro Area (e.g. Corsetti et al.; 2022; Almgren et al.; 2022; Pica; 2023).

Figure 2 shows the correlation between the maximum response of consumption to a monetary policy shock, my proxy for the strength of monetary policy transmission, the share of ARMs, and the share of households that are both HtM and have an ARM.[14]

[12] Appendix A details the sources of the data used in all analyses presented in this section.

[13] Appendix B.1 shows the impulse response functions of this coefficient for each Euro Area country in the sample.

[14] Appendix B.3 shows that the results are robust to considering the average effect of a monetary policy

Consistent with findings by Pica (2023), the left panel shows a strong negative correlation between the peak response of consumption and the share of households with ARMs: the correlation coefficient is -0.589 and the p-value is well below 10%. Importantly, the right panel shows that the correlation between the potency of transmission and the fraction of HtM households with ARMs is even stronger: the correlation coefficient is -0.919 and the p-value is below 1%.

This result suggests that the ability of ARMs to amplify monetary pass-through can be influenced by the presence of liquidity-constrained households. Accordingly, I further investigate the role of the interaction between ARMs and HtM households for transmission in the next sections.

2.2 Panel local projections

In my second exercise, I advance my analysis by directly estimating the effects of ARMs and their interaction with the share of HtM households on the strength of monetary transmission. Unlike the first exercise, which focused on unconditional correlations, this second analysis controls for a set of variables. The sample of countries remains the same as in the previous section, with the data covering the period from 1999Q1 to 2019Q4. Using local projections (Jordà; 2005) adapted for panel analysis, I estimate the following fixed-effects regression:

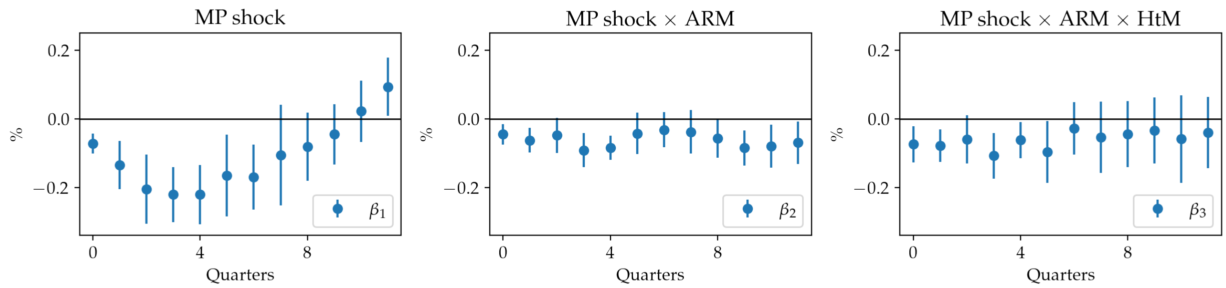
$$\begin{aligned} y^c_{t+h} =& \beta^h_0 + \beta^h_1 \epsilon^{MP}_t + \beta^h_2 \epsilon^{MP}_t ARM^c + \beta^h_3 \epsilon^{MP}_t ARM^c HtM^c + \\ &+ \beta^h_4 \epsilon^{MP}_t HtM^c + \Gamma^h X^c + u^c_{t+h}, \qquad h = 0, 1, 2, \ldots \end{aligned} \tag{2}$$

where y^c is the logarithm of consumption in country c, ϵ^{MP} is the monetary policy shock by Jarociński and Karadi (2020), ARM^c is the share of ARMs in country c in the second wave of the HFCS, HtM^c is the share of HtM households in country c in the second wave of the HFCS, and X is a set of control variables.[15] The variables ARM^c and HtM^c are standardized, so that $ARM^c = 1$ means that the country has a share of ARMs that is one standard deviation above the Euro Area average. X includes the variables interacted with

shock rather than its maximum effect, as well as changing the horizon of the response of $\beta^{h,c}$ from 12 to 8 quarters. In addition, it shows that the results presented in this section are robust to alternative definitions of the shares of ARMs across Euro Area countries.

[15] Appendix B.4 shows the results obtained using an alternative specification that investigates the additional effects of monetary policy shocks depending on the variable $ARMxHtM$, which captures the share of households in the population that are both HtM and have ARMs. The analysis suggests that the strength of transmission is greater in Euro Area countries with high $ARMxHtM$ shares.

Figure 3: Response of consumption to a monetary policy shock



Notes: Responses to a one standard deviation contractionary monetary policy shock. The blue dots in each panel show the evolution, over a 12-quarter horizon, of coefficients β_1 to β_3 estimated using equation (2). The vertical blue lines represent 90% confidence intervals.

the monetary policy shock, ARM^c, $ARM^c HtM^c$, and HtM^c, two lags of the left-hand-side variable, two lags of the monetary policy shock, two lags of GDP and CPI in country c, and two lags of Euro Area GDP, CPI and short-term interest rate.[16]

The coefficient β_1 in the regression captures the effect of a monetary policy shock on consumption when ARM and HtM are at their Euro Area averages. The coefficients of interest are β_2, which captures the additional effects of a monetary policy shock in economies with ARM one standard deviation higher than the Euro Area average and HtM at its Euro Area average, and β_3, which is particularly interesting since it captures the additional impact of the shock in economies with both ARM and HtM one standard deviation above their Euro Area averages.

The left panel of figure 3 shows the impulse response function of coefficient β_1: a one standard deviation contractionary monetary policy shock is associated with a statistically significant drop in consumption of up to approximately -0.22 percentage points when ARM and HtM are at their Euro Area averages. As expected, a contractionary shock has a recessionary effect.

The middle and right panels of figure 3 show the impulse response functions of the variables of interest. The middle panel shows the additional effects of the monetary policy shock when ARM is one standard deviation higher than its average. The coefficient, which peaks at a value of approximately -0.09 percentage points and is often statistically significant, indicates that monetary policy shocks have stronger effects in Euro Area

[16] Robustness exercises where I use data from alternative survey waves of the HFCS and alternative measures of the share of ARMs in each Euro Area country are presented in appendix B.5.

countries with high shares of ARMs.

Finally, the right panel displays the effect of the interaction between ARM and HtM on the effectiveness of monetary policy pass-through. When both ARM and HtM are one standard deviation above their Euro Area means, a recessionary monetary policy shock is associated with an even larger drop in consumption. The coefficient has a magnitude similar to that of the coefficient on the effect of high ARM (coefficient β_3 peaks at -0.11 percentage points, coefficient β_2 peaks at -0.09 percentage points), and it is statistically significant for approximately six quarters. The size of these coefficients indicates that when the HtM share increases from the Euro Area average to one standard deviation above it, the impact of the interaction between the monetary policy shock and the ARM share nearly doubles. This is a crucial result: across Euro Area countries, the strength of transmission is particularly pronounced in economies that display both a high share of ARMs *and* a high fraction of liquidity-constrained households.

The next section provides further evidence on the relevance of the interaction between ARMs and HtM households for the potency of transmission using Italian time-series data.

2.3 Evidence in Italian time series

After having exploited the cross-country variation in share of ARMs and fraction of HtM households across Euro Area economies, my last exercises leverages the time variation of these variables within a single country: Italy.[17] This setting allows me to control for potential country-specific unobserved factors correlated with ARM and HtM, which could inflate the relationships estimated in the previous section. However, due to the limited availability of the HtM time series, this analysis covers a shorter period than the previous one, spanning from 2007Q1 to 2019Q4.

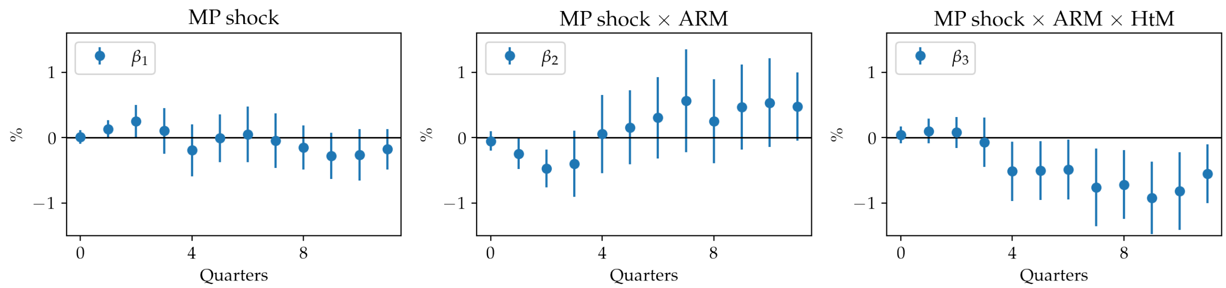
I estimate the following regression using local projections (Jordà; 2005):

$$\begin{aligned} y_{t+h} =& \beta_0^h + \beta_1^h \epsilon_t^{MP} + \beta_2^h \epsilon_t^{MP} ARM_{t-1} + \beta_3^h \epsilon_t^{MP} ARM_{t-1} HtM_{t-1} + \\ &+ \beta_4^h \epsilon_t^{MP} HtM_{t-1} + \Gamma^h X + u_{t+h}, \qquad h = 0, 1, 2, \ldots \end{aligned} \tag{3}$$

where y is the logarithm of consumption in Italy, ϵ^{MP} is the monetary policy shock by Jarociński and Karadi (2020), ARM and HtM are the standardized shares of ARMs and

[17] The time series for the share of HtM households was provided by the authors of Slacalek, Tristani and Violante (2020), who reconstructed it based on the exercises they implement in their analysis. The time series for the share of outstanding ARMs was provided by economists at the Bank of Italy. I am grateful to both for sharing their data with me.

Figure 4: Response of consumption to a monetary policy shock in Italy



Notes: Responses to a one standard deviation contractionary monetary policy shock. The blue dots in each panel show the evolution, over a 12-quarter horizon, of coefficients β_1 to β_3 estimated using equation (3). The vertical blue lines represent 90% confidence intervals.

HtM households, respectively, while X is a set of control variables.[18]

The choice of variables included in X is constrained by the limited time frame available to estimate the coefficients in equation (3), which begins in 2007Q1. To avoid overfitting, the model needs to be parsimonious. Accordingly, X includes fewer variables than those used in the panel analysis of the previous section. Specifically, X consists of the variables interacted with the monetary policy shock, ARM_{t-1}, $ARM_{t-1}HtM_{t-1}$, and HtM_{t-1}, two lags of consumption, two lags of the monetary policy shock, two lags of Italian CPI, and two lags of the average Italian mortgage rate.[19]

Similarly to my previous exercise, the coefficients of interest are β_2, which captures the additional effects of a monetary policy shock when ARM is one standard deviation higher than its Italian average while HtM is at its average, and β_3, which captures the effects of the interaction between HtM and ARM, measuring the additional impact of the shock when both HtM and ARM are one standard deviation above their averages.

Figure 4 presents the impulse response functions of coefficient β_1 and of the variables of interest. The left panel shows the evolution of coefficient β_1, suggesting that a one standard deviation contractionary monetary policy shock does not lead to a statistically significant change in Italian consumption when ARM and HtM are at their averages in the post-2007 period, with the coefficient that fluctuates around zero.

The middle panel indicates that when ARM is one standard deviation above its av-

[18]Note that the time subscripts on ARM and HtM imply that the regression estimates the differential effects of a monetary policy shock depending on ARM and HtM shares in the quarter *prior* to the shock.

[19]Appendix B.6 contains robustness exercises using alternative specifications and control variables relative those used in equation (3).

erage, the effects of the monetary policy shock are not particularly amplified: while the coefficient is negative and statistically significant in the second and third quarters after the shock, it turns positive and loses significance thereafter. This response suggests that high shares of ARMs in Italy do not correlate with greater transmission.

Finally, the right panel shows that when both ARM and HtM are one standard deviation above their means, the effects of a monetary policy shock are amplified, with a statistically significant peak impact of approximately -0.92 percentage points. This finding suggests that while ARMs alone may not have a substantial effect, their influence becomes critical when combined with a high share of HtM households, significantly enhancing monetary policy pass-through.[20]

This result highlights the complementary relationship between ARMs and HtM households in strengthening monetary transmission: consistent with the cross-country analysis in the previous section, transmission is stronger when the economy is characterized by a high share of ARMs *and* a large fraction of liquidity-constrained households.

2.4 Summary of empirical facts

The analysis in this section establishes one key empirical fact: the interaction between the shares of ARMs and liquidity-constrained households is positively correlated with the strength of monetary policy transmission in the Euro Area. Motivated by this finding, the remainder of the paper develops a quantitative model to rationalize this empirical relationship and to quantify the extent to which differences in transmission across Euro Area countries can be attributed to ARMs.

3 Model

This section presents the model I developed to explore how ARMs and MPCs interact in the transmission of monetary policy. The model builds on the household block developed by Wong (2020), where households are allowed to make housing and mortgage decisions. Two important features distinguish it from Wong (2020): first, given the prominent role of ARMs in the Euro Area, the model incorporates this mortgage feature and disregards the refinancing option; second, instead of overlapping generations, the model relies on an infinitely-lived household framework.

[20] Figure B.15 in appendix B.6 shows that the sum of coefficients β_2 and β_3 is negative and statistically significant.

Three key elements characterize the model. First, households face idiosyncratic uncertainty due to exogenous productivity shocks, generating income heterogeneity that results in varying MPCs across households. This feature enables the study of how different MPC levels influence monetary policy transmission through mortgages. Second, households decide on the size of their housing stock and on the amount of mortgage they want to take on. This feature allows the model to accommodate transmission through the mortgage channel, which is central to this study. Third, the model distinguishes between households with ARMs and those with fixed-rate mortgages (FRMs). Households with ARMs experience fluctuating mortgage payments in response to monetary policy changes, while FRM holders have mortgage payments that are insulated from interest rate fluctuations. This distinction enables the investigation of how different shares of ARMs affect the potency of monetary policy transmission.

The model is used to: (i) account for the empirical findings, providing a rationale for the critical role of the interaction between ARMs and MPCs in strengthening transmission; (ii) explore the mechanism by which ARMs and MPCs influence monetary policy transmission through mortgages; and (iii) quantify how much of the difference in transmission across Euro Area economies can be attributed to variations in transmission through ARMs.

This section is organized as follows. First, I describe each of the model blocks in turn. Second, I present the model calibration. Third, I discuss the performance of the model in matching some important untargeted moments. Appendix C.1 describes the algorithm I developed to solve the model.

3.1 Model blocks

The description of the model proceeds as follows. I first describe the variables affecting the decisions that households make, and then introduce the value functions associated with such decisions.

Preferences Time is discrete and the economy is populated by a unit mass of infinitely-lived households indexed by i. Households discount the future at rate β. The momentary utility of a household is given by:

$$u(c,h) = \frac{\left(c^{\alpha}h^{1-\alpha}\right)^{1-\sigma}}{1-\sigma} \tag{4}$$

where $\sigma > 0$. c and h denote flexible consumption and the stock of housing, respectively. This specification assumes that the service from housing is equal to its stock, in line with Eichenbaum, Rebelo and Wong (2022). Households cannot freely adjust their housing stock, but may always freely adjust the other consumption good.

Housing stock Households enter each period with a stock of housing inherited from the previous period. The law of motion for the housing stock is

$$h' = (1 - \delta)h, \tag{5}$$

which dictates that the stock that households inherit is $(1 - \delta)h$, where h is the previous period's housing stock and δ is the rate of depreciation.

Each period, households must choose whether to change their house or remain in their current one. In either case, their updated housing stock h' will be the relevant one for the period's utility. If households decide to change, they have to sell the house they inherited. Revenues from the sale are $(1 - f)p(1 - \delta)h$, where p is the price of a unit of housing stock and f is a proportional adjustment cost which captures the loss that households incur when they decide to change their house.[21] Households then purchase a new house of size h' at unit price p.

Income process Households are subject to idiosyncratic uncertainty. In particular, income of household i at time t is

$$y_{i,t} = we_{i,t} \tag{6}$$

where w is the real wage in the economy and $e_{i,t}$ is the household's current productivity. Following standard practice in the literature (e.g., Guerrieri and Lorenzoni; 2017; Auclert et al.; 2020, 2021, 2023), I assume that $e_{i,t}$ behaves according to the following AR(1) process:

$$\log e_i' = \rho_e \log e_i + \epsilon_i \tag{7}$$

where $|\rho_e| < 1$ and ϵ_i is an idiosyncratic shock drawn from a normal distribution with standard deviation σ_e. Accordingly, at each point in time, households will vary in their

[21] This is a standard feature of housing models (see, e.g., Kaplan and Violante; 2014; Kaplan et al.; 2018; Berger et al.; 2018; Wong; 2020; Eichenbaum et al.; 2022) which captures the closing fees and costs that are associated with the sale of a house. In addition, the presence of adjustment costs implies that households change their housing stock infrequently, which is a realistic feature of the model.

productivity level $e_{i,t}$. This feature of the model, together with the presence of borrowing constraints, implies that households have different MPCs. Since the aim of this study is to analyze how the effectiveness of ARMs depends on MPCs, this is a crucial feature of the model.

Risk-free assets Households can invest in one-period ahead risk-free assets. A household's position in these assets is denoted by a'. These assets pay interest rate r. I introduce incomplete markets in the economy by constraining households to save in these assets, that is, $a' \geq 0$.

Mortgages Households may take out loans with their house as collateral. These loans are modelled as a proportional repayment plan: each period, households pay back a fixed proportion μ of the remaining balance. Accordingly, households entering the period with an outstanding mortgage balance of b will see their mortgage balances evolve as follows:

$$b' = (1 - \mu)b. \tag{8}$$

Households can open a mortgage only to finance part of their housing purchase:

$$b' \in [0, \lambda p h'] \tag{9}$$

where λ is a pre-specified loan-to-value cap, p is the price of a housing unit and h' is the level of the housing stock a household wants to purchase. Hence, households cannot use mortgages as a saving device (the mortgage amount needs to be positive) and can borrow up to a fraction λ of the value of the house they wish to buy.

The mortgage interest rate r^b is defined as

$$r^b = r + \Delta^b \tag{10}$$

where r is the risk-free rate and Δ^b is a constant spread that creates a positive wedge between r^b and r.

Households entering the period with an outstanding mortgage balance of b must make a mortgage payment, M, which includes both interest and principal repayment, as follows:

$$M = (r^b + \mu)b. \tag{11}$$

Equation (11) captures the main transmission channel of ARMs. Following a monetary shock that leads to a change in r, the mortgage rate r^b adjusts according to the dynamics in equation (10). As a result, households with ARMs experience changes in their mortgage payments, M, while those with FRMs see no impact on their payments from changes in r^b. Within the economy, the fraction of ARMs is captured by the parameter γ.

Taxes At each point in time, household i, with idiosyncratic productivity level e_i, pays a time-invariant tax to the government, denoted $\tau(e_i)$. While the individual amount $\tau(e_i)$ remains constant over time, it is proportional to the household's idiosyncratic productivity level e_i, ensuring that wealthier households pay higher taxes than poorer ones.[22]

Value functions The vector of household states is $\{e, h, b, a\}$, which keeps track of the productivity level e, the housing stock h, the mortgage balance b, and the liquid balance a that households have at the beginning of the period. At each point in time, households need to make a discrete choice and decide whether to buy a new house and possibly open a new mortgage, or staying in their current home. The value functions associated with these two choices, buying or staying, are denoted by $V^{buy}(e, h, b, a)$ and $V^{stay}(e, h, b, a)$, respectively. The overall value function is

$$V(e, h, b, a) = \max\{V^{buy}(e, h, b, a), V^{stay}(e, h, b, a)\}. \tag{12}$$

A common problem in models with discrete choices is that, due to the presence of the *max* operator, there can be kinks in the value function and discontinuities in the agents' optimal policy functions for continuous variables. As a consequence, it is not possible to make use of derivatives in the solution algorithm, which creates significant complications when solving these models.[23] To overcome these problems, I follow the methodology in Iskhakov et al. (2017), Bardóczy (2022) and Beraja and Zorzi (2024), and rewrite the overall value function as:

$$V(e, h, b, a) = \max\{V^{buy}(e, h, b, a) + \sigma_\epsilon \epsilon_b, V^{stay}(e, h, b, a) + \sigma_\epsilon \epsilon_s\} \tag{13}$$

[22]Note that since $\tau(e_i)$ is constant over time across productivity levels, taxes will not play a role in the analysis. They are introduced so that the model features a convenient steady-state property. Let $A = \int a_i(e, h, b, a)di$ represent the overall amount of savings that households have in steady-state. In steady-state, households make new savings A and obtain return on their assets $(1 + r)A$, where r is the steady-state short-term interest rate. I calibrate $T = \int \tau_i$ so that $T = rA$. It then follows that the aggregate return on asset net of taxes, $(1 + r)A - T$ conveniently equals the overall amount of new savings A. Such a definition of T resembles a common general equilibrium specification of T, where the government follows a tax rule to keep its debt level constant over time (see, e.g., Auclert, Rognlie and Straub; 2020).

[23]In particular, this implies that the endogenous grid-point method (EGM) developed by Carroll (2006) cannot be directly applied.

where ϵ_b and ϵ_s are independent and identically distributed taste shocks drawn from a type 1 extreme value (Gumbel) distribution with scale parameter σ_ϵ.[24] The computational value of the taste shocks is to smooth out the value function around the discrete choice, allowing the use of derivatives in the solution algorithm. In addition, the use of taste shocks allows the model to better capture the fact that, in reality, the probability of choosing to buy a new house changes smoothly: without them, the model would imply a discontinuous change in these probabilities as soon as $V^{buy}(e, h, b, a)$ exceeds $V^{stay}(e, h, b, a)$.

The assumption on the distribution of the taste shocks implies that the probability that households choose to change their housing stock as a function of their state $\{e, h, b, a\}$ is given by the multinominal logit form:

$$P(b|e, h, b, a) = \frac{exp\left(\frac{V^{buy}(e,h,b,a)}{\sigma_\epsilon}\right)}{exp\left(\frac{V^{buy}(e,h,b,a)}{\sigma_\epsilon}\right) + exp\left(\frac{V^{stay}(e,h,b,a)}{\sigma_\epsilon}\right)} \tag{14}$$

and the value function is given by:

$$V(e, h, b, a) = \sigma_\epsilon \log\left(exp\left(\frac{V^{buy}(e, h, b, a)}{\sigma_\epsilon}\right) + exp\left(\frac{V^{stay}(e, h, b, a)}{\sigma_\epsilon}\right)\right). \tag{15}$$

Finally, I introduce the value functions associated with the two discrete choices. Households that decide to purchase a new house, the *buyers*, have decisions that are characterized by the following value function:

$$\begin{aligned} V^{buy}(e, h, b, a) = &\max_{c,h',b',a'} u(c, h') + \beta \mathbb{E}\left[V(e', h', b', a')|e\right] \\ \text{s.t. } c + a' + ph' - b' &\leq y + (1 + r)a - (1 + r^b)b + (1 - f)p(1 - \delta)h - \tau(e) \\ b' &\in [0, \lambda ph'] \\ a' &\geq 0 \end{aligned} \tag{16}$$

where $u(c, h')$ is specified in equation (4), y in equation (6), and $\tau(e)$ represents lump-sum taxes. According to this definition, households choosing to purchase a new home make four continuous choices: the size of their consumption basket c, the size of their new home h', the amount of new mortgage debt b' to cover part of the housing cost ph', and the portion of their resources to allocate to liquid savings a'. Importantly, before purchasing a new home and taking out a new mortgage, households must settle any outstanding mortgage debt, making a total payment of $(1 + r^b)b$, and sell any house they already own, generating revenue of $(1 - f)p(1 - \delta)h$.

[24] These are linearly additive taste shocks à la McFadden (1973).

Stayers, those households that decide to remain in their current home, have decisions that are characterized by the following value function:

$$
\begin{aligned}
V^{stay}(e,h,b,a) &= \max_{c,a'} u(c,h') + \beta \mathbb{E}\left[V(e',h',b',a')|e\right] \\
\text{s.t. } c + a' &\leq y + (1+r)a - M - \tau(e) \\
M &= (r^b + \mu)b \\
h' &= (1-\delta)h \\
b' &= (1-\mu)b \\
a' &\geq 0
\end{aligned}
\tag{17}
$$

where $u(c,h')$ is specified in equation (4), y in equation (6), and $\tau(e)$ represents lump-sum taxes. In this case, households face a standard consumption-saving problem where part of their resources are used to cover mortgage payments M. These payments contribute to the reduction of mortgage debt in line with the dynamics of equation (8).

3.2 Calibration

The model is calibrated to a reference country: Spain. This country is chosen to facilitate comparability with other similar Euro Area studies, such as Corsetti, Duarte and Mann (2022) and Pica (2023), which use Spain as their reference economy. I use European data sources, which provide information on the Spanish economy, to calibrate most parameters of the model. Nonetheless, a few parameters have not been estimated for Spain nor for any other European economy. For these parameters, which I discuss below, I rely on US estimates.

Two parameters are particularly critical in the analysis, since they control the MPC level in the economy and the share of ARMs: β, the discount factor, and γ, the fraction of ARMs in the economy. Since my goal is to study the role that ARMs and MPCs play in the transmission of monetary policy, I first calibrate these parameters for the Spanish economy, and then conduct counterfactual exercises modifying them. These exercises allow me to investigate how variations in ARMs and MPCs affect monetary policy pass-through.

Households The model is calibrated to a quarterly frequency. The coefficient of risk aversion σ is set to 2, which is a standard value in the literature (see, e.g., McKay, Nakamura and Steinsson; 2016).

Table 1: Parameter values

Parameter	Explanation	Value	Target/Source
Households			
β	Discount factor	0.984	Net assets/GDP=0.53
σ	Inverse EIS	2	Standard value
α	Consumption share	0.714	H/C ratio=5.96
r	Short-term interest rate	1.05%	Mean Eonia rate 2003-2018
w	Real wage	1	Standard value
ρ_e	Persistence, productivity	0.967	McKay, Nakamura and Steinsson (2016)
σ_e^2	Variance, productivity	0.033	McKay, Nakamura and Steinsson (2016)
σ_ε	Scale parameter	0.1	Beraja and Zorzi (2024)
$\underline{a}$	Borrowing constraint	0	McKay, Nakamura and Steinsson (2016)
Housing			
γ	ARM share	75.6%	ECB HFCS
Δ^b	Mortgage rate spread	1.95%	Mean mortgage rate 2003-2018
f	Adjustment cost	0.1	OECD (2012)
λ	Mortgage borrowing limit	0.85	Pica (2023)
δ	Yearly housing depreciation	2%	BEA estimate (Fraumeni; 1997)
μ	Mortgage repayment speed	0.015	Mortgage maturity $=$ 25 years
$\bar{H}$	Housing stock	19.58	$p^{ss} = 1$

Notes: See text for a discussion on the sources and targets.

The discount rate β is set to match the average ratio between liquid asset holdings net of mortgage debt and annual GDP over the period 2012–2018, which is equal to 0.53.[25,26] The parameter α, controlling for the non-durable share in the utility function, is calibrated

[25]The time period 2012-2018 is the one available in the ECB Distributional Wealth Accounts (DWA), the source of data for this calibration. I use the DWA as the source of data for my targets because it harmonizes the Quarterly Sector Accounts statistics complied by the ECB with information from the HFCS, which I used as the main source of data in the empirical analysis. More information on the DWA dataset can be found here.

[26]To compute liquid assets, I match the categories in Guerrieri and Lorenzoni (2017) and McKay, Nakamura and Steinsson (2016), which provide a definition of liquid assets for the United States, in the DWA. In particular, I sum the following entries: *Deposits*, *Debt Securities*, *Listed Shares*, and *Investment Fund Shares*. The entry *Mortgage Debt* accounts for mortgages in the calculation of net assets.

to match the average housing stock to annual consumption ratio over 2012–2018, which equals 5.96.[27] These targets yield $\beta = 0.984$ and $\alpha = 0.714$.

The short-term interest rate, r, is set to the average annual short-term rate in the Euro Area (Eonia) during the 2003-2018 period: 1.05%. Following standard practice in the literature (see, e.g., McKay, Nakamura and Steinsson; 2016; Wong; 2020), the borrowing constraint on these assets is set to 0, so that households are only allowed to borrow through mortgages.

The real wage w is set to 1, and income heterogeneity arises solely due to difference across households in their idiosyncratic productivity levels. This value for the real wage is the standard one that would arise in a model with a fully developed supply side, where output Y is produced using labor N as the sole input of production according to the linear technology $Y = N$.

The persistence and variance of the productivity process described in equation (6), ρ_e and σ_e^2, have not been estimated for Spain. Accordingly, they are calibrated following McKay, Nakamura and Steinsson (2016), which rely on US estimates by Floden and Lindé (2001). The autoregressive coefficient ρ_e is set to 0.967, matching the evidence in Floden and Lindé (2001). With regards to the variance of the process, the evidence in Floden and Lindé (2001) would imply $\sigma_e^2 = 0.017$. Nonetheless, McKay, Nakamura and Steinsson (2016) discuss how such a value would imply too little volatility in earnings relative to the more recent empirical evidence in Guvenen, Ozkan and Song (2014), and therefore consider an alternative calibration with $\sigma_e^2 = 0.033$. Since additional evidence as shown that earning volatility is larger than previous annual estimates would imply (Ganong et al.; 2024), I use this higher value in my calibration. The process is discretized into five states using the Rouwenhorst method.

The scale parameter $\sigma_\varepsilon = 0.1$ in equation (13) is chosen based on the analysis in Beraja and Zorzi (2024).[28]

Housing The share of ARMs in the total mortgage stock, γ, is taken from the HFCS, where it stands at 75.6% for Spain.[29] In order to implement counterfactual exercises tar-

[27] To compute the H/C ratio, I use the variable *Housing Wealth* in the DWA to measure the end-of-period housing stock H, while C is taken from National Accounts statistics provided by Eurostat.

[28] Beraja and Zorzi (2024) provide a set of reasonable values for σ_ε, ranging from 0.1 to 0.45. I choose to use the value 0.1 because the authors find it to be reasonable based on the evidence in Bachmann et al. (2021) which, using European data, is particularly relevant for the present study.

[29] To match the share of ARMs in the total mortgage stock, I proceed as follows. For households with positive mortgage balances in steady-state, I assume that a fraction γ holds ARMs, while the remaining

geting other Euro Area countries, γ is adjusted to reflect the share of ARMs that these countries have in the HFCS.[30]

The spread between the risk-free rate r and the mortgage rate r^b, Δ^b, is set to match the average annual mortgage rate in Spain over the period 2003-2018. Since the average is equal to 3%, the spread is set to 1.95%. The rate of depreciation of the housing stock, δ, is set to an annual value of 2%, in the middle of the estimates of the Bureau of Economic Analysis (Fraumeni; 1997). The parameter governing the speed of mortgage repayment, μ, is set to 0.015 to match the typical duration of a Spanish mortgage, where the average mortgage maturity is 25 years (van Hoenselaar et al.; 2021). Appendix C.2 provides additional details on the procedure I followed to calibrate this parameter.

In line with the evidence provided in OECD (2012), the parameter f, controlling the fraction of transaction fees associated with the sale of housing, is calibrated to 10% for Spain. This is higher than the estimate of 5% which is commonly used in the literature (see, e.g., Berger et al.; 2018; Wong; 2020; Diaz and Luengo-Prado; 2010), accounting for the larger transaction costs that characterize housing sales across European economies.

The parameter governing the maximum loan-to-value ratio, λ, is set to match the evidence in Pica (2023). This parameter is calibrated to 0.85, slightly higher than its standard value of 0.8 (see, e.g., Berger, Guerrieri, Lorenzoni and Vavra; 2018; McKay and Wieland; 2021), in line with the empirical LTVs across Euro Area countries. The fixed supply of housing stock, $\bar{H}$, is set to normalize the the steady-state price of a unit of housing to 1.

3.3 Model fit

This section shows that the model is able to match important untargeted moments in the data.

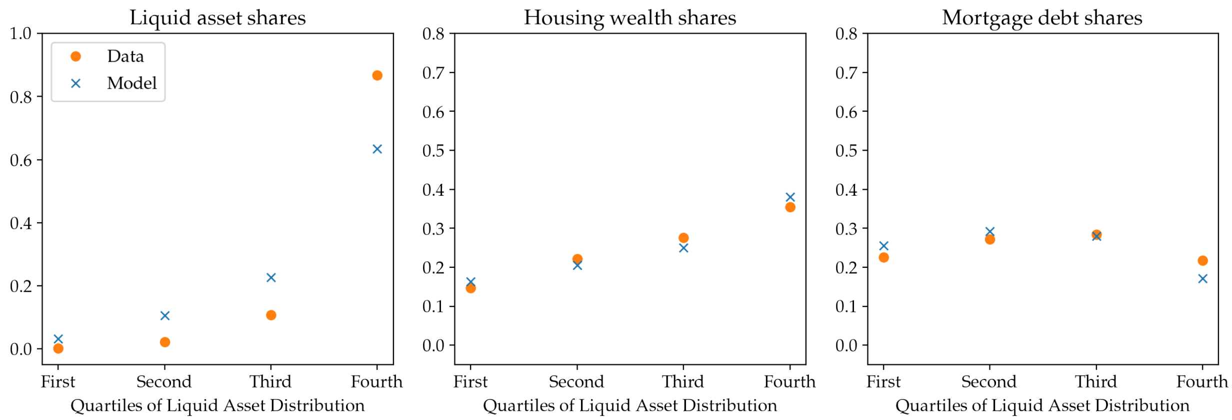
Figure 5 compares the distribution of assets and mortgage debt in the model and in the HFCS data.[31] The model successfully replicates the upward trends in the distribution

$(1-\gamma)$ does not. For households without positive mortgage balances in steady-state, I assume that if they decide to take out a mortgage after a monetary policy shock, a fraction γ will have ARMs, while the remaining $(1-\gamma)$ will not.

[30] In line with my empirical analysis, where I used the share of ARMs in the total mortgage stock as the variable of interest, I target the share of ARMs in the total mortgage stock in the model. Nonetheless, appendix C.5 presents robustness exercises where I target the share of households with ARMs in the population of each economy instead.

[31] In the HFCS data, I calculate liquid assets using the definition provided by Almgren et al. (2022). Further details on the construction of this variable are available in Appendix B.2. To capture housing wealth, I

Figure 5: Distributions of assets and debt in the model and in the data



Notes: In each panel, households are ranked based on their position in the liquid asset distribution. Each dot represents the fraction of total liquid assets (left panel), housing wealth (middle panel), and mortgage debt (right panel) held by a specific quartile in the model (in blue) and in the Spanish HFCS data (in orange).

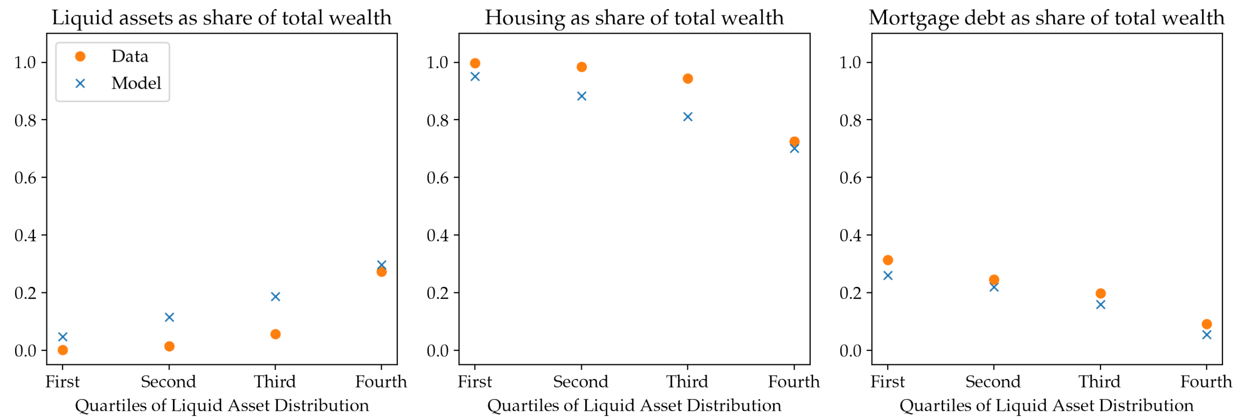
of liquid assets and housing wealth. Notably, the fourth quartile of the liquid asset distribution owns the vast majority of assets (approximately 80% in the data and above 60% in the model) and holds the largest share of housing wealth (around 40% in both cases). Additionally, the model mirrors the empirical hump-shaped profile of the mortgage debt distribution, where the fraction of total mortgage held by the bottom and top quartiles of the liquid asset distribution is slightly less the fraction held by the second and third quartiles.

Figure 6 compares the composition of household wealth in the model and in the data. The left panel of the figure displays the ratio of total liquid assets to total wealth across different quartiles, where total wealth is computed as the sum of liquid assets and housing wealth held by each quartile. Both in the model and the data, households in the lower quartiles hold very little of their wealth in liquid assets: as shown in the middle panel, most of their wealth is concentrated in housing. In addition, the right panel of figure 6 shows the ratio between mortgage debt and total wealth along the liquid asset distribution. The model accurately captures the declining pattern of this ratio in the data, where debt represents a lower fraction of total wealth as households increase their holdings of liquid assets.

Overall, both in the data and in the model, lower income households primarily accu-

use the variable *da1110* ("Value of household's main residence"), and to measure the amount of outstanding mortgages, I use the variable *dl1110* ("Outstanding balance of household's main residence mortgages").

Figure 6: Composition of total wealth in the model and in the data



Notes: In each panel, households are ranked based on their position in the liquid asset distribution. Each dot represents the ratio between total liquid assets and total wealth (left panel), total housing wealth and total wealth (middle panel), and total mortgage debt and total wealth (right panel) in the four quartiles in the model (in blue) and in the Spanish HFCS data (in orange).

mulate wealth in the form of housing and carry substantial mortgage debt relative to their assets.[32] This is important, since it indicates that fluctuations in mortgage conditions are especially significant for this cohort of households, which is characterized by high MPCs.

4 Results

This section presents the quantitative results on the role of ARMs and MPCs for monetary policy transmission. The analysis is conducted in a partial equilibrium framework, where consumption adjusts solely in response to changes in the short-term rate r and the mortgage rate r^b, without broader general equilibrium feedbacks affecting other variables. This setting is ideal to study how varying levels of ARMs and MPCs affect transmission through mortgages in isolation. The analysis is divided into two parts.

First, I examine the response of consumption exclusively to changes in the mortgage rate r^b: this allows me to analyze how transmission takes place through the mortgage channel, which is the central focus of this study. The analysis has two main objectives: (i) to investigate the role of MPCs in amplifying transmission through ARMs, and (ii) to show that, in line with the empirical evidence of section 2, the model predicts transmis-

[32] Appendix C.3 provides a description of the policy functions for the *buyers*, shedding light to the mechanism through which lower income households end up having large debt positions in the model.

sion to be stronger when high ARMs are paired with high MPCs. In addition, I present an important prediction of the model: for a given fraction of ARMs in the economy, transmission through mortgages is stronger when ARMs are concentrated among low-income (high-MPC) households.

Second, I analyze a complete monetary policy shock, where both r and r^b are affected. I first confirm that the main finding from the earlier analysis holds: the interaction between ARMs and MPCs continues to amplify transmission. I then extend the analysis in two ways. First, I quantify the extent to which empirical cross-country differences in monetary transmission within the Euro Area can be explained by different transmission through ARMs. Second, I explore the welfare effects of monetary policy shocks across different income cohorts.

The key intuition delivered by the model on the roles of ARMs and MPCs in transmission is as follows. Households' income heterogeneity affects both their MPC and their mortgage choices: poorer households have higher MPCs and opt for mortgages with higher loan-to-value ratios. When a monetary policy shock occurs, households with ARMs are immediately impacted by the rapid pass-through of short-term interest rates to mortgage rates, reducing their available resources for consumption. Wealthier households, whose mortgage payments constitute a small fraction of their overall income, hardly change their consumption choices. In contrast, poorer households, with higher MPCs and more burdensome mortgage payments, must make significant adjustments. Therefore, the impact of a monetary policy shock through the mortgage channel is stronger when a larger fraction of households hold ARMs, as they are the ones affected by changes in mortgage payments, and when a higher proportion of households have high MPCs, since they are the ones making larger consumption adjustments.[33]

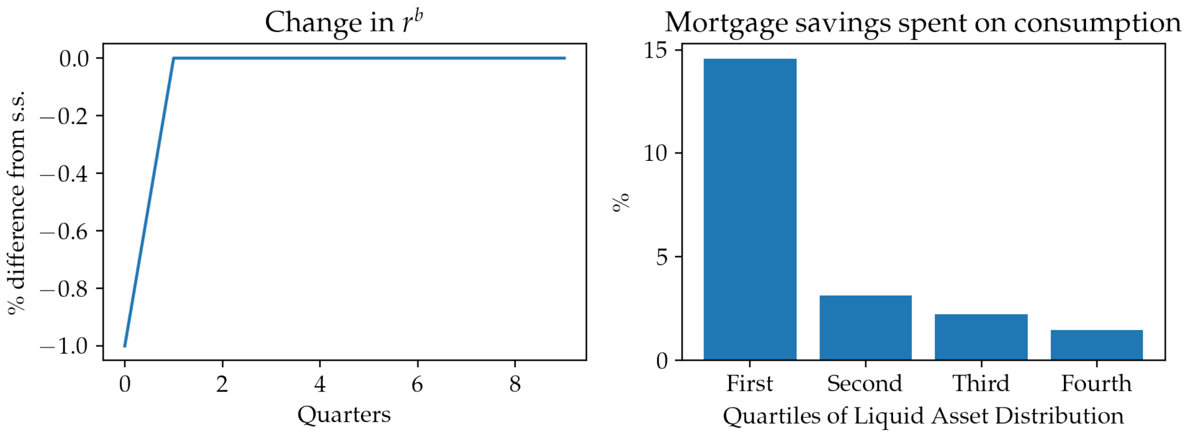
4.1 Changes in the mortgage rate r^b

This section conducts exercises to analyze the mechanism through which ARMs and MPCs shape the transmission of monetary policy through mortgages.

I first investigate the role of MPCs for transmission through mortgages, then show that the model predicts an important role in transmission for the interaction between ARMs and MPCs, and finally highlight that the distribution of ARMs in the economy

[33]Robustness results for all exercises in this section are provided in appendix C.5, where I target the share of households with ARMs in the population rather than the share of ARMs in the outstanding mortgage stock.

Figure 7: Transmission of mortgage rate shock to consumption by asset quartile



Notes: The left panel shows the dynamics of the mortgage rate. In the right panel, households are ranked based on their position in the liquid asset distribution. Each bar shows the average fraction of mortgage savings, arising from the one-time reduction in r^b, that is spent on consumption.

is an important variable to consider in order to anticipate the effects of monetary policy shocks through the mortgage channel.

4.1.1 The role of the MPC

To examine how MPCs influence the transmission of monetary policy through mortgages, I conduct the following exercise. I assume that all households in the Spanish economy have ARMs ($\gamma = 1$), and shock the economy with a one-time reduction in the mortgage interest rate r^b. The left panel of figure 7 shows the evolution of the mortgage rate, which decreases by 100 basis points on impact. As a result, all households with outstanding mortgage balances experience a one-time decrease in mortgage payments. I then investigate the relationship between households' MPCs and the magnitude of their consumption adjustment following the shock.

The right panel of figure 7 displays the fraction of mortgage savings from the rate reduction that are allocated to consumption across different quartiles of the liquid asset distribution. Households in the lowest quartile, who have the highest MPCs, quickly channel their mortgage savings into increased consumption. As we move up the liquid asset distribution, MPCs decline, and a smaller fraction of savings is allocated to consumption. This is intuitive: as households become wealthier, they have more resources to meet their consumption needs, so that lower mortgage payments are more likely to result in increased savings rather than higher consumption.

This result is important, as it highlights the critical role of MPCs in transmission through mortgages: the effect of lower mortgage rates on consumption hinges on the MPC of the households benefiting from these reductions. Hence, even with a high fraction of ARMs in the economy, mortgages may not serve as an effective transmission mechanism if the economy is characterized by low MPCs.

4.1.2 The interaction between ARMs and MPCs

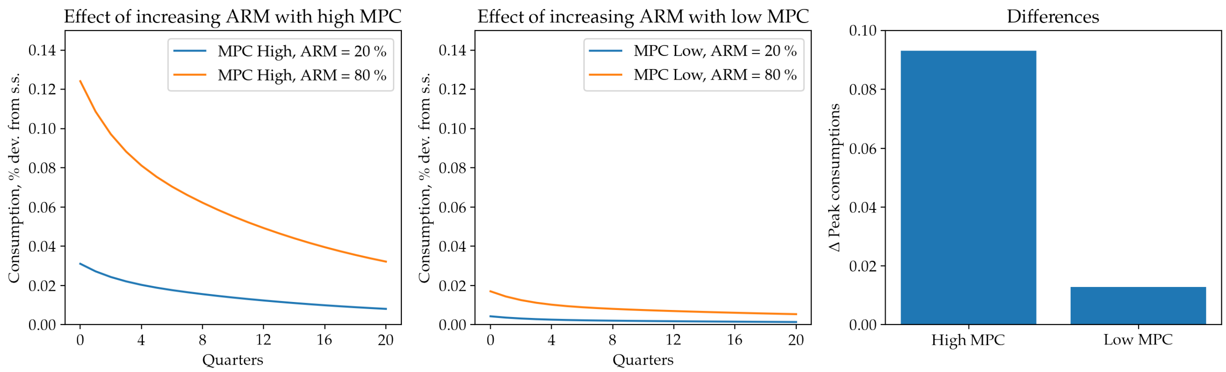
After having analyzed the role of MPCs for monetary policy transmission through mortgages, this section shows that the model reproduces the key empirical fact highlighted in section 2: transmission is stronger when high ARM shares are paired with high MPCs.

The analysis compares two economies that differ in both their shares of ARMs and their MPC levels. The first economy is Spain, serving as the representative country for this study. The second economy is calibrated identically to Spain, except for the parameter β, which is adjusted to generate an MPC half that of Spain. I then analyze the consumption response in both economies following a mortgage rate shock under two scenarios: one where the share of ARMs is 20%, and another where the share is 80%. The shock is calibrated such that r^b drops by 100 basis points on impact.

Figure 8 presents the results of this exercise. The Spanish economy is labeled *"MPC High"*, while the counterfactual economy with lower MPC is labeled *"MPC Low"*. The left and middle panels show that, within each economy, increasing the share of ARMs leads to a stronger response of consumption: in line with our expectations, a higher fraction of households whose mortgage payments are affected by the shock implies a larger change in consumption.

Crucially, the right panel of figure 8 compares the peak consumption responses in the two economies, showing that the magnitude of the increase in consumption depends on the MPC level: as ARM shares rise from 20% to 80%, the rise in consumption is significantly larger in the economy with the higher MPC. The intuition for this result is straightforward based on the analysis in section 4.1.1: while higher ARM shares raise the number of households directly affected by lower mortgage rates, higher MPCs lead to larger consumption adjustments following the shock. Accordingly, in the model, MPCs interact with ARMs by amplifying their effect on monetary policy transmission, consistent with the empirical evidence from section 2. This finding is crucial, as it underscores that ARMs must be paired with high MPCs to be an effective channel of monetary policy transmis-

Figure 8: Interaction between ARMs and MPCs after a mortgage rate shock



Notes: The left and middle panels show the consumption response, in percentage deviations from its steady-state value, to a mortgage rate shock in the high and low MPC economies, respectively. The blue line shows the response when the share of ARMs in the economy is 20%, while the orange line shows the response when the share is 80%. The right panel displays the difference in the peak response of consumption when the share of ARMs increases from 20% to 80%. The mortgage rate shock is calibrated to lead to a 100 basis points reduction in r^b on impact, and it follows an AR(1) process with a persistence of 0.75.

sion.

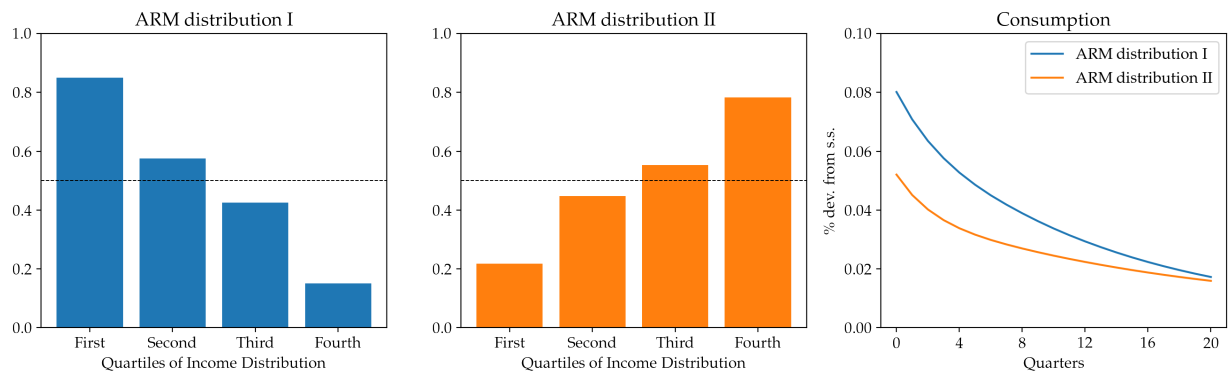
4.1.3 The distribution of ARMs

Before moving to the analysis of a complete monetary policy shock, I explore how the distribution of ARMs within the economy affects the strength of transmission. In order to do so, I take the baseline Spanish calibration and assume that the ARM share in the economy is 50%. I then alter the allocation of ARMs in the population, so that the analysis compares two economies that have equal shares of ARMs and MPC levels, but differ in their distributions of ARMs.

The left and middle panels of figure 9 illustrate these two distributions. In each panel, the vertical bars represent the fraction of ARMs within total mortgages for each quartile of the income distribution.[34] *Distribution I* features a higher concentration of ARMs among low-income households, whereas *distribution II* has the opposite pattern. Accordingly, *distribution I* has ARMs concentrated among high-MPC households, while the majority of ARMs are concentrated among low-MPC households in *distribution II*.

[34]Note that the two distributions are not perfectly symmetric because the overall amount of mortgages is not symmetric across income quartiles (i.e., the first quartile and the fourth quartile do not hold the same amount of mortgage debt).

Figure 9: Transmission of mortgage rate shock depending on the ARM distribution



Notes: The left and middle panels show the share of ARMs in different income quartiles. The horizontal dashed line indicates the overall ARM share in the two simulations, equal to 50%. The right panel shows the response of consumption to a reduction in the mortgage rate r^b. The mortgage rate shock is calibrated to lead to a 100 basis points reduction in r^b on impact, and it follows an AR(1) process with a persistence of 0.75.

The right panel of figure 9 shows the response of consumption to the same 100 basis points reduction in the mortgage rate r^b in the two economies. In the first, characterized by *distribution I*, the consumption response peaks at approximately 0.08%. In contrast, the economy with *distribution II* experiences a significantly smaller peak of about 0.05%. Accordingly, this analysis shows that skewing the ARM distribution toward lower-income households results in a much stronger consumption response, with the peak being roughly 1.6 times larger than in the economy characterized by the opposite distribution of ARMs.

This result builds on previous analyses, which highlighted the importance of high MPCs for strong transmission through mortgages, to provide a key insight: for a given share of ARMs, transmission is more effective when these mortgages are concentrated among low-income (high-MPC) households. This finding underscores the importance for policymakers to monitor the distribution of ARMs in the population to better anticipate the strength of transmission through the mortgage channel.

4.1.4 Summary

The mortgage rate exercises show how ARMs and MPCs interact in the transmission of monetary policy through mortgages. While ARMs control the fraction of households directly affected by changes in mortgage rates, MPCs govern the sensitivity of consumption to changes in mortgage payments. Strong transmission through the mortgage channel requires both a high ARM share, so that a significant fraction of households experiences the shock, and high MPCs, so that the response of consumption is pronounced. Accordingly, transmission is particularly strong when high ARMs are matched with high MPCs, consistent with the empirical evidence on their interaction discussed in section 2.

4.2 Complete monetary policy shocks

After establishing the mechanism through which ARMs and MPCs interact in the transmission of monetary policy through mortgages, this section shifts to the analysis of complete monetary policy shocks. Within this framework, monetary policy impacts both the real interest rate r and, through the pass-through described in equation (10), the mortgage rate r^b.

I begin this analysis by showing that the key mechanism highlighted in the previous section holds in the new framework: the interaction between ARMs and MPCs significantly amplifies the strength of transmission. I then use the model to assess how much of the transmission differences across Euro Area countries can be attributed to different transmission through ARMs. Finally, I evaluate the welfare consequences of contractionary monetary policy shocks on the overall economy and across different household cohorts.

4.2.1 The interaction between ARMs and MPCs in a complete monetary experiment

As a first analysis, I replicate the monetary policy experiment from section 4.1.2 to show that the model finds the interaction between ARMs and MPCs to be relevant for transmission also in the context of a complete monetary policy experiment.

The results of this experiment are presented in table 2. Similarly to section 4.1.2, *"High MPC"* is the baseline Spanish economy, while *"Low MPC"* is the counterfactual economy with MPC half the one of Spain. Moreover, *"Low ARM"* represents a scenario where 20% of mortgages have adjustable-rates, while *"High ARM"* represents a scenario where the share of ARMs is 80%. Each entry in the table shows the maximum consumption response in the different scenarios.

The last row of the table presents the key result from this exercise: increasing the ARM share from 20% to 80% leads to a peak consumption increase of 0.012% (a 5.6% rise from its previous value) in the low-MPC economy and 0.093% (a 39% rise) in the high-MPC economy. This result highlights the importance of the interaction between ARMs and

Table 2: Interaction between ARMs and MPCs after a complete monetary policy shock

	Low MPC	High MPC	Δ MPC
Low ARM	0.214%	0.237%	0.023%
High ARM	0.226%	0.330%	0.104%
Δ ARM	0.012%	0.093%	0.116%

Notes: High MPC refers to the reference Spanish economy, while *Low MPC* refers to the counterfactual economy with MPC half that of Spain. *Low ARM* and *High ARM* refer to ARM shares of 20% and 80%, respectively. Each entry represents the peak consumption response after a monetary policy shock. The entries in the Δ *ARM* and Δ *MPC* column row show the differences in peak consumption. As detailed in section 4.2, the shock leads to a reduction in r of 100 basis points on impact and follows an AR(1) process with a persistence of 0.75.

MPCs: higher ARM shares lead to stronger transmission in high-MPC economies, even when considering complete monetary policy shocks.

4.2.2 The role of ARMs in explaining transmission heterogeneity

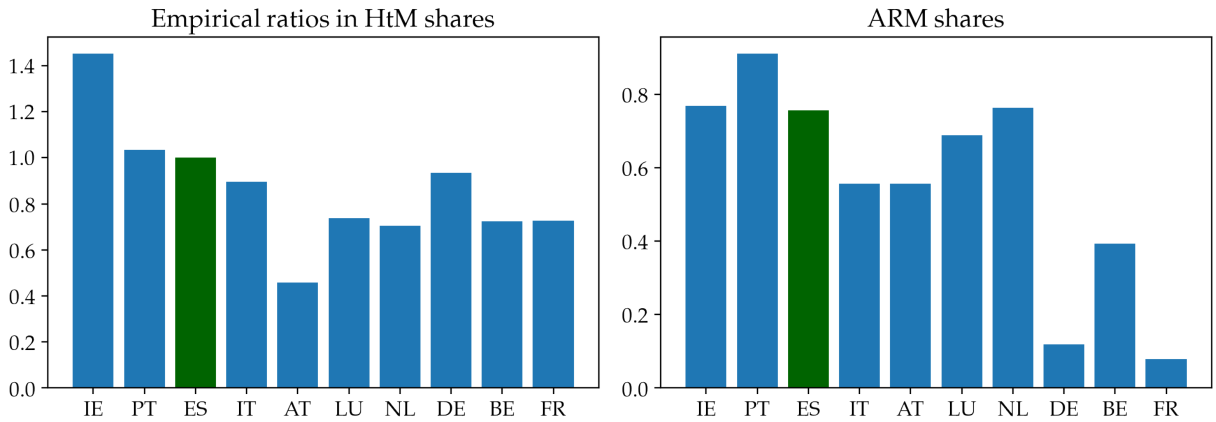
To evaluate how much of the variation in monetary policy transmission across Euro Area countries can be attributed to differences in transmission through ARMs, I proceed as follows.

First, I calculate the empirical differences in monetary policy transmission across Euro Area countries. In section 2, I estimated the strength of transmission for each country using local projections (equation 1). Based on these estimates, I compute the difference in the peak consumption response of each country relative to Spain, the reference economy.

Second, I use the model to estimate the differences in transmission between Euro Area countries and Spain resulting from variations in transmission through ARMs. To do this, I first calibrate the monetary policy shock so that the model's peak consumption response for Spain matches the data.[35] I then adjust the parameters β, the discount factor, and γ, the share of ARMs, to create counterfactual Spanish economies with MPC levels and ARM shares of other Euro Area countries. Since I have data on HtM shares but not MPCs, I assume that the empirical HtM ratios approximate the unobserved MPC ratios (i.e., if a country's HtM share is double that of Spain, its MPC is assumed to be similarly doubled).

[35] This implies a 170 basis points reduction of r on impact. The shock is assumed to follow an AR(1) process with a persistence of 0.75.

Figure 10: Shares of ARMs and HtM households in the data



Notes: The left panel shows the ratio between HtM households in Euro Area countries and Spain. The right panel shows the fraction of households with ARMs across Euro Area countries. Countries are ranked by the strength of monetary policy transmission, from Ireland (strongest) to France (weakest), in line with estimates from equation (1) shown in figure 1. The source of the data is the HFCS.

For each Euro Area country c, I modify β so that the ratio MPC^{ES}/MPC^{c} matches the empirical HtM^{ES}/HtM^{c} ratio, and calibrate γ to align with the country's observed ARM share in the data. Figure 10 shows the HtM ratios relative to Spain and the fraction of ARMs in the HFCS, which I use for the calibration of β and γ. This procedure allows me to calculate the peak consumption response in each of these counterfactual economies.

Importantly, MPCs affect transmission both through the standard interest rate channel via r and through the mortgage channel via r^b. To isolate the effect of MPC differences on transmission through mortgages, I exclude the impact of MPCs on consumption through r and focus solely on their effect through r^b.[36] This approach enables me to obtain counterfactual consumption responses that deviate from Spain's baseline only due to transmission differences through ARMs, which is the core focus of my analysis.

As a third and final step, I compare the empirical and model-implied differences in transmission, quantifying how much of the variation in monetary policy transmission across Euro Area countries is driven by differences in transmission through ARMs.[37]

[36] Appendix C.4 provides details on how I isolate the impact through r^b from the standard interest rate channel.

[37] This section presents the baseline results, where ARMs and MPCs are assumed to be independent. In particular, this means that the ARM share is the same across all income levels. Appendix C.6 provides robustness results incorporating an exogenous correlation between ARMs and MPCs.

Table 3: ARM and MPC contributions to overall transmission

	Difference			Contribution		
	Data	Model	% Explained	ARM	MPC	Interaction
AT	0.236	0.148	63%	4%	71%	25%
BE	0.314	0.140	45%	21%	43%	40%
DE	0.295	0.150	50%	52%	8%	40%
FR	0.350	0.160	46%	26%	8%	66%
IE	-0.728	-0.225	34%	1%	97%	2%
IT	0.172	0.107	62%	20%	59%	21%
LU	0.284	0.122	43%	4%	87%	9%
NL	0.287	0.121	42%	−1%	102%	−1%
PT	-0.239	-0.078	32%	43%	47%	10%
Averages	0.311	0.139	46%	19%	57%	24%

Notes: For each country, the table shows the difference in percentage points in the peak consumption response to a monetary policy shock relative to Spain. This difference is presented both in the data (second column) and in the model (third column). The fourth column shows the fraction of this difference captured by the model. The last three columns report the fraction of the model-implied differences between each country and Spain that are attributable to differences in ARMs, MPCs, and their interaction. The last row presents the average values of the column variables across countries.

Table 3 displays the results of this analysis. The *Difference* section includes three columns for each country: the empirical peak consumption response relative to Spain (*Data*), the model-implied peak consumption response relative to Spain (*Model*), and the percentage of the empirical difference captured by the model (*% Explained*). The *Contribution* section breaks down the contributions of differences in ARMs, MPCs, and their interaction to explain the model-implied differences in consumption responses across countries relative to Spain. This decomposition is achieved by separately adjusting ARMs and MPCs and computing counterfactual consumption responses, thereby isolating the impact of each factor on the overall consumption response.[38]

[38] As an illustrative example, the observed peak consumption response difference between Spain and Austria in the data is 0.236. In the model, the difference between Spain's peak consumption response and that of a counterfactual Spanish economy with Austria's MPC and ARM share is 0.148. This indicates that the model accounts for 63% (0.148/0.236) of the observed difference in transmission between the two countries. To disentangle the contributions of ARMs, MPCs, and their interaction to the model-implied

The model is able to explain between 32% and 63% of the differences in response across Euro Area economies, with an average of 46%. 19% of the differences in the response of consumption in the model are due to ARMs, with their contribution varying between -1% to 52% across countries. This contribution is particularly pronounced in economies with significant differences in ARMs but smaller differences in MPCs compared to Spain, such as Portugal and Germany, where more than 40% of the overall differences are due to ARMs. Differences in MPCs explain 57% of the variation on average, with notable impacts in the Netherlands and Ireland, where differences in MPCs are more substantial than differences in ARMs relative to Spain. Finally, interactions between ARMs and MPCs contribute to 24% of the explained differences on average.

These results highlight the importance of accounting for MPC differences when evaluating monetary policy transmission through mortgages. The 19% ARM contribution figure implies that a counterfactual model with only ARM heterogeneity would explain approximately 9% of the empirical differences in transmission across Euro Area economies (that is, 19% of the overall 46% empirical differences captured by the model). By including MPC heterogeneity, thanks both to its direct effect and to its interaction with the ARM share, the model explains an additional 37%, bringing the total explained differences to 46% of the overall empirical differences.

An interesting case that illustrates the importance of accounting for differences in MPCs when assessing transmission through mortgages is the Netherlands (NL in Table 3). Despite having a higher share of ARMs than Spain, the Netherlands has a lower MPC. As a result, a counterfactual economy with Dutch MPC and Spanish ARMs has a smaller consumption response than an economy with both Dutch MPC and Dutch ARMs. This discrepancy, reflected in a negative ARM contribution of -1%, indicates that without adjusting for the lower MPC, transmission in the Dutch economy would be overestimated. However, once the model incorporates the lower Dutch MPC, it more accurately aligns with the empirical data, predicting lower transmission in the Netherlands than in Spain.

Overall, the results presented in this section have two implications. First, accounting for 46% of the empirical differences, the mortgage channel has an important role in explaining transmission heterogeneity across Euro Area countries. Second, in order to obtain a complete estimate of the different effects of monetary policy shocks through the

transmission difference of 0.148, I conduct a series of counterfactual exercises. In each exercise, I modify either ARMs or MPCs in isolation while holding the other constant, and calculate the fraction of the model-implied transmission difference attributable to each factor. The portion of the difference that cannot be explained by changes in ARMs or MPCs alone is then attributed to the interaction between the two.

mortgage channel across Euro Area economies, it is crucial to account for the heterogeneity in MPCs across these countries.

4.2.3 Welfare effects

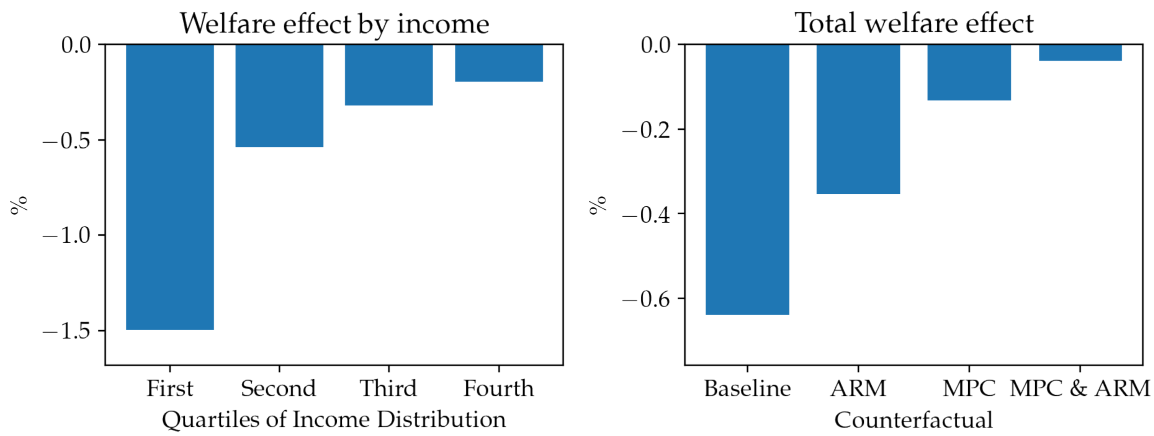
In this section, I use the model to examine the welfare effects of recessionary monetary policy shocks on different income groups and on the overall economy. I measure the welfare impact as the average percentage change in households' utility over a three-year period after the shock, with larger declines indicating greater welfare losses.

The left panel of figure 11 illustrates these effects across different income quartiles in the Spanish economy. Households in the lowest income quartile experience the most significant welfare loss, as their limited savings force them to make larger cuts in consumption in response to rising mortgage payments. As we move up the liquid income distribution, households are characterized by lower MPCs, so that the negative welfare effects are gradually reduced: the increased resources these households have allow them to avoid suffering from large drops in consumption following an increase in interest payments.

The right panel of the figure illustrates the counterfactual welfare effects across several scenarios. The left bar shows the overall welfare drop after the shock in the baseline Spanish economy. The bar labeled *"ARM"* shows the welfare effects in an economy with Spanish MPC, but ARM share that is half the one of Spain. The bar labeled *"MPC"* shows the welfare effects in an economy with Spanish ARM share, but MPC half the one of Spain, and the bar labeled *"MPC & ARM"* shows the welfare effects in an economy with both ARM share and MPC level half those of Spain. Consistent with previous findings, the welfare drop diminishes when fewer households are immediately affected by the increase in mortgage payments (lower ARM share) and when households are less financially constrained (lower MPC), since these conditions imply lower reductions in consumption.

Overall, these results indicate that the reduction in welfare is more severe with higher ARM shares and greater MPC levels in the economy. Moreover, these adverse adverse effects are disproportionately felt by households at the lower end of the income distribution, who experience larger welfare losses compared to higher-income households. Accordingly, an important implication of the model is that policies that alleviate the burden of mortgage payments for lower-income families are particularly effective in mitigating welfare losses following interest rate increases.

Figure 11: Welfare consequences of a contractionary monetary policy shock



Notes: The left panel shows the average welfare drop after a recessionary monetary policy shock for households in different quartiles of the income distribution in the baseline Spanish calibration. The right panel shows the total welfare drop in the baseline Spanish calibration, in a counterfactual calibration with ARM share half that of Spain (*ARM*), in a counterfactual calibration with MPC half that of Spain (*MPC*), and in a counterfactual calibration with ARM share and MPC level half those of Spain (*MPC & ARM*). The welfare effect is computed as the average percentage change in utility that households experience over a 12-quarter period following the shock. The shocks follows an AR(1) process with persistence 0.75 and it is calibrated to lead to an increase in r of 170 basis points on impact. The shock is exactly the one considered in section 4.2.2, with the only exception that it is recessionary instead of expansionary.

A recent example of such a policy has been implemented by the Spanish government. In response to inflationary pressures following the Covid-19 pandemic, the European Central Bank has raised interest rates, significantly increasing monthly mortgage payments for households with ARMs.[39] To alleviate the burden on lower-income households, the Spanish government has introduced a set of reforms aimed at reducing mortgage costs, particularly for vulnerable families. One key measure has been lowering the applicable ARM interest rate from Euribor + 0.25% to Euribor - 0.10% for these households.[40] Given the welfare consequences of contractionary monetary policy shocks discussed in this section, this policy appears well-targeted, as it mitigates the impact of higher rates on the most adversely affected households.

[39]See International Monetary Fund (2024) for an evaluation of the changes in mortgage service costs across Euro Area economies after the post-pandemic monetary policy hike.

[40]A detailed explanation of the complete set of Spanish policy measures can be found here.

5 Conclusion

This paper shows that the role of ARMs in monetary policy transmission is strongly influenced by the fraction of liquidity-constrained households in the economy. Through a set of empirical exercises, I document a key empirical fact: monetary policy transmission is stronger in Euro Area countries where high shares of ARMs are matched with high shares of HtM households. To account for this finding, I build a heterogeneous-agent model with housing and mortgage choices that flexibly accommodates different ARM shares. The model illustrates how ARMs and MPCs interact in monetary transmission: while higher ARM shares imply that more households experience changes in mortgage payments following a monetary shock, it is the MPC that determines the sensitivity of consumption to these changes. Accordingly, ARMs effectively enhance monetary transmission only in economies characterized by high MPCs. Using counterfactual exercises, I show that 46% of the empirical differences in transmission across Euro Area economies can be attributed to differences in transmission through ARMs, with MPC heterogeneity accounting for approximately half of this effect.

These findings carry important policy implications. First, the distribution of ARMs across the population is a key variable to monitor for predicting the strength of monetary policy transmission. In economies with high ARM uptake, transmission is particularly potent when ARMs are concentrated among low-income, high-MPC households. Second, while a larger share of constrained households enhances transmission, it also exacerbates the negative welfare effects these households experience after contractionary monetary shocks. Therefore, it is essential to consider policy measures to mitigate these welfare losses, especially in the context of sizable and prolonged contractionary monetary policy interventions.

Finally, expanding the analysis in this paper along two key dimensions would be particularly valuable. First, the Euro Area literature has highlighted the importance of home-ownership rates in shaping monetary policy transmission, making it particularly interesting to incorporate this dimension of heterogeneity. Second, the current model operates within a partial equilibrium framework; extending it to a general equilibrium model would allow for a deeper exploration of whether the partial equilibrium effects hold when incorporating a more comprehensive supply side. These extensions will be the focus of my future research.

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A Data sources

The following are the sources of the data used in the analyses.

Gross Domestic Product: *Gross Domestic Product at Market Prices*, chain linked volumes, seasonally and calendar adjusted, quarterly frequency. Source: Eurostat, table NAMQ 10 GDP.

Consumption: *Final Consumption Expenditure of Households and NPISH at Market Prices*, chain linked volumes, seasonally and calendar adjusted, quarterly frequency. Source: Eurostat, table NAMQ 10 GDP.

Consumer Price Index: *All-items HICP*, monthly frequency averaged to convert into quarterly frequency. Source: Eurostat, table PRC HICP MIDX.

Short-term interest rate: *Euro Area day-to-day rate*, quarterly frequency. Source: Eurostat, table IRT ST Q.

Share of ARM households: Entry DL1110 ("Outstanding balance of HMR mortgage") filtered using entry DL1110ai ("Has adjustable interest rate HMR mortgage"). Source: ECB Household Finance and Consumption Survey (HFCS), waves one, two and three.

Share of hand-to-mouth households: This variable is constructed following the procedure detailed in Almgren et al. (2022) (see appendix B.2 for more details). Source: ECB Household Finance and Consumption Survey (HFCS), waves one, two and three.

Outstanding amount of ARMs - Italy: *Consistenze di prestiti per l'acquisto di abitazioni famiglie consumatrici a tasso variabile*, quarterly frequency. Source: Bank of Italy.

Share of hand-to-mouth households - Italy, time series: Provided by the ECB on the basis of the series constructed for the analysis in Slacalek, Tristani and Violante (2020), quarterly frequency.

Mortgage interest rate - Italy: *Cost of borrowing for households for house purchase*, monthly frequency averaged to convert into quarterly frequency. Source: ECB SDW, MIR dataset.

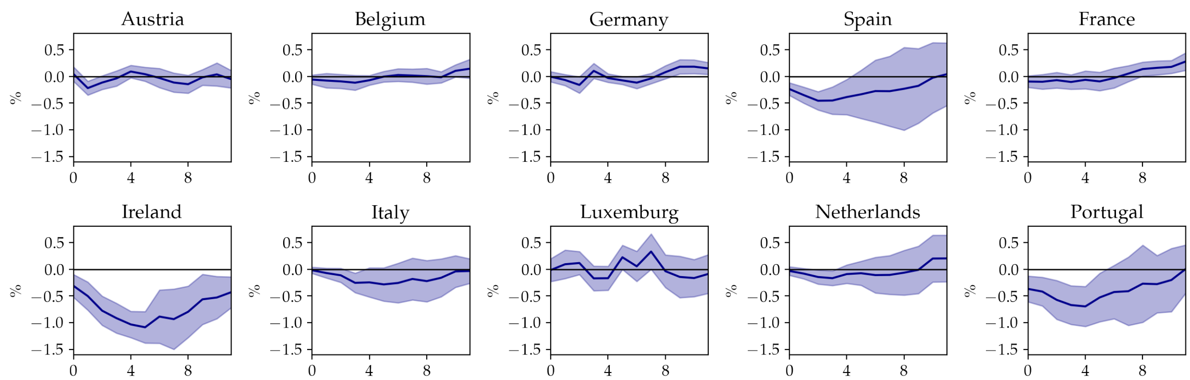
Monetary policy shocks: Monetary policy shocks by Jarociński and Karadi (2020), series updated until October 2022, monthly frequency summed up to convert into quarterly frequency. Source: Marek Jarocinski's website: https://marekjarocinski.github.io.

B Empirics – Additional figures

B.1 Euro Area impulse response functions

Figure B.1 shows the IRFs for each Euro Area country in the sample estimated using equation (1).

Figure B.1: IRFs of consumption to a contractionary monetary policy shock



Notes: Responses to a one standard deviation recessionary monetary policy shock. The shaded blue areas are 90% confidence intervals.

B.2 Methodology to construct HtM shares

I construct the share of HtM households in each Euro Area economy using data from the HFCS and applying the methodology by Kaplan and Violante (2014), adjusted for the analysis using Euro Area data by Almgren et al. (2022). In particular, letting y_i denote monthly income, m_i denote liquid wealth, and $\underline{m_i}$ denote a credit limit for household i in the HFCS, a household is categorized as being HtM if:

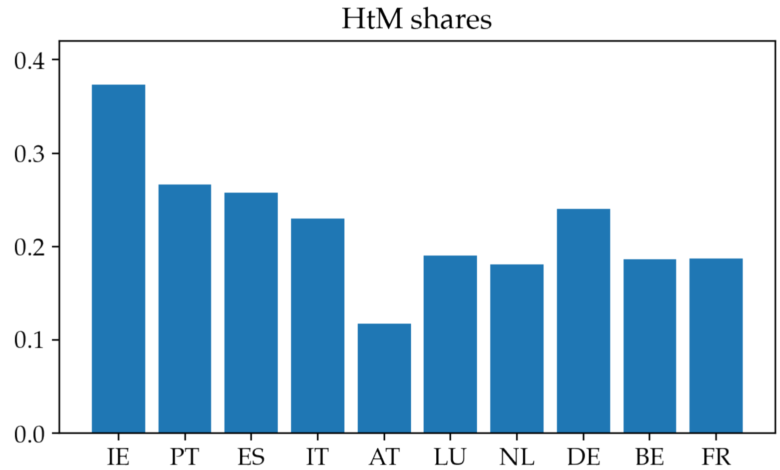
$$0 \leq m_i \leq \frac{y_i}{2}$$

or:

$$m_y \leq 0 \quad \text{and} \quad m_i \leq \frac{y_i}{2} - \underline{m_i}.$$

The first condition highlights that if households have positive liquid wealth, they are classified as HtM if this wealth is less than half their monthly income. The second condition states that if households have negative liquid wealth, then they are classified as HtM if this wealth is less than half of their monthly income minus their credit limit, which is set equal to the household's monthly income. The idea behind this last condition is that household can use a credit card that needs repayment once a month. In line with the analysis in Almgren et al. (2022), very few households are classified as HtM based on this second condition. Figure B.2 shows the fraction of HtM households in each Euro Area economy considered in the analysis.

Figure B.2: Shares of HtM households in Euro Area countries



Notes: See text for the methodology used to construct these shares. Countries are ranked by the strength of monetary policy transmission, from Ireland (strongest) to France (weakest), in line with the estimates from equation (1) shown in figure 1.

Classification of assets in ECB HFCS I follow Almgren et al. (2022) to categorize variables in the ECB HFCS. In particular, *liquid wealth* is computed as *liquid assets* minus *liquid debt*. The variables included in *liquid assets* are:

1. **hd1110**: value of sight accounts (scaled by 1.0556 to adjust for cash missing in the HFCS)
2. **da2102**: mutual funds, total
3. **da2103**: bonds
4. **da2105**: shares, publicly traded
5. **hd1210**: value of saving accounts

The variables included in *liquid debt* are:

1. **hc0220**: amount if outstanding credit line/overdraft balance
2. **hc0320**: amount of outstanding credit cards balances.

B.3 Alternative correlations

Tables B.1 and B.2 show the correlation coefficients and p-values under alternative specifications relative to the one considered in section 2.1. Each column shows the metric used to proxy the potency of monetary policy transmission: maximum response of consumption over a two year period (*Max 2Y*), maximum response of consumption over a three year period (*Max 3Y*), average response of consumption over a two year period (*Mean 2Y*), and average response of consumption over a three year period (*Mean 3Y*). Each row shows the specification considered. *Baseline* refers to the baseline specification in section 2.1. *Before 2012* cuts the sample for the estimation of regression (1) to the period before 2012, the one considered in Almgren et al. (2022). *After 2007* starts the sample in 2007, following Corsetti, Duarte and Mann (2022) and Pica (2023). *3 Lags* shows the alternative correlations in a specification of regression (1) where the controls have 3 lags instead of 2. *Other shock* shows the correlations where the shock in equation (1) is the one constructed in Altavilla et al. (2019) (2-year OIS change). Relative to section 2, table B.1 reports the correlations with the share of HtM households exclusively, which confirm the results in Almgren et al. (2022): the strength of monetary policy is positively correlated with the fraction of HtM agents in the Euro Area.

Table B.1: Correlations with HtM and ARM in alternative specifications

	HtM				ARM			
	Max 2Y	Max 3Y	Mean 2Y	Mean 3Y	Max 2Y	Max 3Y	Mean 2Y	Mean 3Y
Baseline	-0.865	-0.865	-0.879	-0.869	-0.589	-0.589	-0.538	-0.593
	(0.001)	(0.001)	(0.001)	(0.001)	(0.073)	(0.073)	(0.108)	(0.071)
Before 2012	-0.667	-0.680	-0.708	-0.723	-0.634	-0.689	-0.472	-0.555
	(0.035)	(0.030)	(0.022)	(0.018)	(0.049)	(0.027)	(0.168)	(0.095)
After 2007	-0.577	-0.697	-0.842	-0.830	-0.479	-0.525	-0.296	-0.308
	(0.080)	(0.025)	(0.002)	(0.003)	(0.160)	(0.119)	(0.406)	(0.387)
3 Lags	-0.798	-0.796	-0.816	-0.732	-0.706	-0.727	-0.669	-0.755
	(0.006)	(0.006)	(0.004)	(0.016)	(0.023)	(0.017)	(0.034)	(0.012)
Other shock	-0.806	-0.810	-0.774	-0.768	-0.625	-0.619	-0.614	-0.671
	(0.005)	(0.005)	(0.009)	(0.009)	(0.053)	(0.056)	(0.059)	(0.034)

Notes: Each line shows the correlation coefficient and p-value (in parenthesis) of the response of consumption to a one-standard deviation recessionary shock.

Table B.2: Correlations with HtM & ARM households in alternative specifications

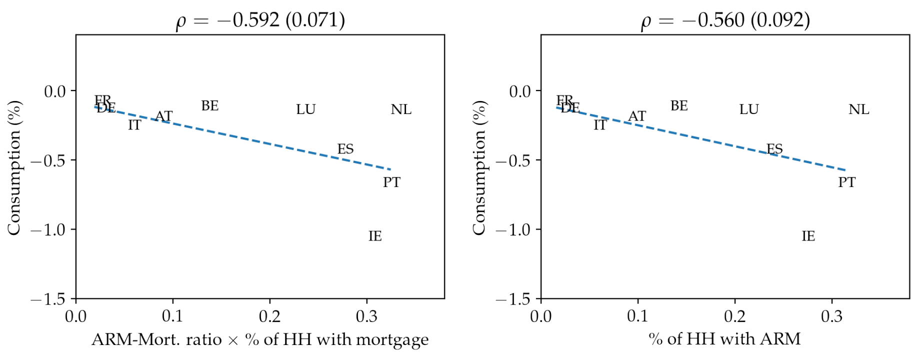
	HtM & ARM			
	Max 2Y	Max 3Y	Mean 2Y	Mean 3Y
Baseline	-0.888	-0.919	-0.909	-0.920
	(0.000)	(0.000)	(0.000)	(0.000)
Before 2012	-0.691	-0.721	-0.730	-0.767
	(0.026)	(0.018)	(0.016)	(0.001)
After 2007	-0.793	-0.874	-0.861	-0.835
	(0.006)	(0.001)	(0.001)	(0.003)
3 Lags	-0.918	-0.910	-0.915	-0.893
	(0.000)	(0.000)	(0.000)	(0.001)
Other shock	-0.885	-0.889	-0.865	-0.892
	(0.000)	(0.000)	(0.001)	(0.000)

Notes: Each line shows the correlation coefficient and p-value (in parenthesis) of the response of consumption to a one-standard deviation recessionary shock.

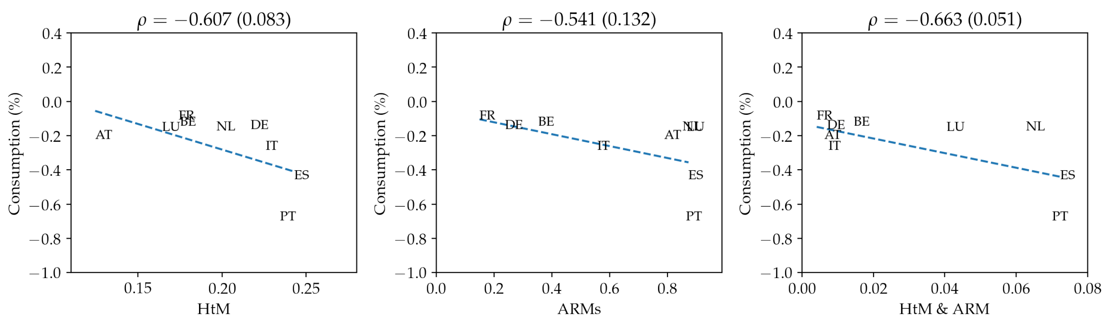
The top two panels in figure B.3 shows the alternative correlations that would arise considering different ARM shares. The left panel shows the correlation with the product between the share of outstanding ARMs and the fraction of households that have a mortgage in each country in the HFCS. The idea is that this variable is high not only when most mortgages have an ARM, but also when mortgages are widespread in the economy. The right panel shows the correlation with the fraction of households in the population that have an ARM instead of the share of ARMs within the total mortgage stock. The figure shows that the results from section 2.1 are robust to these alternative measures of the ARM share.

The middle and bottom panels of figure B.3 show the alternative correlations of the two variables of interest computed in different waves of the HFCS, which are consistent with the main ones in section 2.1.

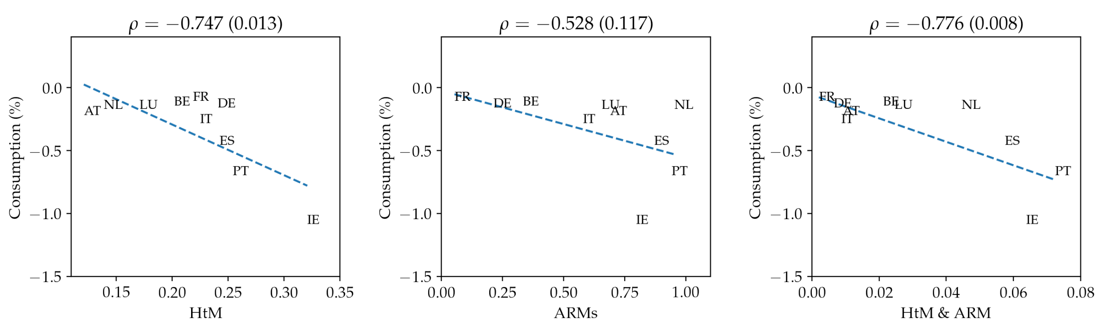
Figure B.3: Alternative correlations between the potency of transmission and HtM and ARM shares



(a) Alternative ARM shares



(b) Wave 1



(c) Wave 3

Notes: The y-axes show the peak response of consumption to a one standard deviation recessionary monetary policy shock estimated using equation (1). On top of each chart I show ρ, the correlation coefficient, together with its p-value in parenthesis.

B.4 Panel local projections – Effect of higher share of HtM households with ARMs

This section provides alternative evidence on the relevance of HtM households with ARMs for the strength of monetary policy transmission in the Euro Area, mirroring the empirical evidence provided in the scatterplots of section 2.1. While the results presented in section 2.2 distinctively capture the effects of a high share of ARMs, ARM, and of a high share of HtM households, HtM, I here estimate the additional effect of a monetary policy shock in economies that have a high share of HtM households with ARMs.

In particular, I estimate the following fixed-effects regression using panel local projections (Jordà; 2005):

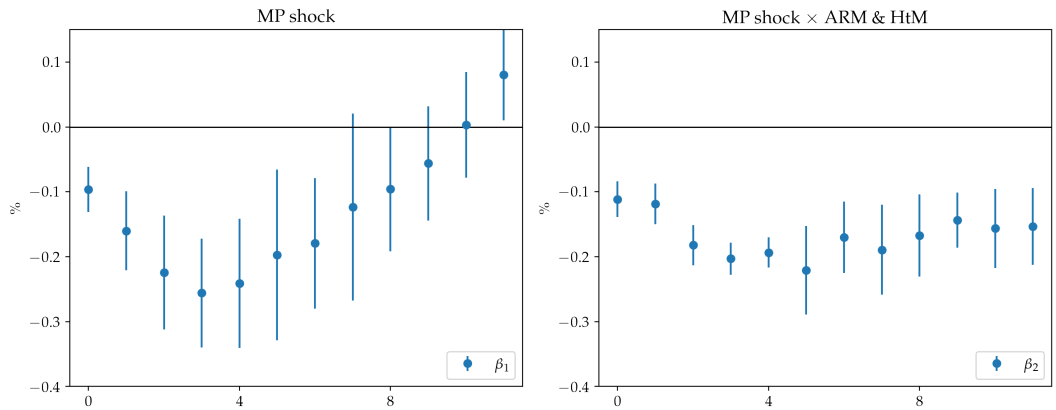
$$y^c_{t+h} = \beta^h_0 + \beta^h_1 \epsilon^{MP}_t + \beta^h_2 \epsilon^{MP}_t ARMxHtM^c + \Gamma^h X^c + u^c_{t+h}, \qquad h = 0, 1, 2, \ldots \tag{18}$$

where y^c is the logarithm of consumption in country c, ϵ^{MP} is the monetary policy shock by Jarociński and Karadi (2020), X is the same set of contemporaneous and lagged control variables in specification (2), and $ARMxHtM^c$ is the fraction of HtM households that have ARMs in country c.[41] The coefficient of interest in this analysis is β_2, which captures the additional effect of a monetary policy shock in economies that have a share of households that are both HtM and have ARMs one standard deviation higher than the Euro Area average.

The results from this analysis are presented in figure B.4. The left-hand-side panel shows the evolution of coefficient β_1: a recessionary monetary policy shock is associated with a statistically significant reduction in consumption in economies with shares of HtM households that have ARMs that are at the Euro Area average. The right-hand-side panel shows the evolution of coefficient β_2. The coefficient is always negative and statistically significant, suggesting that the strength of monetary policy transmission is greater in Euro Area economies that have a share of households that are both HtM and have ARMs that is one standard deviation higher than the Euro Area average. This result is in line with the evidence presented in section 2.1, which detected a strong correlation between the strength of monetary policy transmission and the fraction of households that are HtM and have ARMs.

[41] The variable $ARMxHtM$ is standardized.

Figure B.4: Response of consumption to a monetary policy shock, results from equation (18)

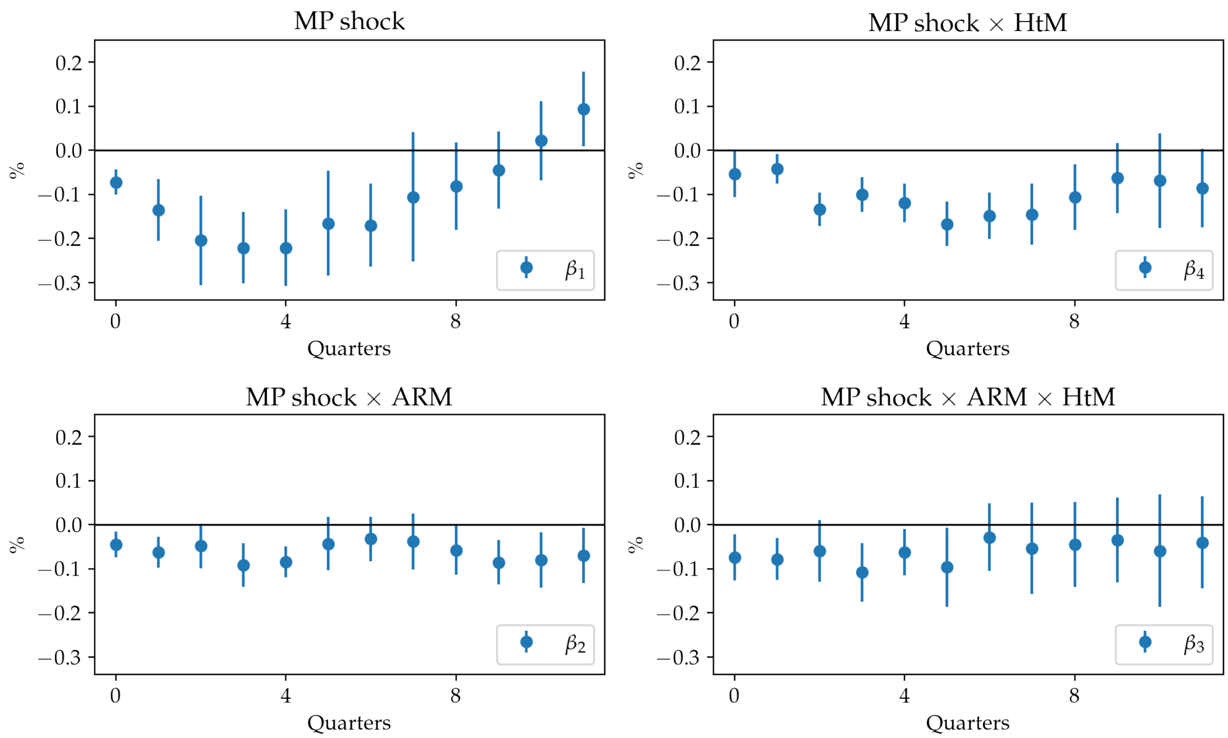


Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

B.5 Panel local projections – Robustness

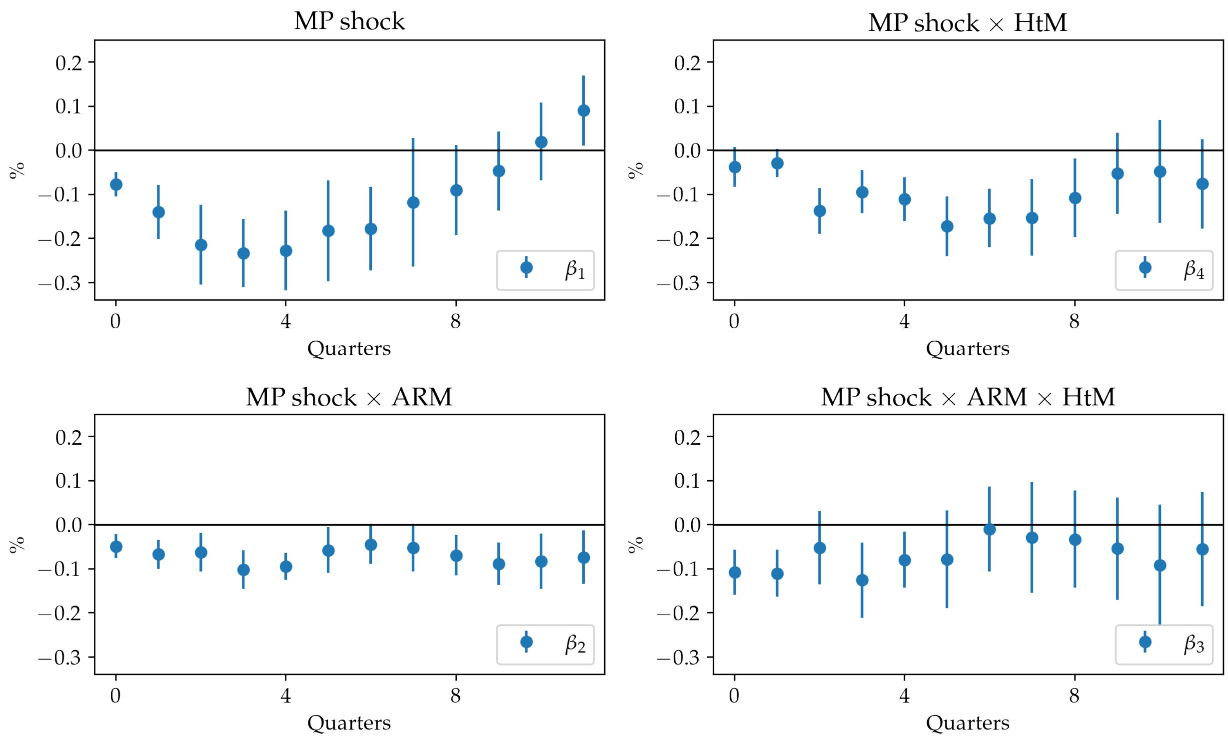
The results presented in section 2.2 use data from the second wave of the HFCS. I here consider alternative specifications using data from the other two waves of the survey. Figure B.5 reproduces the main coefficients estimated using equation (2) for reference. As a first robustness exercise, figure B.6 shows the IRFs of the coefficients of interest estimated using the specification in equation (2), where ARM and HtM are the average HtM and ARM shares across the three ECB HFCS survey waves. As a second robustness exercise, I interpolate the HtM and ARM shares values between the three survey waves, and re-estimate the coefficients of interest using equation (2). The results are displayed in figure B.7. As a third robustness exercise, I once again use the interpolated values of the HtM and ARM shares across survey waves, but I start the sample in 2010, when the first survey was conducted. The results of this exercise are shown in figure B.8. Additionally, figures B.9 and B.10 show robustness exercises where the the variable ARM in specification (2) is replaced (i) with the product between ARM and the share of households with a mortgage, and (ii) with the fraction of households with an ARM in the population of each country. Overall, the results are line with the ones presented in section 2.2 across the different robustness exercises.

Figure B.5: Response of consumption to a monetary policy shock, baseline results from equation (2)



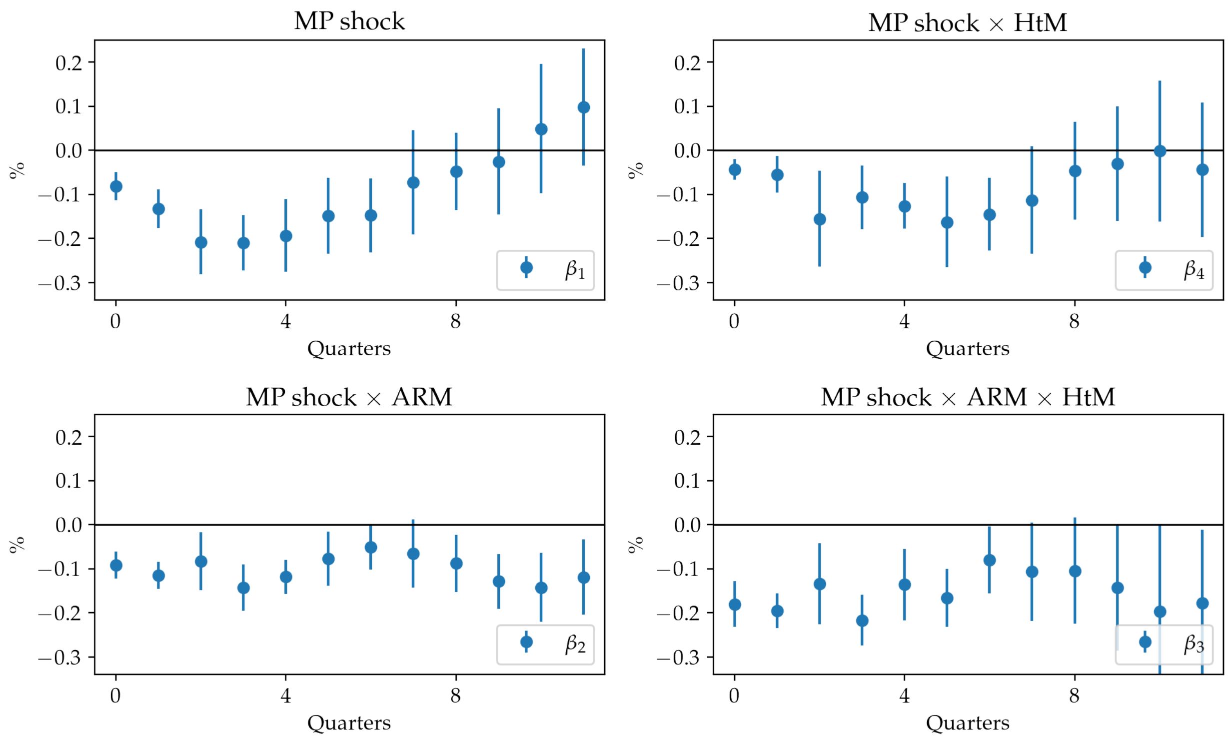
Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

Figure B.6: Response of consumption to a monetary policy shock, average HtM and ARM values across HFCS waves



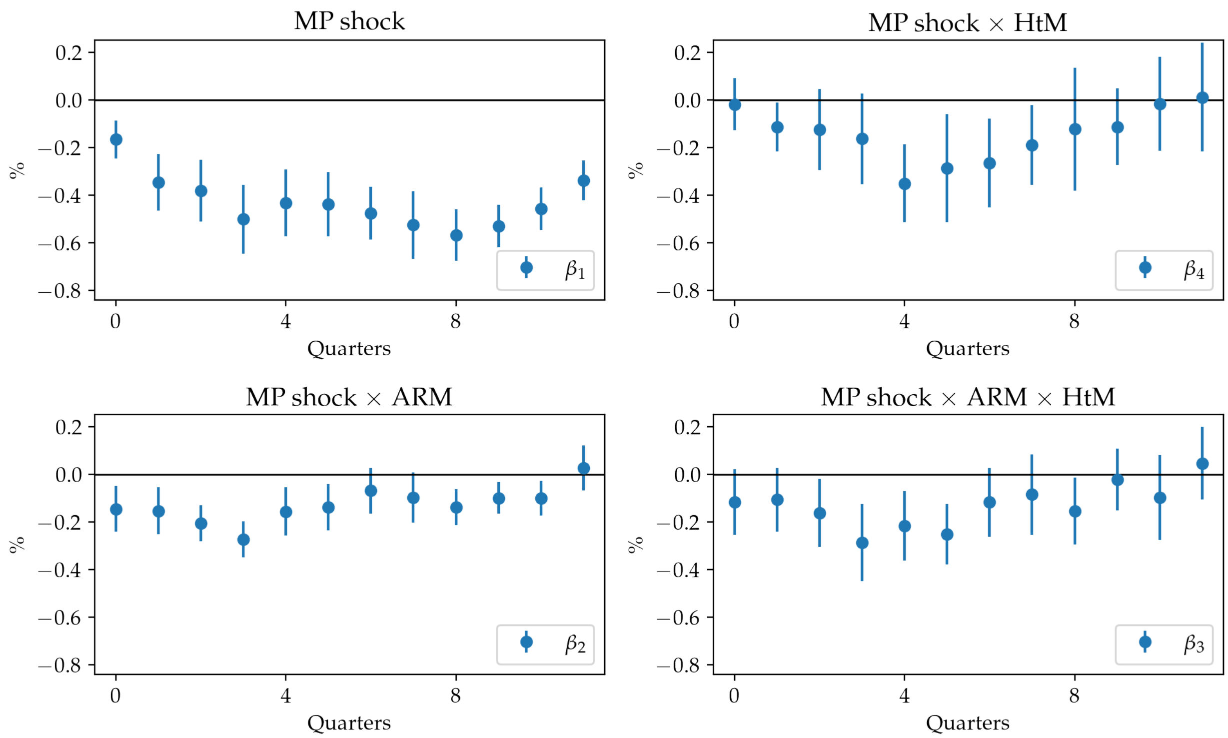
Notes: Responses to a one standard deviation recessionary monetary policy shock. The shared blue areas represent 90% confidence intervals.

Figure B.7: Response of consumption to a monetary policy shock, interpolated HtM and ARM values across HFCS waves



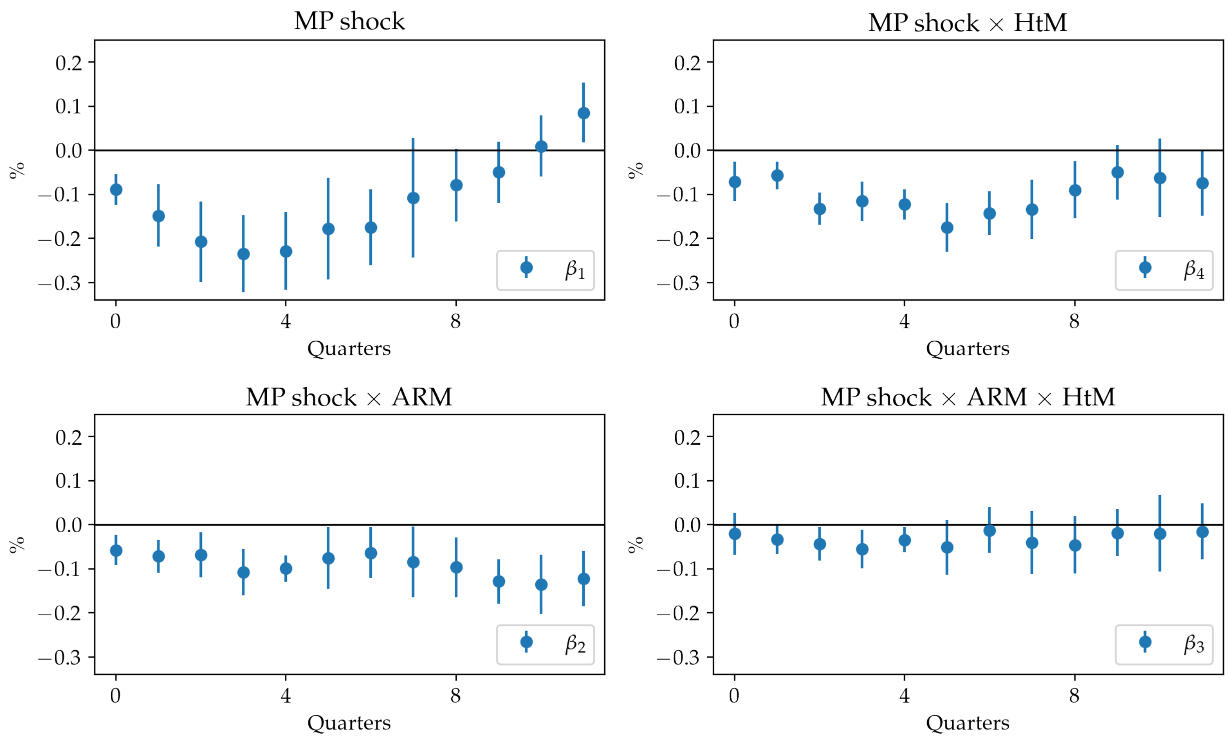
Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

Figure B.8: Response of consumption to a monetary policy shock, interpolated HtM and ARM values across HFCS waves and sample beginning in 2010



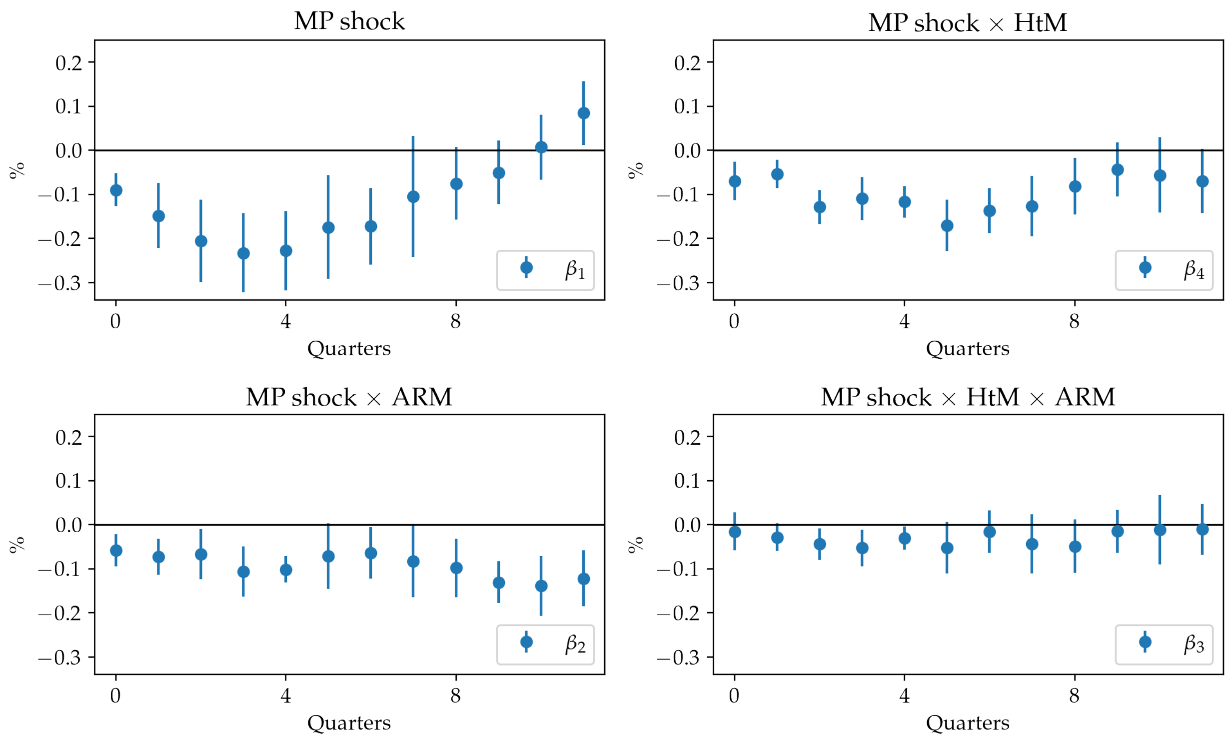
Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

Figure B.9: Response of consumption to a monetary policy shock, using *ARM* × *Share of mortgagors*



Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

Figure B.10: Response of consumption to a monetary policy shock, using *Share of HH with ARM*



Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

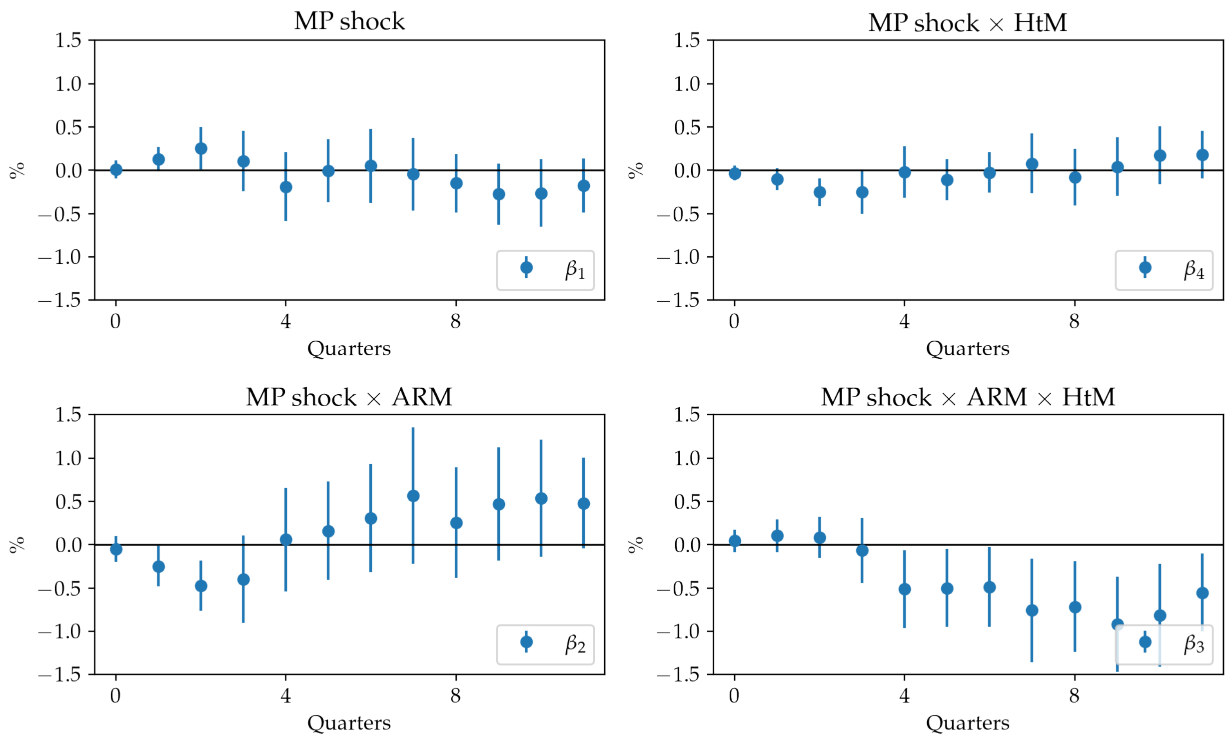
B.6 Italian local projections – Robustness

One main concern with the empirical exercise in section (2.3) is that the coefficients estimated could be many relative to the observations available. In order to overcome this concern, the model in equation (3) contains a restricted number of control variables. This appendix provides a series of robustness exercises changing the variables included in the control vector X. The main message from this section is that the main coefficient of interest, β_3, the one capturing the effect of the interaction between ARM and HtM, remains negative and statistically significant throughout the different specifications.

Figure B.11 shows the responses of regression (3) for comparison. Figure B.12 shows the responses where the set of controls X includes only the left-hand-side variable, consumption, and the average Italian mortgage rate. Figure B.13 shows the responses where only the left-hand-side variable and Euro Area variables are included in X, namely: Euro Area GDP, cpi and short-term interest rate. Finally, figure B.14 shows the responses where X includes a large number of variables (more similar to the specification of the panel model in equation (2)): the left-hand-side variable, Italian cpi and average mortgage rate, as well as Euro Area GDP, cpi and short-term interest rate. Throughout the specifications, the coefficient of interest β_3 remains negative and statistically significant.

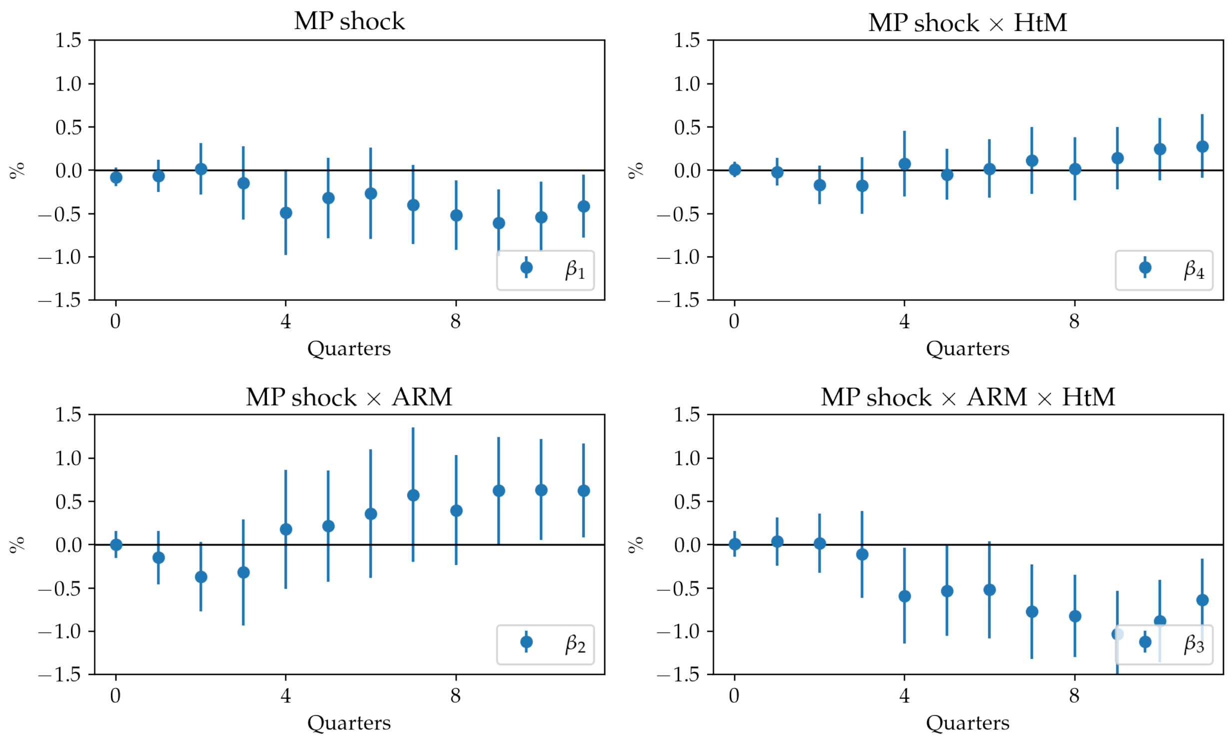
In addition, figure B.15 shows the evolution of the sum of coefficients β_2 and β_3 from the baseline specification (3).

Figure B.11: Response of consumption to a monetary policy shock, baseline results from equation (3)



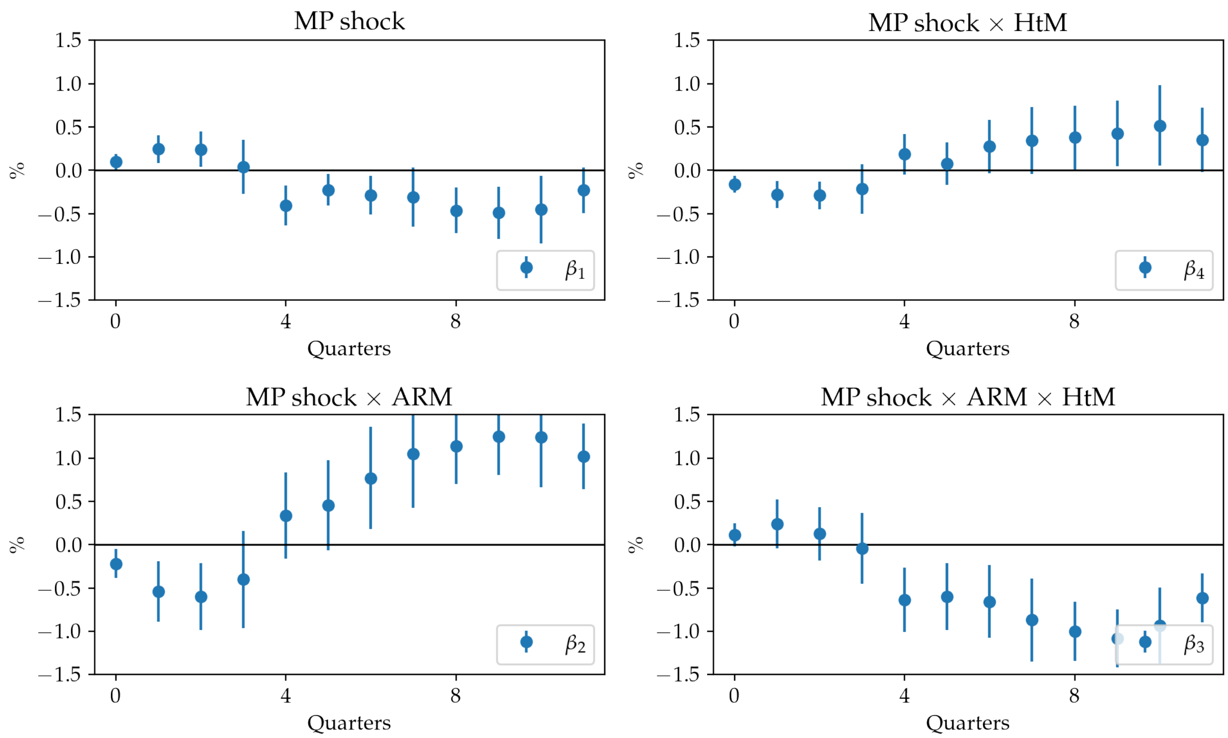
Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

Figure B.12: Response of consumption to a monetary policy shock, only consumption and Italian mortgage rate as controls



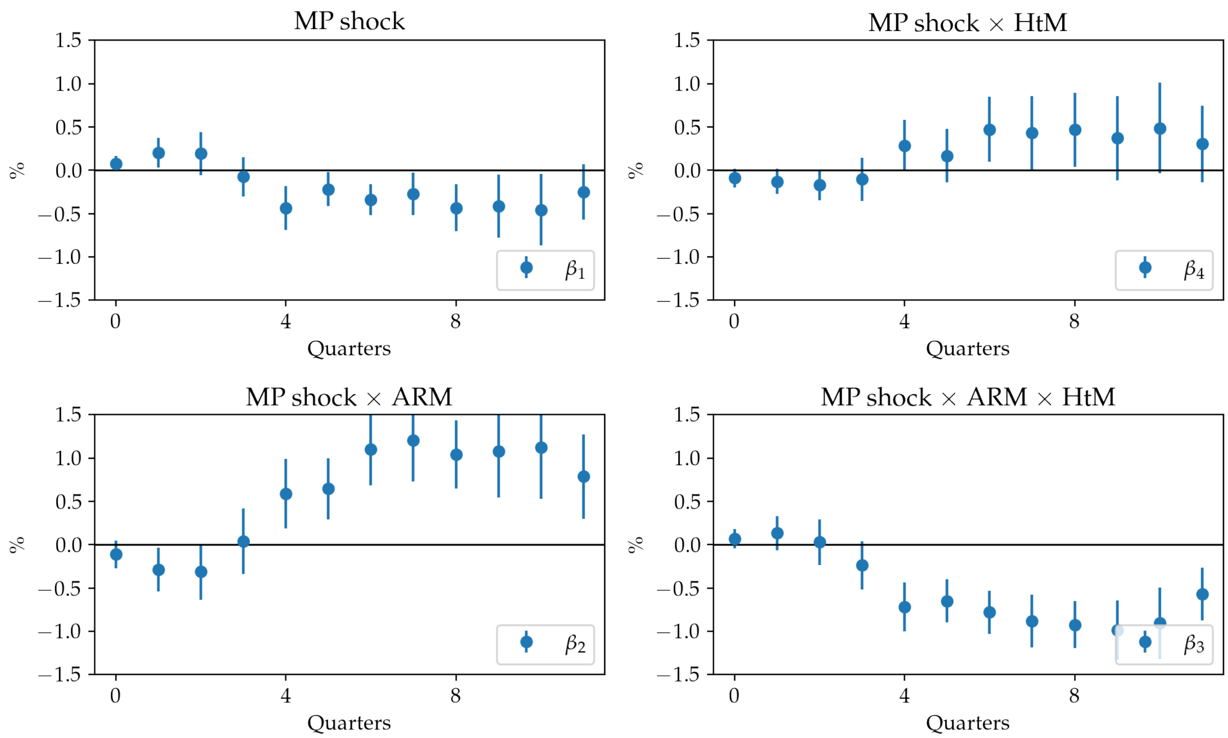
Notes: Responses to a one standard deviation recessionary monetary policy shock. The shaded blue areas represent 90% confidence intervals.

Figure B.13: Response of consumption to a monetary policy shock, only Euro Area controls



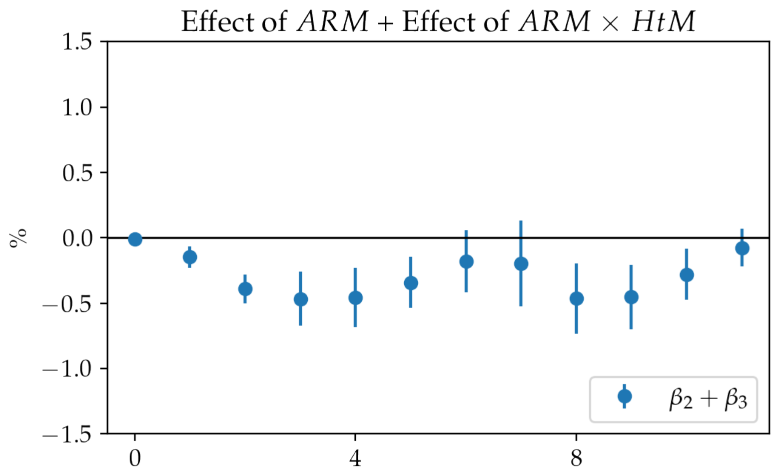
Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

Figure B.14: Response of consumption to a monetary policy shock, both Euro Area and Italian controls



Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

Figure B.15: Response of consumption to a monetary policy shock, baseline results from equation (3), sum of coefficients β_2 and β_3



Notes: Responses to a one standard deviation recessionary monetary policy shock. The vertical blue lines represent 90% confidence intervals.

C Model - Derivations and additional material

C.1 Algorithm to solve the household problem

This appendix describes the algorithm used to solve the household block of the model. Let s be the vector of household states $\{y, h, b, a\}$. The value functions associated with adjustment (*buyers* in section 3) and non-adjustment (*stayers* in the section 3) are denoted by $V^a(s)$ and $V^n(s)$, respectively.

The non-adjuster's consumption and savings decisions are characterized by the following value function:

$$V^n(s) = \max_{c,a'} u(c, h') + \beta \mathbb{E}\left[V(s')|y\right] \tag{19}$$

$$\begin{aligned} \text{s.t. } c + a' &\leq y + (1+r)a - (r^b + \mu)b \\ h' &= (1-\delta)h \\ b' &= (1-\mu)b \\ a' &\geq 0 \end{aligned}$$

Similarly, the adjuster's decisions are characterized by:

$$V^a(s) = \max_{c,h',b',a'} u(c, h') + \beta \mathbb{E}\left[V(s')|y\right] \tag{20}$$

$$\begin{aligned} \text{s.t. } c + a' + ph' - b' &\leq y + (1+r)a + p(1-f)(1-\delta)d - (1+r^b)b \\ b' &\in [0, \lambda p h'] \\ a' &\geq 0 \end{aligned}$$

Note that, for notation convenience, I am disregarding the term τ, so that y in value functions (19) and (20) should be interpreted as post-tax income.

General set-up Before getting to the main algorithm, the above problem needs to be re-written to have households choosing a loan-to-value ratio, rather than the size of the loan directly. Without this modification, each household would need to have a grid for mortgages depend on the size of their durable choice. Now, let $\tilde{b} = \frac{b}{ph}$. The re-written value functions are then:

$$V^n(y,h,\tilde{b},a) = \max_{c,a'} u(c,h') + \beta\mathbb{E}\left[V(y',h',\tilde{b}',a')|y\right] \tag{21}$$
$$\text{s.t. } c + a' = y + (1+r)a - (r^b+\mu)\tilde{b}p^- h$$
$$a' \geq 0$$
$$\tilde{b}' = \frac{(1-\mu)}{(1-\delta)}\frac{p^-}{p}\tilde{b}$$
$$h' = (1-\delta)h$$

and

$$V^a(y,h,\tilde{b},a) = \max_{\{c,h',\tilde{b}',a'\}} u(c,h') + \beta\mathbb{E}\left[V(y',h',\tilde{b}',a')|y\right] \tag{22}$$
$$\text{s.t. } c + a' + (1-\tilde{b}')ph' = y + (1+r)a + (1-f)(1-\delta)ph - (1+r^b)\tilde{b}p^- h$$
$$a' \geq 0$$
$$\tilde{b}' \in [0,\lambda].$$

First-order and envelope conditions For the non-adjustment problem, the first order condition with respect to a' is

$$[a']\colon u_c(c,h') \geq \beta\mathbb{E}\left[V_a(y',h',b',a')|y\right], \tag{23}$$

and the envelope conditions are

$$V^n_a(y,h,\tilde{b},a) = (1+r)u_c\left(c,h'\right), \tag{24}$$
$$V^n_h(y,h,\tilde{b},a) = (1-\delta)\Big(u_h(c,h') + \beta\mathbb{E}\left[V_h(y',h',\tilde{b}',a')|y\right]\Big)$$
$$- (r_b+\mu)\tilde{b}p^-)u_c(c,h',n), \tag{25}$$
$$V^n_{\tilde{b}}(y,h,\tilde{b},a) = \frac{(1-\mu)}{(1-\delta)}\frac{p^-}{p}\beta\mathbb{E}\left[V_b(y',h',\tilde{b}',a')|y\right] + (r^b+\mu)u_c(c,h',n)p^-h. \tag{26}$$

For the adjustment problem, the first order conditions for a', h', and b' are

$$[a']\colon u_c(c,h') \geq \beta\mathbb{E}\left[V_a(y',h',\tilde{b}',a')|y\right], \tag{27}$$
$$[h']\colon u_d(c,h') + \beta\mathbb{E}\left[V_d(y',h',\tilde{b}',a')|y\right] = p(1-\tilde{b})u_c(c,h'), \tag{28}$$
$$[\tilde{b}']\colon \begin{cases} ph'u_c(c,h') + \beta\mathbb{E}\left[V_{\tilde{b}}(y',h',\tilde{b}',a')|y\right] = 0 & \text{if } \tilde{b}' \in (0,\lambda) \\ ph'u_c(c,h') + \beta\mathbb{E}\left[V_{\tilde{b}}(y',h',\tilde{b}',a')|y\right] > 0 & \text{if } \tilde{b}' = \lambda \\ ph'u_c(c,h') + \beta\mathbb{E}\left[V_{\tilde{b}}(y',h',\tilde{b}',a')|y\right] < 0 & \text{if } \tilde{b}' = 0 \end{cases}, \tag{29}$$

and the envelope conditions are

$$V_a^a(y,h,\tilde{b},a) = (1+r)u_c(c,h') \tag{30}$$

$$V_h^a(y,h,\tilde{b},a) = \Big((1-f)(1-\delta)p - (1+r^b)\tilde{b}p^-\Big)u_c(c,h') \tag{31}$$

$$V_{\tilde{b}}^a(y,h,\tilde{b},a) = -(1+r^b)p^- h u_c(c,h'). \tag{32}$$

For the algorithm, I further rewrite the adjustment problem. Since the adjustment problem re-optimizes a', $\tilde{b}'$ and h', the household does not need to know the individual values for a, $\tilde{b}$ and h, but rather the total resources they contribute to their budget. To save time in the computation, I drop dependence on these states, and instead write the value function in terms of assets-on-hand defined as

$$z = (1+r)a + (1-f)(1-\delta)ph - (1+r^b)\tilde{b}p^- h. \tag{33}$$

Note that it is relatively easy to move from the solution in terms of the state variables y and z, and the solution in terms of the original state variables h, $\tilde{b}$, and a. For each combination $\{h, \tilde{b}, a\}$ there is a corresponding z, for which the solution is known.

For the algorithm, it is also convenient to re-express the adjustment problem as three staged problems

$$V^a(y,z) = \max_{h'} \underbrace{\left\{ \max_{\tilde{b}' \in [0,\lambda]} \underbrace{\left\{ \max_{a' \geq 0, c} u(y+z-p(1-b')h'-a',h') + \beta \mathbb{E}\left[V(y',h',b',a')|y\right] \right\}}_{V^{a,(1)}(y,z,h',b')} \right\}}_{V^{a,(2)}(y,z,h')} \tag{34}$$

The innermost problem will solve for c and a', taking decisions for h' and $\tilde{b}'$ as given. This can be written as:

$$V^{a,(1)}(y,z,h',\tilde{b}') = \max_{c,a'} u(c,h') + \beta \mathbb{E}\left[V(y',h',\tilde{b}',a')|y\right] \tag{35}$$

$$\text{s.t. } c + a' = y + z - p(1-\tilde{b}')h'$$

$$a' \geq 0.$$

This has first order condition for a'

$$[a']\colon u_c(c,h') \geq \beta \mathbb{E}\left[V_a(y',h',\tilde{b}',a')|y\right], \tag{36}$$

and envelope conditions

$$V^{a,(1)}_{h}(y,z,h',\tilde{b}') = u_h(c,h') + \beta\mathbb{E}\left[V_h(y',h',\tilde{b}',a')|y\right] - p(1-\tilde{b})u_c(c,h') \tag{37}$$
$$V^{a,(1)}_{\tilde{b}'}(y,z,h',\tilde{b}') = ph'u_c(c,h') + \beta\mathbb{E}\left[V_{\tilde{b}}(y',h',\tilde{b}',a')|y\right] \tag{38}$$

Given the solution for the inner problem, the middle problem will solve for $\tilde{b}'$ taking the decision for h' as given:

$$V^{a,(2)}(y,z,h') = \max_{\tilde{b}'} V^{a,(1)} \tag{39}$$
$$\text{s.t. } \tilde{b}' \in [0,\lambda].$$

Given the solution for the middle problem, the outer problem will take a decision for h':

$$V^{a}(y,z) = \max_{h'} V^{a,(2)} \tag{40}$$

Note that the first order conditions of the three stages collapse to the first order conditions written above. For convenience, I define the post-decision value function as $W(s) = \beta\mathbb{E}\left[V(s')|y\right]$.

Algorithm. I start with a guess for the value function and its partial derivatives, defined over a discretized grid. I then iterate backward until convergence. Π denotes the transition matrix of the exogenous income state, y.

0. **Preamble**. Create grids for a, $\tilde{b}$, h, and z, and discretize exogenous income process using the Rouwenhorst method.

1. **Initial guess**. Create guess for V, V_h, $V_{\tilde{b}}$, and V_a.

2. **Common** $\underline{y' \to y}$. By definition

$$W(y,h',\tilde{b}',a') = \beta\Pi V(y',h',\tilde{b}',a') \tag{41}$$
$$W_a(y,h',\tilde{b}',a') = \beta\Pi V_a(y',h',\tilde{b}',a') \tag{42}$$
$$W_h(y,h',\tilde{b}',a') = \beta\Pi V_h(y',h',\tilde{b}',a') \tag{43}$$
$$W_{\tilde{b}}(y,h',\tilde{b}',a') = \beta\Pi V_{\tilde{b}}(y',h',\tilde{b}',a') \tag{44}$$

3. **Non-adjustment problem**. Solve the non-adjustment problem, given guesses for V, V_h, $V_{\tilde{b}}$, and V_a. Note that I suppress the n superscript on all policy functions in this section for notation convenience. Thus, the $a'(y,h,\tilde{b},a)$ that I find below is the a' choice *conditional* on the choice of not adjusting.

(i) **Unconstrained** $\underline{a' \to a}$. Assume that the constraint on assets does not bind. Then (23) can be re-written to define c as

$$c(y, h', \tilde{b}', a') = u_c^{-1}\Big(W_a(y, h', \tilde{b}', a'), h'\Big). \tag{45}$$

Note that because the guess W_a is defined in terms of h' and $\tilde{b}'$, this problem will initially be defined in terms of these rather than h and $\tilde{b}$, which are the state variables of the problem. There is a one to one mapping between the two. Using the budget constraint, we get $a^{endo}(y, h', \tilde{b}', a')$, which is the a that implies the household chooses $\{c(y, h', \tilde{b}', a'), a'\}$. This is:

$$a^{endo}(y, h', \tilde{b}', a') = \frac{1}{1+r}\Big(c(y, h', \tilde{b}', a') + a' + \frac{p(\mu + r^b)}{1-\mu}\tilde{b}'h' - y\Big). \tag{46}$$

(ii) **Upper Envelope**. Let `agrid` denote the pre-computed grid for the discretized values of a. Normally, $a'(y, h', \tilde{b}', a)$ can be found via interpolation, putting $\big(a^{endo}(y, h', \tilde{b}', a'), \texttt{agrid}\big) \to \big(\texttt{agrid}, a'(y, h', \tilde{b}', a)\big)$.[42] However, because this problem features a discrete choice, there may be discontinuities in W_a that lead to non-unique solutions for the inversion.

To correct for this, I take the upper envelope of the solution. For each non-unique solution of the inversion, the upper envelope algorithm chooses the point for which the value function gives greater utility. The steps of the upper envelope algorithm are detailed below for the 'non-adjustment problem'. Please refer to those steps, simply substituting z^{endo} with a^{endo} and `zgrid` with `agrid`.

The algorithm delivers both the policy function $a'(y, h', \tilde{b}', a)$ as well as an updated value function $V^n(y, h', \tilde{b}', a)$. At the end of this step, it is possible to calculate $W_{\tilde{b}}(y, h', \tilde{b}', a)$ and $W_h(y, h', \tilde{b}', a)$ by interpolation, evaluating $W_{\tilde{b}}$ and W_h at the policy function $a'(y, h', \tilde{b}', a)$.

(iii) **Update state** $\underline{h' \to h}$. Using interpolation, re-write $a'(y, h', \tilde{b}', a)$, $V^n(y, h', \tilde{b}', a)$, $W_{\tilde{b}}(y, h', \tilde{b}', a)$ and $W_h(y, h', \tilde{b}', a)$ in terms of h rather than h'. Do this by evaluating each at $h' = (1-\delta)$.

(iv) **Update state** $\underline{\tilde{b}' \to \tilde{b}}$. Using interpolation, re-write $a'(y, h, \tilde{b}', a)$, $V^n(y, h, \tilde{b}', a)$, $W_{\tilde{b}}(y, h, \tilde{b}', a)$ and $W_h(y, h, \tilde{b}', a)$ in terms of $\tilde{b}$ rather than $\tilde{b}'$. Do this by evaluating each at at $\tilde{b}' = \frac{(1-\mu)}{(1-\delta)}\frac{p^-}{p}\tilde{b}$.

[42] This would be the standard procedure in the endogenous grid-point method by Carroll (2006).

(v) **Update guesses**. First calculate $c(y,h,\tilde{b},a)$ as

$$c(y,h,\tilde{b},a) = y + (1+r)a - (\mu + r^b)p^-\tilde{b}h - a'(y,h,\tilde{b},a) \tag{47}$$

Note that there will be some states for which it is impossible to have positive consumption. In particular, states with very low assets but very high durable consumption. For these states, force consumption to be a very low value, such as $1e-9$.

Then, use the envelope conditions to update guesses as follows:

$$V_a^n(y,h,\tilde{b},a) = (1+r)u_c\left(c(y,h,\tilde{b},a),(1-\delta)h\right), \tag{48}$$

$$\begin{aligned} V_h^n(y,h,\tilde{b},a) &= (1-\delta)\Big(u_h(c(y,h,b,a),(1-\delta)h) + W_h(y,h,\tilde{b},a)\Big) \\ &\quad - (r^b+\mu)p^-\tilde{b}u_c(c(y,h,\tilde{b},a),(1-\delta)h), \end{aligned} \tag{49}$$

$$\begin{aligned} V_{\tilde{b}}^n(y,h,\tilde{b},a) &= \frac{(1-\mu)}{(1-\delta)}\frac{p^-}{p}W_{\tilde{b}}(y,h,\tilde{b},a) \\ &\quad + (r^b+\mu)p^-hu_c(c(y,h,\tilde{b},a),(1-\delta)h). \end{aligned} \tag{50}$$

Note that $V^n(y,h,\tilde{b},a)$ was already obtained in previous steps, and does not need explicit updating in this step.

4. **Adjustment problem**. Solve the non-adjustment problem, given guesses for V, V_h, $V_{\tilde{b}}$, and V_a. Note that I suppress the a superscript on all policy functions in this section for notation convenience. Thus, the $a'(y,h,\tilde{b},a)$ that I find below (and analogous policy functions for h' and $\tilde{b}'$) is the a' choice *conditional* on the choice of adjusting.

(i) **Unconstrained** $\underline{a' \to z|h',\tilde{b}'}$. Here we solve the first order condition of the 'inner' maximization problem, where we solve for c and a' taking the choice for h' and $\tilde{b}'$, as well as states y and z, as given.

Assume that the constraint on assets does not bind. Then (27) can be re-written to define c as

$$c(y,h',b',a') = u_c^{-1}\Big(W_a(y,h',b',a'),h'\Big). \tag{51}$$

Using the budget constraint, we get $z^{endo}(y,h',\tilde{b}',a')$, which is the z that implies the household chooses $\{c(y,h',\tilde{b}',a'),a'\}$. This is

$$z^{endo}(y,h',\tilde{b}',a') = a' + c(y,h',b',a') + p(1-\tilde{b}')h' - y$$

(ii) **Upper envelope**. Let `agrid` denote the pre-computed grid for the discretized values of a. We use the upper envelope to go from $\left(z^{endo}(y,h',\tilde{b}',a'),\texttt{agrid}\right) \rightarrow \left(\texttt{agrid},a'(y,z,h',\tilde{b}')\right)$. These are steps in the upper-envelope algorithm.

   i. **Initialize value function.** Initialize an empty value function at minus infinity:

   $$V^u(y,h',\tilde{b}',a') = -\infty$$

   ii. **Create endogenous segments.** Let $a(j)$ be j^{th} point on the grid for a. Conditional on all other states, $s = (y,h',\tilde{b}')$, create a segment $[z(s,j),z(s,j+1)]$. $z(s,j)$ and $z(s,j+1)$ represent the values of z for which households choose $a' = \texttt{agrid}[j]$ and $a' = \texttt{agrid}[j+1]$, respectively.

   iii. **Interpolate.** Find all values of $\texttt{zgrid} \in [z(s,j),z(s,j+1)]$. By knowing that $a' = \texttt{agrid}[j]$ when $z = z(s,j)$ and $a' = \texttt{agrid}[j+1]$ when $z = z(s,j+1)$, implement a standard interpolation to back out what a' is when $z \in [z(s,j),z(s,j+1)]$.

   iv. **Choose the solution that maximizes the value function.** Because of the discrete choice, it is possible that multiple values of `zgrid` fall in the segment $[z(s,j),z(s,j+1)]$. Accordingly, for each candidate a' obtained from the previous steps, compute its associated value function and choose the a' that maximizes it.

   v. **Enforce the constraint** For each candidate solution a', check that the constraint is not binding. If it is, substitute $a' = 0$. Fill the values of the initialized value function $V^u(y,h',\tilde{b}',a')$.

   The results of upper envelope step are a policy function $a'(y,z,h',\tilde{b}')$ and a value function $V^a(y,z,h',\tilde{b}')$ which are in terms of the state variables $\{y,z\}$ and the choice variables $\{h',\tilde{b}'\}$. At the end of this step, we can calculate $W_b(y,h',\tilde{b}',a)$ and $W_d(y,h',\tilde{b}',a)$ by interpolation, evaluating $W_{\tilde{b}}$ and W_d at the policy function $a'(y,z,h',\tilde{b}')$.

(iii) **Choose** $\tilde{b}'|h'$. For the next two stages of the adjustment problem, we can no longer employ endogenous grid-point method and must instead employ a root finding algorithm on the first order condition.

   The first order condition for $\tilde{b}'$ taking the choice of h' as given as well as the optimal solution for both c and a' is the envelope condition of the 'inner' problem with respect to $\tilde{b}'$, equation (29).

$$V_{\tilde{b}'}^{a,(1)} = ph' u_c(c(y,z,h',\tilde{b}'),h') + W_b(y,z,h',\tilde{b}') \tag{52}$$

There are three cases of solutions for the above equation. The first, if (52) is always positive, then $\tilde{b}'$ takes on the corner solution $\tilde{b}' = \lambda$. The second, if (52) is always negative, $\tilde{b}'$ takes the corner solution $\tilde{b}' = 0$. If the above equation crosses zero at least once, there is an interior solution. We use a root finding algorithm to find the grid points between which the equation crosses zero. If there are multiple inflection points, we use the value function to choose the true maximum and pick between multiple inflection points using the value function.

The root finding algorithm also exploits that for some state values of the problem (combinations $\{y,z,h'\}$), there is either no solution for $\tilde{b}'$ such that cash on hand is strictly positive, or there is a further restricted set of $\tilde{b}'$ values for which $\tilde{b}'$ is positive. It searches over this restricted set, and sets $\tilde{b}'$ to its maximum possible value for areas of the state space where there is no solution.

The resulting policy function is $\tilde{b}'(y,z,h')$. At the end of this step, we can calculate $V^a(y,z,h')$, $W_d(y,z,h')$ and $a'(y,z,h')$ by evaluating $V^a(y,z,h',\tilde{b}')$, $W_d(y,z,h',\tilde{b}')$ and $a'(y,z,h','\tilde{b}')$ at the policy function $b'(y,z,h')$. $c(y,z,h')$ can be calculated using the budget constraint

$$c(y,z,h') = y + z - a'(y,z,h') - p(1 - \tilde{b}'(y,z,h')h' \tag{53}$$

Where any negative value of c is replaced with $1e-9$.

(iv) **Choose** h'. Like with the choice for $\tilde{b}'$, we use a root finder over the first order condition. The first order condition for the outer problem is the envelope condition of the middle problem with respect to h', which in turn is the envelope condition of the inner problem with respect to h'. This is

$$V_{h'}^{a,(2)} = u_d(c(y,z,h'),h') + W_d(y,z,h') - p(1-\tilde{b})u_c(c(y,z,h'),h') \tag{54}$$

As above, we use a root finding algorithm to find all local maximum points, and use $V^a(y,z,h')$ to determine the global maximum. The root finding algorithm exploits that for each state value $\{y,z\}$ there are values of h' which push cash-on-hand negative and cannot be solutions.

The resulting policy function is $h'(y,z)$. At the end of this step, we can calculate $V^a(y,z)$, $a'(y,z)$, and $\tilde{b}'(y,z)$ by evaluating $V^a(y,z,h')$, $a'(y,z,h')$, ad $\tilde{b}'(y,z,h')$ at $h'(y,z)$.

5. **Interpolate** $z \rightarrow \{h, \tilde{b}, a\}$. Because we need our guesses for V, V_a, $V_{\tilde{b}}$, V_h to be in terms of the original state space $\{y, h, \tilde{b}, a\}$, we interpolate for each combination of $\{y, h, a\}$ to put all policy functions and guesses onto the original grid.

6. **Update guesses**. First calculate $c(y, h, \tilde{b}, a)$ as

$$c(y,h,\tilde{b},a) = y + (1+r)a + \Big(p(1-f)(1-\delta) - (1+r^b)\tilde{b}p^-\Big)h \\ - a'(y,h,\tilde{b},a) - p(1-\tilde{b}'(y,h,\tilde{b},a))h'(y,h,\tilde{b},a) \tag{55}$$

   As in the non-adjustment problem, there may be some states for which it is impossible to have positive consumption. For these states, we force consumption to $1e-9$.

   Then, we can use the envelope conditions to update guesses as follows:

$$V_a^a(y,h,\tilde{b},a) = (1+r)u_c(c(y,h,\tilde{b},a), h'(y,d,b,a)) \tag{56}$$

$$V_d^a(y,h,\tilde{b},a) = \Big((1-f)(1-\delta)p - (1+r^b)\tilde{b}p^-\Big)u_c(c(y,h,\tilde{b},a), h'(y,h,\tilde{b},a)) \tag{57}$$

$$V_{\tilde{b}}^a(y,h,\tilde{b},a) = -(1+r^b)p^- h u_c(c(y,h,\tilde{b},a), h'(y,d,\tilde{b},a)). \tag{58}$$

7. **Discrete choice**. Given solutions for both the adjustment and non-adjustment problem, calculate the adjustment probabilities and solve the discrete choice problem using equations (14) and (15). This will give updated guesses for V, V_a, $V_{\tilde{b}}$ and V_h.

   Go back to step 2, repeat until convergence.

C.2 Calibration of μ

The parameter governing the speed of mortgage repayment is calibrated to match the duration of a typical Spanish mortgage. In particular, given the maturity of a mortgage equal to T and mortgage interest rate r^b, the duration formula is given by:

$$Duration = \frac{\sum_{t=1}^{T} tPV_t}{\sum_{t=1}^{T} PV_t} = \frac{\sum_{t=1}^{T} tPV_t}{P} \tag{59}$$

where t is the time until a mortgage payment will be made and PV_t is the present value of that mortgage payment. P represents the present value of all future mortgage payments, which is the principal. Since mortgage payments M are computed such that:

$$P = \sum_{t=0}^{T} \frac{M}{(1+r^b)^t} \tag{60}$$

it follows that:

$$M = \frac{r^b P(1+r^b)^T}{(1+r^b)^T - 1}. \tag{61}$$

Applying this definition of M, it follows that equation (59) can be re-written as:

$$Duration = \sum_{t=1}^{T} \frac{t}{(t+r^b)^t} \frac{r^b(1+r^b)^T}{(1+r^b)^T - 1}. \tag{62}$$

Given the mortgage repayment structure in the model, where $M^{model} = (r^b + \mu)b$, it follows that $M_t^{model} = (r^b + \mu)(1-\mu)^{t-1}P$, where P is the principal amount of the mortgage. Accordingly, the duration in the model will be:

$$Duration^{model} = \frac{\sum_{t=1}^{T} \frac{t(r^b+\mu)(1-\mu)^{t-1}P}{(1+r^b)^t}}{P} = \frac{1+r^b}{1+\mu}. \tag{63}$$

It follows that in order for $Duration = Duration^{model}$, it has to be the case that:

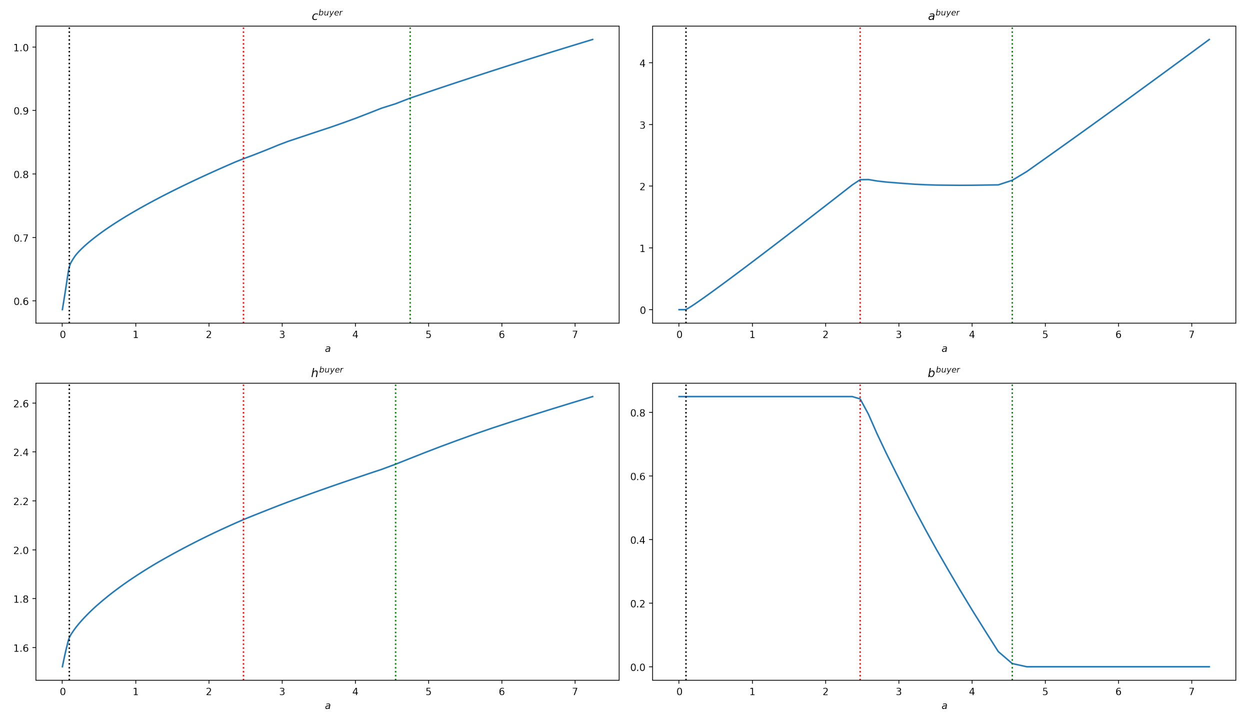
$$\mu = (1+r^b)\left(\sum_{t=1}^{T} \frac{r^b t(1+r^b)^T}{((1+r^b)^T - 1)(1+r^b)^t}\right)^{-1} - r^b. \tag{64}$$

Given my targets of $T = 25$ years and $r^b = 3\%$, and quarterly calibration, it follows that $\mu = 0.015$.

C.3 Policy functions

This appendix describes the policy functions that characterize the optimal behaviour of the *buyers*, those households who choose to adjust their housing stock. It is of interest to study their policy functions since they solve a particularly involved problem.

Figure C.16: Policy functions for *buyers*, households adjusting their housing stock



Notes: The x-axis is the state variable a, representing the liquid balances a household enters the period with. The policy functions are those of a representative household that enters the period with average productivity shock e and low mortgage debt b.

Figure C.16 shows the policy functions for the four continuous choices that *buyers* make: consumption c, liquid balances a, housing stock h, and loan-to-value ratio b (note that b captures the loan-to-value ratio and not the overall amount of mortgages outstanding in the figure). The functions displayed are those of a representative household that starts the period with average income and low mortgage debt. Three vertical lines divide each chart into four areas, each characterized by a different behaviour.

The first area is the one on the left of the black vertical dotted line. This represents the area where households are at their liquid balance constraint, implying that they are not on their Euler equation. This can be seen in the policy function for a, which shows that households choose to not save any resources ($a = 0$). In this region, households have so little resources that they cannot afford their desired consumption bundle. For this reason, any additional resource they get is used to increase durable and non-durable consumption (the policy functions for c and h area particularly steep in this region), and they borrow as much as possible through mortgages (b is at the LTV constraint).

The second area is the one between the black and red lines. In this area households are on their Euler equation and have more resources than those they need to satisfy their consumption needs. Therefore, households need to choose whether to save these resources in the form of liquid balances a, or to reduce their mortgage uptake b. The figure shows that households decide to keep b at the LTV constraint and save in liquid assets a. This is the optimal behaviour due to the presence of two forces in the model. First, due to idiosyncratic uncertainty, households find it optimal to keep positive liquid savings in case of negative productivity shocks. Second, due to the presence of adjustment costs, households understand that mortgages can be accessed infrequently. Hence, when opening a mortgage with low resources, it is optimal to borrow more than what would be strictly necessary for house purchase, saving part of these resources for future needs.

The third area is the one between the red and green lines. In this area households reach the satisfactory amount of liquid savings that are necessary to face adverse productivity shocks, and decide to use their additional resources to reduce the amount they borrow through mortgages, decreasing future mortgage payments.

The fourth area is the one of the right of the green line. In this area households have enough resources to satisfy their consumption needs and do not need to open a mortgage to buy their house. Hence, any additional resource they have is saved in the form of liquid balances a.

Overall, these policy functions show that poorer households are the ones who tend to borrow as much as possible through mortgages for their house purchase, while richer households can rely on their resources to a larger extent.

C.4 Isolating the impact of MPCs in transmission through ARMs

The model presented in section 3 states that each household i has a consumption function that depends on the risk-free rate r, mortgage rate r^b, the house price p, as well as a set of idiosyncratic state variables $\{e, h, b, a\}$. Letting $z = \{e, h, b, a, p\}$, we can write the consumption function of household i as $c^i(r, r^b, z)$.

In section 4.2.2, I consider a monetary policy shock that changes r by dr, and, following the dynamics of equation (10), also changes r^b by dr^b. Since I'm implementing this exercise in partial equilibrium, it follows that the change in consumption in country c is given by:

$$dC^c = \underbrace{\int \frac{\partial c^i}{\partial r} dr di}_{\text{direct effect of } dr \text{ in } c} + \underbrace{\int \frac{\partial c^i}{\partial r^b} \frac{\partial r^b}{\partial r} dr di}_{\text{indirect effect of } dr \text{ through ARMs in country } c} . \tag{65}$$

The *indirect* effect, $\int \frac{\partial c^i}{\partial r^b} \frac{\partial r^b}{\partial r} dr di$, is a function of the fraction of households with ARMs, since FRM holders are insulated from changes in r^b. Both *direct* and *indirect* effects depend on households' MPCs. Therefore, differences in MPCs across countries result in a change in the response of consumption due to changes in both the *direct* effect and the *indirect* effect.

To isolate the difference in transmission across countries that arise solely due to different transmission through ARMs (i.e., the *indirect* effect), I proceed as follows. For Spain, the reference country, I calculate the consumption response to a monetary policy shock using equation (65):

$$dC^{ES} = \underbrace{\int \frac{\partial c^i}{\partial r} dr di}_{\text{direct effect of } dr \text{ in } ES} + \underbrace{\int \frac{\partial c^i}{\partial r^b} \frac{\partial r^b}{\partial r} dr di}_{\text{indirect effect of } dr \text{ through ARMs in } ES} . \tag{66}$$

To compute the counterfactual response of consumption in Spain, assuming it had the ARM transmission of another Euro Area economy c, I adjust Spain's MPC and ARM share to match those of c. This adjustment affects transmission both through the *direct* and the *indirect* effects. Since my focus is on identifying the change in consumption relative to Spain that arises solely due to different transmission through the *indirect* ARM channel, I compute the change in consumption in the counterfactual economy c as:

$$dC^c = \underbrace{\int \frac{\partial c^i}{\partial r} dr di}_{\text{direct effect of } dr \text{ in } ES} + \underbrace{\int \frac{\partial c^i}{\partial r^b} \frac{\partial r^b}{\partial r} dr di}_{\text{indirect effect of } dr \text{ through ARMs in country } c} . \tag{67}$$

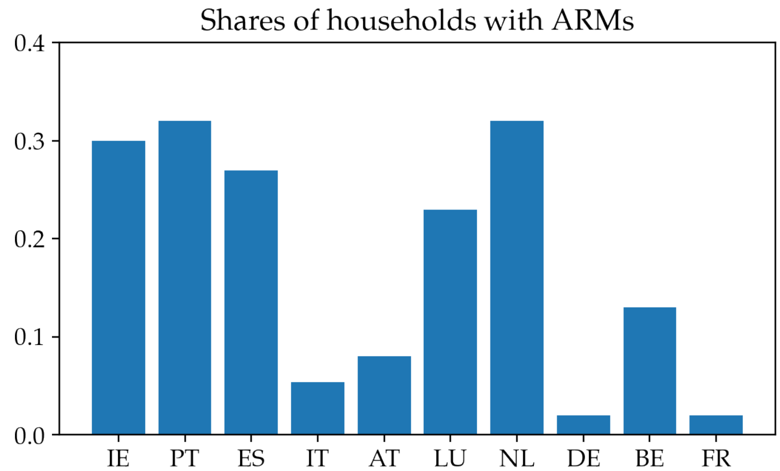
In this counterfactual response, I impose that the *direct* effect remains the same as in Spain, while the *indirect* effect reflects the specific MPC and ARM share of economy c. As a result, I partial out the effect of changing MPCs on the *direct* effect, so that dC^c captures the counterfactual response of consumption in an economy c that differs from Spain only due to the *indirect* effect, i.e. transmission to consumption through ARMs.

The model-implied difference in transmission (displayed in column *Model* in table 3) will be given by $dC^{ES} - dC^c$ so that, effectively, differences arise only due to transmission through ARMs.

C.5 Results matching the fraction of households with ARMs in the population

This section replicates all results from section 4 where, in the calibration of the model, I match the fraction of households with ARMs in the population instead of the fraction of ARMs within the total stock of mortgages. Figure C.17 shows the fraction of households with ARMs in each Euro Area economy.

Figure C.17: Shares of households with ARMs across Euro Area countries



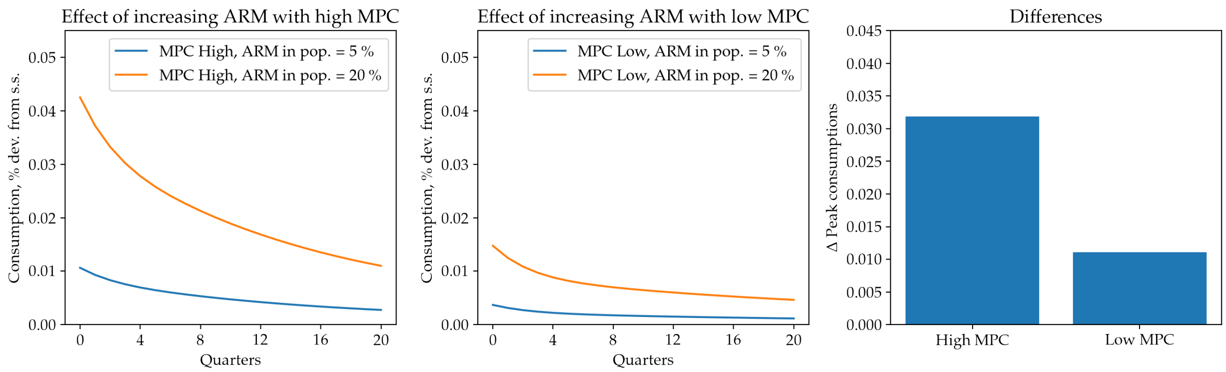
Notes: Each bar represents, for each Euro Area country, the fraction of households with ARMs in the population. Countries are ranked by the strength of monetary policy transmission, from Ireland (strongest) to France (weakest), in line with the estimates from equation (1) shown in figure 1.

Figure C.18 replicates the exercise in section 4.1.2, showing that the model keeps predicting a positive interaction between ARMs and MPCs also when using this alternative definition of the share of ARMs.

Table C.3 replicates the exercise in section 4.2.1, showing that the model keeps predicting a positive interaction between ARMs and MPCs when considering a complete monetary policy shock also under this alternative definition of the share of ARMs. In particular, the percentage increase in the peak response of consumption increases by 5% in the low MPC economy and by 15% in the high MPC economy.

Finally, table C.4 replicates the results in section 4.2.2. Relative to the analysis in section 4.2.2, where I implement counterfactual exercises adjusting the share of ARMs within the total mortgage stock, I here implement counterfactual exercises adjusting the share of

Figure C.18: Interaction between ARMs and MPCs after a mortgage rate shock, alternative ARM share



Notes: The left and middle panels show the consumption response, in percentage deviations from its steady-state value, to a mortgage rate shock in the high and low MPC economies, respectively. The blue line shows the response when the share of households with ARMs in the economy is 5%, while the orange line shows the response when the share is 20%. The right panel displays the difference in the peak response of consumption when the share of households with ARMs increases from 5% to 20%. The mortgage rate shock is calibrated to lead to a 100 basis points reduction in r^b on impact, and it follows an AR(1) process with persistence 0.75.

Table C.3: Interaction between ARMs and MPCs after a complete monetary policy shock, alternative ARM share

	Low MPC	High MPC	Δ MPC
Low ARM	0.213%	0.217%	0.004%
High ARM	0.224%	0.249%	0.025%
Δ ARM	0.011%	0.032%	0.036%

Notes: High MPC refers to the reference Spanish economy, while *Low MPC* refers to the counterfactual economy with MPC half that of Spain. *Low ARM* and *High ARM* refer to shares of households with ARMs of 5% and 20%, respectively. Each entry represents the peak consumption response after a monetary policy shock. The entries in the Δ *MPC* column and Δ *ARM* row show the differences in peak consumption. The shock is calibrated to lead to a reduction in r of 100 basis points on impact and it follows an AR(1) process with a persistence of 0.75.

Table C.4: ARM and MPC contributions to overall transmission

	Difference			Contribution		
	Data	Model	% Explained	ARM	MPC	Interaction
AT	0.236	0.089	38%	28%	21%	51%
BE	0.314	0.075	24%	35%	31%	34%
DE	0.295	0.094	32%	69%	2%	29%
FR	0.350	0.096	27%	46%	4%	50%
IE	-0.728	-0.103	16%	11%	80%	9%
IT	0.172	0.086	50%	58%	8%	33%
LU	0.284	0.058	20%	12%	75%	13%
NL	0.287	0.044	15%	−20%	142%	−22%
PT	-0.239	-0.037	15%	50%	42%	8%
Averages	0.311	0.084	27%	32%	45%	23%

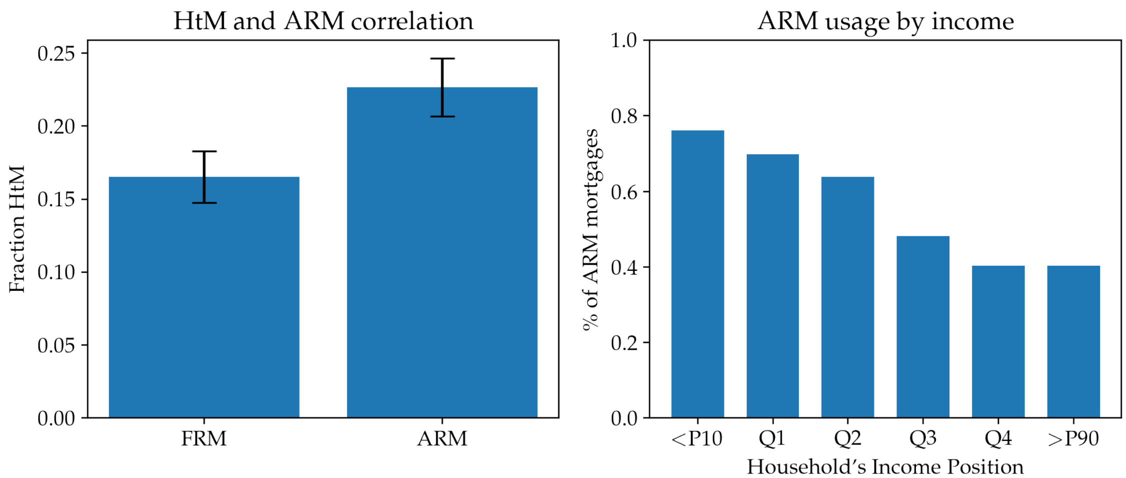
Notes: For each country, the table shows the difference in percentage points in the peak consumption response to a monetary policy shock relative to Spain. This difference is presented both in the data (second column) and in the model (third column). The fourth column shows the fraction of this difference captured by the model. The last three columns report the fraction of the model-implied differences between each country and Spain that are attributable to differences in ARMs, MPCs, and their interaction. The last row presents the average values of the column variables across countries.

households in the population with ARMs. The main message from table 3 is preserved. In particular, 27% of the empirical differences in transmission across Euro Area countries are captured by the model, lower than the 46% figure of the baseline results, but still large enough to conclude that transmission differentials through ARMs are an important source of overall transmission heterogeneity across Euro Area countries. In addition, with an individual contribution of 45% (slightly lower than 57% in the baseline results), MPCs keep playing a crucial role to capture transmission differentials through ARMs across Euro Area economies.

C.6 Results with MPC-ARM correlation

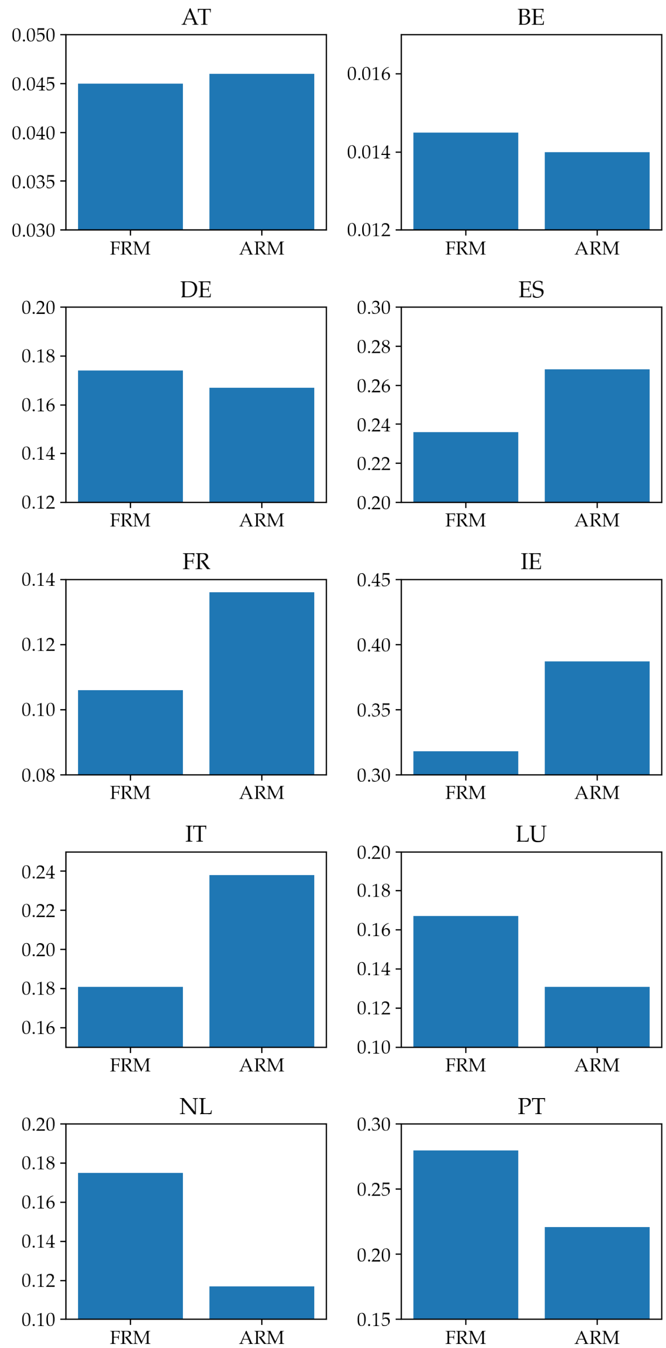
Figure C.19 shows that, in the data, ARMs tend to be more widespread across lower-income households in the Euro Area, implying that a larger fraction of households with ARMs is HtM relative to households that choose to have fixed-rate mortgages (FRMs). This appendix presents the counterfactual results generated by introducing this correlation into the model. In particular, this is achieved by calibrating a different fraction of ARM households for each income level, so that the ratio of HtM households with FRMs (HtM^{FRM}) to those with ARMs (HtM^{ARM}) in the model matches the empirical ratio observed in the HFCS for each country in the sample. Figure C.20 shows the fraction of HtM households among households with ARMs and FRMs in the HFCS for individual Euro Area countries, which I use to calibrate the different shares of ARMs across income levels in the model. Importantly, the correlations are not always in the same direction.

Figure C.19: Correlation between HtM and ARM in the Euro Area



Notes: The source of the data is the HFCS. The left panel shows the share of HtM agents among households that have fixed-rate mortgages (FRM) and adjustable-rate mortgages (ARM). The vertical lines represent confidence intervals. The right panel shows the average fraction of mortgages that have an adjustable-rate for households across the income distribution (P stands for "percentile", Q stands for "quartile").

Figure C.20: Correlation between HtM and ARM in individual countries



Notes: The source of the data is the ECB HFCS. The chart shows the share of HtM agents among households that have fixed-rate mortgages (FRM) and adjustable-rate mortgages (ARM)

Table C.5 shows the counterfactual results of this analysis. The results mirror closely the ones in table 3, suggesting that accounting for the HtM-ARM correlation does not change the main message from section 4.2.2, and the average fraction of empirical differences captured by the model moves from 46% to 47% only. This is mainly the consequence of the fact that introducing the correlation does not help the model better capture differences in transmission between Spain and all other Euro Area economies. In particular, economies such as Germany or the Netherlands, which are characterized by having FRM households being more constrained than ARM households, have smaller transmission through the mortgage channel in this analysis, which implies that the model captures a larger fraction of the empirical difference in the response of consumption between these economies and Spain. Nonetheless, Portugal is also characterized by having FRM households being more constrained than ARM households, which pushes the model to predict stronger transmission through mortgages in Spain than in Portugal, decreasing the ability of the model to capture the overall transmission differential (since the response of consumption in Portugal is larger than the one of Spain in the data).

Table C.5: ARM and MPC contributions to overall transmission

	Difference			Contribution		
	Data	Model	% Explained	ARM	MPC	Interaction
AT	0.236	0.150	64%	4%	72%	24%
BE	0.314	0.142	45%	16%	45%	34%
DE	0.295	0.153	52%	51%	9%	40%
FR	0.350	0.165	46%	26%	8%	66%
IE	-0.728	-0.228	36%	1%	97%	2%
IT	0.172	0.105	62%	18%	60%	22%
LU	0.284	0.126	44%	3%	89%	8%
NL	0.287	0.127	44%	−0%	101%	−1%
PT	-0.239	-0.072	30%	45%	39%	16%
Averages	0.311	0.141	47%	18%	58%	24%

Notes: For each country, the table shows the difference in percentage points in the peak consumption response to a monetary policy shock relative to Spain. This difference is presented both in the data (second column) and in the model (third column). The fourth column shows the fraction of this difference captured by the model. The last three columns report the fraction of the model-implied differences between each country and Spain that are attributable to differences in ARMs, MPCs, and their interaction. The last row presents the average values of the column variables across countries.