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Monetary policy, agent heterogeneity and inequality: insights from a three-agent New Keynesian model

Abstract

In this paper I develop a New Keynesian dynamic stochastic general equilibrium model which features three different types of representative agents (THRANK): the poor hand-to-mouth, the wealthy hand-to-mouth and the non-hand-to mouth households. Compared to a full-scale HANK model, this model is easier to compute while reproducing many of the same monetary policy shock transmission channels. I show that monetary policy transmission takes place through a redistribution channel, as emphasised by Auclert (2019). In particular, the effects of a monetary policy shock are amplified as resources are redistributed from high-MPC households to low-MPC households. Monetary policy therefore becomes more effective compared to models with homogeneous MPC rates. Consumption inequality is countercyclical in this setting and a high degree of leverage amplifies the redistribution channel. These findings have important implications for understanding the effects of both monetary and macroprudential policy.

Non-technical summary

This paper examines monetary policy transmission in a model of three households. A three-household model captures better the different responses of different type of households to a monetary policy shock than traditional models with only one representative household. In addition, compared to more complicated models of full household heterogeneity, a simpler model of three households captures and quantifies more easily the transmission of monetary policy through different channels.

Apart from the traditional non-hand-to-mouth household with unlimited ability to save and borrow from the financial markets, the model includes a poor hand-to-mouth household with no access to the financial markets living only from its labour income, and a wealthy hand-to-mouth household with restricted access to financial markets through borrowing against its housing wealth. Especially the inclusion of the wealthy hand-to-mouth household makes the transmission of monetary policy more effective in the economy compared to an economy modelled with only a non-hand-to-mouth household. This comes through the effect of monetary policy on the wealthy hand-to-mouth household's balance sheet: an increase in the interest rate in form of a contractionary monetary policy shock reduces the value of the household's housing wealth which forces the household to cut back on lending and consume less. Furthermore, the lower inflation created by the monetary policy tightening reinforces this effect by increasing the real interest payments of the mortgage. The decrease in consumption spills over to the rest of the economy, making also the poor hand-to-mouth household's labour income sink more than in the absence of the wealthy hand-to-mouth households.

The model provides a richer picture of monetary policy transmission than a traditional one representative household model, as these models rely almost solely on substitution from consumption to saving as of monetary policy transmission channel. There is a considerable amount of households that are unable to adjust their consumption smoothly when facing economic shocks and the three-agent model is able to take these households into account. In addition, the model gives insights into how distributions of wealth, income and consumption change in response to monetary policy shocks. The non-hand-to-mouth households suffer less from a contractionary monetary policy shock while monetary easing benefits the hand-to-mouth households relatively more. The housing market and the loan-to-value ratio set by macroprudential policy have a central role in monetary policy transmission, and wealth and inequality between the households: a

higher LTV ratio increases the wealth level of the wealthy hand-to-mouth households but makes their consumption more sensitive to monetary policy shocks. This sensitivity also increases the overall effectiveness of monetary policy in the economy, making responses to monetary policy shocks sharper.

1 Introduction

Contrary to the standard assumption in traditional representative agent New Keynesian models (RANK), not all households are alike. In recent years, models have been introduced that are able to reproduce the empirical evidence on heterogeneous responses to shocks by matching empirical distributions of income and wealth. These heterogeneous agent New Keynesian models (HANK) utilise heterogeneity in wealth and income to create optimal responses for various agents and aggregating them into aggregate consumption and output responses. Central for these models is the arrival of heterogeneous shocks on labour income as incomplete insurance markets lead to uninsurable idiosyncratic shocks. This feature contrasts with RANK models in which shocks are only aggregate due to the presence of complete insurance markets.

However, HANK models are computationally more complicated than RANK models and their transmission mechanisms can be difficult to understand. Therefore, simple models still have their place, especially if they can produce the same transmission channels to a shock than more complicated models. In this paper, I develop New Keynesian model featuring three types of representative agents (THRANK) whose characteristics follow the division introduced by Kaplan, Violante, and Weidner (2014). Households are divided into non-hand-to-mouth households which behave in a manner consistent with Ricardian households in RANK models, wealthy hand-to-mouth households which have a considerably amount of illiquid assets but close to zero liquid assets, and poor hand-to-mouth households which have very low levels of both illiquid and liquid assets. I show that this model can match many of the monetary policy transmission channels of a HANK model.

I approximate the behaviour of each of these groups in a dynamic stochastic general equilibrium (DSGE) model and simulate a contractionary monetary policy shock. Non-hand-to-mouth and wealthy hand-to-mouth households are similar to the patient and impatient households from Iacoviello (2005), whereas the poor hand-to-mouth behaviour is similar to the rule-of-thumb households in Bilbiie (2008), Campbell and Mankiw (1989) or Galí, López-Salido, and Vallés (2007). In the literature, the closest model to what follows is provided by Cloyne, Ferreira, and Surico (2020), who study the transmission of monetary policy through the housing market and use a comparable three-agent structure.

The model presented below allows me to discuss the consequences of a contractionary monetary policy shock in a setting that features household heterogeneity. This is of special interest at

a time in which many central banks around the world are again at the zero lower bound and will eventually again begin to normalise their monetary policy[1]. I discuss which kind of implications the differing positions of households create for monetary policy, especially regarding inequality between different types of households. I find that the redistribution channel identified by Auclert (2019) for HANK models is also present in the three-agent model. Resources are redistributed from agents with high marginal propensities to consume (MPCs) to low MPC agents. Because of the differences in MPCs, this resource redistribution leads to an even larger redistribution in consumption. As the low MPC households typically have higher income and wealth than the high MPC households, inequality between agents in income and consumption is countercyclical, rising with contractionary monetary policy shocks. Due to the resource redistribution from high-MPC to low-MPC households, monetary policy is more effective in this three-agent model compared to models in which agents have equal MPCs, such as the RANK model.

Finally, I test for different parameter values to see how they change the consumption inequality between the agents and the aggregate response. It turns out that the share of the wealthy hand-to-mouth and the credit constraint they have in form of a loan-to-value (LTV) ratio become central for the magnitude of the response of the economy to a monetary policy shock. In particular, the response of the wealthy hand-to-mouth spills over to the whole economy and through that to the poor hand-to-mouth, which creates a co-movement between the consumption responses of the wealthy and poor hand-to-mouth households. Also, the degree of illiquidity in the illiquid asset increases cyclical inequality.

There are several important reasons for studying agent heterogeneity and inequality, as listed by Coibion et al. (2017). First, inequality between agents has not received too enough attention, although the interest has increased in the recent years. For central bankers and politicians, it is crucial to know how different groups are affected by monetary policy. Second, heterogeneity and inequality can shed light on new transmission mechanisms of monetary policy, as in Auclert (2019). Inequality varies over the monetary policy cycle, providing evidence that monetary policy affects it and that the transmission of monetary policy is different depending on the agent heterogeneity and inequality prevailing in the economy at a given time. Third, agent heterogeneity affects macroeconomic stability. If a larger share of agents are credit constrained,

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[1]Monetary policy normalisation in the current context also refers to gradually abandoning unconventional montary policy measures. However, in this paper, the effects of an interest rate hike are tested. For a discussion of the effects of unconventional policy on redistribution and inequality, see for instance Ampudia et al. (2018) or Pugh, Bunn, and Yeates (2018). Generally, expansionary monetary policy, whether conventional or unconventional, increases equality and contractionary monetary policy decreases it.

the economy becomes more responsive and is vulnerable to booms and busts. As will be shown below, testing for the LTV ratio provides evidence that inequality can be constrained using macroprudential policy at the same time as macroeconomic stability is improved. Finally, in the setting presented in this paper, heterogeneity amplifies the responses of aggregate variables such as output and inflation, compared to models with less heterogeneity, such as RANK or TANK.

This paper proceeds as following: in Section 2 I review the related literature and discuss how heterogeneity has been modelled in macroeconomics. In Section 3, I develop a new DSGE model with three types of agents and compare it to the widely-used RANK and TANK models. I describe different monetary policy transmission channels and discuss their presence in my model in Section 4. I test the sensitivity of the model to changes in parameter values in Section 5. Finally, a discussion of insights for both macroeconomic modellers and policy-makers, and a summary of main conclusions conclude the paper.

2 Literature review

Earlier macroeconomic models, such as the New Keynesian DSGE models have only featured one type of agent, the so-called representative agent (see for instance Clarida, Galí, and Gertler (2000)). The ability to borrow and save without limitations enables this agent to smooth out all temporary changes to income. Only truly unexpected shocks can cause large sudden adjustments. However, Campbell and Mankiw (1989) found that unlike the permanentn income hypothesis (PIH) predicts, consumption is insensitive to changes in interest rate. This led to the introduction of Keynesian hand-to-mouth (HtM) or rule-of-thumb (RoT) households into macroeconomic models. These HtM agents do not have access to the credit market and therefore they are insensitive to changes in the interest rate, but highly sensitive to changes in their labour income.

Since then, these RoT or HtM consumers have gained ground especially in fiscal policy research, although Bilbiie (2008) has shown that these households matter also for the transmission of monetary policy. Galí, López-Salido, and Vallés (2007) show that if an economy features a large enough share of HtM consumers, the response of consumption to fiscal expansion can be positive, in line with the empirical evidence but contrary to the theory of Ricardian equivalence. The rationale behind this are the differing marginal propensities to consume (MPC). MPC is defined as the share of windfall income that the agent would consume instantly instead of saving

it for later consumption. Permanent income hypothesis states that the MPC out of windfall income is close to zero, as agents view the increase in income as a change in their permanent income and not current income, and distribute the effect between many periods. In contrast, HtM households without access to the credit markets have MPC equal to one, as they will always consume the additional income in the same period.

Hence, the differences between the Ricardian and the HtM consumers in fiscal policy models can be explained by their differences in their MPCs. However, monetary policy research has until recently largely neglected this agent heterogeneity, most likely because of the dominant view that in the long run, monetary policy is neutral regarding income and wealth distribution (Auclert 2019). The assumption of policy neutrality might indeed be true for the long run, i.e. over many business cycles. However, this does not exclude the possibility that monetary policy might have redistributive effects and consequences for inequality in the short run. Times of expansionary monetary policy tend to favour households with high amounts of debt, whereas contradictions favour households with savings. Also, the general equilibrium effects of monetary policy affect the HtM households, even if they do not have any savings or debt. A second source of differences emerges if the agents' income compositions are different, for instance if some agents live from labour income and some more from asset income, such as in Auclert (2019), Coibion et al. (2017) or Hedlund et al. (2017).

Introducing households with debt and savings requires heterogeneity on households' balance sheets. A simple way to include heterogeneity is by making some agents credit constrained. Bernanke and Gertler (1995) introduced the credit channel of monetary policy, emphasising the business cycle-varying wedge between internal and external funding costs. Since then numerous models have been developed regarding both the household and the firm sector that assume frictions in funding (Kiyotaki and Moore (1997), Aoki, Proudman, and Vlieghe (2004), Iacoviello (2005)). In all these models borrowers have lower discount factors than lenders which makes them hit their borrowing limit. Being at the credit constraint makes these agents vulnerable to labour income shocks, similar to the poor HtM households in TANK models, as well as to shocks to their wealth. In particular, if the credit constrained agents are required to provide a collateral to compensate for the risk of a credit default, they become sensitive to changes in the value of their collateral too, as their credit constraint moves in accordance with it.

The most recent models feature a full spectrum of heterogeneous agents. In contrast to RANK or TANK models that only feature aggregate shocks, these HANK models feature an

incomplete insurance market which ensures that the agents in these models are unable to insure each other against heterogeneous labour income shocks. This leads to differences on household balance sheets, creating unequal distributions of wealth and income. The agents maximise their utility given the wealth they own and their specific income shock process, which can be described through the frequency and magnitude of the shock arrival. In the absence of an insurance market, insuring has to take place through precautionary savings, similar to Carroll (1997). As all agents have a probability of being hit by a negative labour income shock, even the non-HtM households engage in precautionary saving (Carroll et al. 2017). Some notable HANK models in the field of monetary policy include Kaplan, Moll, and Violante (2018), Carroll et al. (2017), Hedlund et al. (2017), Guerrieri and Lorenzoni (2017), McKay, Nakamura, and Steinsson (2016), Wong (2021) and Luetticke (2021)

Some features of HANK models cannot be reproduced in simpler models without movements from one agent group to another. For instance, because of the precautionary savings motive monetary policy shocks can have asymmetric effects depending on whether they are positive or negative, and the magnitude of the shock might be different from a simple multiplicative effect (Kaplan and Violante 2018). This effect results from the fact that all agents save some share of the income they receive from a positive shock, leading to a smaller consumption response. Furthermore, when hit by a negative shock, some households that were previously unconstrained may become constrained, which also increases the magnitude of the output response (Hedlund et al. 2017). Applications of such an asymmetry in HANK models include for instance solving the forward guidance puzzle emphasised by Del Negro, Giannoni, and Patterson (2012) (McKay, Nakamura, and Steinsson (2016) and Bilbiie (2020)). Also, Hedlund et al. (2017) conclude that the asymmetry in responses to contractionary and expansionary monetary policy shocks is further amplified if the liquidity of the housing market changes procyclically with monetary policy.

Regarding monetary policy transmission, these HANK models suggest that the largest share of the monetary policy effects comes through indirect general equilibrium effects and not through the direct intertemporal substitution channel affecting the incentives to save and consume, as suggested by RANK models. This makes it possibly more demanding for monetary policy setters to control the final effect of a shock, as the effects through direct channels are easier to predict than effects through indirect channels (Kaplan, Moll, and Violante 2018).

In HANK models, varying MPCs play a role in monetary policy responses, as they do in

fiscal policy. Empirical evidence suggests that the differences in MPCs result from differences in household balance sheets. Particularly, the amount of liquid assets is a key determinant of the MPC rate: a higher level of liquid wealth reduces the MPC (Kaplan, Violante, and Weidner 2014). Unconstrained households holding more liquid wealth have MPCs close to zero, in line with the permanent income hypothesis, whereas for HtM households the MPCs come close to one (Carroll et al. (2017), Kaplan, Moll, and Violante (2018)). Furthermore, Hedlund et al. (2017) find that MPCs are closely linked to the leverage levels of households, as highly leveraged households are unlikely to be able to smooth consumption with their low levels of liquid wealth. According to their findings, households with a loan-to-value (LTV) ratio over 0.85 have on average MPC of 0.27, whereas the MPC for households with LTV lower than 0.85 is on average 0.19. Also Mian, Rao, and Sufi (2013) find that MPCs vary with leverage ratios, in addition to income.

Thus, as the amount of liquid wealth is crucial for the heterogeneity in MPC rates, a typical feature of HANK models is the presence of at least two types of assets[2]. For instance, Kaplan, Moll, and Violante (2018) assume that households can save in two types of assets: a liquid asset which can be accessed without a cost, and an illiquid asset with a higher return that can be accessed only by paying a transaction cost. The different frequencies and magnitudes of income shocks ensure that agents have different balance sheet structures: frequent but mild shocks make it desirable to hold liquid assets whereas large but infrequent shocks favour holding illiquid assets. Importantly, this process creates some agents that have a positive and large amount of illiquid assets on their balance sheets, but low amount of liquid assets.

Instead of having a full spectrum of heterogeneous agents, the presentation of heterogeneity can be simplified. Kaplan, Violante, and Weidner (2014) observe the balance sheets of consumers and find that consumers can roughly be divided into three groups: non-hand-to-mouth, wealthy hand-to-mouth and poor hand-to-mouth. The wealthy HtM differ from the poor HtM by having large amount of illiquid assets on their balance sheet. However, both have only a low amount of liquid assets, whereas non-HtM households have a positive and relatively higher level of liquid assets. Kaplan, Violante, and Weidner (2014) find that both wealthy HtM and poor HtM have high MPCs, the wealthy HtM having an even higher MPC than the poor HtM[3]. However, their high MPCs are due to different constraints: the poor HtM find themselves at the zero

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[2]In some simplifications this assumption is dropped. See for instance the one-asset HANK in Ahn et al. (2018).

[3]This evidence is in line with Wong (2021), who finds that young mortgagors have 2-3 times higher MPCs than the average MPC in USA. These households fit the description of a "wealthy hand-to-mouth".

kink of their budget constraint, whereas for the wealthy HtM the kink comes from a borrowing constraint. These three representative types of households will serve as the foundation for the model developed in Section 3.

Compared to the poor hand-to-mouth who tend to have low income, the wealthy hand-to-mouth income is not much lower than that of non-HtM consumers and therefore their share of the aggregate consumption is significant. According to Kaplan, Violante, and Weidner (2014), roughly one third of US-households can be classified as HtM, with two thirds of these HtM households being wealthy HtM households. Hence, the wealthy HtM are a considerable group, representing a relatively large amount of the aggregate income, whereas the poor HtM share of aggregate income is very small.

Kaplan, Moll, and Violante (2018) find that the presence of these wealthy HtM household is central for the results of their HANK model. However, as the subsequent analysis will show, building and computing a full HANK model is not necessary to get similar results. The intuition behind this result may be captured by reflecting the key lines among which HANK models introduce heterogeneity (Debortoli and Galí 2017):

1. Changes in consumption between agent groups.

2. Changes in consumption within the agent groups.

3. Changes in the shares of the agent groups.

When it comes to modelling the first source of heterogeneity, a simple TANK model can provide similar results as a HANK model, as argued by Debortoli and Galí (2017). On a similar line, a simple HANK model can match the third source (Bilbiie 2020). Only in cases where the second source of heterogeneity needs to be modelled a full-scale HANK model is needed.

Considering the representation of the first line of heterogeneity, a simple TANK model presents all the HtM agents as poor HtM agents. It therefore neglects the wealthy HtM, who are most important drivers of the aggregate results in HANK models (Kaplan, Moll, and Violante (2018), Wong (2021), Luetticke (2021)). In particular, the the effects arising from the the wealthy HtM balance sheets are left out. Furthermore, when all three groups are included; the non-HtM, wealthy HtM and poor HtM; their differing responses and the possible spill-over effects from one group to another can be captured correctly. Especially, an important application of the HANK models is modelling the redistributive effects of monetary policy shocks

and consequently the inequality that follows from the different consumption responses (Auclert (2019), Hedlund et al. (2017)). Some of these redistributive effects work through balance sheet heterogeneity and are therefore impossible to model in a TANK setting. In short, a model with three types of agents can provide an easy way to study the redistribution and inequality caused by a monetary policy shock.

3   Model

This section introduces a three-agent New Keynesian model (THRANK) that features financial frictions in the form of credit constrained agents. Its basic characteristics follow Iacoviello (2005). However, the firm sector is simplified by leaving out the entrepreneurs, as in Rubio (2011). Furthermore, to concentrate on the households and to keep the model as simple as possible, no capital is included in the production, again similar to Rubio (2011).

The household sector is divided into three types of agents along the lines of Kaplan, Violante, and Weidner (2014), thereby adding RoT households into the Iacoviello model. All agents are infinitely living but they differ in their access to the credit market, which is a one-period bond market. The non-HtM have unlimited access to saving and borrowing, the wealthy HtM can borrow up to their borrowing constraint and the poor HtM are completely excluded from the credit market. Furthermore, only non-HtM and wealthy HtM can own housing. The model does not feature a division between liquid and illiquid assets with differing rates of return as for instance in Kaplan, Moll, and Violante (2018). However, the adjustment of housing holdings comes with a cost, making housing illiquid. In addition, the housing holdings of the wealthy HtM and non-HTM will be included in their utility function, which makes housing more illiquid in the sense that these agents would prefer adjusting their bonds, which are not included in the utility function, making them the liquid assets in the economy.

In the literature, the model proposed by Cloyne, Ferreira, and Surico (2020) to match their empirical evidence is probably the closest one to the model presented below. However, there are three small differences. First, their model distinguishes between durable and non-durable consumption, whereas the model in this paper does not. I decide not to distinguish between the types of consumption, since separating them is usually done with the assumption that the prices of durables are less sticky than the prices of non-durables. However, empirical evidence shows that this is not necessarily the case, and that housing is the only durable good that has prices

that are more flexible than those of the non-durables (Cantelmo and Melina 2018). Second, Cloyne, Ferreira, and Surico (2020) use differences in housing preferences to separate the groups of wealthy and poor HtM (in their model labelled as mortgagors and renters), whereas these groups' shares are directly exogenously given in the present model. This difference is small and only technical as the method in Cloyne, Ferreira, and Surico (2020) leads to an exogenously given share as well. Third, in their model, debt contracts are long-term. I opt for short-term contracts so that the model becomes comparable to most HANK models which use a short-term structure, as for instance in Kaplan, Moll, and Violante (2018).

3.1 Households

Non-HtM

The first type of agents, and the largest group in the economy, are the unconstrained households. They are Ricardian households that have unlimited access to credit market. They can optimise their consumption intertemporally by borrowing or saving in bonds. These agents maximise their utility function

$$E_0 \sum_{t=0}^{\infty} \beta^{'t} \left(\ln c_t^{'} + j_t \ln h_t^{'} - \frac{(L_t^{'})^{\eta}}{\eta} \right) \tag{1}$$

which is subject to a budget constraint in the form of

$$c_t^{'} + q_t(h_t^{'} - h_{t-1}^{'}) + \frac{R_{t-1} b_{t-1}^{'}}{\pi_t} + \frac{\phi q_t}{2} \left(\frac{h_t^{'} - h_{t-1}^{'}}{h_{t-1}^{'}} \right)^2 h_{t-1}^{'} = b_t^{'} + w_t^{'} L_t^{'} + F_t \tag{2}$$

where $\beta^{'}$ is the non-HtM discount rate, $c_t^{'}$ is the consumption level at time t, q_t is the real housing price, $h_t^{'}$ are the housing holdings of the non-HtM, R_t is the nominal interest rate set by the central bank and $b_t^{'}$ is the real amount of debt or savings when money is borrowed to other agents in the economy, depending on the sign[4]. π_t is the period t inflation rate, defined as $\pi_t = \frac{P_t}{P_{t-1}}$, where P_t is the price level of period t. ϕ is the housing adjustment cost. $w_t^{'}$ is the wage rate of the unconstrained households, $L_t^{'}$ is their labour supply and finally, F_t are the profits paid out to households from the monopolistically competitive intermediate producers. Thus, the non-HtM agents retrieve income from labour, from owning the firms, from their savings and from increases in the value of their housing. They use this income to finance their consumption, to save, or to buy more housing.

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[4]In this model the non-HtM only have savings due to the impatience of the wealthy HtM.

The problem gives rise to the same first-order conditions as in the baseline model of Iacoviello (2005), except for the added housing adjustment costs in the third condition, which are the same as in the extended model of the same paper:

$$\frac{1}{c'_t} = \beta' E_t \frac{R_t}{\pi_{t+1} c'_{t+1}} \tag{3}$$

$$w'_t = (L'_t)^{\eta-1} c'_t \tag{4}$$

$$\frac{1}{c'_t}\left(q_t + \phi q_t\left(\frac{h'_t - h'_{t-1}}{h'_{t-1}}\right)\right) = \frac{j_t}{h'_t} + \frac{\beta'}{E_t c'_{t+1}}\left(E_t q_{t+1} + \frac{\phi}{2} E_t q_{t+1}\left(\frac{E_t h'^2_{t+1} - h'^2_t}{h'^2_t}\right)\right) \tag{5}$$

where the first one is the first order condition with respect to b'_t, the second one to L'_t and the third one to h'_t.

Wealthy HtM

In addition, there are some credit constrained households in the economy. These agents maximise the same form of utility function but their discount factor is slightly smaller than that of the unconstrained households' discount factor. This feature ensures that these consumers become the debtors in the economy.

$$E_0 \sum_{t=0}^{\infty} \beta''^t\left(\ln c''_t + j_t \ln h''_t - \frac{(L''_t)^\eta}{\eta}\right) \tag{6}$$

where $\beta'' < \beta'$

$$c''_t + q_t(h''_t - h''_{t-1}) + \frac{R_{t-1} b''_{t-1}}{\pi_t} + \frac{\phi q_t}{2}\left(\frac{h''_t - h''_{t-1}}{h''_{t-1}}\right)^2 h''_{t-1} = b''_t + w''_t L''_t \tag{7}$$

Thus, their income can come from labour, savings, or increases in housing wealth. However, their discount factor is lower than the discount factor of the patient households. Since the latter determines the interest rate in the economy, the prevailing interest rate is lower than what would be required for the wealthy HtM to be indifferent between consumption today and future consumption. Therefore, the wealthy HtM will borrow as much as they can. They face a constraint governing the amount of debt that they can borrow. This limit is given by

$$b''_t \le m E_t \frac{q_{t+1} h''_t \pi_{t+1}}{R_t} \tag{8}$$

where m represents the maximum LTV ratio in the economy.

The first order conditions for the credit constrained households are the following, again the same as in the baseline model of Iacoviello (2005) with the exception of the housing adjustment cost, which is from the extended model:

$$\frac{1}{c_t''} = \beta'' E_t \frac{R_t}{\pi_{t+1} c_{t+1}''} + \lambda_t'' R_t \tag{9}$$

$$w_t'' = (L_t'')^{\eta-1} c_t'' \tag{10}$$

$$\frac{1}{c_t''}\left(q_t + \phi q_t \left(\frac{h_t'' - h_{t-1}''}{h_{t-1}''}\right)\right) = \frac{j_t}{h_t''} + \frac{\beta''}{E_t c_{t+1}''}\left(E_t q_{t+1} + \frac{\phi}{2} E_t q_{t+1}\left(\frac{E_t h_{t+1}''^2 - h_t''^2}{h_t''^2}\right)\right) +$$
$$\lambda_t'' m E_t q_{t+1} \pi_{t+1} \tag{11}$$

Poor HtM

As opposed to the models of Iacoviello (2005) and Rubio (2011), the current model also features hand-to-mouth households. The utility function of this agents group looks slightly simpler, as these households are excluded from the housing and debt market:

$$E_0 \sum_{t=0}^{\infty} \beta'''^t \left(\ln c_t''' - \frac{(L_t''')^\eta}{\eta}\right) \tag{12}$$

The discount factor of the poor HtM agents can be different from the other types of agents, but it could also be the same. As they will consume all their income in each period in any case and cannot lend or borrow, the value of their discount factor does not matter for their optimisation problem. Labour income is their only source of income. Therefore, their budget constraint reads as

$$c_t''' = w_t''' L_t''' \tag{13}$$

giving rise to a labour-market first order condition

$$w_t''' = (L_t''')^{\eta-1} c_t''' \tag{14}$$

The poor HtM are excluded from the debt market, as in Hedlund et al. (2017) and Cloyne, Ferreira, and Surico (2020), who both exclude renters from the debt market and only allow

homeowners to borrow money. In Hedlund et al. (2017) the division to different types of households arises endogenously, whereas the share of excluded households in the present model is assumed to be exogenous, similarly to Cloyne, Ferreira, and Surico (2020). Cloyne, Ferreira, and Surico (2020) provide evidence that the shares of mortgagors, outright homeowners and renters do not vary over time, and especially that they do not change in the aftermath of a monetary policy shock. This suggests that assuming an exogenous share is a good proxy. Kaplan, Violante, and Weidner (2014) and Wong (2021) further find evidence suggesting that the status of being non-HtM, wealthy HtM or poor HtM are to some extent related to age and position in the life-cycle. Therefore, one can assume that the shares remain roughly constant over time if age cohorts are not too different in size.

3.2 Firm sector

The model features two types of firms: monopolistically competitive intermediate goods producers and perfectly competitive final goods producers. Here the model differs from the Iacoviello (2005) model, as it does not feature entrepreneurs producing intermediate goods. Rather, the structure follows Rubio (2011).

Intermediate goods producers

The intermediate goods producers have a production function of the form

$$Y_t = A_t (L_t')^{\alpha} (L_t'')^{\gamma} (L_t''')^{1-\alpha-\gamma} \tag{15}$$

Where A_t is technology which evolves according to an autoregressive process

$$\log(A_t) = \rho_A \log(A_{t-1}) + u_{A_t} \tag{16}$$

α is the unconstrained households' share of the labour income, γ is the share of the collateral constrained households of the labour income and $1 - \alpha - \gamma$ is the share of the hand-to-mouth households.

The first order conditions for labour demand are the following

$$w_t' = \frac{\alpha Y_t}{X_t L_t'} \tag{17}$$

$$w_t'' = \frac{\gamma Y_t}{X_t L_t''} \tag{18}$$

$$w_t''' = \frac{(1 - \alpha - \gamma)Y_t}{X_t L_t'''} \tag{19}$$

where X_t is the markup.

The intermediate goods producers face Calvo price-setting and have a probability of $1 - \theta$ to be able to reset their prices in each period (Calvo 1983). Therefore, the optimal reset price solves

$$\sum_{k=0}^{\infty} (\beta'\theta)^k E_t \left\{ \Lambda_{t,k} \left(\frac{P_t^*(z)}{P_{t+k}} - \frac{\varepsilon/\varepsilon - 1}{X_{t+k}} \right) Y_{t+k}^*(z) \right\} = 0 \tag{20}$$

where the steady state property of $X = \frac{\varepsilon}{\varepsilon - 1}$ has been used. $\Lambda_{t,k} = \beta' \frac{c_t'}{c_{t+k}'}$ is the patient household relevant discount factor.

The aggregate price level then evolves according to

$$P_t = \left(\theta P_{t-1}^{1-\varepsilon} + (1 - \theta)(P_t^*)^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} \tag{21}$$

The intermediate goods producers maximise their profits $F_t = \left(1 - \frac{1}{X_t} \right) Y_t$ that are paid out to the patient households who own the firms.

Final goods producers

The final goods producers use intermediate goods to produce final goods according to the production function

$$Y_t = \left[\int_0^1 Y_t(z)^{\frac{\varepsilon - 1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon - 1}} \tag{22}$$

The final goods producers are identical and choose $Y_t(z)$ to minimise their costs, which results in the following demand function for intermediate goods:

$$Y_t(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} Y_t \tag{23}$$

This again leads to the following price index:

$$P_t = \left[\int_0^1 P_t(z)^{1-\varepsilon} dz \right]^{\frac{1}{\varepsilon - 1}} \tag{24}$$

There is perfect competition in the production of final goods, so no profits are made and therefore also not paid out.

3.3 Monetary policy

Finally, there is a central bank which conducts monetary policy according to an interest rate smoothing Taylor rule, responding to past inflation and output. The rule is given as

$$R_t = (R_{t-1})^{r_R} \left(\pi_{t-1}^{1+r_\pi} \left(\frac{Y_{t-1}}{Y} \right)^{r_Y} \overline{rr} \right)^{1-r_R} e_{R,t} \tag{25}$$

which is identical to Iacoviello (2005). $\overline{rr}$ is the steady-state real rate and Y is the steady-state level of output. Interest rate smoothing takes place when $r_R > 0$.

3.4 Equilibrium

The steady state of the model is solved in shares. The equilibrium satisfies the equations described in the previous parts. There are four markets that clear: the housing market, the goods market, the labour market and the market for loans. The clearing conditions are the following: the real estate market clears with $h_t' + h_t'' = H$, the goods market with $c_t' + c_t'' + c_t''' + \frac{\phi q_t}{2} \left(\frac{h_t' - h_{t-1}'}{h_{t-1}'} \right)^2 h_{t-1}' + \frac{\phi q_t}{2} \left(\frac{h_t'' - h_{t-1}''}{h_{t-1}''} \right)^2 h_{t-1}'' = Y_t$, the labour market with $L_t' = L_t'$, $L_t'' = L_t''$ and $L_t''' = L_t'''$, and the market for loans with $b_t' + b_t'' = 0$. In the steady state, $R = \frac{1}{\beta'}$. The steady state shares are

$$\frac{qh''}{Y} = \frac{j}{1 - \beta'' - m(\beta' - \beta'' - j(1-\beta'))} \frac{\gamma}{X} \tag{26}$$

$$\frac{b''}{Y} = \frac{j\beta' m}{1 - \beta'' - m(\beta' - \beta'' - j(1-\beta'))} \frac{\gamma}{X} \tag{27}$$

$$\frac{c''}{Y} = \frac{1 - \beta'' - m(\beta' - \beta'')}{1 - \beta'' - m(\beta' - \beta'' - j(1-\beta'))} \frac{\gamma}{X} \tag{28}$$

$$\frac{c'}{Y} = \frac{1}{X} \left(X + \alpha - 1 + \frac{\gamma j m(1-\beta')}{1 - \beta'' - m(\beta' - \beta'' - j(1-\beta'))} \right) \tag{29}$$

$$\frac{c'''}{Y} = \frac{(1 - \alpha - \gamma)}{X} \tag{30}$$

$$\frac{h''}{H} = \frac{\gamma(1-\beta')}{\gamma(1-\beta')(1+jm) + (X + \alpha - 1)(1 - \beta'' - m(\beta' - \beta'' - j(1-\beta')))} \tag{31}$$

The log-linerised system of equations governing the dynamics of the model can be expressed

as

$$\hat{Y}_t = \frac{c'}{Y}\hat{c}'_t + \frac{c''}{Y}\hat{c}''_t + \frac{c'''}{Y}\hat{c}'''_t \tag{32}$$

$$\hat{c}'_t = E_t(\hat{c}'_{t+1}) - \widehat{rr}_t \tag{33}$$

$$\frac{c''}{Y}\hat{c}''_t = \frac{b''}{Y}\hat{b}''_t - \frac{qh''}{Y}(\hat{h}''_t - \hat{h}''_{t-1}) - \frac{Rb''}{Y}(\hat{R}_{t-1} + \hat{b}''_{t-1} - \hat{\pi}_t) + \frac{\gamma}{X}(\hat{Y}_t - \hat{X}_t) \tag{34}$$

$$\hat{c}'''_t = \hat{Y}_t - \hat{X}_t \tag{35}$$

$$q_t + \phi(\hat{h}''_t - \hat{h}''_{t-1}) = \beta_w E_t\hat{q}_{t+1} + (1 - \beta_w)(\hat{j}_t - \hat{h}''_t) - (1 - m)\beta'' E_t\hat{c}''_{t+1} + (1 - m\beta')\hat{c}''_t -$$
$$m\beta'\widehat{rr}_t + \beta''\phi(E_t\hat{h}''_{t+1} - \hat{h}''_t) \tag{36}$$

$$\hat{q}_t + \phi\iota(\hat{h}''_{t-1} - \hat{h}''_t) = \beta' E_t\hat{q}_{t+1} + (1 - \beta')\hat{j}_t + (1 - \beta')\iota\hat{h}''_t + \hat{c}'_t - \beta' E_t\hat{c}'_{t+1} +$$
$$\beta'\phi\iota(\hat{h}''_t - E_t\hat{h}''_{t+1}) \tag{37}$$

$$\hat{b}''_t = E_t\hat{q}_{t+1} + \hat{h}''_t - \widehat{rr}_t \tag{38}$$

$$\hat{Y}_t = \frac{1}{\eta - 1}\Big(\eta\hat{A}_t - \hat{X}_t - \alpha\hat{c}'_t - \gamma\hat{c}''_t - (1 - \alpha - \gamma)\hat{c}'''_t\Big) \tag{39}$$

$$\hat{\pi}_t = \beta' E_t\hat{\pi}_{t+1} - \kappa\hat{X}_t + \hat{u}_t \tag{40}$$

$$\hat{R}_t = r_R\hat{R}_{t-1} + (1 - r_R)((1 + r_\pi)\hat{\pi}_{t-1} + r_Y\hat{Y}_{t-1}) + \hat{e}_{R,t} \tag{41}$$

where $\beta_w = m\beta' + (1 - m)\beta''$, $\iota = \frac{h''}{H}\frac{1}{1 - \frac{h''}{H}}$, $\kappa = (1 - \theta)\frac{(1 - \beta'\theta)}{\theta}$ and the change in the real

interest rate is defined as $\widehat{rr}_t = \hat{R}_t - E_t(\hat{\pi}_{t+1})$. The equation (32) is the log-linearisation of the aggregate output, (33) the Euler equation for the non-HtM or patient households. (34) is the budget constraint of the wealthy HtM and (35) of the poor HtM. (36) combines the Euler and the housing demand of the wealthy HtM and (37) is the housing demand of the non-HtM. (38) is the log-linearised borrowing constraint and (39) results from the production function and labour market equilibrium. (40) is the forward-looking Phillips-curve and finally (41) is the monetary policy reaction function.

3.5   Calibration

The calibration of the parameters is done for the US economy. I mostly follow the values given in Iacoviello (2005). I deviate in the case of the LTV ratio by setting $m = 0.9$ as in Rubio (2011), instead of 0.89 in Iacoviello, but the change is not large. I pick a high LTV ratio, so that the wealthy HtM present the highly indebted agents in the economy, unlike for instance Calza, Monacelli, and Stracca (2013), who pick a value of $m = 0.7$ to represent the mean value of LTV ratios. I also set the wealthy-HtM discount factor to $\beta'' = 0.98$ as in Rubio (2011). The housing adjustment cost parameter ϕ is set to 0.05, as in Iacoviello and Pavan (2013).

For each agent group, I calculate its respective share of labour income based on the numbers given in Kaplan, Violante, and Weidner (2014). Using the empirical observation of Kaplan, Violante, and Weidner (2014) that about one third of households are some form of HtM, and that two thirds of these are wealthy HtM, I set the shares of wealthy HtM and poor HtM to 0.22 and 0.11 of the population, respectively. Next, Kaplan, Violante, and Weidner (2014) report the average income for the different types of agents. I use the income at the peak of the earnings cycle, which is reported by Kaplan, Violante, and Weidner (2014) to be approximately 70 000\$ for non-HtM households, 50 000\$ for wealthy HtM households and 20 000\$ for poor HtM households. I normalise these incomes by the non-HtM income. Next, I multiply the population shares by the normalised shares of income to get the total labour income of the agent group. I calculate the shares of each group of the new aggregate by dividing the aggregate income of each group by the whole aggregate income. The calculations show that non-HtM have a share of labour income of 0.78, wealthy HtM 0.18 and poor HtM 0.04.

The share of non-HtM is slightly higher than their respective labour income share, which is 0.64 in Iacoviello (2005). However, I consider this result to be robust, as Iacoviello and Neri (2010) report the share of labour income of the unconstrained households to be 0.78. Debortoli and Galí (2017) set the share of Keynesian households to 0.21 in a TANK model to 0.79, leaving a share of to Ricardian households. In their model, this is the population share of the HtM households, but in models expressing the sizes of groups as population and not as income shares the income is the same across groups, which makes the number almost equivalent to mine. Thus, instead of using only the population shares, the current model takes into account the fact that the share of the aggregate consumption that the HtM groups make up is smaller than their population share due to their lower income.

Parameter	Interpretation	Value
β'	Non-HtM discount factor	0.99
β''	Wealthy HtM discount factor	0.98
α	Labour income share of the non-HtM	0.78
γ	Labour income share of the wealthy HtM	0.18
j	Housing preference parameter	0.1
η	Labour market parameter	1.01
X	Steady-state markup	1.05
θ	Calvo parameter	0.75
m	Maximum LTV ratio	0.9
ϕ	Housing adjustment cost parameter	0.05
r_R	Interest rate persistence/smoothing parameter	0.73
r_π	Taylor rule inflation parameter	0.27
r_Y	Taylor rule output parameter	0.13
ρ_u	Inflation shock persistence	0.59
ρ_j	Housing preference shock persistence	0.85
ρ_A	Technology shock persistence	0.03
σ_u	Inflation shock standard deviation	0.17
σ_j	Housing preference shock standard deviation	24.89
σ_A	Technology shock standard deviation	2.24
σ_R	Monetary policy shock standard deviation	0.29

Table 1: Parameter calibration

In addition, I deviate from Iacoviello (2005) by setting the weight of the output in the Taylor rule to 0.13, a number consistent with the Dynare code provided by Iacoviello[5]. Other values are as in the original paper. A summary of the parameter values is given in Table 1. All parameter values chosen are in line with typical values in the literature.

3.6 Impulse responses and comparison to RANK and TANK

Figure 1 displays the impulse responses from the THRANK model to a one standard deviation contractionary monetary policy shock. Output sinks following the negative shock as saving is encouraged through the higher interest rate and consumption is discouraged. As in RANK models, the shape of the non-HtM consumption response follows closely the interest rate with a mirror image. Interest rate undershoots, which in turn leads to overshooting in non-HtM consumption and housing prices. These humped-shaped responses are similar to the ones found by Rubio (2011) and Iacoviello (2005) and follow from the strong reaction of the interest rate to the response of inflation.

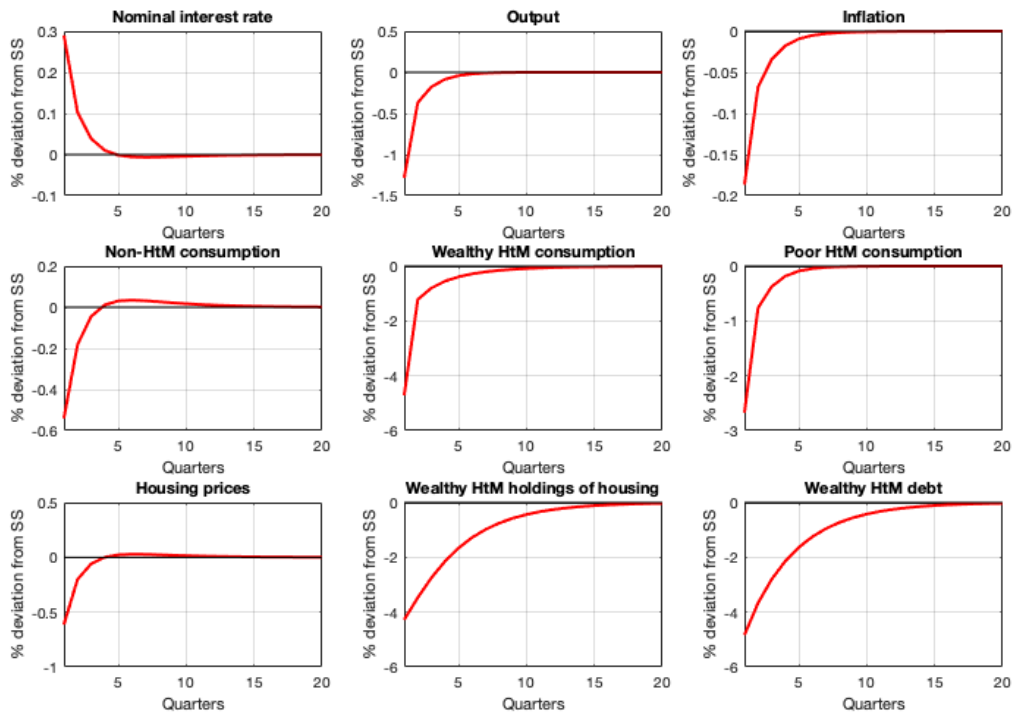[5]https://www2.bc.edu/matteo-iacoviello/research.htm

Figure 1: The impulse responses to a one standard deviation monetary policy shock.

The poor HtM and the wealthy HtM experience larger consumption reductions than the non-HtM due to their inability to smooth consumption. The wealthy HtM experience the largest effects: as in Iacoviello (2005), the contractionary monetary policy leads to a decrease in housing prices, as financing costs for housing increase and the housing demand declines. Through the LTV ratio this leads to a decreasing borrowing limit which forces the collateral constrained households to deleverage. This deleveraging process reduces the wealthy HtM consumption further. The wealthy HtM also face increasing borrowing costs, due to the falling inflation, as the borrowing costs are expressed in nominal terms. This debt deflation channel further reduces the consumption of the wealthy HtM.

From the poor HtM consumption response one can detect the general equilibrium effects of the monetary policy shock. This group's consumption falls as wages and overall labour income decrease. The response of poor HtM is smaller in magnitude than the response of the wealthy HtM because of the additional collateral channel and debt deflation channel that the wealthy HtM experience. The order of the size of the consumption responses is the same as in Cloyne,

Ferreira, and Surico (2020): the wealthy HtM experience the largest response, followed by the poor HtM. The non-HtM reduce their consumption the least. The wealthy HtM are the most important driver of the aggregate result, as in HANK models (Kaplan, Moll, and Violante (2018), Wong (2021)). Overall, however, the reactions seem quite standard, and a little can be said about how the THRANK model differs from others without a direct comparison to other models. Therefore, I will compare this model's responses to the responses produced by the widely-used RANK and TANK models[6].

Results from comparison

Figure 2 displays the impulse responses of the three different models. All models show a similar picture characterised by a declining output. The responses have the smallest magnitude in the RANK model, marked with black dashed line. The reactions of the output and non-HtM consumption are the same, as the economy is only populated by the non-HtM. Housing prices follow the non-HtM consumption path in all three models.

The TANK model, whose responses are marked with a solid blue line, takes the middle ground between the RANK model and the THRANK. Here, output reacts more strongly than in the RANK model but less than in the three-agent model. Increasing heterogeneity in the form of an additional agent group makes also the response of inflation greater. Notable is that the response of the poor HtM agents is stronger in the THRANK than in the TANK model. Due to the presence of the wealthy HtM agents who react to the collateral channel and debt deflation channel in addition to the labour income channel, the aggregate output declines more than in the case of the TANK model. This leads to a relatively larger drop in labour income, which in turn is directly visible in the response of the poor HtM.

Kaplan and Violante (2018) compare the impulse responses to different economic shocks in a HANK model and a RANK model. They find that even though the responses of the models look similar, the channels through which the effect comes may be very different. The same reasoning applies here. There are no large differences in the aggregate output responses, but the differences come from the presence of monetary policy transmission channels. The output response of this paper's THRANK is larger than the response of the RANK model, which is in line with the

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[6]The full model descriptions for the RANK and TANK models are provided in the appendix. The calibration follows the baseline three-agent model as closely as possible, except for the shares of aggregate income. In the RANK model, non-HtM agents have the whole labour income, whereas in the TANK model the poor-HtM labour income share is set to match the share of all HtM agents in the baseline calibration, which in 0.21.
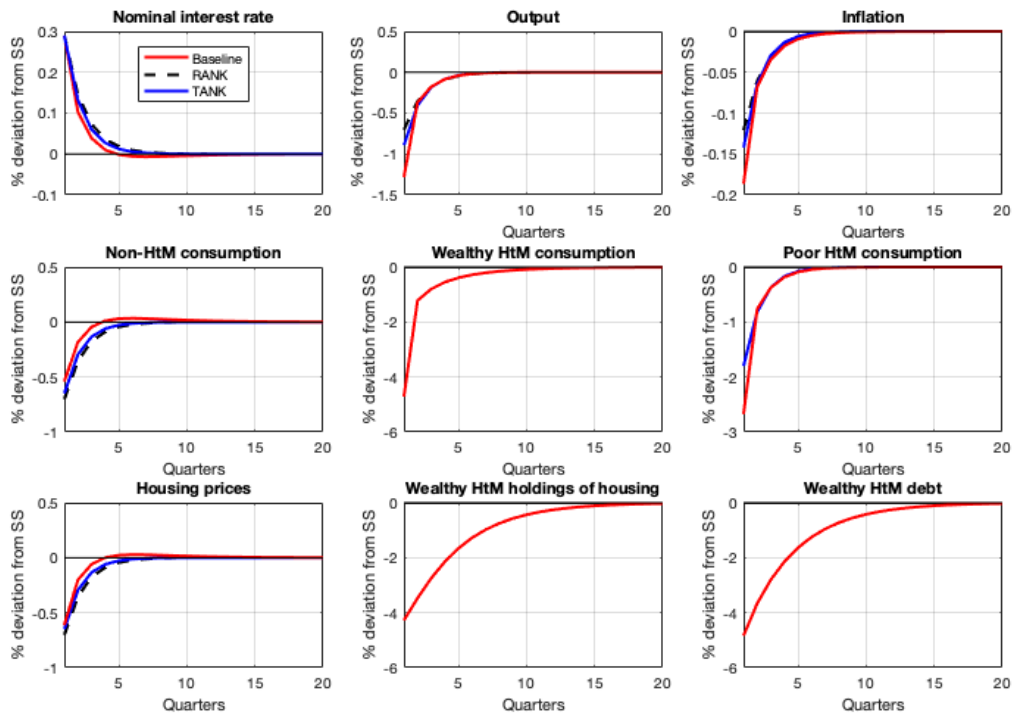
Figure 2: The impulse responses to a one standard deviation monetary policy shock. Baseline model: red solid line, RANK model: black dashed line, TANK model: blue solid line.

result of Luetticke (2021), finding that the output response of HANK is larger than that of RANK. On the other hand, in Kaplan and Violante (2018) the response of the HANK model is smaller than the RANK model's response. However, these result may be sensitive to changes in parameter values and drawing definite conclusions on which model produces the largest output responses is difficult and should be done with caution.

Debortoli and Galí (2017) argue that a TANK model approximates reasonably well the aggregate output response of the HANK model and the heterogeneous responses between agent groups, even though it misses the diverting responses within the agent groups and the changes in relative group sizes. The same holds here for the THRANK, but the level of heterogeneity between groups is even higher due to the presence of one additional agent type. In the THRANK, the intertemporal substitution effect is present in the non-HtM behaviour, whereas both wealthy and poor HtM react to the labour income channel. Additionally, the wealth effect amplifies the response of the wealthy HtM households. Since central bankers need understand through which channels the aggregate effect emerges in an attempt to control the effects of monetary

policy (Kaplan, Moll, and Violante 2018), I will discuss these channels in the next section. Furthermore, Auclert (2019) argues that traditional RANK and TANK models only capture the aggregate effects that are similar for each agent, while the redistributive channels of monetary policy remain undiscovered. In contrast, I argue that these redistribution channels are present in the THRANK model developed above.

4 Monetary policy transmission channels

The finding that the impulse responses are similar but the channels through which monetary policy transmits might be different raises the question through which exact channels the differing effects arise. The distinction between direct and indirect effects of monetary policy in Kaplan, Moll, and Violante (2018) suggests that some of the channels of monetary policy may not be captured accurately by models that feature only one type of agent. In the following, I present and describe in more detail the different channels of monetary policy that have been emphasised in the literature. The terminology follows Haldane (2018) and Kaplan, Moll, and Violante (2018). I first divide the channels into direct and indirect effects as in Kaplan, Moll, and Violante (2018) and then further into more detailed channels. I will discuss to which extent the different channels are present in the three-agent model and compare their presence to empirical results. I will also discuss the redistributive channels of monetary policy that are emphasised by Auclert (2019).

4.1 Direct effects

Direct effects are the first-round effects following a monetary policy shock resulting directly from the change in the interest rate. There are two direct channels of monetary policy: the intertemporal substitution channel and the cash-flow channel.

Intertemporal substitution

As discussed earlier, with only Ricardian type of households present, the largest effect of monetary policy comes from the direct effect of intertemporal substitution. The central bank can control consumption and output by affecting the returns from bonds. A decrease in the interest rate makes the households want to save less and consume more today and vice versa. Kaplan, Moll, and Violante (2018) estimate that the direct effects account for over 90% of the effects of a monetary policy shock in a traditional RANK model with any reasonable parametrisation.

For instance, with the parametrisation of the RANK model in the previous section the share of direct effects is 96.4%, as the share of direct effects can be calculated with the following formula given in Kaplan, Moll, and Violante (2018) and Bilbiie (2020):

$$\omega = \frac{1 - \beta}{1 - \beta\rho}$$

where β is the discount factor and ρ is the interest rate persistence parameter[7], 0.99 and 0.73 respectively in the current model.

Cash-flow channel

When a model features both creditors and debtors, a cash-flow channel emerges. The cash-flow channel is the direct effect of redistribution of income between creditors and debtors, resulting from the interest payments paid on savings or on debt. When the interest rate rises, the interest payments on debt increase but agents with savings receive higher returns. Money is transferred from borrowers to lenders. If all households had the same MPCs, these effects would cancel each other out and the aggregate effect would be the same as in a RANK model. However, as borrowers tend to have higher MPCs than lenders, a rise in interest rates is likely to decrease the output to a higher extent than predicted by a model with homogeneous agents. Naturally, the inverse holds for a monetary expansion.

The cash-flow effect is more significant when debt contracts extend through several periods. For a large effect, the monetary policy easing also needs to last for several periods. In DSGE models with a short-term debt structure and a one-time monetary policy shock that dies out the effect of the cash-flow channel is limited (Garriga, Kydland, and Šustek (2017), Cloyne, Ferreira, and Surico (2020)).

For the existence of the effect it is also crucial whether households have mortgages with variable or fixed interest rates. Comparing adjustable rate (ARM) and fixed-rate mortgages (FRM) in a setting with credit constrained households, Calza, Monacelli, and Stracca (2013) and Rubio (2011) find that an ARM structure accelerates the transmission of monetary policy, since the interest rate payments are always the same with FRMs. In this case monetary policy only transmits through the effect on the interest rate of new loan contracts. This is the so-called price effect, whereas the decrease in the payments on existing debt is the income effect (Garriga,

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[7]In this paper the persistence parameter is r_R.

Kydland, and Šustek 2017). However, with fixed-rate mortages an additional easing channel may arise if mortages are refinanced during periods of monetary policy easing (Wong (2021), Hurst and Stafford (2004)), with ARMs a refinancing takes automatically place each period.

Flodén et al. (2021) study the cash-flow effect empirically. They find that high-LTV households with large debt-to-income ratios are at special risk of either defaulting or having to cut down their consumption considerably in the wake of an interest rate increase in case they have an ARM. Further, Di Maggio et al. (2017) find that lower interest payments boosted the consumption of mortgagors considerably during the Financial Crisis when the mortgagors faced a decrease in their interest rates after a fixed period. However, they find that a considerable amount of the easing effect also channeled to a deleveraging process of the indebted households.

The RANK or TANK models feature no cash-flow effect, but in the THRANK or a two-agent model such as Iacoviello (2005) two similar effects to the cash-flow channel arise. First, the borrowing limit of the wealthy HtM is negatively related to the interest rate in period t (equation (8)), building a price effect on new loans rolled over. Second, a cash-flow channel emerges from the change in the nominal interest rate, but in the THRANK the effect emerges from the debt deflation channel (Iacoviello 2005). From the budget constraints of the wealthy HtM and non-HtM (equations (2) and (7)) it can be seen that the costs borrowing and returns from savings depend on the interest rate of the previous period and therefore there is no direct cash-flow channel. However, the costs and the returns depend on the inflation rate between periods $t - 1$ and t. As the second effect is indirect, arising from the lower inflation rate, it will be discussed under the inflation channel in indirect effects.

4.2 Indirect effects

Indirect, or also second round effects, are the effects resulting from changes in other variables caused by the initial change in the nominal interest rate. These effects can be divided into three classes: labour income channel, resulting from income and substitution effects following changes in wages; wealth channel, summarising the changes in the value of the households' balance sheets; and the inflation channel, capturing the fact that most debt contracts are written in nominal terms, which leads to a redistribution between debtors and creditors when the inflation rate changes.

Labour income channel

The labour income channel is the effect that results from the shock on the income that the agents receive from working. As the goods market needs to clear, the decrease in consumption caused by the direct effects results in a decrease in the aggregate demand and output. This presses the wages down. Kaplan, Moll, and Violante (2018) find that in a heterogeneous agents setting these labour income effects, in their paper labelled general equilibrium effects, dominate the direct effect of intertemporal substitution, even so much that the indirect effects account for 80% of the monetary policy shock transmission. In TANK models the share of labour income effect is usually approximately equal to the share of HtM agents in the economy, thus, the indirect effects still dominate but less so than in RANK models.

Wealth channel

The wealth channel summarises the changes in the prices of assets on the agents' balance sheets. Households who are credit constrained may become sensible to movements in their asset prices, either because they can sell their assets to finance consumption or they can borrow against the value of their assets. The agents' wealth can consist of all kinds of assets such as stocks or bonds, but probably the most common asset households hold is housing[8], as in the THRANK model. As interest rates go up, the financing costs of housing go up as well, which reduces the demand for housing and its price (Mishkin 2007). Housing prices therefore experience cyclical developments: during severe downturns housing prices stagnate or might even go down, which possibly exposes households to large negative wealth effects.

In the current setting, the wealth channel is reinforced by the existence of an endogenous debt limit, which is tied to the value of the housing ownings of the wealthy HtM. The collateral constraint exhibits pro-cyclical behaviour along with the housing prices. A binding constraint forces the households to deleverage when housing prices are declining but enables more borrowing when housing prices are increasing. This additional effect can be separately called the collateral channel (Iacoviello 2005). A constraint is used due to the possibility of a bankruptcy as well as information asymmetries and it further accelerates the wealth channel (Aoki, Proudman, and Vlieghe 2004). This reflects the view that frictions in the credit market can function as financial accelerators in the macroeconomy as costs of finance depend on the balance sheet

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[8]As housing plays such a large role, it can also be called separately the housing price channel (Hedlund et al. 2017).

of the borrower, with strong balance sheets lowering the external finance premium (Bernanke, Gertler, and Gilchrist 1999).

Empirically, Hedlund et al. (2017) find that the decrease in housing prices accounts for approximately 20% of the decrease in consumption after a contractionary monetary policy shock. High LTV households experience the strongest decreases in consumption. Iacoviello and Neri (2010) find through simple regression analysis that collateral effects increase the elasticity of consumption to housing wealth by 2.5%, representing the financial accelerator effect on consumption responses. From evidence during the Financial Crisis, Mian, Rao, and Sufi (2013) find that the MPC out of financial wealth is 5-7 cents per dollar decrease in housing prices. The authors conclude that this effect can be due to a normal wealth effect, or it can be reinforced by the collateral channel if the decline in housing prices forces the households to deleverage and cut back on consumption.

Note that in the current setting the collateral constraint is always binding. In reality, instead of deleveraging, households can go "underwater", in which case the value of their housing asset is lower than the value of their debt outstanding. As these households are above the maximum LTV ratio, they are also unable to refinance their mortgages, which makes their consumption independent of changes in the value of their housing asset until they have reached the LTV ratio again (Guren et al. 2021). Guerrieri and Iacoviello (2017) find that collateral constraints can also be only occasionally binding. Constraints tend to become binding in recessions, making the recessions asymmetrically more severe than upturns, as during upturns the constraints are non-binding.

Thus, as housing prices are strongly cyclical, there is an amplifying effect on consumption over the business cycle. Especially durable consumption reacts strongly to changes in housing prices (Aoki, Proudman, and Vlieghe (2004), Cloyne, Ferreira, and Surico (2020), Cantelmo and Melina (2018)). The current model does not separate durable and non-durable consumption, but it creates groups of agents who do not experience any wealth effects as they have zero assets (the poor HtM), some who have to adjust one-to-one to changes in housing prices (the wealthy HtM) and agents who do have assets, but are able to smooth any changes in their value by borrowing or saving (the non-HtM). The additional wealth and collateral effects are the main explanation why in the THRANK the negative response of the wealthy HtM is larger than the negative response of the poor HtM. The other ones are the cash-flow channel and the inflation channel.

Inflation channel

The inflation channel works through the effect of interest rates on inflation. As nominal interest rate rises, inflation tends to decrease. When debt contracts are written in nominal terms, a decrease in the inflation rate benefits debtors but hurts borrowers, as emphasised by Iacoviello (2005). The inflation channel has the largest effects in an FRM setting with long-term debt. In an FRM setting the nominal interest rate on the debt is constant, and thus variation in the inflation rate causes variation in the real interest rate paid on the debt. In an ARM setting the rise in the inflation rate is often offset by the increase in the nominal interest rate, leaving the effects on real interest rate small or even positive (Garriga, Kydland, and Šustek 2017). Furthermore, when the debt is long-term, the reduction on the outstanding debt payments is greater than in the case of short-term debt.

For the THRANK, the response of inflation causes the debt deflation channel, which increases the real borrowing costs of the wealthy HtM and leading to the cash-flow-like effect from wealthy HtM to non-HtM. As interest payments are determined based on the nominal interest rate and the amount of real debt from the previous period, an decrease in the inflation rate between periods $t = t - 1$ and $t = t$ causes an increase in the real interest rate and vice versa. This in turn transmits into higher real interest rate payments, leading to a cash-flow-like effect between the debtors and creditors.

4.3 Redistribution effects

So far, the heterogeneous effects of monetary policy have only depended on the balance sheets or credit constraints that the agents face. In the terminology introduced above, cash-flow channel, wealth channel and inflation channel redistribute resources between agents. In recent years, more and more attention has been drawn to the redistribution of income and consumption caused by monetary policy changes (Auclert (2019), Coibion et al. (2017), Hedlund et al. (2017), Luetticke (2021), Ampudia et al. (2018), Pugh, Bunn, and Yeates (2018)). HANK models are able to study the redistributive effects unlike RANK and TANK models. I will show how the THRANK can incorporate these redistributive effects in a simple way.

Redistribution channels in HANK models

Auclert (2019) and Hedlund et al. (2017) discuss the redistribution channels that are at work in HANK models. Auclert identifies three channels through which monetary policy redistributes between agents: the earnings heterogeneity channel, the interest rate exposure channel and the Fisher channel. The Fisher channel corresponds to the inflation channel, while the interest rate exposure channel and the earnings heterogeneity channel stem from heterogeneity in balance sheets and composition of earnings. Many of these redistributive channels can be modelled in the present setting without a computationally heavier HANK model. In the following, I will discuss how these effects are present in the THRANK.

Auclert (2019) defines in his paper the earnings heterogeneity channel as

$$Cov(\hat{MPC}_i, Y_i) < 0 \tag{42}$$

Thus, there is a negative covariance between the marginal propensity to consume and income on agent level. Therefore, when income is distributed from high-income to low-income agents the consumption response is larger than when the MPCs are constant and vice versa.

In the THRANK there is no heterogeneity in labour earnings shocks or income distribution, unlike in HANK models. However, when earnings are summerised to include labour income and profits from dividends, a similar earnings heterogeneity channel as in Auclert (2019) arises. The earnings heterogeneity channel combines also the heterogeneity arising from different composition of labour and profit income, resembling rather the income composition channel in the empirical terminology of Coibion et al. (2017). Therefore, this channel is present in the current model by combining the labour income and the dividend income of the non-HtM.

The interest rate exposure channel relates to the maturities of the agents' assets and liabilities. If the household in $t = 0$ needs to net save between periods to meet a balanced budget without borrowing in $t = 1$, there is a negative unhedged interest rate exposure (URE) and vice versa. This means that the currently-maturing liabilities exceed currently-maturing assets and therefore in the long run the assets exceed the liabilities to achieve a balanced intertemporal budget constraint. Assets and liabilities are very widely defined in Auclert's terminology, as assets include income and liabilities planned consumption. An increase in the real interest rate lowers the price of future consumption at the expense of consumption today, which hurts the agents with negative UREs and benefits the ones with positive UREs.

Holders of adjustable-rate debt have negative UREs, whereas large savings in short maturities create positive UREs (Auclert 2019). The opposite positions can also easily be seen from the bond market clearing condition $b'_t + b''_t = 0$, which gives $b''_t = -b'_t$. In the THRANK model, therefore, the wealthy HtM have negative UREs, the non-HtM positive UREs and for the poor HtM the URE is zero. Hence, the wealthy HtM are negatively exposed when the interest rate rises, whereas for the non-HtM the exposure is positive. Especially, note that for the UREs, a similar covariance condition holds as for the earnings heterogeneity channel.

$$Cov(\hat{MPC}_i, URE_i) < 0 \tag{43}$$

Finally, the Fisher channel arises from the net nominal position (NNP) of the agents, summarising whether the agent has more nominal assets or liabilities when everything is discounted to the present value. When the liabilities exceed the assets, the NNP is negative and vice versa. A decrease in the inflation rate hurts the agent with negative interest NNPs and benefits the agents with positive NNPs. Typically, the NNP is negative for mortgage households and positive for outright homeowners. However, no Fisher channel emerges if all assets are in real terms, as in the THRANK or also in many of the most common HANK models. Thus, for all agents the NNPs are zero.

In cases where there is no market for assets with long maturities, such as in the present model where debt is only one term, the real interest rate effects through the URE play a large role in the response while the role of the NNPs is limited (Auclert 2019). Following the negative covariances, when resources are redistributed from the high MPC agents to low MPC agents, the negative consumption response is even larger than the redistribution of resources would indicate when all agents have the same MPC.

Coming to the actual values of the MPCs in the THRANK, the non-HtM have MPCs close to zero, in line with the PIH and positive URE, whereas for both HtM consumers the MPC is one. This results from the fact that the agents who find themselves at their credit constraint or who cannot access to the credit market will always have an MPC of one Auclert (2019). If the credit constraint is binding and the constraint adjusts to changes in monetary policy, the consumption and labour supply responses of the constrained agent become dependent on the constraint adjustment.

Table 2 summarises the channels of Auclert (2019) and how they are present in the THRANK.

Source	Auclert (2019) redistribution channel	Hedlund et al. (2017) redistribution direction
Labour income Business (dividend) income	Earnings heterogeneity channel	From households who rely on labour income to households with more asset income
Intertemporal budget constraints and current balance sheets	Interest rate exposure channel	From debtors to lenders
Housing prices	-	Away from home owners

Table 2: Redistributive effects

The business income and labour income are added up to constitute aggregate earnings, which gives rise to an earnings heterogeneity channel. The interest rate exposure channel emerges from the intertemporal budget constraint and current balance sheets that the agents have. Furthermore, there is a housing price channel that is not present in Auclert (2019). However, this channel is present in Hedlund et al. (2017), who summarise the directions of redistributions for expansionary monetary policy. Here they go the other way around: a contractionary monetary policy shock directs income away from households living from labour income towards households living to a larger extent from asset income, from debtors to lenders and away from home owners[9].

Thus, in the THRANK income is redistributed from agents with an extremely high MPC to agents to agents which have extremely low MPCs. The differing MPC rates are in the three-agent model are created by the borrowing constraints that the agents have. Unlike in HANK models where the MPC rates would be on a spectrum between zero and one, here they are sharply divided between extremely high and extremely low values.

As emphasised by Auclert (2019), the response of the wealthy HtM consumption depends on the adjustment of their borrowing limit. In the Appendix I show a version of the model which includes an exogenous borrowing limit. This brings the model somewhat closer to the HANK setting of Kaplan, Moll, and Violante (2018), as in their model the exogenous credit constraint is tied to the quarterly income. Therefore, their model also lacks the collateral constraint effect coming from housing. Notably, the introduction of an exogenous constraint to a model with housing brings the initial responses of the output and inflation very close to the responses of the RANK model and the HANK model of Kaplan, Moll and Violante (2018). For instance, in the RANK model the aggregate output response is approximately -0.7% and in the exogenous borrowing limit model -0.86%. If income experiences less procyclical behaviour than housing prices, which seems to be a plausible assumption, this could explain why the output response of

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[9]The housing market is slightly different to markets for other forms of wealth: an increase in stock prices induces an expected increase in future dividends, for instance through an increase in productivity, whereas housing price changes only redistribute wealth, but do not increase it in aggregate (Aoki, Proudman, and Vlieghe 2004).

the HANK model in Kaplan and Violante (2018) is slightly smaller than in the RANK model, whereas in my baseline setting it is considerably stronger.

Comparison to empirical findings

The most extensive study of the empirical effects of monetary policy on cyclicality of inequality is the one by Coibion et al. (2017). They find that the evidence in favour of a significant earnings heterogeneity channel in form of labour income is rather small. Nonetheless, there is an increase in income inequality, pointing towards an income composition channel. Some households may have additional sources of income besides labour earnings. For instance, the effect of a contractionary monetary policy shock on financial income is positive. In addition, some households might have business income which reacts even more procyclically to monetary policy than wages, decreasing strongly after a contractionary shock. Especially, the households which get a large share of their income from financial or business income tend to be overrepresented in the upper part of the income distribution.

Turning to the effects related to wealth, the inequality literature has gone into more detail in explaining where the effects originate, especially compared to the traditional literature on monetary policy transmission channels. Coibion et al. (2017) emphasise the financial segmentation channel, relating to the differences in households' access to the financial markets; the savings redistribution channel which combines the effects of the cash-flow and inflation channel; and the portfolio channel which summarises the heterogeneity in the assets that households have on their balance sheets.

These empirical effects can be modelled in the THRANK. Table 3 summarises the different sources of income and wealth that each households type posesses, similar to the effects in Coibion et al. (2017). The components follow from the agents' budget constraints (2), (7) and (13). Table 3 also indicates for each component separately the direction in which the agents' income and wealth are drawn following a contractionary monetary policy shock. The results refer to effects in the first period after the shock is realised. For instance, debt serving costs may actually decrease compared to the costs before the shock if after the initial shock agents engage in a large enough deleveraging process. Thus, the directions are for a ceteris paribus -setting.

There is no heterogeneity in the wage development and all agents see their labour income decrease. For the business income the THRANK suggests that the response of the dividend income that the non-HtM receive is positive. This effect follows from the property that prices

Agent type	Effect	Direction
Non-HtM	Labour income	↓
	Business (dividend) income	↑
	Savings returns	↑
	Housing prices	↓
	Overall	?
Wealthy HtM	Labour income	↓
	Debt serving costs	↓
	Housing prices	↓
	Overall	↓
Poor HtM	Labour income	↓
	Overall	↓

Table 3: Income and wealth effects following a contractionary monetary policy shock

are rigid, as shown by the equations (20) and (21), but wages are flexible. Markups increase when there is a contractionary monetary policy shock, as prices are not able to adjust downward immediately. The increase in markups leads to an increase in profits and dividends[10].

The empirical evidence on business income points in another direction, but the countercyclicality is a convenient way of adding an income composition channel that benefits the agents on top of the income distribution, the non-HtM, in the event of a monetary policy tightening. Furthermore, although the dividends are paid for the shares in intermediate goods firms that the non-HtM agents own, the fact that these assets cannot be traded makes them a permanent part of their income and different to income from financial assets that can be traded.

The portfolio channel arises from the differing assets on the balance sheets of the agents. The non-HtM have positive balance sheets on housing and bonds, and they posses shares of intermediate goods producers that cannot be sold. The wealthy HtM have positive quantities of housing on their balance sheets, but their balance on bonds is negative. The poor HtM have no financial assets at all, which can also be quickly seen from their budget constraint (13).

Since the only assets traded in the present model are bonds and housing, the financial fragmentation channel arises from having access to those markets. The housing market is more similar to the financial fragmentation channel in Coibion et al. (2017), who emphasise that an expansionary monetary policy benefits the agents that are present in the financial market,

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[10]The positive effect on the dividends can also be seen from the log-linearisation of the equation $F_t = \left(1 - \frac{1}{X_t}\right)Y_t$ which gives $\frac{F}{Y}\hat{F}_t = (1-X)\hat{Y}_t + X\hat{X}_t$. Knowing that the steady state value of X is larger than one (1.05), from which it also follows that the steady state fraction $\frac{F}{Y} = \left(1 - \frac{1}{X}\right)$ is positive, and that the response of $\hat{Y}_t$ to a contractionary monetary policy shock is negative and that of $\hat{X}_t$ is positive, it follows that $\hat{F}_t > 0$.

whereas agents who cannot access the market lose in relative terms. The direction in the housing market is the same: expansionary monetary policy benefits agents that own housing, whereas for a contractionary shock the effect is the opposite. Thus, the non-HtM and wealthy HtM experience a negative wealth effect from holding housing. Finally, there is a savings redistribution channel following from the positive position of the non-HtM in bonds and the negative position of the wealthy HtM. The non-HtM now receive higher real returns for their savings whereas the wealthy HtM pay higher real interest rates for their debt.

Overall, both wealthy HtM and poor HtM see their income and wealth decline. The effect on the non-HtM is ambiguous as their dividend income and savings returns rise, so the calibration of the model will play a role in determining the sign of the effect. These theoretical effects are in line with the empirical evidence provided by Coibion et al. (2017) who find that income inequality rises following a negative monetary policy shock. Here the effect stems from the fact that the non-HtM are the well-off in the economy, and when their income rises, stays constant or drops less than that of the HtM agents, the income inequality in the economy rises.

In addition, the Coibion et al. (2017) article studies the effects of monetary policy on consumption and expenditure inequality. From having different effect of income and wealth (Table 3), it does not follow from this redistribution that a similar consumption response takes place. The credit constraints that the agents have affect their consumption response: the non-HtM will smooth their consumption, whereas the HtM agents are sensitive to the income and wealth effects. Through the MPC distribution, a redistribution to low MPC agents implies that consumption inequality should rise more than income inequality.

Coibion et al. (2017) indeed conclude that consumption inequality increases more than income inequality following a contractionary monetary policy shock, and that expenditure inequality rises even more than consumption inequality. Fore the THRANK the increase in consumption inequality can be seen from the varying consumption responses to a monetary policy shock, displayed in Figure 1. The non-HtM cut their consumption only by -0.5%, whereas the poor HtM experience a cut of -2.7% and the wealthy HtM of -4.8%. Keeping in mind the differences in average earnings, this means that consumption inequality is rising. Furthermore, if expenditure inequality is thought to combine the responses of consumption and housing demand, expenditure inequality rises as well, and by even more than consumption inequality. This follows from the fact that the consumption response is negative for all groups, but the non-HtM always increase

their housing demand when the wealthy HtM decrease it[11].

5 Sensitivity analysis

In this section, I test for changes in some of the steady-state parameter values. It has become clear that the wealthy HtM play a central role for the response of the whole economy. It is therefore interesting to see how the results change when some central parameter values that affect this agent group are altered. I first test for changes in the LTV ratio, then for changes in the shares of the different agent groups and finally for changes in the degree of illiquidity in housing by altering the housing adjustment costs. To note is that the changes in the model structure or parameter values can also change the steady state. The steady state shares for some model specifications are reported in Table A1 in the appendix. Overall, the consumption shares of the agent types stay unchanged unless they are intentionally changed, whereas the housing holdings share of the wealthy HtM, the housing prices and the output-to-debt ratios adjust.

5.1 LTV ratio

In this part, I test for different values of the LTV ratio. Apart from the interest rate, the LTV ratio is another policy variable in the model that can be intentionally altered by policy makers. As it has become clear that the wealthy HtM are central for the response of the aggregate economy, changes that make the wealthy HtM more responsive should amplify the responses of the aggregate economy as well. In the literature, a higher LTV ratio increases the sensitivity of an economy to monetary policy shocks (Calza, Monacelli, and Stracca 2013). In the baseline setting I have $m = 0.9$, which is the value used by Rubio (2011), and also very close to the values of 0.85 in Iacoviello and Neri (2010) and 0.89 in Iacoviello (2005).

Figure 3 shows the impulse response of the aggregate output in the first period after the shock responses of the economy with different LTV ratios. Figure A4 in the appendix shows full responses for some values of m to see the exact channels through which the effect transmits. Overall, higher LTV ratios amplify the effect of monetary policy, especially at the higher end of the values. The effect comes from a stronger consumption response of the wealthy HtM, and

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[11]This can be easily seen by log-linearising the housing market clearing condition $h_t^{'} + h_t^{''} = H$, which gives $\hat{h}_t^{'} = -\frac{\frac{h^{''}}{H}}{1-\frac{h^{''}}{H}}\hat{h}_t^{'}$. As $\frac{\frac{h^{''}}{H}}{1-\frac{h^{''}}{H}} > 0$ when $1 > \frac{h^{''}}{H} > 0$, the changes in the housing ownings will always have the opposite signs.

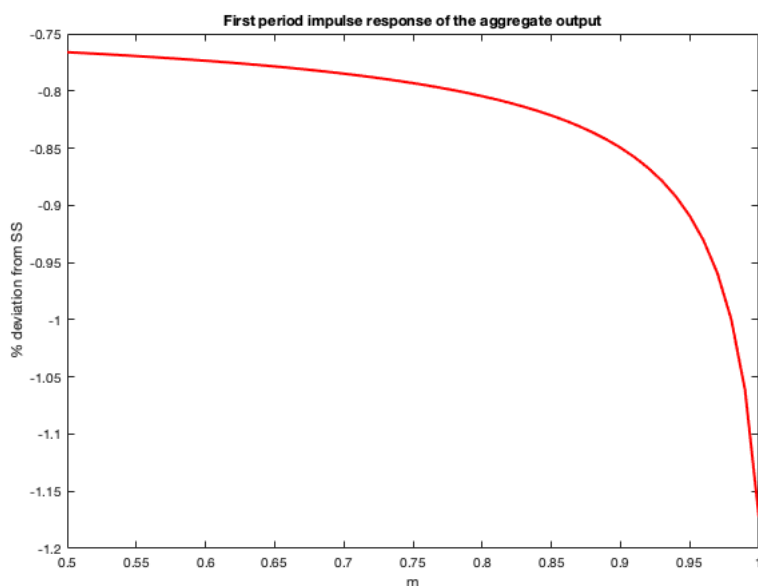**First period impulse response of the aggregate output**

Figure 3: The impulse response of the output in the first period following a one standard deviation monetary policy shock

their housing demand and debt. The non-HtM response is close to the baseline and does not offset the effect on the HtM consumers, leading to a larger aggregate response.

Notable is that the steady state of the model changes slightly: the share of housing increases with a higher LTV ratio, as does the value of the housing owned by the wealthy-HtM. This results from both the increase in the share of housing that they own and an increase in steady state price of the housing stock. The higher value of the wealthy HtM housing holdings $\frac{qh''}{Y}$ makes their consumption smoothing by selling housing more efficient than in other cases. However, as the ability to borrow against the value of the house also increases with a higher LTV ratio, the cost of selling is high, and therefore the eventual return back to steady state is faster. A long period of adjustment in housing holdings would limit the ability to borrow as much as possible.

A higher LTV ratio leads to a higher debt-to-output ratio, and a larger share of the housing stock owned by the wealthy HtM, thus, a more equal distribution in housing holdings. However, the higher the LTV ratio is, the stronger the housing holdings and consumption of the wealthy HtM respond. Hence, there is a trade-off between a more equal housing wealth distribution in the steady state and more cyclical inequality around the steady state.

5.2 Share of hand-to-mouth agents

In this part, I test for a larger share of HtM households in the population. Luetticke (2021) finds that the fraction of constrained households is an important driver of the aggregate effects. In addition, varying the share of different groups is interesting since the share of different groups might somewhat vary between economies. In particular, Kaplan, Violante, and Weidner (2014) find that in the Eurozone there is variation between the countries in the shares of the household groups, with a lower HtM household share in Southern European countries. This could explain why the same monetary policy shock can spark different size of responses in different countries. Also, there is some variation in the literature with respect to the share of credit constrained households. For instance, Iacoviello (2005) and Rubio (2011) use a labour share of income of 0.36 for constrained households, double as much as in the baseline specification. A larger share of HtM should amplify the effect, as a larger share of the population is constrained and cannot smooth out the effects of the shock. In addition, if a larger share of HtM agents are wealthy HtM, the effect should be further amplified due to the presence of additional monetary policy channels for a larger share of households. I compare the current shares to a setting where $\alpha = 0.64$ and $\gamma = 0.24$, which gives the poor HtM a share of 0.12. This setting would be roughly equivalent to the population shares of Kaplan, Violante, and Weidner (2014), indicating that with my parameter interpretation there would be no differences in the average earnings. I also test for a case the share of the HtM households very high, higher than any numbers that have been given in the literature. Here I set $\alpha = 0.4$ and $\gamma = 0.45$.

Figure 4 shows the results of the comparison. Altogether, the responses are larger when the HtM households make up a larger share of the economy. When the change is smaller (green line), the wealthy HtM experience some, but not too large effects from having a larger share of the labour income. However, the poor HtM experience a large effect, as their consumption drops by approximately 1% more compared to the baseline model. This is due to the larger aggregate response. Likewise, inflation reacts more strongly, which causes a larger undershooting in the interest rate. The undershooting then drives the effect on non-HtM consumption and the housing prices, making the hump-shaped pattern more pronounced. An increase in the share of poor HtM mutes the effect somewhat, but for larger differences in responses the differences in the shares would have to be larger.

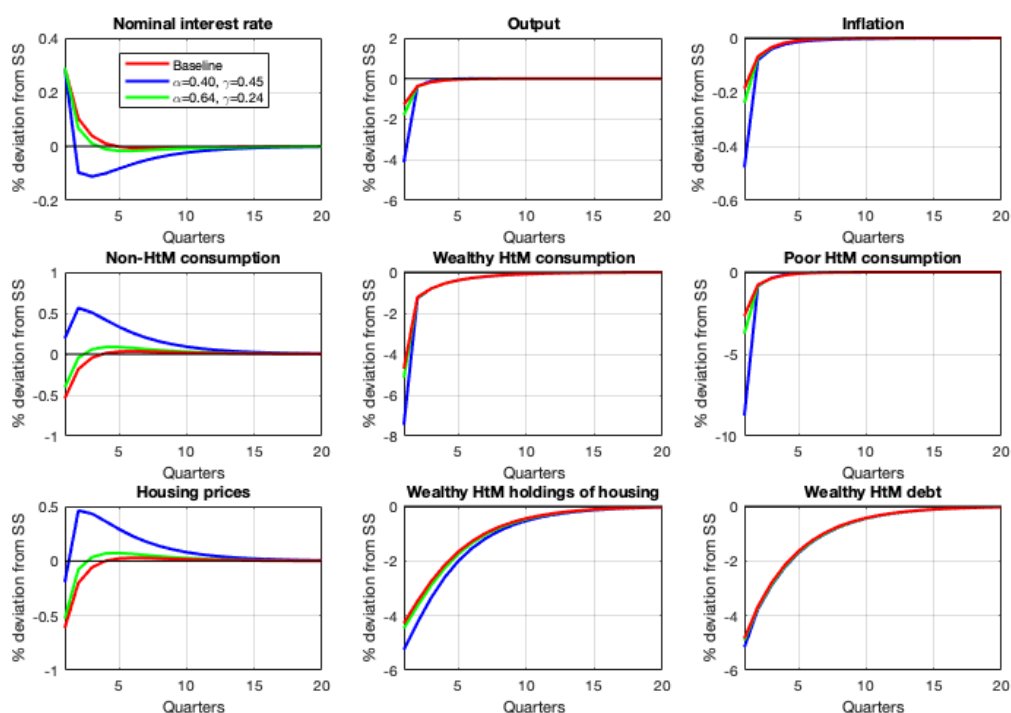When the share of the HtM households becomes very high (blue line), the inflation and

Figure 4: The impulse responses to a one standard deviation monetary policy shock. Baseline model $\alpha = 0.78, \gamma = 0.18$: red solid line, $\alpha = 0.64, \gamma = 0.24$: green solid line, $\alpha = 0.4, \gamma = 0.45$: blue solid line.

output responses are highly amplified, which leads to a large interest rate undershooting. This undershooting turns into a positive consumption response by the non-HtM agents, leading also to a positive response in housing prices. As the wealth effect from housing prices is now positive, the consumption response of the wealthy HtM is smaller than the consumption response of the poor HtM. The wealthy HtM still deleverage, as they reduce their housing holdings to finance consumption, but the increase in housing prices mutes their consumption response. Furthermore, in this setting a higher number of poor HtM amplifies the aggregate output, as their response is now larger than that of the wealthy HtM. The adjustment back to steady state is faster if a larger share of the agents are poor HtM, as the adjustment of the aggregate output is slowed down by a large share of wealthy HtM, who adjust their consumption and housing for a longer period.

A higher share of HtM households amplifies the inequality in consumption responses between the HtM and the non-HtM agents and the aggregate response. As the share of wealthy HtM

increases, so does their share of housing in the same relation. This causes an increase in the the debt-to-output ratio in the economy, but the steady state prices of the housing stock are lower than in the baseline.

Overall, an increasing share of heterogeneity in the form of a larger share of HtM households amplifies the effect of the aggregate output and inflation. As long as the consumption response of the non-HtM and the housing price response remain negative, a larger share of wealthy HtM amplifies the result to a larger extent than a larger share of poor HtM. However, with reasonable shares of the different agent groups, the aggregate share of HtM households is a more important driver to inflation and output than their exact composition. This result confirms the conclusions drawn earlier from a comparison between the baseline model and RANK and TANK models, namely that increasing heterogeneity amplifies the aggregate output response and the consumption inequality between the agent groups in response to a monetary policy shock.

5.3 Housing adjustment cost – the illiquidity of housing

Finally, I test for a lower value of the housing adjustment cost. The housing adjustment cost determines the degree of illiquidity of housing: with zero cost housing is liquid.

Figure 5 shows a mapping of different values of ϕ to the impulse response of the aggregate output in the first period following the monetary policy shock. Zero adjustment costs increase the ability of the wealthy HtM to smooth their consumption by selling housing. This also spills over to the aggregate output and on the poor HtM consumption. Non-HtM consumption is affected only to a very small extent. Figure A5 in the appendix shows a full comparison between the baseline $\phi = 0.05$ to zero costs $\phi = 0$

This result has interesting implications if there is cyclical variation in the adjustment costs of housing. For instance, if the time needed to sell a house increases in a recession, as argued by Hedlund et al. (2017), and this increases the adjustment cost [12], then the housing adjustment term can be another factor increasing the cyclical inequality in consumption between the agent groups.

Trade-off between steady state and cyclical inequality

Altogether, the LTV ratio has the largest impact on the impulse responses of the three parameters tested, both on the aggregate responses and on the inequality dynamics. As shown several

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[12]For instance, the real estate agent needs to be paid more, opportunity costs of searching for new housing etc.
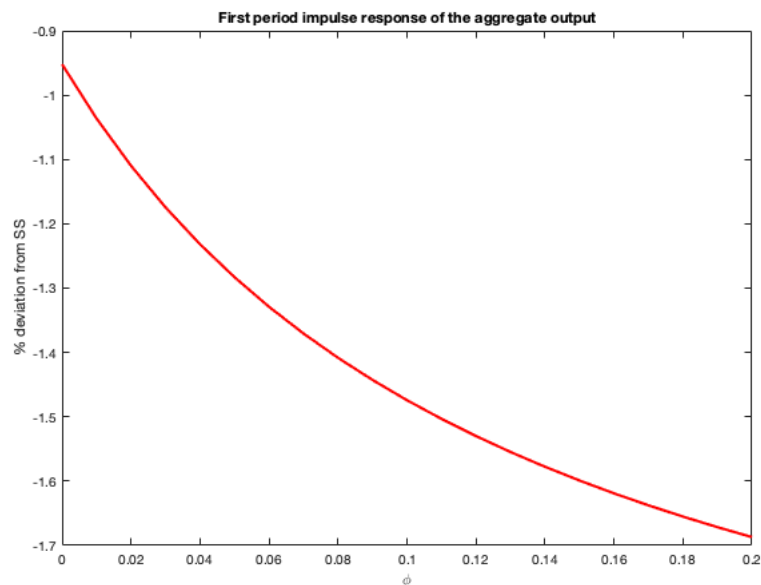
Figure 5: The impulse response of the output in the first period following a one standard deviation monetary policy shock

times, a crucial role is played by the share of HtM households: a higher level of heterogeneity and a higher share of constrained households make the aggregate response larger. With lower housing adjustment costs the wealthy HtM response is smaller as the housing stock that they own is used more to cushion the effect on consumption due to a larger degree of liquidity. A more equal distribution of wealth stemming from a larger share of housing owned by the wealthy HtM implies higher inequality in the response consumption and housing holdings dynamics over the business cycle. Furthermore, a larger labour income share of HtM agents has similar effects, increasing the inequality in the impulse responses and dynamics back to the economy's steady state.

6   Discussion

Compared to RANK models, HANK models introduce three lines of heterogeneity (Debortoli and Galí 2017): changes in consumption between agent groups, changes in consumption within the agent groups and changes in the share of the agent groups can all be modelled. Debortoli and Galí (2017) argue that even though a simple TANK model only captures the first of these three heterogeneity dimension, it can reasonably well match the aggregate results. However,

as discussed previously, a simple TANK model does not capture the balance sheet effects of monetary policy, which are central for the redistributive effects of monetary policy and can be modelled in the THRANK. Furthermore, the THRANK adds more heterogeneity between the agent groups, therefore providing a more realistic picture.

In the THRANK, monetary policy transmits through an intertemporal substitution channel, a labour income channel, a wealth channel, amplified by a collateral channel and a debt deflation channel, combing elements of the inflation channel and cash-flow channel. Compared to the simple RANK and TANK models, the THRANK adds the last two of these channels through the modelling of the wealthy HtM households, which are also central for the results of the HANK models. In addition, compared to models such as Iacoviello (2005) that model all the transmission channels but only between two groups of agents, the THRANK adds the interaction between two types of credit market participants and agents that are excluded from the credit market. The results from the THRANK presented in the previous sections suggest that

1. The RANK and TANK models miss some of the monetary policy transmission channels.

2. These missed channels have a large impact not only on the agents that are present at the credit market but also on the aggregate output, and through general equilibrium effects on the households that do not participate in the credit market.

3. Redistribution between agents with different MPCs takes place. This means that monetary policy has a larger effect in the THRANK than in a RANK model in which all agents have the same MPCs, or in a simple TANK model where a large part of the redistributive channels are not at work.

4. The aggregate effects are further amplified if there are more hand-to-mouth households in the economy, especially wealthy hand-to-mouth households.

In HANK models over 80% of monetary policy transmission takes place through indirect channels, as opposed to RANK models where this share is with any usual parametrisation less than 10%. In the THRANK, the share of indirect effects on the output response in the first period is over 60%, when calculated from the consumption shares and responses of each group[13].

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[13]This calculation uses the fact that almost the entire responses of both HtM groups are driven by indirect effects. Furthermore, the response of the non-HtM always follows the interest rate as in the RANK model, so I use the share of 3.6% for indirect effects in a RANK model as a proxy for the share of indirect effects in the non-HtM response.

This effect is far larger than in a typical TANK model, as they rarely feature a share of HtM consumers larger than 50%. This result is also not far from the HANK value, while being achieved in a model that is very much easier and quicker to compute.

Furthermore, with the emergence of the HANK literature, a theoretical framework for the redistributive and inequality effects of monetary policy has emerged. The THRANK can reproduce the redistribution channels to a similar extent that many HANK models. First, a simple earnings heterogeneity channel stems from the differences in the agents' income composition: the non-HtM receive countercyclically rising dividend income from owning the intermediate goods producers. Second, the model can reproduce the interest rate exposure channel by featuring short-term debt, as in Iacoviello (2005). The Fisher channel is not present, as assets are expressed in real terms[14] but it is not present in many of the HANK models either, because they feature balance sheets that are likewise written in real terms (for instance in Kaplan, Moll, and Violante (2018)).

With a contractionary monetary policy shock resources are redistributed from labour income to asset income, from debtors towards lenders and away from home owners (Hedlund et al. 2017). Matching the empirical evidence, the flow of resources in the model goes from from low-income households to high-income households (Luetticke (2021), Coibion et al. (2017)). The more vulnerable HtM agents experience larger drops in their income than the better-off Ricardian agents. Resources are redistributed from high MPC agents to low MPC agents, which leads to even higher redistribution in consumption and expenditure inequality. Also, during a contractionary monetary policy shock the housing holdings of the wealthy HtM decreases, whereas those of the non-HtM increase. This leads to increasing inequality in housing in addition to the increasing consumption inequality, since the non-HtM own the majority of the housing stock in the steady state. As housing is the only form of wealth that is distributed over more than one agent group, wealth concentration also increases following a contractionary shock.

Regarding policy, if inequality and large aggregate output responses are unwanted, the differences in MPCs ensure that fiscal policy is effective. First, even when the MPC rates would be equal across the groups, consumption responses can be equalised by choosing proper transfers from low-MPC to high-MPC agents. Second, when income is redirected from the low-MPC Ricardian agents to the high-MPC wealthy and poor HtM, the aggregate response of the economy becomes muted. It is another question if this is desirable, as Auclert (2019) argues that this re-

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[14]Only bond returns are written in nominal terms.

distribution channel is a monetary policy transmission channel just as intertemporal substitution or wealth effects, and not just an unwanted side-effect.

Furthermore, there is a trade-off between steady state housing distribution inequality and inequality in consumption and expenditure. A higher share of housing owned by the wealthy HtM and a higher debt-to-output ratio increase the cyclical inequality resulting from monetary policy, as they amplify the resource redistribution. The finding that the distribution of housing holdings matters for the response of the aggregate economy to an interest rate shock has is in line with the results of Beraja et al. (2019). Empirically, Bostic and Lee (2008) find that financial innovation that has led to an increasing number of poorer households holding housing wealth, increasing these households' vulnerability. Thus, for HtM households having housing on their balance sheets actually increases their vulnerability. The inequality and redistribution channels in the economy are amplified if there is a higher LTV ratio which sharpens the response of the wealthy HtM consumption and through that the response of the aggregate economy. Thus, a high degree of leveraging brings an accelerator effect that sharpens the business cycles, an effect which has also been found to hold empirically (Jensen et al. 2020)[15].

For monetary policy, a higher LTV ratio may be desirable in the sense that it makes monetary policy transmission more effective through the amplifying collateral effects (Hedlund et al. (2017), Iacoviello (2005)). However, this effect takes place through increasing redistribution: a higher LTV ratio amplifies the redistribution from borrowers to lenders and the house price channel. The larger aggregate response then again spills over to the poor HtM, making their response more negative as well. At the same time the response of the interest rate mutes the response of the non-HtM. The increasing redistribution leads to a higher consumption and expenditure inequality, as discussed in the previous parts, because of the varying MPCs.

Compared to redistribution by fiscal policy, the LTV ratio is actually able to change the factors causing the inequality in responses, whereas fiscal policy will not change the equilibrium but only redistribute resources. Therefore, regarding macroprudential policy, my results suggest that a reduction in the maximum LTV ratio not only mutes business cycle fluctuations, but also lowers the inequality in consumption and housing holdings responses. In terms of the redistribution channels, the interest rate exposure channel is mitigated through muted UREs, as a lower

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[15]However, financial innovations leading to a higher LTV ratio can also decrease the share of households that find themselves at the collateral constraint, if more for some households the constraint then becomes non-binding (Iacoviello and Neri 2010). This evidence is in line with the evidence of Jensen, Ravn, and Santoro (2018) for the aggregate economy.

LTV lowers the exposure to interest rate changes. This mitigates the aggregate output response, which leads to smaller decreases in wages and a smaller earnings heterogeneity channel. Particularly, now the households that are excluded from the credit market face smaller fluctuations in income. This is an important feature, because these agents are extremely vulnerable due to the fact that they have a lower income compared to other agents, but experience large fluctuations. However, a lower LTV ratio leads to a lower housing share of the wealthy HtM, making the housing distribution more unequal. Thus, there is again a trade-off between cyclical inequality in consumption responses and steady-state inequality in housing holdings.

Regarding future research on simple models approaching HANKs, one feature of HANK models cannot be produced in the current setting: the precautionary savings motive, arising from uninsured idiosyncratic labour income shocks. This feature leads to asymmetric responses to monetary policy shocks, depending on if they are positive or negative. Especially, negative shocks have a larger effect on the output. Because of the precautionary savings motive, in response to a positive shock the agents save a part of their income instead of consuming it all. Additionally, after a contractionary monetary policy shock the agents who face a tightening budget constraint tend to outnumber those who face a looser constraint. This can lead to larger share of wealthy HtM or poor HtM agents in the economy, along with the third line of heterogeneity introduced by Debortoli and Galí (2017), for instance when some households in the wealthy HtM group are forced to sell their illiquid assets.

Nevertheless, the THANK can match a HANK model on a level that is enough for many monetary policy questions, for instance inequality between the agent groups, especially if the shares of the three groups stay relatively constant in response to monetary policy shocks. However, there are additional features that could be incorporated to make the three-agent model match the HANK models even better. For instance, the introduction of occasionally binding constraints in the housing credit market can also create a deeper response to a contractionary monetary policy shock (Guerrieri and Iacoviello 2017). A simple precautionary savings motive without asymmetric responses can be introduced by including assets in the utility function as suggested by (Kaplan and Violante 2018). Finally, to produce shifts from one agent group to another fixed probabilities to shifting from unconstrained Ricardian type of agent to poor HtM type of agent could be introduced in the style of the analytical HANK model by Bilbiie (2020).

7 Conclusions

In this paper, I have developed a three-agent New Keynesian DSGE model (THRANK), featuring Ricardian agents and two types of hand-to-mouth agents, wealthy and poor. This theoretical setting is in line with the empirical evidence about heterogeneous agents provided by Kaplan, Violante, and Weidner (2014). Compared to TANK or RANK models, the model developed in this paper is able to capture interactions between three groups of agents. In particular, it shows how the poor hand-to-mouth agents that cannot access the credit market are dependent on the responses of the agents that are present at the credit market. The wealthy hand-to-mouth agents that are credit constrained have a large impact on the aggregate response when their share of labour income is non-negligible. Since this seems to be a feature in all advanced economies, this is an important insight. The size of this group's share can make a difference for the transmission of monetary policy: in the Eurozone, for instance, the variation in their share can cause differences in the economies' responses to monetary policy shocks.

Monetary policy transmission is more efficient in the three-agent setting than in the RANK or TANK models, as it leads to larger output and inflation responses. The effects take place mostly through the indirect channels of monetary policy transmission. This poses new challenges to monetary policy because the precision with which the effects of monetary policy can be estimated beforehand decreases with a larger share of the transmission coming through indirect effects.

Furthermore, I have shown that the THRANK can match the monetary policy channels created in a HANK model, but in a simpler setting. Especially, monetary policy in this model is transmitting through redistributive channels, moving resources from high-MPC agents to low-MPC agents. These MPC differences result from the differences in the agents' credit constraints. These constraints limit the agents' abilities to smooth the effect of a monetary policy shock: only the non hand-to-mouth agents can smooth the effects of a the shock, whereas both hand-to-mouth households are sensitive to changes in their income and wealth.

The inequality in consumption and housing holdings responses can be muted by macroprudential policy, as the results suggest that adjusting the LTV ratio can effectively control the magnitude of responses to monetary policy shocks. However, a lower LTV ratio means that housing holdings concentrate on the non-HtM agents in the economy's steady state. Hence, there is a trade-off between inequality in housing holdings in the steady state and the cyclical inequality responses in consumption and housing holdings. Due to the MPC heterogeneity

present in the model, fiscal policy can redistribute income between agents and mitigate the effects of the redistribution caused by the monetary policy.

It is a central question whether or not it is desirable to mitigate the effects on resource and consumption inequality. Auclert (2019) argues that redistribution should merely be seen as a channel of monetary policy just like intertemporal substitution. Contractionary and expansionary monetary policy shocks that redistribute income between high MPC and low MPC agents make monetary policy transmission more efficient. It remains to future research and normative considerations to examine if this increase in the policy's effectiveness outweighs the stronger fluctuations in inequality.

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Appendix

RANK and TANK models

RANK-model

The RANK model used for the comparison deviates from a standard RANK model by featuring housing. However, it will become clear from the impulse responses that the inclusion or removal of housing is not central for the results as housing prices and output are perfectly comoving. The non-HtM household problem remains unchanged but all the other agent types are removed. Intermediate goods firms now only produce with one type of labour, and therefore the production function shrinks down to

$$Y_t = A_t L_t^{'} \tag{A1}$$

which gives only one first-order condition for labour

$$w_t^{'} = \frac{Y_t}{X_t L_t^{'}} \tag{A2}$$

The price-setting behaviour and the problem for final goods producers remain unchanged. Likewise, monetary policy is as before. As the economy now consists only of Ricardian households, no steady-state shares are needed. The housig adjustment cost terms drop out of the log-linearisation, as $h^{'} = H$ and the housing stock is fixed. The log-linearised system comprises six equations:

$$\hat{Y}_t = \hat{c}_t^{'} \tag{A3}$$

$$\hat{c}_t^{'} = E_t(\hat{c}_{t+1}^{'}) - \widehat{rr}_t \tag{A4}$$

$$\hat{q}_t = \beta^{'} E_t(\hat{q}_{t+1}) + (1 - \beta^{'})\hat{j}_t + \hat{c}_t^{'} - \beta^{'} E_t(\hat{c}_{t+1}^{'}) \tag{A5}$$

$$\hat{Y}_t = \frac{1}{\eta - 1}\big(\eta \hat{A}_t - \hat{X}_t - \hat{c}_t^{'}\big) \tag{A6}$$

$$\hat{\pi}_t^{''} = \beta^{'} E_t(\hat{\pi}_{t+1}) - \kappa \hat{X}_t + \hat{u}_t \tag{A7}$$

$$\hat{R}_t = r_R \hat{R}_{t-1} + (1 - r_R)\big((1 + r_\pi)\hat{\pi}_{t-1} + r_Y \hat{Y}_{t-1}\big) + \hat{e}_{R,t} \tag{A8}$$

TANK-model

The problem of the Ricardian households is again as before. In addition, however, poor HtM households are added to the model, which makes it equivalent to models such as Campbell and Mankiw (1989) or Bilbiie (2008). The poor HtM problem is also the same as in the THRANK. The intermediate goods producers produce now with the following production function

$$Y_t = A_t (L_t^{'})^{\alpha} (L_t^{'''})^{1-\alpha} \tag{A9}$$

where α is the labour income share of the Ricardian households, set to 0.78 as in the baseline. Hence, all HtM households are now poor HtM. The first order conditions for labour demand are now the following

$$w_t^{'} = \frac{\alpha Y_t}{X_t L_t^{'}} \tag{A10}$$

$$w_t^{'''} = \frac{(1-\alpha) Y_t}{X_t L_t^{'''}} \tag{A11}$$

The final goods producers' problem and monetary policy are the same as previously. Due to changed aggregation the consumption share of each type of household has to be calculated. They are given as

$$\frac{c^{'}}{Y} = \frac{X + \alpha - 1}{X} \tag{A12}$$

$$\frac{c^{'''}}{Y} = \frac{1 - \alpha}{X} \tag{A13}$$

The consumption share of the Ricardian households is slightly larger than their labour income share since they own the monopolistically competitive firms and get their profits paid out as dividends in each period.

Also, some of the log-linearised equations change because of the new aggregation. The log-linearised model is now given as

$$\hat{Y}_t = \frac{c^{'}}{Y} \hat{c}_t^{'} + \frac{c^{'''}}{Y} \hat{c}_t^{'''} \tag{A14}$$

$$\hat{c}_t^{'} = E_t(\hat{c}_{t+1}^{'}) - \widehat{rr}_t \tag{A15}$$

$$\hat{c}_t^{'''} = \hat{Y}_t - \hat{X}_t \tag{A16}$$

$$\hat{q}_t = \beta^{'} E_t(\hat{q}_{t+1}) + (1 - \beta^{'}) \hat{j}_t + \hat{c}_t^{'} - \beta^{'} E_t(\hat{c}_{t+1}^{'}) \tag{A17}$$

$$\hat{Y}_t = \frac{1}{\eta - 1}\left(\eta\hat{A}_t - \hat{X}_t - \alpha\hat{c}_t' - (1-\alpha)\hat{c}_t'''\right) \tag{A18}$$

$$\hat{\pi}_t'' = \beta' E_t(\hat{\pi}_{t+1}) - \kappa\hat{X}_t + \hat{u}_t \tag{A19}$$

$$\hat{R}_t = r_R\hat{R}_{t-1} + (1-r_R)\left((1+r_\pi)\hat{\pi}_{t-1} + r_Y\hat{Y}_{t-1}\right) + \hat{e}_{R,t} \tag{A20}$$

In the main part, I have used models for which I have recalculated all the model equations as given above. The same results can be retrieved from the basic model by setting the share of wealthy HtM households close to zero. Setting their share exactly to zero is not possible because of the log-linearisation of their budget constraint (34). However, by setting their share very low (0.0001), it is possible to show that the RANK and TANK models nest in the three-agent model. The impulse responses for for these two models can be found in the appendix: for the RANK model the responses are given in Figure A1, for the TANK model in Figure A2. The calibrations are as in the baseline except for the shares of labour income.

Model with exogenous borrowing limit

I only present the equations insofar as they differ from the baseline.

The wealthy HtM now face an exogenous borrowing constraint, similar to Eggertsson and Krugman (2012) and the exogenous borrowing constraint version of the Cloyne, Ferreira, and Surico (2020) model

$$b_t'' = \bar{b}E_t\left(\frac{\pi_{t+1}}{R_t}\right) \tag{A21}$$

The non-HtM and poor HtM probelms remain identical to the baseline. The exogenous borrowing constraint now determines the level of resources of the wealthy HtM, since, as before, they will always find themselves at their borrowing limit. The wealthy-HtM now have to optimise their resource spending between consumption and housing. The last first-order condition now reads as

$$\frac{1}{c_t''}\left(q_t + \phi q_t\left(\frac{h_t'' - h_{t-1}''}{h_{t-1}''}\right)\right) = \frac{j_t}{h_t''} + \frac{\beta''}{E_t c_{t+1}''}\left(E_t q_{t+1} + \frac{\phi}{2}E_t q_{t+1}\left(\frac{E_t h_{t+1}''^2 - h_t''^2}{h_t''^2}\right)\right) \tag{A22}$$

The steady-state shares feature small changes, becoming

$$\frac{b''}{Y} = \frac{\bar{b}}{Y}\beta' \tag{A23}$$

$$\frac{c''}{Y} = (\beta' - 1)\frac{\bar{b}}{Y} + \frac{\gamma}{X} \tag{A24}$$

$$\frac{qh''}{Y} = \frac{j}{1 - \beta''}\frac{c''}{Y} \tag{A25}$$

$$\frac{c'}{Y} = \frac{\alpha + X - 1}{X} + (1 - \beta')\frac{\bar{b}}{Y} \tag{A26}$$

$$\frac{c'''}{Y} = \frac{1 - \alpha - \gamma}{X} \tag{A27}$$

$$\frac{h''}{H} = \frac{1}{1 + \frac{j}{1 - \beta'}\frac{c'}{Y}\left(\frac{qh''}{Y}\right)^{-1}} \tag{A28}$$

The log-linearisation is now

$$\hat{Y}_t = \frac{c'}{Y}\hat{c}'_t + \frac{c''}{Y}\hat{c}''_t + \frac{c'''}{Y}\hat{c}'''_t \tag{A29}$$

$$\hat{c}'_t = E_t(\hat{c}'_{t+1}) - \widehat{rr}_t \tag{A30}$$

$$\frac{c''}{Y}\hat{c}''_t = \frac{b''}{Y}\hat{b}''_t - \frac{qh''}{Y}(\hat{h}''_t - \hat{h}''_{t-1}) - \frac{Rb''}{Y}(\hat{R}_{t-1} + \hat{b}''_{t-1} - \hat{\pi}_t) + \frac{\gamma}{X}(\hat{Y}_t - \hat{X}_t) \tag{A31}$$

$$\hat{c}'''_t = \hat{Y}_t - \hat{X}_t \tag{A32}$$

$$\hat{q}_t + \phi(\hat{h}''_t - \hat{h}''_{t-1}) = \beta'' E_t(\hat{q}_{t+1}) + (1 - \beta'')(\hat{j}_t - \hat{h}''_t) + \hat{c}''_t - \beta'' E_t(\hat{c}''_{t+1}) + \beta'' \phi(E_t\hat{h}''_{t+1} - \hat{h}''_t) \tag{A33}$$

$$\hat{q}_t + \phi\iota(\hat{h}''_{t-1} - \hat{h}''_t) = \beta' E_t\hat{q}_{t+1} + (1 - \beta')\hat{j}_t + (1 - \beta')\iota\hat{h}''_t + \hat{c}'_t - \beta' E_t\hat{c}'_{t+1} +$$
$$\beta'\phi\iota(\hat{h}''_t - E_t\hat{h}''_{t+1}) \tag{A34}$$

$$\hat{b}''_t = -\widehat{rr}_t \tag{A35}$$

$$\hat{Y}_t = \frac{1}{\eta - 1}\left(\eta\hat{A}_t - \hat{X}_t - \alpha\hat{c}'_t - \gamma\hat{c}''_t - (1 - \alpha - \gamma)\hat{c}'''_t\right) \tag{A36}$$

$$\hat{\pi}_t = \beta' E_t(\hat{\pi}_{t+1}) - \kappa\hat{X}_t + \hat{u}_t \tag{A37}$$

$$\hat{R}_t = r_R\hat{R}_{t-1} + (1 - r_R)\left((1 + r_\pi)\hat{\pi}_{t-1} + r_Y\hat{Y}_{t-1}\right) + \hat{e}_{R,t} \tag{A38}$$

$\frac{\bar{b}}{Y}$ is calibrated to 1.3, which gives the same debt-to-output ratio for the economy as the LTV calibration in the baseline model.

Tables and figures

Model	$\frac{c'}{Y}$	$\frac{c''}{Y}$	$\frac{c'''}{Y}$	$\frac{b''}{Y}$	$\frac{qh''}{Y}$	$\frac{h''}{H}$	$\frac{qH}{Y}$
Baseline	0.80	0.16	0.04	1.28	1.44	0.15	9.48
RANK	1	-	-	-	-	-	-
TANK	0.79	-	0.21	-	-	-	-
Exogenous constraint	0.80	0.16	0.04	1.29	0.79	0.09	9.03
$m = 0.95$	0.80	0.16	0.04	1.41	1.50	0.16	9.54
$m = 0.7$	0.80	0.16	0.04	0.87	1.25	0.14	9.24
$m = 0.55$	0.80	0.17	0.04	0.62	1.14	0.13	9.11
$\alpha = 0.64, \gamma = 0.24$	0.68	0.21	0.11	1.71	1.92	0.22	8.67
$\alpha = 0.4, \gamma = 0.45$	0.46	0.40	0.14	3.21	3.60	0.44	8.21
$\phi = 0$	0.80	0.16	0.04	1.28	1.44	0.15	9.48

Table A1: Descriptions of the steady states
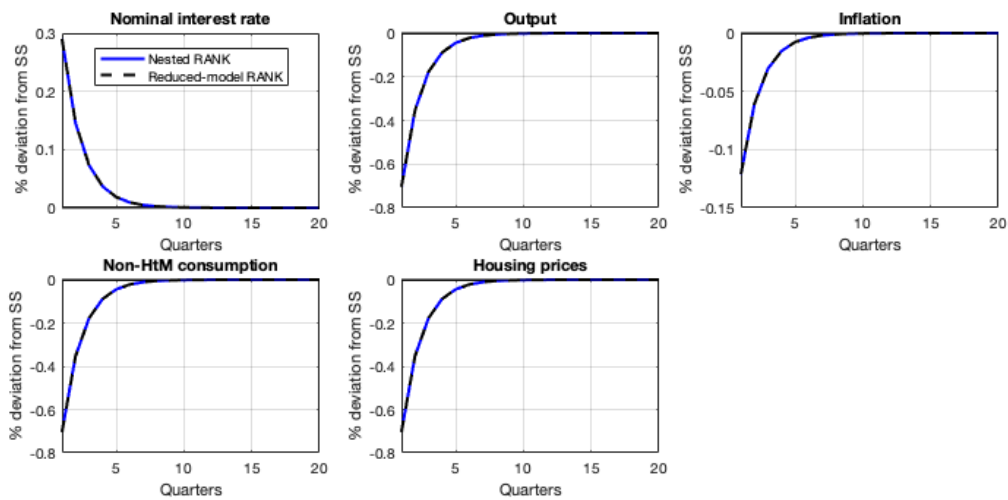
Figure A1: The impulse responses to a one standard deviation monetary policy shock. Nested RANK model: black dashed line, reduced-model RANK: blue solid line.
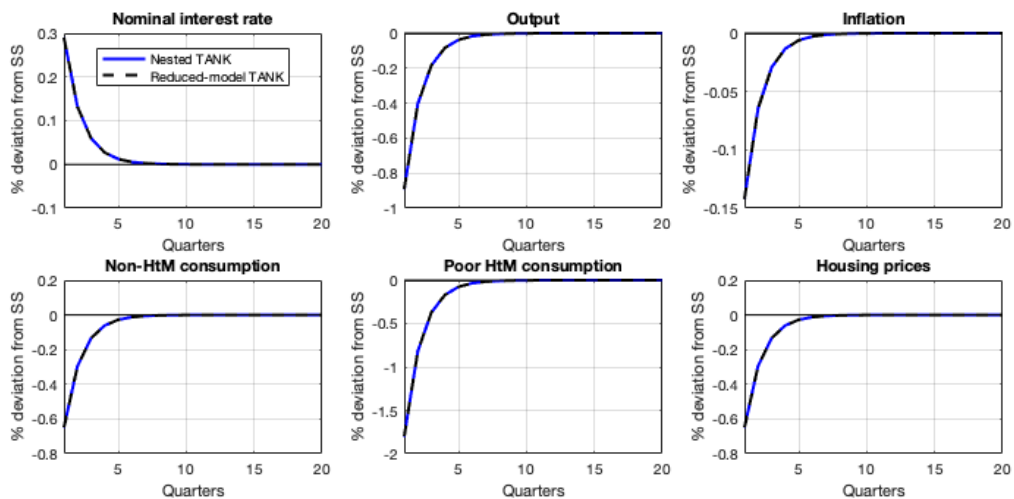
Figure A2: The impulse responses to a one standard deviation monetary policy shock. Nested TANK model: black dashed line, reduced-model TANK: blue solid line.
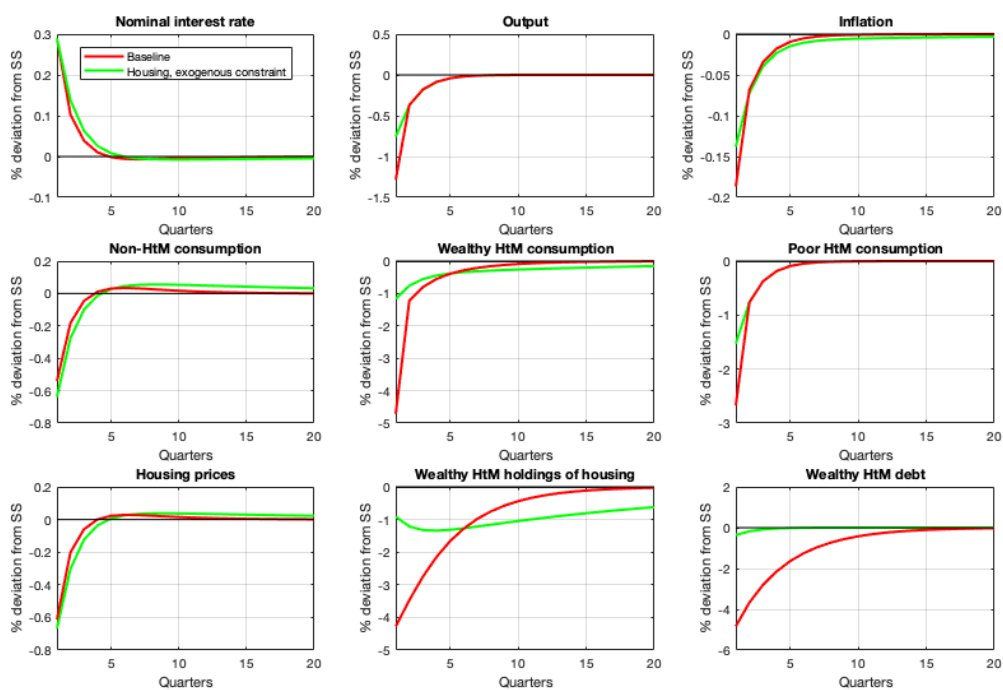
Figure A3: The impulse responses to a one standard deviation monetary policy shock. Baseline model: red solid line, exogenous borrowing limit: green solid line.
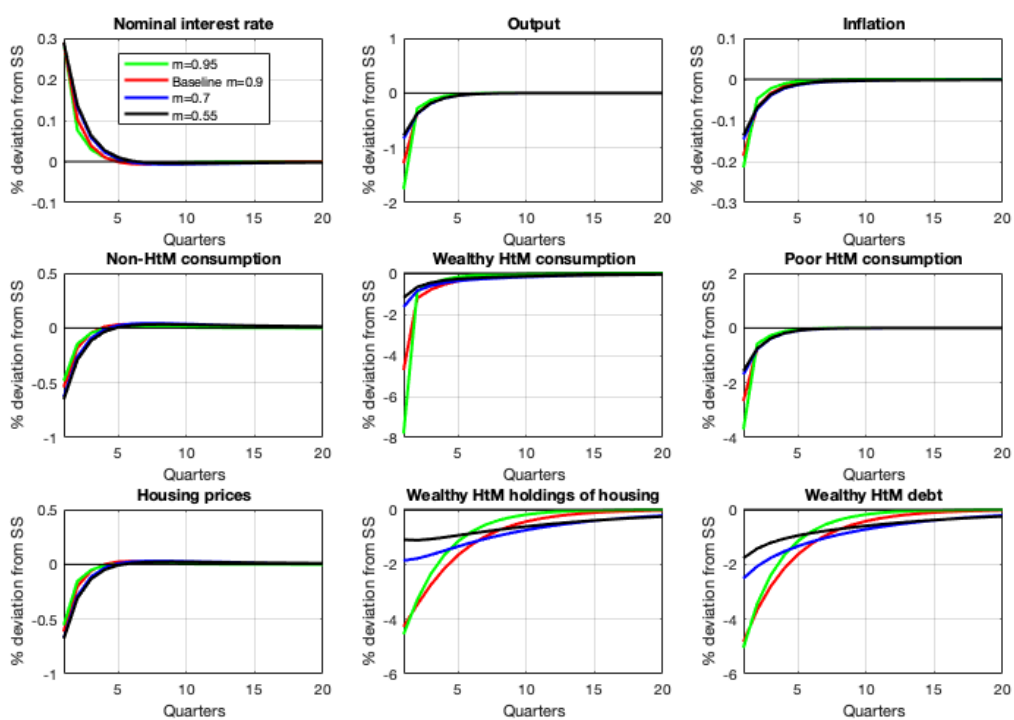
Figure A4: The impulse responses to a one standard deviation monetary policy shock. $m = 0.95$: green solid line, baseline model $m = 0.9$: red solid line, $m = 0.7$: blue solid line, $m = 0.55$: black solid line.
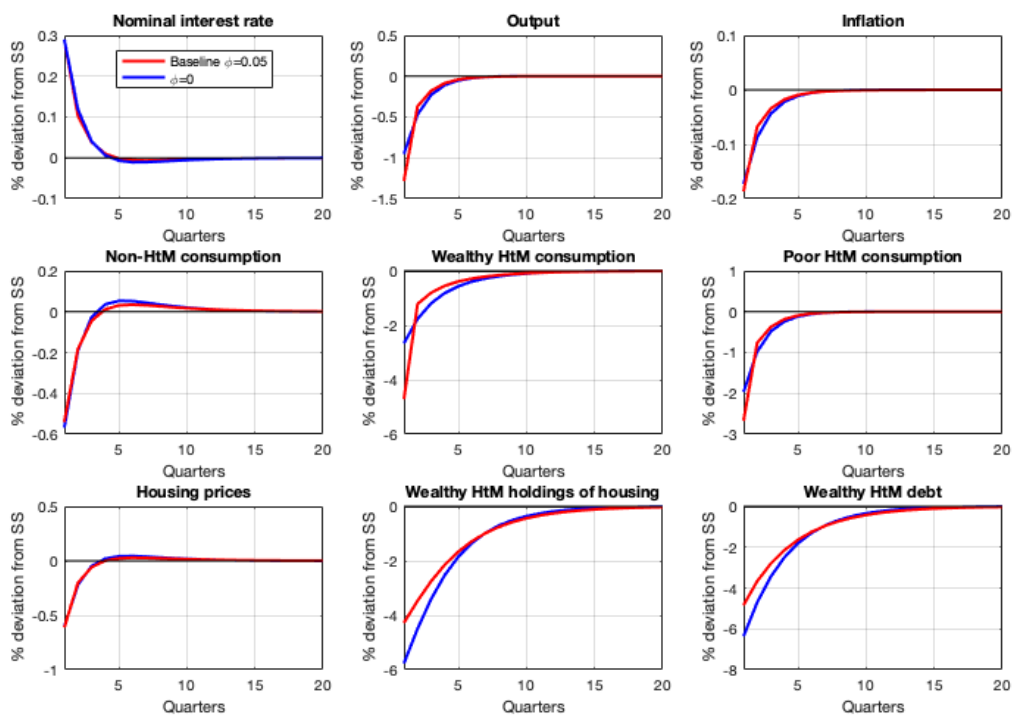
Figure A5: The impulse responses to a one standard deviation monetary policy shock. Baseline model $\phi = 0.05$: red solid line, $\phi = 0$: blue solid line.

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