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Monetary Policy and the Persistent Aggregate Effects of Wealth Redistribution

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Abstract

We identify a sizable wealth redistribution channel which creates a monetary policy trade-off whereby short-term economic stimulus is followed by persistently lower output over the medium term. This trade-off is stronger in economies with more nominal household debt but weakened by a more aggressive monetary policy stance and under price-level targeting. Given this trade-off, low-for-long episodes can lead to persistently depressed output. The medium-term implications of the wealth redistribution channel rely on the presence of labor supply heterogeneity, which we show both analytically and in the context of an estimated New Keynesian general equilibrium model with household heterogeneity.

Topics: Monetary policy framework, Monetary policy transmission

JEL codes: E21, E50

1 Introduction

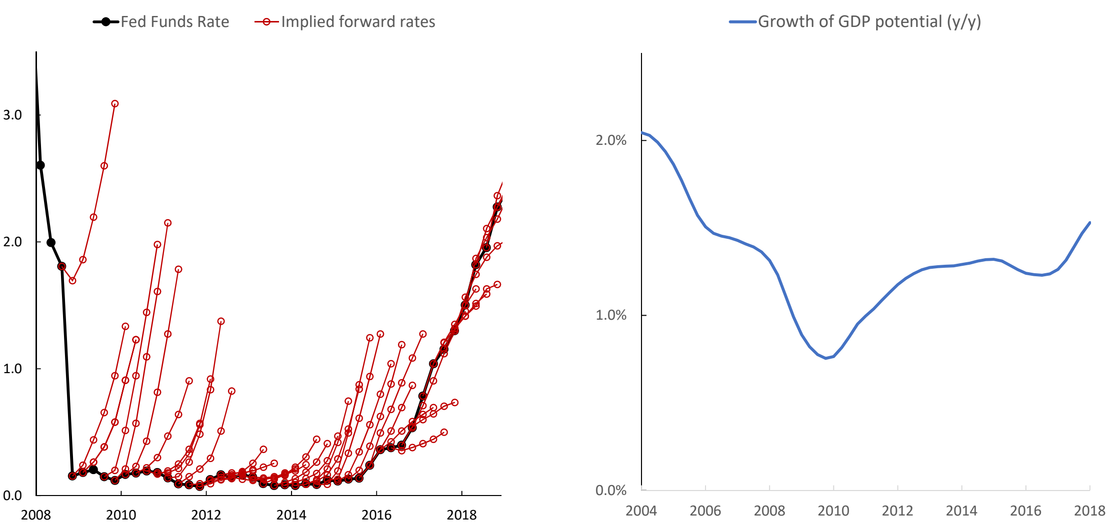
Household heterogeneity has important implications for the macroeconomy and the transmission of monetary policy (e.g., Kaplan et al. 2018 and Cloyne et al. 2019). Most recent work has focused on short-term implications of heterogeneity. We show that aggregate shocks have redistributive consequences that in turn have persistent aggregate implications over the medium term, due to asymmetric responses of working versus retired households. We build on Doepke and Schneider (2006b) and Doepke and Schneider (2006a), who find that inflation shocks in partial equilibrium can have persistent macroeconomic effects. In a general equilibrium setup, we show that the redistributive consequences of monetary policy in the presence of heterogeneous agents create a trade-off between short-term and medium-term effects. The strength of this redistribution channel depends on the monetary policy stance and its framework.

Labor supply heterogeneity and nominal household debt are critical for aggregate shocks to have redistributive effects with medium-term aggregate consequences. We establish this both analytically and in a small-scale New Keynesian dynamic stochastic general equilibrium (DSGE) model. Our analysis proceeds in three steps. First, we use a simple partial equilibrium perpetual-youth model with incomplete financial markets. We analytically show the mechanism by which labor supply heterogeneity impacts the transmission of aggregate shocks with persistent implications for aggregate consumption and labor supply in an economy with nominal debt. The presence of these persistent effects is consistent with evidence from empirical studies of household responses to transitory income shocks (e.g., Cesarini et al. 2017, Imbens et al. 2001 and Fagereng et al. 2018). Next, we confirm the findings and show that they lead to persistent implications for output. This is done in a small-scale heterogeneous agent DSGE model with idiosyncratic and aggregate uninsurable risks and lumpy housing, which can serve as collateral for nominal borrowing. Finally, we use our DSGE model to draw implications for the conduct of monetary policy. We identify a wealth redistribution channel which creates a policy trade-off: a short-term monetary stimulus of the economy is followed by persistently lower output over the medium term. This trade-off is stronger for economies with more nominal household debt. Monetary policy can reduce this trade-off by taking a more aggressive stance or adopting a less redistributive policy framework such as price-level targeting (PLT). The latter result provides an additional rationale for PLT's desirability but this time reliant on the presence of household heterogeneity. The wealth redistribution channel also implies that episodes of persistently low interest rates have medium-term output costs. This effect might have contributed to slower potential output growth associated with the low-for-long interest rate period following the global financial crisis.

Using monetary policy shocks in the context of labor heterogeneity, we can identify a wealth redistribution channel of monetary policy due to the presence of nominal debt. An expansionary monetary policy shock redistributes wealth from savers to borrowers. Within the group of unconstrained households, savers have larger medium-term consumption elasticities to the negative wealth transfer than the respective elasticities of borrowers to a positive wealth shock. This is because borrowers are poorer and in the labor force. So, they adjust not only consumption but also the intensive and extensive labor supply margins. In contrast, savers are wealthier and thus closer to retirement (or are already retired). Hence, they adjust current and future labor supply less (or not at all) and consumption more. This asymmetry between saver and borrower reactions has aggregate implications, which in turn persist, since households try to spread wealth gains and losses over their lifetime. As a result, in the aggregate the expansionary monetary policy shock leads to a medium-term decline of consumption, labor and output.

Therefore, the identified wealth redistribution channel implies a trade-off for monetary policy in general equilibrium. A short-term stimulus comes at the expense of lower consumption and output over the medium term. These negative consequences dissipate slowly, while the standard positive aggregate consequences wear off quickly. We investigate further by varying the responsiveness of monetary policy to inflation and by contemplating alternative frameworks such as PLT or average inflation targeting (AIT). Our findings suggest that the monetary policy trade-off is weaker for a more aggressive monetary policy stance, which stabilizes aggregate variables and thus implies less redistribution. The trade-off is also weaker for less redistributive monetary policy regimes that are history dependent. A prime example is PLT, for which shocks to inflation are offset to bring prices back to target. This implies that the initial redistributive effects of shocks are counteracted, resulting in a weaker wealth redistribution channel. We run simulations of our model with estimated demand and supply shocks and show that all policy regimes are more restricted in their ability to stabilize inflation and output when debt contracts are nominal. However, PLT reduces redistribution, and thus better stabilizes inflation and output.

Finally, we investigate the implications of the wealth redistribution channel during low-for-long policy episodes. After the financial crisis of the late 2000s, interest rates stayed persistently low, while the market continued to expect a faster lift-off of interest rates over the whole period 2008–2016 (see Figure 1). These serial surprises led to a significant redistribution from savers to borrowers, which according to our model resulted in medium-term output reductions. Hence, our redistribution channel likely contributed to the perception of lower potential output growth as it was recorded over this period (see Figure 1).



(a) Delayed normalization of rates

(b) Slower growth of potential

Figure 1: Low-for-long episode (Sources: Federal Reserve Board, Bloomberg, Congressional Budget Office)

In a robustness section, we assess the importance of different model elements for our results. First, we show that nominal debt is critical for the redistribution channel and the medium-term consequences of a monetary policy shock. To do that we solve a real debt version of our model. Second, we assess the importance of real asset revaluation of capital and housing in response to a monetary policy shock. We confirm that real assets' values appreciate following a monetary easing, but because this appreciation is short lived, it cannot offset persistent effects of nominal debt depreciation. Third, we investigate the presence of more restrictive borrowing constraints on the medium-term aggregate effects. In the benchmark economy, households with sufficient equity in their home can smooth idiosyncratic shocks by tapping into those funds. In an alternative version of the model, we restrict the amount of equity households can withdraw in any period. We show analytically in a partial equilibrium model that more binding constraints tend to amplify the negative effect of monetary easing on medium-term consumption because constrained borrowers do not smooth the increases of consumption over time.[1] In general equilibrium, we identify small offsetting effects of additional constraints on medium-term labor supply, but qualitatively our results remain unchanged. Fourth, we show that while price and wage stickiness influence the effects of monetary shocks in the short run, they do not affect the persistent medium-term implications. Finally, we take a close look at the monetary stimulus following the global financial crisis and how it affected labor supply. In a multi-country panel, we show that the countries with more monetary stimulus also had lower medium-term labor supply both at the extensive and intensive margins. While this result is purely suggestive, it is consistent with one of our model implications.

Empirical evidence on persistent effects of shocks While we are the first to highlight the endogenous labor force participation channel in a heterogeneous agent New Keynesian model, various microdata-based studies of household behavior have found persistent responses to unanticipated income shocks. Cesarini et al. (2017), for Sweden, and Imbens et al. (2001), for Massachusetts, analyze the consequences of small one-time lottery earnings using administrative data or survey data in the case of Imbens et al. (2001). Lottery earnings studied by Cesarini et al. (2017) are paid fully at the time of winning, and thus the income shock is transitory, while lottery earnings analyzed by Imbens et al. (2001) are paid out over 20 years. Both studies document that households respond to an income shock by persistently reducing labor earnings. Cesarini et al. (2017) find a roughly constant effect over time that lasts for more than ten years and is driven both by persistent adjustments of

[1] Consistent with this, Fagereng et al. (2018) find that households with fewer liquid assets tend to consume more on impact, while households with more liquid assets tend to smooth consumption over time.

hours worked (intensive margin) and exits from the labor force (extensive margin). Imbens et al. (2001) identify persistent negative effects on labor supply over the whole 6 years of the survey. Our model results are quantitatively in line with the labor supply implications in these studies (see Section 4.3 on marginal propensities to earn, or MPE). Also, related to our results, older Dutch households, according to Christelis et al. (2017), have a higher consumption response than younger ones, while Jappelli and Pistaferri (2014) find mixed results regarding age for Italy.

Contributions to literature Our paper mainly relates to three strands of the literature. First, we contribute to the literature on the role of heterogeneity for the macroeconomy. Early work in this area suggested that heterogeneity has limited effects on the macroeconomy and that there is no need to keep track of the economic agents' distribution beyond the mean (Krusell and Smith 1998, Ríos-Rull 1996 or Khan and Thomas 2008). More recent theoretical and empirical work find that household heterogeneity matters for monetary policy transmission (Kaplan et al. 2018, Cloyne et al. 2019 or Auclert 2019). But this literature has focused on short-term effects. A notable exception is Auclert et al. (2018) who study the effects of fiscal policy explicitly taking into account the reaction of households to fiscal policy over time.

Second, we add to the literature that studies the redistribution effects of unanticipated inflation shocks in heterogeneous household models with unhedged net nominal positions (Doepke and Schneider 2006b, Meh and Terajima 2011 and Adam and Zhu 2015) and shows that an inflation shock can have negative and persistent aggregate implications in overlapping generations models with retirement (Doepke and Schneider 2006a and Meh et al. 2010). The latter papers analyze the effect of an unexpected one-time inflation shock in partial equilibrium setups. Meh et al. (2010) find that if this shock is later reversed, as under a PLT regime, then the redistribution and its negative consequences are weaker. We contribute to this literature in three ways. First, we show analytically in a partial equilibrium model that the medium-term aggregate implications of labor supply heterogeneity are driven by the presence of retirement and are amplified by occasionally binding borrowing constraints. Second, we study the redistribution effects associated with unhedged nominal positions in a general equilibrium New Keynesian model. Here, monetary policy follows a Taylor rule and responds to supply and demand shocks, influencing prices and economic agents' decisions. Similar to Meh et al. (2010), we find that PLT implies lower redistribution from inflation due to the offsetting of shocks to inflation. We add the insight that in a general equilibrium model, where inflation responds endogenously to shocks, the expectation channel, which reduces the impact response of price setters to shocks, is the driving force behind smaller redistributive effects under PLT. In fact, if we were to generate the same inflation response on impact under PLT and inflation targeting (IT) as in Meh et al. (2010) with standard monetary shocks, the redistribution would be higher under PLT due to the larger impact on the nominal interest rate that also has distributional effects. The importance of the expectation channel under PLT has been stressed before, e.g., by Svensson (1999), Woodford (2003) and Vestin (2006), in the context of representative-agent setups. Third, we study the interaction of heterogeneous labor supply and borrowing constraints, which both imply persistent effects.

Finally, our result regarding the persistent effects of aggregate shocks contributes to the literature on labor market hysteresis and the long-term consequences of recession for individual households (Kahn 2010, Oreopoulos et al. 2012 or Liu et al. 2016). Importantly, our finding that low-for-long episodes can contribute to persistently reduced medium-term output provides an additional mechanism to the existing ones explaining the secular stagnation hypothesis (Summers 2015 or Eggertsson et al. 2019).

The remainder of the paper is organized as follows. Section 2 presents the New Keynesian DSGE model with households who are facing uninsured idiosyncratic and aggregate shocks and borrow to buy lumpy, illiquid houses. Section 3 analytically solves a simplified partial equilibrium model without housing and builds the intuition for the main mechanism. Section 4 discusses the calibration of the general equilibrium model. Section 5 shows that the welfare redistribution effects persist in general equilibrium and derives implications for monetary policy. Section 6 probes the robustness of our results to the presence of nominal debt, real assets, additional borrowing constraints and price and wage stickiness and verifies the model implications for low-for-long episodes in a multi-country panel. We conclude in Section 7.

2 General equilibrium model

Building on the perpetual-youth environment of Blanchard (1985) and Yaari (1965), we develop a heterogeneous agent model with lumpy, illiquid and collateralizable housing. Households borrow using mortgages subject to a borrowing constraint; they endogenously choose labor force participation and save in a mutual fund. Rich household heterogeneity arises due to mortality risk and earnings shocks. Other aspects of the model are more standard: a New Keynesian framework with monopolistically competitive intermediate goods producers, price adjustment costs à la Rotemberg (1983) and monetary policy set by a Taylor rule, Taylor (1993).

2.1 Model setup

2.1.1 Households

The economy is populated by a continuum of households (indexed by i), which are characterized by their holdings of bonds, $b_{i,t-1}$, and housing, $h_{i,t-1}$, assets at the beginning of period t, as well as their idiosyncratic labor productivity, $z_{i,t}$. An individual's state vector is given by $s_{i,t} \equiv \{b_{i,t-1}, h_{i,t-1}, z_{i,t}\}$. Therefore, the joint distribution of households $\mu_t(b, h, z)$ is part of the state space characterizing the economy.

Households die with probability γ and are replaced by new households, which are born without bonds and housing $b_i = h_i = 0$. There is a life-insurance market that redistributes wealth from recently deceased households to surviving households in proportion to their asset holdings. As a result, the return on assets of surviving households is adjusted by $1/(1-\gamma)$.

Households derive utility from consumption $c_{i,t}$, housing services[2] $h_{i,t}$, and utility from leisure 1-$l_{i,t}$. They choose their consumption, bond holdings $b_{i,t}$, housing $h_{i,t}$ and labor supply $l_{i,t}$ to maximize the lifetime utility function given by

$$E \sum_{t=0}^{\infty} \beta^t (1-\gamma)^t \left[\nu_t \log(c_{i,t}) + \psi \log(1 - l_{i,t}) + \phi \log(h_{i,t} + \underline{h})\right], \tag{2.1}$$

[2]Each unit of housing produces one unit of housing services.

subject to $l_{i,t} \geq 0$ and the budget constraint

$$
\begin{aligned}
& q_t(h_{i,t} + \tau^H \mathbf{1}_{h_{i,t}<h_{i,t-1}} + \tau^I \mathbf{1}_{h_{i,t}>h_{i,t-1}}) + b_{i,t} + c_{i,t} \\
& \leq \frac{1}{1-\gamma}\left(\left(\frac{(R^b_{t-1}+\zeta)}{\pi_t}\mathbf{1}_{b_{i,t-1}<0} + R^s_{t-1}\mathbf{1}_{b_{i,t-1}>0}\right) b_{i,t-1} + (1-\delta_h) q_t h_{i,t-1}\right) \quad (2.2) \\
& \quad + W_t z_{i,t} l_{i,t}(1-\tau_{soc}) + T^U_{i,t} + T^G_t + T^f_t + T^P_t, \quad (2.3)
\end{aligned}
$$

where W_t is the competitive real wage per unit of effective labor supply, R^b_{t-1} is the risk-free nominal interest rate applied to household savings in bonds between periods $t-1$ and t, ζ is the spread between the borrowing and saving rates, $\pi_t \equiv P_t/P_{t-1}$ is the inflation rate and P_t is the price level. The average return on household savings reflects that households' financial portfolios consist of nominal bonds and real assets, in our case direct claims on capital:

$$
R^S_{t-1} = \frac{R^b_{t-1}}{\pi_t}(1-s^e_{t-1}) + \frac{r_t + (1-\delta)q^k_t}{q^k_{t-1}} s^e_{t-1}, \quad \text{where } s^e_{t-1} - \frac{\chi^e k_{t-1} q_{t-1}}{k_{t-1} q_{t-1} + D^h_{t-1}}, \quad (2.4)
$$

and $D^h_{t-1} = \int b_{i,t-1}\mathbf{1}_{b_{i,t-1}<0} d\mu_{t-1}$ is the size of gross household debt in the economy.[3] τ_{soc} is the labor income tax rate that finances the government-organized unemployment insurance, $\tau^H q_t$ are the transaction costs of selling the house, $\tau^I q_t$ are the mandatory mortgage insurance costs, T^G_t are lump-sum transfers from the government, T^f_t and T^P_t are lump-sum transfers of profits from an investment fund and from goods producers, respectively, and $T^U_{i,t}$ are unemployment benefits. Unproductive households receive unemployment benefits equal to a fixed fraction of average steady-state wage $\bar{W}^*$ and conditional on the household willingness to work if productive: $T^U_{i,t} = b^U \bar{W}^* \mathbf{1}_{z_{i,t}=0} \mathbf{1}_{l_{i,t}(z_{i,t}>0)>0}$.[4] The preference for nondurable consumption is affected by a demand shock ν_t which follows a stochastic AR(1) process: $\log(\nu_t) = \rho^\nu \nu_{t-1} + e^\nu_t$. The minimum level of housing services available to every household is given by $\underline{h}$, which determines the utility of housing services to non-house owners.

The utility function belongs to the King-Plosser-Rebelo class of preferences. Importantly,

[3] For simplicity we fix the share of capital financed directly (through equity) χ^e by households.

[4] The idiosyncratic productivity state serves two purposes: It captures variations in labor productivity and creates unemployment spells. In the empirical section, we focus on the latter aspect since that is the greatest idiosyncratic income risk for households.

this specification admits the possibility that households decide to not work (i.e., choose the corner $l_i = 0$ for any positive z_i level).[5] Specifically, after paying off their mortgage, households continue to save and eventually, after their wealth reaches a certain level, decide to stop working in the marketplace, effectively retiring.[6]

Households are also subject to a borrowing constraint restricting the loan-to-value (LTV) ratio:

$$-b_{i,t}(R_t^b + \zeta) \leq \theta E_t h_{i,t} q_{t+1} \pi_{t+1}. \tag{2.5}$$

To capture the notion that households use fixed-term mortgages (and save in fixed-term saving instruments), the interest rate at which a household contract is persistent can be expressed as

$$R_t^b = \rho^b R_{t-1}^b + (1-\rho^b) R_t, \tag{2.6}$$

where R_t is the risk-free nominal rate set by the monetary authority. This restriction on interest rate adjustments captures the sluggish transmission from monetary policy to mortgage holders, while keeping the model computationally tractable.[7]

Lumpy housing Just as in reality, housing in our model is lumpy and illiquid. A household is either a renter ($h_{i,t} = 0$) or a homeowner ($h_{i,t} = 1$). Households pay a housing transaction fee $\tau^H q_t$ when selling a house. These fees capture standard real estate costs and legal fees. Households also buy a mandatory mortgage insurance, $\tau^I q_t$, when using a mortgage to buy a house. This insurance reflects the requirement that in Canada any mortgage with an LTV ratio above 80 per cent needs to be insured by a government-backed insurance company.

[5] Our results hold for the more general King et al. (1988) utility functions: $u(c,l) = \left[\left(c(1-l)^{\psi}\right)^{1-\sigma} - 1\right] / (1-\sigma)$.

[6] As Meh et al. (2010) show in Table 1, older people have positive net nominal positions across all income levels. While we do not have a large heterogeneity of wealth among retirees, we calibrate the model parameters to match the average wealth share of retirees in the population.

[7] Adding the contract duration and interest rate to the individual state would bring our model closer to the real-world problem households solve. However, this would significantly increase the dimensionality of our state space without the obvious benefits given the focus of the paper. Meh et al. (2010) show that the duration of nominal assets has a timing effect on the revaluation of nominal assets, which is heterogeneous across policy regimes. This heterogeneity is weaker in our model since inflation is endogenous and is always more stable under PLT than IT, implying less revaluation of nominal assets of all durations. Moreover, the medium-term effects in our model are driven by unconstrained households who are not pressed to sell temporarily depreciated assets, making them less sensitive to the duration effects of nominal assets.

Since mortgages are insured (or have a low LTV ratio) they are risk-free from a lender's perspective, so we do not need to keep track of the risk premium. The fees are sizable and will be lump-sum rebated via $T_{i,t}$ to all households. In order to find the optimal choice of housing $h_{i,t} \in \{0,1\}$, we define a value function for renters and owners. We define the problem recursively and drop the i subscripts for households (note that b, h denote b_{t-1}, h_{t-1}). We define wealth as $\omega \equiv b + qh$.

$$
\begin{aligned}
V^r(\omega, z) &= E_\xi \max\{v^{rp}(\omega, h, z), v^{op}(\omega, h, z) - \xi\}, \\
V^o(\omega, z) &= E_\xi \max\{v^{rp}(\omega, h, z) - \xi, v^{op}(\omega, h, z)\},
\end{aligned}
$$

subject to the budget and borrowing constraints, where $\xi \sim \mathcal{U}(0, \bar{\xi})$ captures the utility costs of buying or selling a house and

$$
\begin{aligned}
v^{rp}(\omega, h, z) &= \max_{b'} u(c, l, h = 0) + \beta(1-\gamma) E V^r(\omega', z'), \\
v^{op}(\omega, h, z) &= \max_{b'} u(c, l, h = 1) + \beta(1-\gamma) E V^o(\omega', z').
\end{aligned}
$$

Thus in any given period, when making their housing decisions, renters compare the value function of owning a house to that of continuing to rent, while homeowners compare continuing to own a house to selling it and becoming renters.

Income dynamics Earnings dynamics are driven by a Markov chain with transition probabilities, $M_{n\times n}$, between different states of labor productivity, $\bar{z} = \{z_1, .., z_n\}$. To capture unemployment, we introduce a state with $z_1 = 0$.

2.1.2 Investment fund

An investment fund collects all the savings from savers, lends to borrowing households, buys capital from capital producers and rents it to intermediate goods producers. The fund maximizes the net present value of its profits:

$$\max_{k_t} E_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} T^f_\tau,$$

where the discount factor is

$$\Lambda_{t,\tau} = \prod_{s=t}^{\tau} \frac{\pi_{s+1}}{R^b_s}.$$

The fund profits going to households are given by the interest rate spread between borrowing and saving rates on outstanding mortgages as well as the difference between the return to capital and the interest rate of bonds, for the share of capital funded via nominal bonds:

$$T^f_t = \frac{\zeta}{\pi_t} D^h_{t-1} + \left(\frac{r_t + (1-\delta) q^k_t}{q^k_{t-1}} - \frac{R^b_{t-1}}{\pi_t} \right) k_{t-1} q^k_{t-1} (1-\chi^e) - k_t q^k_t + \int b_{i,t} d\mu_t,$$

where the last two terms cancel since in equilibrium net savings equal the value of purchased capital $\int b_{i,t} d\mu_t = k_t q^k_t$.

2.2 Goods and capital production

There is a unit measure of monopolistically competitive firms indexed by j: each firm produces intermediate goods according to the production function

$$y_t = a_t k^\alpha_{t-1} n^{1-\alpha}_t, \tag{2.7}$$

where y_t, k_t, n_t are the aggregate levels of output, capital and labor. The total factor productivity a_t follows a stochastic AR(1) process $\log(a_t) = \rho^a \log(a_{t-1}) + e^a_t$.

Final goods producers Intermediate goods are aggregated into a homogeneous final good by perfectly competitive final goods producers:

$$Y_t = \left(\int y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2.8}$$

where ε is the elasticity of substitution between goods. Cost minimizing final goods producers have a demand for intermediate goods given by:

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\varepsilon} y_t, \text{ where } P_t = \left(\int P_{j,t}^{1-\varepsilon} dj\right)^{\frac{1}{1-\varepsilon}}. \tag{2.9}$$

Based on Rotemberg's (1983) price adjustment costs and profit maximizing behavior of the intermediary price setter, the optimal price setting generates a New Keynesian Phillips curve:

$$\left(\frac{\pi_t}{\pi^*} - 1\right)\frac{\pi_t}{\pi^*} = E_t \frac{\Lambda_{0,t+1}}{\Lambda_{0,t}}\left(\frac{\pi_{t+1}}{\pi^*} - 1\right)\frac{\pi_{t+1}}{\pi^*}\frac{y_{t+1}}{y_t} + \frac{\varepsilon}{\kappa}\left(m_t - m^*\right), \tag{2.10}$$

where the optimal markup in the steady state is $m^* = \frac{\varepsilon - 1}{\varepsilon}$ and the pricing kernel is $\frac{\Lambda_{0,t+1}}{\Lambda_{0,t}} = \frac{\pi_{t+1}}{r_t}$. The profit of goods producers is distributed lump-sum to all households:

$$T_{i,t}^p = (1 - m_t)y_t - \frac{\kappa}{2}\left(\frac{\pi_t}{\pi^*} - 1\right)^2 y_t. \tag{2.11}$$

See Appendix A.8 for the remaining optimality conditions.

Capital producers Capital producers purchase goods from the final goods producers, and they convert them into investment goods x_t, which are sold at price q_t^k. The production of new capital is subject to adjustment costs in investment κ^k and takes place in a perfectly competitive market. Thus, they maximize the discounted stream of profits

$$\max_{x_t} E_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} q_\tau^k \left(k_\tau - (1-\delta)k_{\tau-1}\right) - x_t, \tag{2.12}$$

subject to the law of motion for capital

$$k_t - (1-\delta)k_{t-1} = x_t\left(1 - \frac{\kappa^k}{2}\left(\frac{x_t}{x_{t-1}} - 1\right)^2\right). \tag{2.13}$$

2.3 Government policy

Monetary policy is implemented via a Taylor rule, where the nominal interest rate is given by:

$$\ln(R_t) = \rho^R \ln(R_{t-1}) + (1-\rho^R)\left(\ln(R^*) + \alpha_\pi\left(\ln(\pi_t) - \ln(\pi^*)\right) + \alpha_y\left(\ln(y_t) - \ln(y^*)\right)\right) + e_t^R. \tag{2.14}$$

Here, α_π and α_y are long-run response coefficients to inflation deviations from the central bank's target and the output gap, and ρ^R is a policy rate-smoothing parameter. R^* and y^* are the steady-state values of the nominal interest rate and output, and π^* is the inflation target. The interest rate is subject to monetary shocks e_t^R. Fiscal policy is purely redistributive in that it collects fees (from realtors and the mortgage insurance) and taxes (unemployment insurance) and distributes all the revenue to household (via unemployment benefits and lump-sum transfers), balancing the budget each period.[8] This implies that the lump-sum government transfers are given by:

$$T_{i,t} = \int \left(q_t \tau^H \mathbf{1}_{h_{i,t}<h_{i,t-1}} + q_t \tau^I \mathbf{1}_{h_{i,t}>h_{i,t-1}} - T_{i,t}^U + \tau_{soc} W_t z_{i,t} l_{i,t}\right) d\mu_t. \tag{2.15}$$

2.4 Market clearing conditions

There are four markets in this economy.

A consumption and investment goods market,

$$y_t\left[1 - \frac{\kappa}{2}\left(\frac{\pi_t}{\pi^*} - 1\right)^2\right] = c_t + k_t - (1-\delta)\,k_{t-1} + \delta^h H, \quad \text{where} \quad c_t = \int c_{i,t} d\mu_t,$$

a housing market which ensures that households' aggregate demand equals the exogenous fixed supply H,

$$\int h_{i,t} d\mu_t = H, \tag{2.16}$$

[8] Meh and Terajima (2011) show that an inflation shock would create a windfall for a government with large nominal debt. Our results should remain qualitatively unchanged, unless the resulting revenues/losses are concentrated on a particular subgroup.

a capital rental market,

$$\int b_{i,t} d\mu_t = k_t q_t^k, \tag{2.17}$$

and a labor market in effective hours worked, taking individual productivity levels into account,

$$n_t = \int z_{i,t} l_{i,t} d\mu_t. \tag{2.18}$$

3 Redistribution effects in partial equilibrium

In order to show intuitively the channels through which redistribution effects of aggregate shocks feed back to the aggregate economy, we first consider a simplified household problem in isolation. We analytically derive the redistribution effects of an unexpected monetary policy shock and their impact on aggregate consumption and labor supply. In particular we show that a monetary policy easing persistently reduces aggregate labor and consumption in the presence of labor supply heterogeneity and nominal debt. In later sections, we show that these effects are present in a calibrated New Keynesian general equilibrium model which features standard monetary policy effects such as intertemporal substitution and income effects. We then draw the implications for the conduct of monetary policy.

3.1 Simplified household problem

We simplify the household problem from Section 2.1.1 by assuming that households do not value housing, $\phi = 0$, and have constant labor productivity $z_i = 1$. In order to keep borrowing in the model in the absence of housing, we assume that households start with negative bond holdings $b^0 < 0$.[9] For now we also keep the borrowing constraint sufficiently loose. In section A.3, we show how the analytical results change in the presence of binding borrowing constraints. Finally, we nullify taxes and lump-sum transfers and turn off the demand shock $\nu_t = 1$.

[9]Negative bond holdings at birth are a proxy for nominal debt in the general equilibrium model to finance housing. Leaving the realm of our current model, the initial debt might be due to student loans as households in the model start life at the time of their labor force entry, i.e., corresponding to around 20 years of age in reality.

The household problem simplifies to the maximization of the lifetime utility function

$$\max_{b_{i,t},l_{i,t}} E\sum_{t=0}^{\infty}\beta^t(1-\gamma)^t\left(\log(c_{i,t})+\psi\log(1-l_{i,t})\right), \tag{3.1}$$

subject to $l_{i,t}\geq 0$ and the budget constraint

$$b_{i,t}+c_{i,t}\leq W_t l_{i,t}+\frac{1}{1-\gamma}\left(\frac{R_{t-1}}{\pi_t}b_{i,t-1}\right). \tag{3.2}$$

Optimality conditions First-order conditions (FOCs) with respect to labor $l_{i,t}$ and bond holdings $b_{i,t+1}$ are

$$l_{i,t}=\max\left\{0,1-\frac{\psi}{W_t}c_{i,t}\right\}, \tag{3.3}$$

$$\frac{1}{c_{i,t}}=\beta E_t\frac{1}{c_{i,t+1}}\frac{R_t}{\pi_{t+1}}. \tag{3.4}$$

3.2 Interest rate shocks, redistribution and economic consequences

To isolate how the redistribution triggered by monetary policy affects economic choices, we study an unexpected decrease in real interest rates through lower inflation. At $t=1$, gross inflation, π_t, unexpectedly increases for one period to π_1 and then returns to the steady state, $\pi=1$.[10] The real wage and the nominal interest rate are fixed at steady-state levels for all periods $t: W_t=W, R_t=R$. Thus, the shock captures monetary policy easing.

Since the expected return from savings and labor is not affected, the only direct impact of this shock is the redistribution of wealth from savers to borrowers at $t=1$. Specifically, each household is subject to a transitory wealth shock

$$sb_{i,0}\equiv\frac{1}{1-\gamma}\underbrace{\left(\frac{1}{\pi_1}-1\right)}_{<0}R\,b_{i,0},$$

where the size of the wealth transfer and its direction depend on the size and sign of the nominal bond holdings $b_{i,0}$ at $t=0$. We start from an equilibrium allocation at $t=0$ that is characterized by a steady-state bond distribution with zero net supply of nominal bonds,

[10]For simplicity and without loss of generality, we normalize the steady-state gross inflation level to 1.

$\sum_i b_{i,0} = 0$.

3.2.1 Case 1: Labor supply fixed

Suppose households have no utility from leisure, $\psi = 0$. Then households supply all their time endowment as labor, $l_{i,t} = 1,\ \forall i, t$.

In equilibrium, households consume an optimal fraction of their wealth, which is composed of financial wealth (bonds) and discounted lifetime labor income:

$$c_{i,t} = \bar{\eta}\left[b_{i,t-1}\frac{1}{1-\gamma}\frac{R}{\pi_t} + W\frac{1}{1-\frac{1-\gamma}{R}}\right], \tag{3.5}$$

where $\bar{\eta} = 1 - (1-\gamma)\beta < 1$ is the elasticity of consumption to wealth. In response to the temporary monetary policy transfer, households adjust their whole future consumption path proportionally to the change in their respective financial wealth. This implies the following consumption adjustment to a monetary easing surprise:

$$\Delta c_{i,t} = \bar{\eta}(\beta R)^{t-1} s b_{i,0}. \tag{3.6}$$

The individual consumption response of unconstrained households is proportional to their nominal bond holdings and is persistent. It evolves over time at a rate βR.

Since the individual consumption elasticities out of this transfer are the same across households, $\bar{\eta}(\beta R)^{t-1}\ \forall i$, and the net aggregate transfer is zero, the individual consumption responses cancel in the aggregate:

$$\Delta C_t = (1-\gamma)^{t-1}\sum_i \Delta c_{i,t} = \bar{\eta}((1-\gamma)\beta R)^{t-1} s \sum_i b_{i,0} = 0. \tag{3.7}$$

Even if aggregate debt was not zero, the aggregate consumption effects would decline at the rate $(1-\gamma)$, since the households affected by the monetary shock at $t = 1$ survive with probability $(1-\gamma)$ and new households are not affected by the shock that took place prior to their birth.

Proposition 1. *In an economy with fixed labor supply and no borrowing constraints, mon-*

etary policy shocks result in persistent individual consumption responses without aggregate consequences.

Proof. See Appendix A.4. ■

3.2.2 Case 2: Labor supply choice

When households value leisure, $\psi > 0$, they will adjust their labor supply based on the marginal utility of earned wages (3.3). Given the utility function, households with significant wealth and thus sizable consumption will decide to retire in period $T_i(b_{i,0})$.

Households now have an additional margin of adjustment–labor at both the intensive and the extensive margins. A household in the labor force at $t = 1$ who adjusts its labor supply only on the intensive margin (time of retirement is unchanged, $T_i' = T_i$), adjusts consumption less than in the case with fixed labor:

$$\Delta c_{i,t} = \eta(T_i')(\beta R)^{t-1} s b_{i,0}, \tag{3.8}$$

where $\eta(T_i') \mid_{T_i'>1} = \frac{\bar{\eta}}{1+\frac{\psi}{W}\left(1-((1-\gamma)\beta)^{T_i'-1}\right)} < \eta(T_i') \mid_{T_i'\leq 1} = \bar{\eta}$. Note that the consumption elasticity is decreasing in the time of retirement $\frac{d\eta(T_i')}{dT_i'} < 0$. Intuitively, the longer the working lifetime over which labor is adjusted, the smaller the consumption adjustment. Additional labor adjustments at the extensive margin, $T_i' \neq T_i$, reduce the response of consumption further, $\eta(T_i, T_i') \mid_{T_i \neq T_i'} < \eta(T_i, T_i') \mid_{T_i = T_i'}$. While retired households do not adjust their labor margin, they have a higher consumption elasticity equivalent to the case with fixed labor, $\bar{\eta}$.

Importantly, the time of retirement is negatively correlated with initial bond holdings, $cor(b_{i,0}, T_i) < 0$. This means that households' consumption elasticities are correlated with the size of the wealth transfer. Intuitively, richer households retire sooner. As a result, the redistribution shock between workers and retirees leads to individual consumption and labor responses that do not cancel in the aggregate despite the zero net aggregate transfer.[11]

[11] Note that in the absence of retirement in equilibrium, $T_i \to \infty$, the individual persistent adjustments of labor and consumption cancel in the aggregate.

Aggregate consumption is given by

$$\begin{aligned}\Delta C_t &= (1-\gamma)^{t-1}\sum_i \Delta c_{i,t} = ((1-\gamma)\beta R)^{t-1} s\Big(\overbrace{\bar{\eta}\sum_{i|T_i'\le 1\,\cap\, T_i'\le 1} b_{i,0}}^{\text{permanently retired at t=0}} + \overbrace{\sum_{i|T_i>1\,\cup\, T_i'>1}\eta(T_i,T_i')b_{i,0}}^{\text{not yet retired at t=0}}\Big)\\ &= ((1-\gamma)\beta R)^{t-1}\underbrace{s}_{<0}\Big(\underbrace{\bar{\eta}\sum_i \omega_0(b_i)b_i}_{=0} + \underbrace{\sum_{i|T_i>1\,\cup\, T_i'>1}\overbrace{(\eta(T_i,T_i')-\bar{\eta})}^{<0}\omega_0(b_i)b_i}_{\text{net borrowers on average (>0)}}\Big) < 0, \end{aligned} \tag{3.9}$$

where consumption elasticities (marginal propensities to consume) of permanently retired $MPC_{i,t}\mid_{T_i'\le 1\,\cap\, T_i'\le 1} = \bar{\eta}(\beta R)^{t-1}$ exceed the ones of those who are active in the labor market $MPC_{i,t}\mid_{T_i'>1\,\cup\, T_i'>1} = \eta(T_i,T_i')(\beta R)^{t-1}$. Intuitively, retired households are wealthier and thus net savers who lose income due to a temporary decrease in the real rate. Since their consumption responds more than that of working households who are on average net borrowers that benefit from lower real interest rates, the aggregate consumption persistently decreases.

We can similarly obtain the effect on ***aggregate labor*** by aggregating across working households:[12]

$$\begin{aligned}\Delta L_t &= (1-\gamma)^{t-1}\sum_i \Delta l_{i,t} = -\frac{\psi}{W}(1-\gamma)^{t-1}\sum_{i|T_i>1\,\cup\, T_i'>1}\Delta c_{i,t}(b_{i,0})\\ &= -\frac{\psi}{W}((1-\gamma)\beta R)^{t-1}\underbrace{s}_{<0}\underbrace{\sum_{i|T_i>1\,\cup\, T_i'>1}\eta(T_i,T_i')b_{i,0}}_{<0} < 0. \end{aligned} \tag{3.10}$$

Households in the labor force are on average net borrowers and thus they benefit from lower real interest rates and respond by decreasing labor supply. In contrast, wealthier retired households who suffer from the redistribution do not want to increase their labor supply by much or at all since they strictly prefer leisure.

The aggregate effects dissipate in the long run as the households affected by monetary easing are replaced by new households.

Proposition 2. *In an economy with variable labor supply, retirement and no borrowing constraints, temporary monetary policy shocks have persistent individual consumption and labor*

[12] Since labor supply is linear in consumption (up to retirement), it is easy to aggregate.

responses that have an aggregate impact. A temporary monetary policy easing persistently decreases aggregate consumption and labor supply in the medium term. This effect dissipates in the long run.

Proof. See Appendix A.5. ■

4 Calibration, estimation and model fit

To conduct quantitative analysis, we calibrate the general equilibrium model to match key characteristics of the Canadian economy in the steady state and then estimate the parameters for the aggregate shock processes. Given the nature of the model, we use a combination of quarterly aggregate data, household-level survey data and insights from the related literature.

4.1 Calibration of the stationary equilibrium

We solve the stationary equilibrium non-linearly using projection methods, specifically the endogenous gridpoints method (Carroll, 2006). To calibrate the stationary equilibrium relevant parameters, we proceed in two steps. First, we determine parameters either using standard statistics or by setting them to commonly used values from the literature. See Table 1 in Appendix A.1 for these parameters and their values. The probability of dying is set to 0.44 per cent, which corresponds to a life expectancy of 57 years conditional on reaching the working-life age of 25. The elasticity of the substitution parameter among differentiated consumption goods, ε, is set to 10, which corresponds to a price markup of 10 per cent. Regarding the capital income share, we use a standard value in the literature of 0.33. Similarly, the capital depreciation parameter has the commonly used value of 2.5 per cent. Regarding the housing stock depreciation, we make use of the estimates by Kostenbauer (2001) for Canada. He finds an annual depreciation rate of 1.5 per cent, which we convert to quarterly values. Unemployment benefits are set to 55 per cent of the average annual wage income of a Canadian employee, and the funding tax is 3.9 per cent. Both values are taken from the Government of Canada webpage on the Employment Insurance. The minimum down payment requirement is set to 5 per cent in line with current mortgage requirements.

We normalize the housing size of a renter to be 0.05. This normalization is possible, since all that matters for the house buying incentives is the relative utility from buying versus renting. We also introduce a housing transaction fee of 5 per cent. This corresponds to the commonly used real estate commission in Canada payed by the seller.[13] The interest rate spread between the borrowing and the savings interest rates is determined using the difference between the 5-year fixed conventional mortgage rate and the 5-year Guaranteed Investment Certificates (GIC) rate. To obtain a quarterly rate, we remove the term premium by taking out the difference between the 5-year GIC rate and the daily interest rate on large deposits. The resulting spread is 0.39 per cent.[14] The share of capital directly financed by households, i.e., via equity, is set to match the share of real positions (as opposed to nominal) in the portfolio of retired households (70 per cent in SFS 2005; see also Meh et al. (2010)). Regarding the idiosyncratic earnings shock, we use a parsimonious setup with two possible states: employed and unemployed. The advantage is that the parameters guiding the 2-state Markov process, $M_{z',z}$, are easy to estimate from duration data. The focus on only two states comes at the cost of a less rich income distribution, but still captures the main income uncertainty in a working-age person's life. We take this approach mainly to keep the state space contained. From an average unemployment duration of 23 weeks over the period from 1993 to 2019, we determine that the probability of staying unemployed is 48 per cent per quarter. Similarly, from the average job tenure between 95 and 116 months, we determine that the average probability of staying in your job is 97 per cent per quarter.

With these parameters in hand, we proceed to our second step: a simulated method of moments exercise. The aim is to determine the parameters (β, ψ, ϕ, q). These parameters have a significant impact on our results. The discount factor has a big impact on the amount of borrowing and lending in the model, which in turn is important for the redistribution mechanism. The disutility of labor influences the amount of labor supply heterogeneity. The utility from housing services together with the price of housing is critical for the amount of borrowing. To determine these parameters, we focus our attention on the stationary

[13] There is no universally set commission, and the arrival of discount real estate brokers and sales-by-owner has had an impact over the last few decades. However, on average sellers pay 2.5 per cent to their real estate agent and 2.5 per cent to the buyer's real estate agent.

[14] We considered alternative interest rates regarding the savings rates and found a range for the spread from -5 to 40 basis points.

equilibrium and conduct a simulated method of moments exercise. Normally, we would use the house price to clear the housing market. However, that would make our calibration very time consuming. So, we fix the house price and let housing supply adjust to clear the market. This is only done in the stationary model, while in the DSGE model house prices will vary to clear the market.

We are targeting four moments: the mean LTV ratio in the 2016 Survey of Consumer Finance (SCF), 0.51; the average weekly hours worked by employed persons in Canada relative to 100, 0.39; the share of debt to net worth, 0.2; and the share of wealth held by the population older than 65 years, 0.29. The last is matched with the share of wealth held by households in the model that stopped working in the marketplace.

The estimated parameter values are in Table 2, and the model's fit of the data moments can be found in Table 3 in Appendix A.1. We successfully match the LTV ratio and the wealth share of retired households, which is critical given our redistribution mechanism. Regarding the other moments, we are very close but understate some of the moments. Our debt-to-net-worth ratio is 19 per cent instead of 20 per cent, and the average hours worked are 38 per week instead of 39.

4.2 Estimating the aggregate shocks

To find the dynamic general equilibrium solution, we follow the approach of Reiter (2009). We use our stationary equilibrium, which includes a high-dimensional representation of the cross-sectional distribution of households, and obtain a first-order perturbation of the equilibrium. The implementation is done in Dynare (Adjemian et al., 2011), where we use macros to characterize the model with its large state space, including the high-dimensional household distribution and its dynamics.

Regarding the calibration of aggregate processes, we proceed in two steps. First, we determine a subset of dynamic parameters either using standard statistics or by setting them to commonly used values from the literature. Regarding monetary policy, we follow Alpanda et al. (2018), who postulate a 2 per cent inflation target and an inflation focused Taylor rule that has an inflation coefficient of 2.5 and no weight on the output gap. We also set the capital adjustment costs at 2.6 as in Alpanda et al. (2018). To capture the fact that the effective mortgage rate is adjusting only slowly, we introduce a persistence parameter that captures the speed of adjustment. Here we match the fact that the average mortgage term is 2.4 years and obtain a value of $\rho^{rm} = 0.90$.[15]

Second, we use Bayesian estimation to find the persistence and standard deviation of the three aggregate shocks. The shock processes in the model affect total factor productivity, the demand for consumption goods and the effective monetary policy rate. The data we use in our estimation procedure are quarterly from 1993Q1–2019Q4: the overnight money market rate, real household consumption expenditures and total factor productivity. The latter is constructed as a residual using the time series for the capital stock, the gross domestic product, employment and hours worked. To remove trends, we use a one-sided Hodrick-Prescott filter with a parameter value of 1600. Our priors and posteriors are summarized in Table 4 in Appendix A.1. The resulting numbers are broadly in line with the ones found in the standard New Keynesian literature, see Christiano et al. (2005), Smets and Wouters (2003) and Justiniano et al. (2011).

4.3 Marginal propensities to earn

The size and dynamics of the labor response to income shocks is crucial for our results. Therefore, we compute the MPE as defined by Auclert et al. (2021). MPE are the negative of an earnings response to an unexpected one-time payment. Based on the empirical findings in Cesarini et al. (2017) and Imbens et al. (2001), Auclert et al. (2021) compute the average MPE in a given year in response to an income shock within the year, finding a value between 0 and 0.04. In the context of our model, the distribution of quarterly MPEs is reported in Figure 14 in Appendix B and takes the average value of 0.011. Converted to an annual frequency, we find an average MPE of 0.022, which is well within the interval computed by Auclert et al. (2021).[16] Moreover, our earnings response to income is persistent, which is also consistent with the findings in Cesarini et al. (2017) and Imbens et al. (2001).

[15] Even though most mortgages have a contract term no longer than 5 years, the initial amortization period in Canada is between 25 and 35 years.

[16] We compute the annual MPE assuming a uniform distribution of exogenous income over the year. If the income shock takes place at the beginning of the year, the average MPE over the whole year is 0.032.

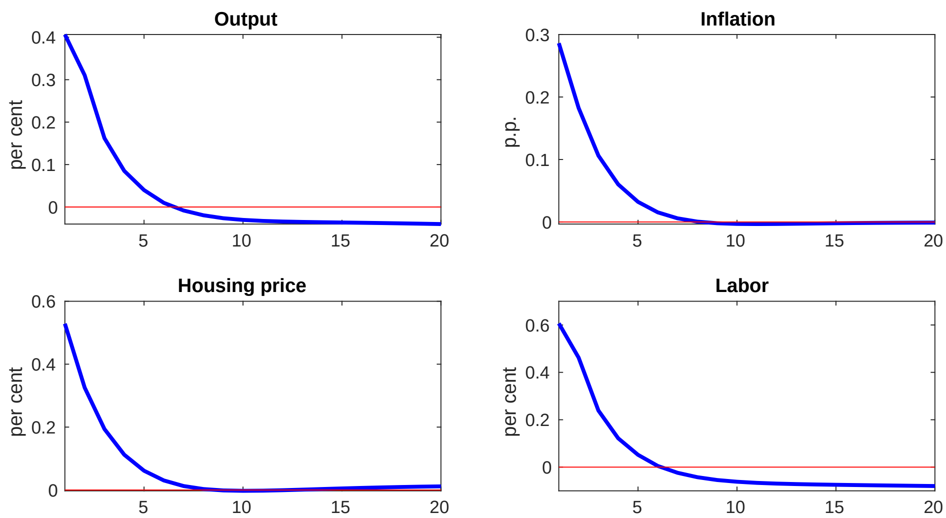


Figure 2: Responses to monetary policy easing

5 Main general equilibrium results

In this section, we show that the wealth redistribution channel as outlined above in a partial equilibrium setup carries over to a general equilibrium version. In particular, the wealth redistribution effect creates a trade-off for monetary policy: a short-term stimulus implies a costly reduction of output over the medium term. Taking this logic further, we consider the trade-off under different monetary policy regimes and assess the implications for stabilizing the economy.

5.1 The wealth redistribution channel

5.1.1 Redistribution effects of a monetary easing shock

Focusing on a monetary easing shock, we use our calibrated general equilibrium model to characterize the wealth redistribution channel; see Figure 2. Monetary policy stimulates output, labor and inflation in the short run similar to what happens in a representative-agent New Keynesian model. However, our model generates persistent negative effects of labor and output over the medium term. This is consistent with the results we previously highlighted in the partial-equilibrium analysis.

To understand the forces behind the medium-term effect, we take a closer look at the

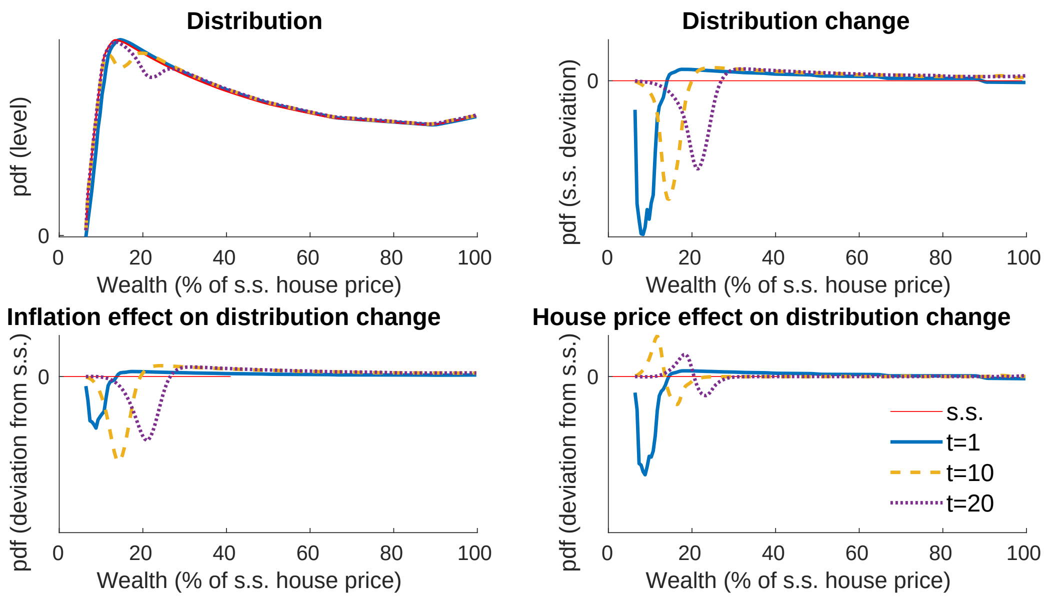


Figure 3: The effects of monetary policy easing on the wealth distribution dissipate slowly and are driven mainly by higher inflation. Top left panel shows the evolution of the wealth distribution of indebted homeowners (we aggregate over income). Top right panel shows the deviation of this distribution from the steady state. Bottom panels isolate direct impacts of inflation and house price on the distribution change.

consequences of the monetary easing shock for the wealth distribution. On impact the shock redistributes wealth from savers to borrowers, and the persistent nature of this redistribution effect is due to the slow-moving household distribution over wealth. Figure 3 shows the effect of monetary easing on the wealth distribution (probability density function) on impact, $t = 1$, in periods 10 and 20, respectively. To better understand the distributional consequences, we focus on indebted homeowners. Following a monetary easing shock, the distribution of borrowers shifts to the right (top left panel in Figure 3). There are fewer homeowners with low wealth (highest level of debt) and more homeowners with higher wealth levels (top right panel in Figure 3). This captures the positive wealth transfer to borrowers, which is proportional to the size of their nominal debt. Crucially for the aggregate response, this change in the distribution is very persistent. The unconstrained homeowners use the extra wealth to repay part of their mortgage, and thus the changes in the distribution slowly move toward higher wealth as affected households continue to accumulate wealth along their life-cycle path. The changes also become more dispersed due to idiosyncratic shocks. In the long run, the distribution will return to its steady state as affected households die and are replaced

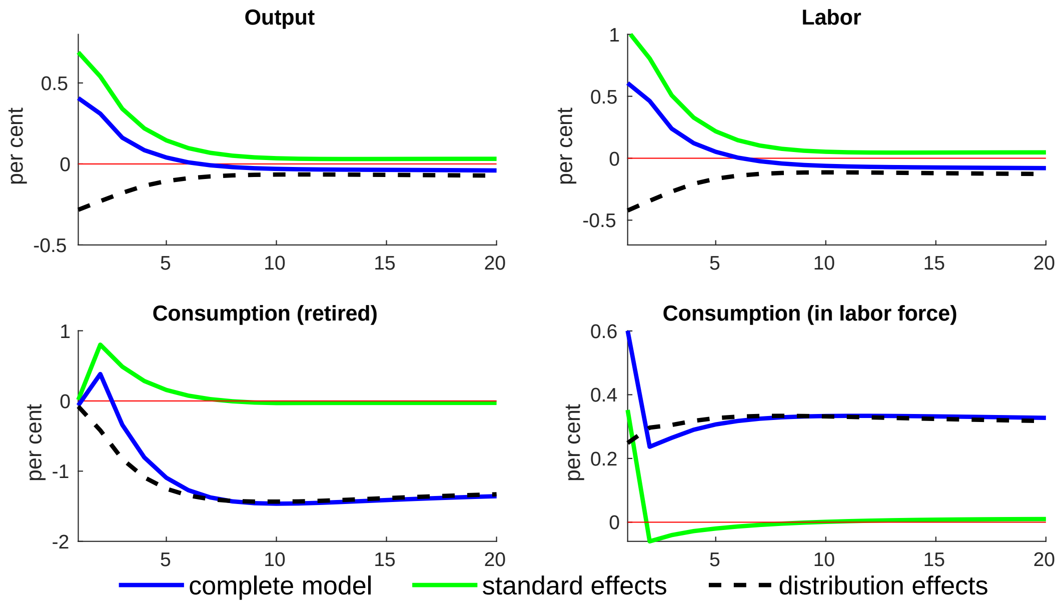


Figure 4: Decomposition of responses to monetary easing into distribution and standard effects. While the standard effect wears off quickly (light green line for model without distribution effects), the distribution effect is very persistent.

by new households. To highlight the importance of the distribution, we analyze consumption and labor supply responses conditional on the wealth level and find that monetary policy has only temporary effects (Figure 15 in Appendix B). So, monetary policy persistently changes the wealth distribution, but has only temporary effects on an individual's behavior conditional on their economic circumstances staying the same.

Next, we decompose the changes in the wealth distribution into cumulative direct effects of changes in prices (final goods prices, house prices, wages and nominal interest rates) and cumulative effects of households' changes in consumption and labor supply. We find that the increase in inflation of final goods is the most significant factor in terms of size and persistence (bottom panels of Figure 3). The induced house price increase also has a large impact on the wealth distribution, but it is only temporary. Twenty quarters after the monetary easing, we can still see a significant shift in the wealth distribution of borrowers due to higher inflation, but the most striking effect of the higher house prices is the lower wealth of households who were first-time home buyers at the time of the monetary easing. The remaining factors, including the change in labor income and the increase in consumption, have much smaller effects on the wealth distribution, as shown in Figure 5.

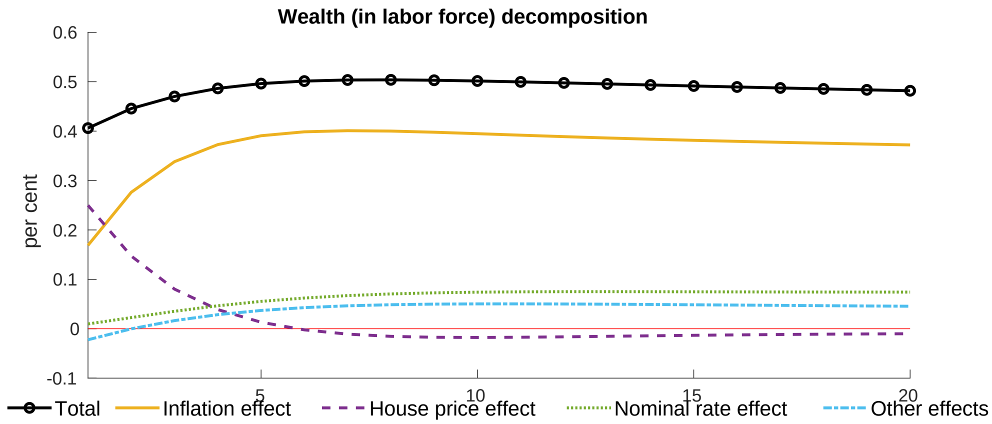


Figure 5: Decomposition of wealth response to monetary easing under IT for households in the labor force. The cumulative inflation response is the main driver of the persistent wealth effect.

5.1.2 Decomposing the distribution effects

Following our partial equilibrium analysis, the aggregate consequences of the distribution effect is easiest to explain by focusing on the responses of two endogenous household groups: households in the labor force and retired households that stopped working and live off their savings. We aggregate across individuals within these groups and decompose their consumption and labor choices into two components:[17]

$$\hat{C}_t \approx \underbrace{\int \hat{c}_t(w)\bar{\mu}(w)dw}_{\text{Standard effect}} + \underbrace{\int \bar{c}(w)\hat{\mu}_t(w)dw}_{\text{Distribution effect}}.$$

The *bar* (hat) above a variable denotes its *steady-state level* (deviation from the steady-state level). Fixing the steady-state distribution, the first component captures the deviation of the consumption (labor) choice of a given household group from its steady state. We obtain it by aggregating the individual consumption (labor) deviations from the steady state, $\hat{c}_t(w)$, in the household group over the steady-state distribution of wealth, $\bar{\mu}(w)$. We refer to this component as the standard effect as it captures the channel present in the representative household models, such as the reaction to prices including the intertemporal substitution effect of real interest rates and the response of labor to wages. Fixing the choices at the steady-state level, the second component isolates the distribution effect. It captures the part

[17] At the first-order approximation level, this decomposition is exact.

of the consumption (labor) deviation driven by endogenous changes in the distribution and is computed by aggregating individual consumption choices of households within the group at the steady-state level, $\bar{c}(w)$, over the deviations of the distribution from the steady state $\hat{\mu}(w)$.

We start with the standard effect, showing the decomposition for consumption and labor for households in the labor force and retirees, including the impact on output; see Figure 4. Not surprisingly and consistent with canonical New Keynesian models, the standard effect dominates in the short run and wears off quickly.[18] In the absence of the distribution effect, both household groups increase their consumption of non-durables in the short term due to the standard intertemporal effect of lower interest rates. Also, households in the labor force enjoy higher wages and in response increase their labor supply.

The distribution effect, on the other hand, is very persistent and dominates over the medium term, pulling output and labor supply down. This persistence is mainly driven by higher inflation; see Figure 5. Following the monetary easing shock, households in the labor force who are on average net borrowers become richer as their nominal debt is devalued in real terms. When unconstrained, they increase their future path of consumption of non-durables and of leisure. This leads to persistently lower aggregate labor. In contrast, retired households see their saving in nominal assets devalued by inflation and become poorer. In response, they lower their future consumption profile. Since retired households adjust consumption more relative to unconstrained households in the labor force, the aggregate consumption declines over the medium term. The persistent labor and consumption declines imply a reduction of aggregate output over the medium term; Figure 4.

Hence, we find a monetary policy trade-off whereby an easing shock stimulates output in the short term at the cost of persistently lowering it over the medium term. The persistently depressed output corresponds to lower potential since an economy with flexible prices features a similar drop in output in the medium term (see Figure 17 in Appendix B).

[18] Note that there is a small positive persistent effect on labor and output in the standard component. This is due to (i) capital adjustment costs leading to a slowly changing capital stock and importantly (ii) the feedback of distribution effects on prices in the general equilibrium setup. Persistently lower labor puts upward pressure on wages, which tends to increase the standard component of labor supply.

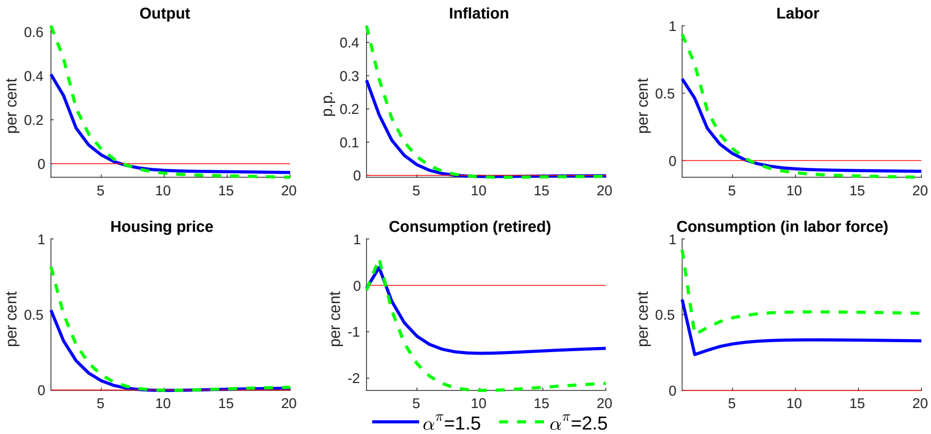


Figure 6: The effect of a more aggressive policy stance on impulse responses to monetary policy easing. More aggressive policy stabilizes the economy more in both the short and medium terms and implies lower redistribution across households.

5.2 Policy implications

Next, we investigate the implication of the wealth redistribution channel and the resulting policy trade-off for the conduct of monetary policy. First, we discuss low-for-long episodes. Then we compare different policy regimes and how redistributive they are. We find that history-dependent regimes such as PLT imply less redistribution and a weaker trade-off than IT.

5.2.1 Low-for-long episodes

The trade-off we characterize has immediate implications for low-for-long episodes. For instance, the period following the financial crisis of 2008 is characterized by persistently low interest rates, which were at odds with market expectations (see Figure 1). The interest rate futures data suggest that throughout 2008–2016 market participants continued to expect an earlier pickup that failed to materialize. In our model, such a period of lower-than-expected interest rate leads to a redistribution from lenders to borrowers and eventually results in depressed output over the medium term. Consistent with this result, the period following the crisis also coincided with slower growth of potential output (see Figure 1).

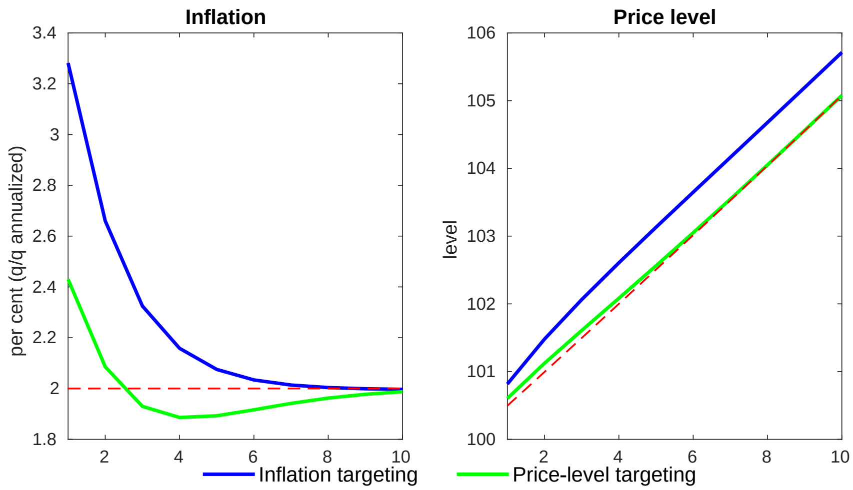


Figure 7: Illustration of the difference between PLT and IT. PLT offsets the initial increase of inflation following a monetary policy shock in order to return to the targeted trend in the price level.

5.2.2 The distributive consequences of different monetary policy regimes

To study the role of the alternative monetary policy frameworks, we compare the following three regimes:

1. Inflation targeting

$$\ln(R_t) = \rho^R \ln(R_{t-1}) + (1-\rho^R)\left(\ln(R^*) + \alpha_\pi \left(\ln(\pi_t) - \ln(\pi^*)\right) + \alpha_y \left(\ln(y_t) - \ln(y^*)\right)\right) + e_t^R;$$

2. Average inflation targeting with n lags (AIT(n))

$$\ln(R_t) = \rho^R \ln(R_{t-1}) + (1-\rho^R)\left(\ln(R^*) + \alpha_\pi \left(\sum_{i=1}^{n} \ln(\pi_{t+i-1}) - n\ln(\pi^*)\right) + \alpha_y \left(\ln(y_t) - \ln(y^*)\right)\right) + e_t^R;$$

3. Price-level targeting

$$\ln(R_t) = \rho^R \ln(R_{t-1}) + (1-\rho^R)\left(\ln(R^*) + \alpha_\pi \left(\ln(P_t) - \ln(P^*)\right) + \alpha_y \left(\ln(y_t) - \ln(y^*)\right)\right) + e_t^R,$$

where P_t is the price level.

For the case of IT, we find that a more aggressive policy stance (higher elasticity of the

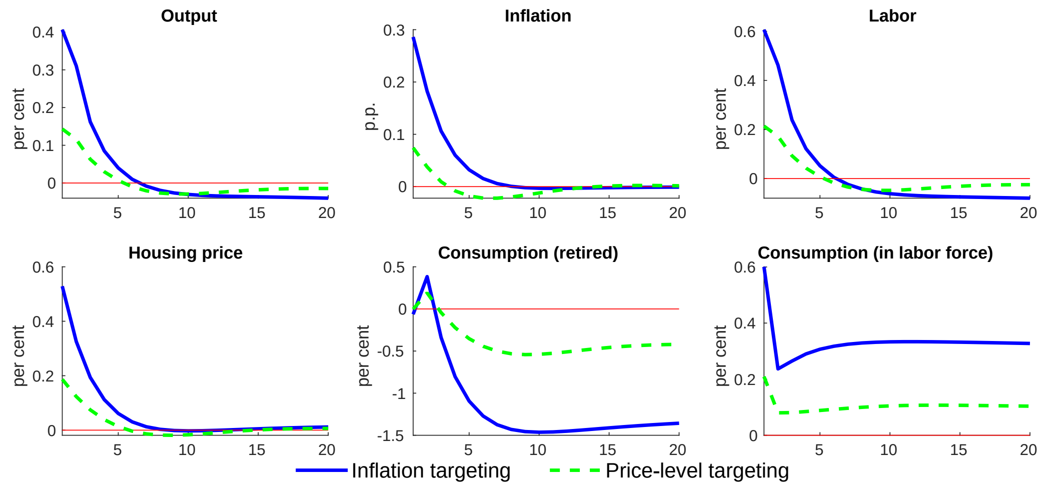


Figure 8: Comparison of monetary policy regimes: impulse responses to monetary policy easing. PLT stabilizes the economy more in both the short and medium terms and implies lower redistribution across households.

nominal rate to inflation, α_π) lowers the redistribution and weakens the persistent medium-term effects. More aggressive policy lowers the volatility of the macroeconomy (e.g., aggregate output and inflation) as well as the volatility of more disaggregated variables (e.g., wealth of subgroups of households); see Figure 6 .

Next, we compare different policy regimes by showing the impulse response to a monetary policy easing under IT and under PLT; see Figure 8. PLT is associated with lower deviations in aggregate output and labor in the short term as well as in the medium term. It also implies less redistribution measured by consumption deviations of both household subgroups: households in the labor force and retired households.

Indeed, PLT leads to smaller medium-term output, labor and consumption gaps than IT due to its weaker redistribution effects. To understand why this is the case, recall that PLT is history dependent (bygones aren't bygones). As Figure 7 illustrates, under PLT an initial increase of inflation after a monetary policy easing will be offset with inflation below the steady state, so that the price level returns back to its steady state. In contrast, under IT the inflation converges monotonically to the steady state, and the price level permanently increases. Two mechanisms reduce the redistribution under PLT. First, the expectation channel reduces the initial impact of the shock. Since forward-looking firms expect the price level to return to the steady state, the inflation increases less on impact. This expectation

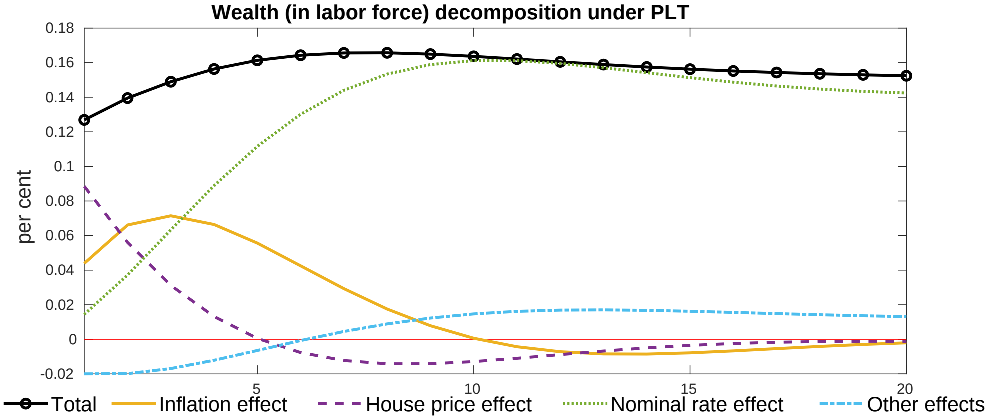


Figure 9: Decomposition of wealth response to monetary easing under PLT for households in the labor force. The cumulative inflation response is offset, and the main driver of the persistent wealth effect are cumulative changes in nominal rates.

channel and its effect on aggregate inflation is well known.[19] In our model, the resulting smaller impact on inflation implies less redistribution due to unhedged nominal positions. Second, while the period of higher-than-steady-state inflation redistributes from savers to borrowers, under PLT it is followed by a period of lower-than-steady-state inflation that redistributes in the opposite direction. The overall result is less redistribution. These two mechanisms reinforce each other. When we decompose the changes in the wealth distribution of monetary easing under PLT, we find that the cumulative effect of inflation has no persistent effect on the distribution because the shocks to inflation are offset as the economy converges back to the same price level. Therefore, redistribution is smaller under PLT. The driving force behind the persistent change in wealth under PLT is the cumulative effect of nominal rate changes, which are larger under PLT. This is because the smaller increase in inflation triggers a weaker systematic policy response that tends to increase nominal rates and thus offsets the initial monetary easing shock; Figure 9.

To highlight the importance of the expectation channel in a general equilibrium setup, we do an inflation shock exercise based on Meh et al. (2010), who show in a partial equilibrium that if inflation shocks are later reversed, as under PLT, they result in less redistribution. When we equalize inflation changes on impact under PLT and IT, to achieve comparability with Meh et al. (2010), we find that the responses of output and redistribution are larger

[19]See for example, Dittmar and Gavin (2000).

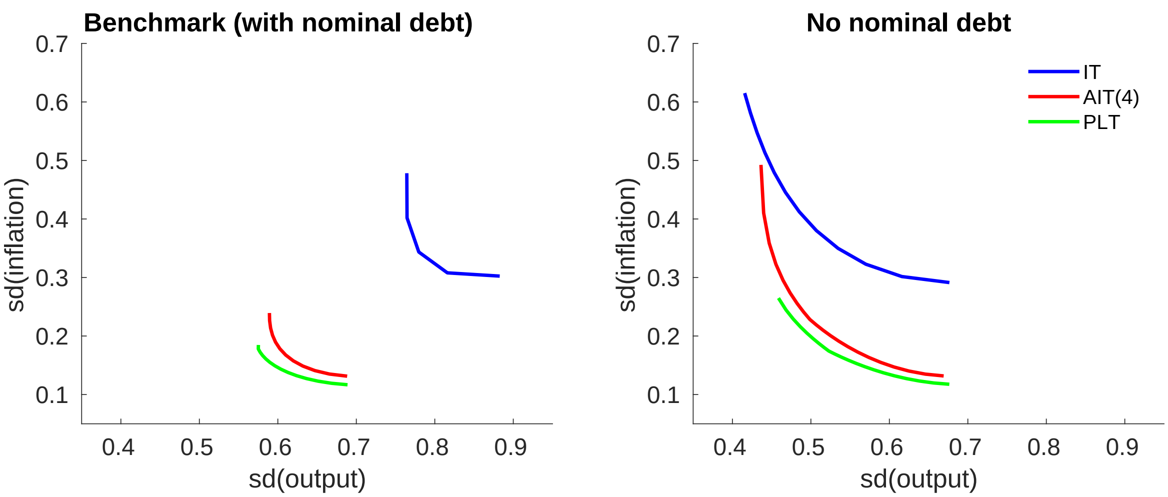


Figure 10: Monetary policy possibility frontier when stabilizing the economy. The left panel shows the trade-off between inflation and output stabilization for the benchmark economy. The right panel shows the same trade-off in an economy where mortgages are specified in real terms and all capital is directly owned by households through equity.

under PLT; Figure 16 in Appendix B. While the return of the price level to target eliminates the persistent redistributive effects of inflation, we need larger monetary shocks in our model to produce the same endogenous response of inflation on impact under PLT. However, larger changes in nominal rates lead in our model to more redistribution under PLT. In contrast, nominal rates are constant in the partial equilibrium setup of Meh et al. (2010). This experiment in combination with the insights from Figure 8 highlight the importance of the expectation channel and the benefits of a general equilibrium setup.

So far, we have focused on monetary policy shocks. To complete the comparison of monetary policy regimes, we simulate the economy for various combinations of Taylor rule parameters, α^{π}, α^{y}, and all three estimated shocks: total factor productivity, demand and monetary shocks. We limit values of Taylor rule parameters to the range considered by Schmitt-Grohe and Uribe (2007) as implementable in the face of communication challenges ($\alpha^{\pi} \leq 3, \alpha^{y} \leq 3$). Then we compare the stabilizing properties of the different regimes by plotting the variability of output and inflation under the three regimes; see Figure 10. The best outcome would be a stabilization of the economy at its steady-state level. The left panel of Figure 10 features the usual trade-off between inflation and output stabilization for our benchmark economy. PLT dominates both AIT(4) and IT since it achieves more stable inflation and output.[20]

To highlight the importance of the redistribution channel and of nominal debt, we obtain monetary policy possibility frontiers for an economy without nominal debt. In this economy, the mortgage rate is predetermined in real terms, and all firms' capital is financed directly via equity.[21] As a result, the direct effect of inflation on the wealth distribution is eliminated. Recall we find that the inflation effect is the main driver for the persistent output implication of monetary shocks. In the right panel of Figure 10, we show the inflation-output trade-off for this alternative economy. Without the redistribution effects of inflation, the economy is easier to stabilized for any monetary regime compared with the benchmark economy. PLT is still preferred when the central bank cares strongly about inflation volatility. However, for a sufficiently large weight on output volatility in the loss function, AIT(4) or IT regimes can be preferred.

6 Robustness checks

Up to now, we have explained our key results and their implications for monetary policy. Now, we assess key model features and how they influence the redistribution channel and its persistent medium-term implications. First, we evaluate the importance of nominal debt. Second, we consider the importance of real asset price adjustments. Third, we evaluate the impact of restricting homeowners' access to credit. Fourth, we evaluate the importance of price and wage stickiness. Finally, we compare the model's medium-term implications to correlations obtained from cross-country data.

6.1 Importance of nominal debt

To gauge the importance of nominal debt, we return to a monetary easing shock, although this time for an economy in which mortgage contracts are real[22] and households own firms'

[20]When we relax the constraints on Taylor rule parameters, we can stabilize the economy more including by reducing the aggregate implications of wealth redistribution; Figure 6. For $\alpha^{\pi} \geq 9$ the IT regime can be preferred by a central bank that puts a high weight on output volatility.

[21]See Section 6.1 for more details.

[22]Real mortgage contracts imply that the mortgage interest rate is predetermined in real terms and thus is not affected by inflation surprises. Nominal debt is in zero net supply, and households are indifferent to

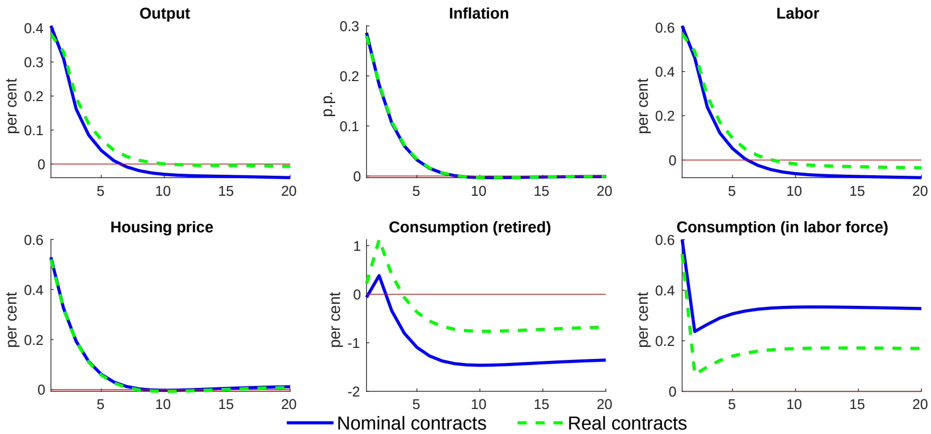


Figure 11: Responses to monetary policy easing. Both models with and without nominal debt have similar short-term responses. But only the model with nominal debt shows the persistent medium-term effects on output.

capital directly through equity. We compare the outcome to the benchmark economy with nominal mortgages and a fraction of capital financed through bonds; see Figure 11. While monetary policy is still able to stimulate output, labor and inflation in the short run, the model with real returns does not generate sizable medium-term output deviations from the steady state. Thus, the presence of sizable nominal debt, as we see in most economies, is critical for the medium-term effects, as highlighted in the partial equilibrium analysis.

6.2 Real asset prices in general equilibrium

A natural question is whether the redistributive impact on savers due to their holdings of nominal bonds might be partially mitigated by valuation effects on their positions in real assets. We investigate that idea by looking at the two real assets in our model: housing and capital. As expected, monetary policy easing reduces the value of nominal debt and increases the value of real assets in our model.

On impact, we find a significant increase in real asset values. Both the price of houses (q) and capital (q^k) go up; see Figure 12. However, this effect wears off quickly and does not offset the effects of a permanent devaluation of nominal debt over the medium term.[23]

holding nominal debt, real mortgages or capital.

[23] Importantly, the price of capital is persistently reduced following period six, due to persistently lower output.

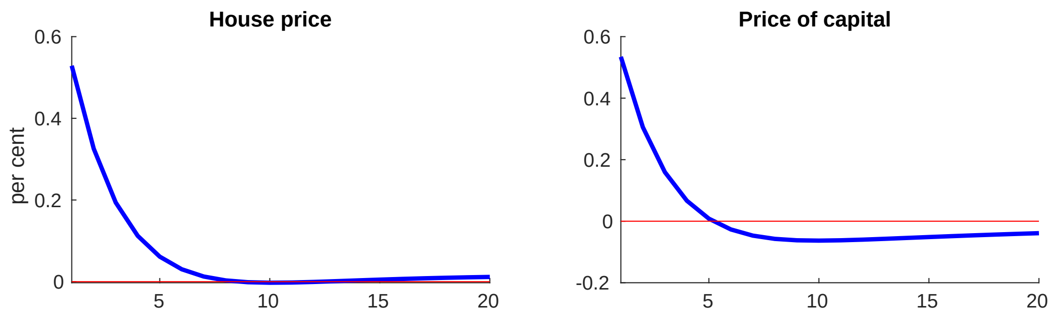


Figure 12: Both house price and capital price increase only temporarily after monetary policy easing. Capital price then remains persistently depressed.

House prices go up on impact since lower mortgage rates increase the demand for housing. The marginal home buyers have relatively small nominal savings, and this endogenous group is relatively quickly replaced by new households who enter the labor market and are not directly affected by the easing shock. As a result, the distributional effects on the house price are limited and short lived. Indeed, the house price converges quickly back to the steady state. As a result, home buyers during the period of temporarily elevated house prices end up with slightly lower wealth following the return of the house price back to its steady-state value; Figure 3. Regarding the supply side, most homeowners stay in their house, so they do not benefit from the temporarily increased house price. There are two groups of house sellers. A small group of stressed sellers are indebted and cannot tap into their home equity due to the borrowing constraints. However, the majority of sales are associated with households that die. The resulting benefits of the temporarily higher house price are distributed among all existing homeowners (borrowers and savers) through the life-insurance mechanism. In conclusion, the temporary house price appreciation does not offset our medium-term effects. We confirm this point in Appendix B, Figure 20, by showing that the persistent medium-term effects remain even if we neutralize the house price with a series of negative housing demand shocks.

6.3 Binding refinancing constraints in general equilibrium

The benchmark general equilibrium model already includes borrowing constraints: renters cannot borrow, and homeowners have to satisfy the LTV constraint. However, conditional on satisfying the LTV constraint, households can access home equity freely, which would correspond to a generous availability of home equity lines of credit. This source of short-term liquidity is missing in some papers that stress the crucial role of borrowing constraints (e.g., Kaplan et al. 2018). To test the impact of more stringent liquidity constraints, we limit the access to home equity by imposing a constraint on mortgage refinancing:

$$-\,b_{i,t} \leq \varphi(-b_{i,t-1}),\ \text{if } h_{i,t} = 1 \text{ and } -\,b_{i,t-1} > \underline{\theta} q_t, \tag{6.1}$$

where $\varphi = 1.01$ and $\underline{\theta} = 0.5$. In our model, 22.6 per cent of households have an LTV that would prevent them from freely accessing their home equity and thus are either directly constrained (typically when unemployed) or repay their debt faster due to precautionary motives associated with the threat of a binding constraint. This share slightly exceeds the 18 per cent share of wealthy hand-to-mouth households reported for Canada by Kaplan et al. (2014).

Figure 13 compares the impulse responses to a monetary policy easing shock in the benchmark model and the model with additional constraints on mortgage refinancing.[24] Intuitively due to tighter constraints, the immediate impact on consumption of households in the labor force is larger. This implies a stronger immediate stimulation of the economy, which in turn increases wages more and thus labor supply as well.

The medium-term effects on labor and output are slightly smaller than in the benchmark economy but remain visibly below the steady-state level. This small difference in the medium-term labor supply is driven by the net effect of two offsetting forces. First, constrained households do not decrease their labor supply over the medium term. This is also identified in the partial-equilibrium model (see Proposition 4 in Appendix A.3). Second, due to more stimulus on impact, the inflation rate increases more, which tends to redistribute more from savers to borrowers. This higher inflation is then partially compensated by the systemic response of monetary policy implying relatively higher nominal rates. The consumption response over the medium term is amplified for retirees since they are negatively affected by relatively lower house prices.

[24] The implications of binding borrowing constraints and their interaction with the endogenous labor supply choice in partial equilibrium are derived analytically in Appendix A.3.

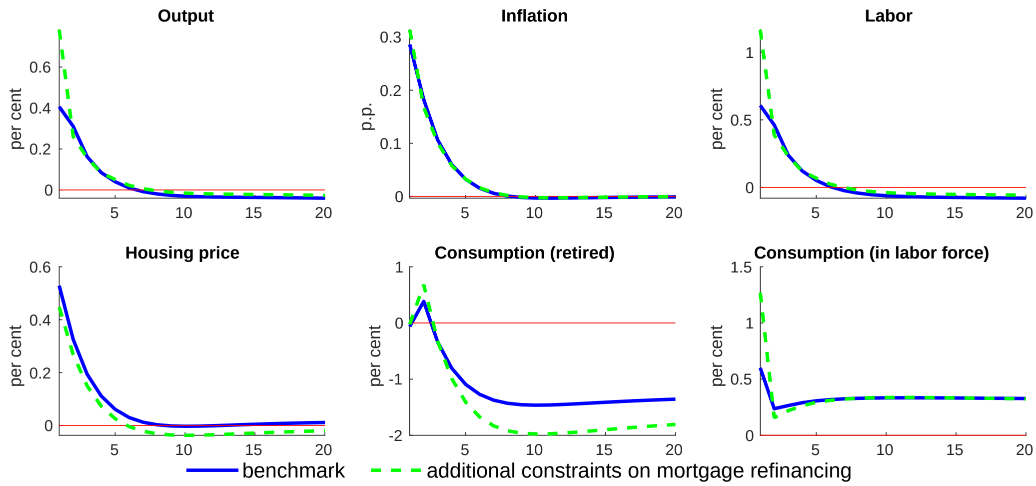


Figure 13: The effect of additional constraints on mortgage refinancing. The effect of monetary policy easing is more pronounced on impact. The medium-term effects on labor and output are marginally reduced but remain negative.

6.4 Price and wage stickiness

Our benchmark model features sticky prices and flexible wages. We evaluate alternative specifications of price and wage setting, namely flexible prices and sticky wages. Under flexible prices, prices fully adjust on impact, and the output does not increase in the short run. However, higher inflation has a similar implication for redistribution due to nominal debt contracts. Thus we find that the negative medium-term output effect of monetary policy easing is similar under both sticky and flexible prices, consistent with the finding that persistent wealth effects of monetary shocks are mostly driven by the inflation response; Figure 17 in Appendix B. Moreover, we find that even with flexible prices monetary easing under PLT has a smaller negative effect on output in the medium term than under IT; Figure 18 in Appendix B.

Focusing on sticky wages, we confirm the persistent negative effect of monetary easing.[25] However, the presence of wage stickiness reduces the response of wages on impact, resulting in a marginally smaller increase of inflation, a higher demand for labor and a stronger positive output response on impact. But there is no noticeable change over the medium term relative to the benchmark model; Figure 19 in Appendix B. This is consistent with the result that

[25] In the model version with sticky wages, a labor union sets the wage subject to Rotemberg-style adjustment costs. The union distributes the labor demand for a given wage across workers so that the marginal rate of substitution is equalized across them.

labor income changes have a relatively small impact on changes in the wealth distribution that drives the persistent effects of monetary policy shocks.

6.5 Cross-country comparison

In an effort to shed light on the trade-off channel, we take a closer look at the period following the global financial crisis. The idea is that this period was marked by low interest rates for many countries and for extensive periods of time. In the context of our model, a larger monetary stimulus reduces the labor supply over the medium term. Consistent with this implication, countries that provided more monetary stimulus measured by the short-term interest rates in the five years following the financial crisis displayed slower growth for various measures of labor supply over the ten years following the crisis (see Figure 21 in Appendix B).

In addition, a simple regression analysis suggests that the negative effect of the stimulus on the change in labor supply is more significant for the extensive measures of the labor supply. We also show that the size of private debt outstanding at the onset of the crisis (in 2007) tends to reduce the labor supply at the extensive margin (see Table 5 in Appendix A.1). This is consistent with our model-based result that a larger amount of nominal debt in the economy amplifies the medium-term effects on labor supply.

7 Conclusion

Using a partial-equilibrium framework, we establish that nominal debt together with labor supply heterogeneity, especially retirement, implies that interest rate shocks have persistent medium-term consequences. The intuition behind the result is that a monetary policy easing shock redistributes from savers to borrowers, where savers are wealthier and retired or closer to retirement than borrowers. As a results savers adjust consumption more and labor less than unconstrained borrowers. When combining the effects, we see that both aggregate consumption and labor supply will be persistently depressed. This insight carries over to an estimated small-scale heterogenous agent DSGE model and extends to persistent effects on output.

When we take a closer look at the DSGE transmission of monetary policy, we are able to identify a wealth redistribution channel that creates a trade-off for monetary policy. According to this channel, a short-term stimulus has medium-term output costs. This trade-off is smaller for more aggressive policy and for less redistributive policy frameworks such as PLT. The wealth redistribution channel also implies that long periods of unexpectedly low interest rates can persistently reduce output. Thus, this channel could have contributed to the perception of lower potential output following the recent global financial crisis with its low-for-long interest rates. We also find that the strength of the channel increases with the amount of nominal debt in the economy and with the share of wealth controlled by the retired population, suggesting that population ageing would increase the channel's strength.

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A Appendix

A.1 Tables

Table 1. Basic Parameters

	Symbol	Value	Rationale
Inflation target (gross, qtr.)	π^*	1.005	2% inflation target
Taylor rule - inflation	a_π	2.5	Alpanda et al. (2018)
- output gap	a_y	0	Alpanda et al. (2018)
Probability of dying	γ	$\frac{1}{57*4}$	Life expectancy of 57 years in Canada at the age of 25
Demand elasticity	ε	10	Markup on prices 10%
Price adjustment parameters	κ	100	Slope of the Phillips curve
Capital income share	α	0.33	
Capital adjustment costs	κ_k	2.6	Alpanda et al. (2018)
Capital depreciation	δ_k	0.025	Smets-Wouters (2007)
Housing stock depreciation	δ_h	$1-(1-0.015)^{1/4}$	Kostenbauer (2001)
Share of capital financed by equity	χ^e	0.52	Portfolio share of real assets SFS
Taxation for unempl. insurance	τ_{soc}	0.038 88	Government of Canada
Unempl. benefits (share of $\bar{W}_t$)	b^U	0.55	Government of Canada
Mortgage insurance fee (share of q_t)	τ^I	0.0078	CMHC
Housing transaction fee (share of q_t)	τ^H	0.05	Standard realtor fee of 5%
Loan-to-value constraint	θ	5%	OSFI
House size (renter)	$\underline{h}$	0.05	Normalized
Interest rate spread	ζ	0.0039	
Persistence of mortgage rate	ρ^b	0.8958	Average mortgage term of 2.4 yr
Idiosyncratic income state	(z)	$(0,1)$	Unemployed / Employed
Idiosyncratic income transitions	$M_{z',z}$	$\begin{pmatrix} 0.48 & 0.52 \\ 0.03 & 0.97 \end{pmatrix}$	Estimates based on state durations

Table 2. Calibrated parameters

	Symbol	Value
Discount factor	β	0.9905
Disutility of labor	ψ	2.0809
Utility from housing services	ϕ	1.1683
House price	q	41.3354

Table 3. Moments		
	Data	Model
Wealth share of retired households (SCF)	0.29	0.29
Average LTV ratio of indebted homeowners (SCF, mean in 2016)	0.51	0.51
Debt to net worth (Statistics Canada)	0.20	0.19
Average hours of employed (relative to 100)	38.5	38.4

Table 4. Shock processes					
	Prior distribution			Posterior distribution	
	Distr.	Mean	St.Dev	Mode	Mean
TFP shock					
ρ^a	Beta	0.75	0.1	0.71	0.72
σ^a	Invgamma	0.009	2	0.0056	0.0057
Demand shock					
ρ^ν	Beta	0.8	0.1	0.89	0.89
σ^ν	Invgamma	0.004	2	0.0057	0.0058
Monetary policy shock					
ρ^r	Beta	0.65	0.1	0.86	0.88
σ^r	Invgamma	0.004	2	0.0022	0.0022

Table 5. Regression results						
	Δ Labor participation		Δ Employment		Δ Hours p.c.	
Constant	5.48^{***}	11.62^{***}	5.69^{***}	9.05^{***}	1	2.2^{***}
Monetary stimulus	-1.07^{***}	-0.57	-1.58^{*}	-1.22	-0.3	-0.1
Private debt in 2007		-3.66^{***}		-1.93^{***}		-0.8

A.2 Data used for calibration

From Statistic Canada

- Job tenure by type of work (full or part time): Statistics Canada Table 14-10-0051-01 Job tenure by type of work (full and part time), annual
- Duration of unemployment: Statistics Canada Table 14-10-0057-01 Duration of unemployment, annual

Other sources

- LTV distribution: Bilyk et al. (2017) for 2014 and 2017; Canada Mortgage and Housing Corporation (2019) for 2019
- Mortgage insurance fees: CMHC - https://www.cmhc-schl.gc.ca/en/finance-and-investing/mortgage-loan-insurance/mortgage-loan-insurance-homeownership-programs/cmhc-mortgage-loan-insurance-cost; Genworth - http://genworth.ca/en/lenders/premium-rate-table.aspx
- Life tables for Canada: Canadian Human Mortality Database, Life table Total 1x1, http://www.bdlc.umontreal.ca/CHMD/prov/can/can.htm
- Interest rates: Bank of Canada webpage
  - 5-year fixed rate conventional mortgage - V80691335
  - 5-year Guaranteed Investment Certificate - V80691341
  - 5-year personal fixed term - V80691336
  - Non-Chequable Savings Deposits - V80691338
  - Daily Interest Savings (balances over CAD 100,000) - V80691337

A.3 Binding borrowing constraints in partial equilibrium

Consider the partial-equilibrium model of Section 3 with the difference that the following borrowing constraint is binding for some households:

$$b_{i,t} \geq \min\left\{0, \underline{\theta} b_{i,t-1}\right\},$$

where $\underline{\theta} \leq 1$. The borrowing constraint represents a reduced-form repayment schedule.

A.3.1 Case with fixed labor supply and borrowing constraints

A constrained household cannot achieve its optimal consumption path due to a binding borrowing constraint:

$$c_{i,t} < \bar{\eta}\left[b_{i,t-1}\frac{1}{1-\gamma}\frac{R}{\pi_t} + W\frac{1}{1-\frac{1-\gamma}{R}}\right]. \tag{A.1}$$

In the steady state, households with bond holdings below a threshold b_0^* are constrained. Monetary policy easing can decrease the number of constrained households. In that case, all households with bond holdings below b_1^* will be constrained, where $b_0^* > b_1^* = W(1-\gamma)\frac{\beta-\frac{1}{R}}{\left(1-\frac{1-\gamma}{R}\right)\left(\nu-\beta\frac{R}{\pi_1}\right)}$.

Due to incomplete markets, constrained households adjust their consumption on impact more than unconstrained ones. The consumption of households who are constrained even after the monetary easing shock, $b_{i,0} < b_1^*$, absorbs the full effect of the temporary transfer in the first period and will not adjust later:

$$\Delta c_{i,1} = \frac{1}{1-\gamma}\frac{R}{\pi_1}b_{i,0}, \tag{A.2}$$

$$\Delta c_{i,t} = 0 \; \forall t \geq 1. \tag{A.3}$$

Households who are not constrained before the monetary easing shock, $b_{i,0} \geq b_0^*$, spread the temporary transfer optimally over their whole consumption path according to equation (3.6). Households who stop being constrained after the shock, $b_1^* \leq b_{i,0} < b_0^*$, manage to spread a fraction $1 - f_i \in \{0, 1\}$ of the temporary transfer over the whole consumption path.

Due to the presence of constrained households, who are relatively poorer, $cor(\lambda_i, b_{i,0}) < 0$, the individual consumption responses do not aggregate away. Since constrained households are borrowers who benefit from monetary policy easing, the aggregate consumption increases on impact in period $t = 1$. But starting from $t = 2$ the aggregate consumption persistently decreases below the steady-state level. Intuitively, constrained borrowers do not react after impact, and unconstrained households who spread their consumption response over time are net savers and thus cut consumption in response to the lower real return on savings.

Proposition 3. *In an economy with binding borrowing constraints and fixed labor supply, aggregate consumption increases on impact following a monetary policy easing and then decreases persistently over the medium term.*

Proof. See Appendix A.6. ■

A.3.2 Case with variable labor supply and borrowing constraints

The presence of variable labor supply and occasionally binding borrowing constraints creates two channels from wealth redistribution to aggregate outcomes.

Given an unanticipated monetary easing, the two effects reinforce each other and result in a more robust decrease in the consumption over the medium term and in an increase in the labor supply on impact. The two effects counteract each other regarding the immediate response of consumption and the medium-term response of labor supply. The total effects, therefore, depend on the relative strength of the two channels given by the wealth distribution.

Proposition 4. *Given an economy with binding borrowing constraints and variable labor supply, a temporary monetary policy easing:*

1. *persistently decreases* ***aggregate consumption*** *starting in the period following the tightening. The effect on impact depends on the proportion of constrained households, which increases aggregate consumption, and the proportion of retired households, which decreases consumption.*

2. *decreases* ***aggregate labor supply*** *on impact. The direction of the persistent effect depends on the proportion of constrained households, which tends to increase aggregate labor supply, and the proportion of retired households, which reduces it.*

Proof. See Appendix A.7. ■

A.4 Proof of Proposition 1

First, we derive the optimal individual consumption of households. We substitute $b_t \; \forall t > 0$ sequentially from the budget constraint to obtain the present value budget constraint:

$$c_{i,1} + \frac{1-\gamma}{R} c_{i,2} + \left(\frac{1-\gamma}{R}\right)^2 c_{i,3} \cdots = b_{i,0} \frac{1}{1-\gamma} \frac{R}{\pi_1} + W l_{i,1} + \frac{1-\gamma}{R} W l_{i,2} + \left(\frac{1-\gamma}{R}\right)^2 W l_{i,3} \cdots . \tag{A.4}$$

Note that we apply a transversality condition according to which:

$$\lim_{t\to\infty} \left(\frac{(1-\gamma)}{R}\right)^{t-1} b_{i,t} = 0.$$

Substituting the FOC of unconstrained households with respect to bond holdings, $\frac{c_{i,t+1}}{c_{i,t}} = \beta R \; \forall i, t > 0$, into (A.4) and aggregating the infinite sums yields:

$$c_{i,1} \frac{1}{1-(1-\gamma)\beta} = b_{i,0} \frac{1}{1-\gamma} \frac{R}{\pi_1} + W \frac{1}{1-\frac{1-\gamma}{R}}. \tag{A.5}$$

Rearranging (A.5) yields (3.5). A monetary policy shock changes the return from bonds from $b_{i,0} \frac{1}{1-\gamma} \frac{R}{1}$ to $b_{i,0} \frac{1}{1-\gamma} \frac{R}{\pi_1}$, resulting in a wealth transfer of $b_{i,0} \frac{R}{1-\gamma} \frac{1-\pi_1}{\pi_1}$, which cancels out in aggregate given our assumption of no net borrowing in $t = 0$. Plugging this transfer into the optimal consumption choice (A.5) gives (3.7).

A.5 Proof of Proposition 2

With variable labor supply, the present value budget constraint for a working household becomes:

$$\begin{aligned} c_{i,1} \frac{1}{1-(1-\gamma)\beta} \;=\; & b_{i,0} \frac{1}{1-\gamma} \frac{R}{\pi_1} + W \max\left\{0, 1 - \frac{\psi}{W} c_{i,1}\right\} + \frac{1-\gamma}{R} W \max\left\{0, 1 - \frac{\psi}{W} c_{i,1} \beta R\right\} \cdots \\ & \cdots + \left(\frac{1-\gamma}{R}\right)^{T_i'-2} W \max\left\{0, 1 - \frac{\psi}{W} c_{i,1} (\beta R)^{T_i'-2}\right\}, \end{aligned} \tag{A.6}$$

where the labor supply is positive until period $T_i' - 1$. At T_i' household i retires and stops supplying labor (a temporary transfer might have changed the retirement time from T_i to T_i'). Summing the finite sums from period 1 until $T_i' - 1$ yields

$$c_{i,1} \left(\frac{1}{1-(1-\gamma)\beta} + \frac{\psi}{W} \frac{1-((1-\gamma)\beta)^{T_i'-1}}{1-(1-\gamma)\beta} \right) = b_{i,0} \frac{1}{1-\gamma} \frac{R}{\pi_1} + W \frac{1-\left(\frac{1-\gamma}{R}\right)^{T_i'-1}}{1-\frac{1-\gamma}{R}}, \tag{A.7}$$

which after rearranging becomes

$$c_{i,t} = \eta(T_i') (\beta R)^{t-1} \left(b_{i,0} \frac{1}{1-\gamma} \frac{R}{\pi_1} + W \frac{1-\left(\frac{1-\gamma}{R}\right)^{T_i'-1}}{1-\frac{1-\gamma}{R}} \right), \tag{A.8}$$

where $\eta(T_i') = \frac{\bar{\eta}}{1+\frac{\psi}{W}\left(1-((1-\gamma)\beta)^{T_i'-1}\right)}$.

This implies that a temporary transfer of wealth carries a consumption multiplier $MPC_{i,t} = \eta(T_i')(\beta R)^{t-1}$ and results in net effect (3.8).

To evaluate the effect on aggregate consumption, we can rewrite (3.9) as follows:

$$
\begin{aligned}
\sum_i \Delta c_{i,t} &= (\beta R)^{t-1} s \left(\bar{\eta} \sum_{i|T_i'\le 1 \,\cap\, T_i'\le 1} b_{i,0} + \sum_{i|T_i>1 \,\cup\, T_i'>1} \eta(T_i, T_i') b_{i,0} \right) \\
&= (\beta R)^{t-1} s \left(\bar{\eta} \underbrace{\sum_i b_{i,0}}_{=0} + \sum_{i|T_i>1 \,\cup\, T_i'>1} (\eta(T_i, T_i') - \bar{\eta}) b_{i,0} \right) \\
&= (\beta R)^{t-1} \underbrace{s}_{<0} \underbrace{\left(\sum_{i|T_i>1 \,\cup\, T_i'>1} (\underbrace{\eta(T_i, T_i') - \bar{\eta}}_{<0}) b_{i,0} \right)}_{<0} < 0.
\end{aligned}
$$

A.6 Proof of Proposition 3

Due to the presence of constrained households, who are relatively poorer, $cor(\lambda_i, b_{i,0}) < 0$, the individual consumption responses do not aggregate away, and the aggregate consumption drops on impact in period $t = 1$ but starting from $t = 2$ persistently increases above the steady-state level:

$$
\begin{aligned}
\sum_i \Delta c_{i,1} &= \overbrace{s}^{<0} \left(\overbrace{\sum_{i|b_{i,0}<b_1^*} 1 b_{i,0} + \sum_{i|b_1^*\le b_{i,0}<b_0^*} f_i b_{i,0}}^{\text{Constrained } (<0)} + \overbrace{\bar{\eta} \sum_{i|b_{i,0}\ge b_0^*} b_{i,0}}^{\text{Unconstrained } (>0)} \right) \\
&= s \left(\bar{\eta} \underbrace{\sum_i b_i}_{=0} + \underbrace{\sum_{i|b_{i,0}<b_1^*} \overbrace{(1-\bar{\eta})}^{>0} b_{i,0} + \sum_{i|b_1^*\le b_{i,0}<b_0^*} \overbrace{(f_i - \bar{\eta})}^{>0} b_{i,0}}_{\text{Borrowers } (<0)} \right) > 0.
\end{aligned}
$$

On impact (at $t = 1$) the constrained households respond more (MPC of 1 if their borrowing constraint remains binding after the transfer or MPC of $f_i(b_i)$) than unconstrained savers ($MPC = \bar{\eta}$), resulting in an increase of aggregate consumption.

$$
\sum_i \Delta c_{i,t} = \bar{\eta}(\beta R)^{t-2} s \left(\sum_{i|b_{i,0}<b_1^*} 0 b_{i,0} + \underbrace{\overbrace{\sum_{i|b_1^*\le b_{i,0}<b_0^*} (1-f_i) b_{i,0} \frac{R}{1-\gamma}}^{\text{Temporary constrained } (<0)} + \overbrace{\sum_{i|b_{i,0}\ge b_0^*} \beta R b_{i,0}}^{\text{Unconstrained } (>0)}}_{Net savers on average (>0)} \right) < 0 \quad \forall\, t > 1.
$$

Constrained households do not adjust consumption in periods after the impact, $t > 1$, or adjust it less if they are temporarily constrained. As a result, the aggregate consumption in period $t > 1$ is dominated by the response of net savers, who cut consumption in response to a negative wealth transfer.

A.7 Proof of Proposition 4

When both endogenous labor supply and borrowing constraints are present, the reaction of consumption on impact is not unequivocal. The reason is that constrained households who are borrowers react more on impact than average households. At the same time, retirees who are net savers also react more on impact than unconstrained households. In theory, thus, the aggregate response would depend on the number of households who are constrained and retired and their holdings of nominal debt. In practice, a realistic calibration implies that the response of constrained households would dominate, as we show in Section 6.3. Aggregate consumption is given by [26]

$$\sum_i \Delta c_{i,1} = s\Big(\overbrace{\sum_{i|b_{i,0}<b_0^*} 1 b_{i,0} + \sum_{i|b_1^*\leq b_{i,0}<b_0^*} f_i b_{i,0}}^{\text{Constrained}} + \underbrace{\sum_{i|T_i>0\,\cup\,T_i'>0} \eta(T_i,T_i')b_{i,0} + \bar{\eta}\overbrace{\sum_{i|T_i'\leq 0\,\cap\,T_i'\leq 0} b_{i,0}}^{\text{Retirees}}}_{\text{Unconstrained}}\Big)$$

But when it comes to the aggregate consumption after impact ($t > 1$), the two effects amplify each other. Retirees who are net savers react more to the transfer. And constrained households who are borrowers react less (if temporarily constrained) or not at all. As a result, the aggregate consumption decreases more:

$$\begin{aligned}\sum \Delta c_{i,t} \;=\;& (\beta R)^{t-2} s\Big(\sum_{i|b_{i,0}<b_1^*} 0 b_{i,0} + \overbrace{\sum_{i|b_1^*\leq b_{i,0}<b_0^*} \eta(T_i,T_i')(1-f_i)b_{i,0}\frac{R}{1-\gamma}}^{\text{Temporary constrained}} \\ & + \underbrace{\bar{\eta}\sum_{i|T_i'\leq 0\,\cap\,T_i'\leq 0} \beta R b_{i,0}}_{\text{retirees at t=0}} + \underbrace{\sum_{i|T_i>0\,\cup\,T_i'>0} \eta(T_i,T_i')\beta R b_{i,0}}_{\text{employed at t=0}}\Big) < 0 \quad \forall\, t > 1\end{aligned}$$

Aggregate labor supply decreases on impact since households in the labor force are net borrowers who increase their consumption (in the case of constrained households, dramatically). Higher wealth and consumption of households in the labor force translates to a lower

[26] Suppose for simplicity that the set of constrained retired households is empty.

labor supply:

$$\sum_i \Delta l_{i,1} = -\frac{\psi}{W} s \Big(\overbrace{\sum_{i|b_{i,0}<b_1^*} 1 b_{i,0} + \sum_{i|b_1^* \leq b_{i,0} < b_0^*} \frac{1}{1+\psi/W} f_i b_{i,0}}^{\text{Constrained}} + \underbrace{\sum_{i|T_i>0 \,\cup\, T_i'>0} \eta(T_i, T_i') b_{i,0}}_{\text{Unconstrained}} \Big) < 0$$

However, the effect on aggregate labor supply after impact ($t > 1$) is not clear. There are two offsetting effects. Constrained households who are most indebted do not adjust their labor supply over the medium term, and neither do the largest savers, who are retired. The overall effect thus depends on the distribution of wealth among unconstrained households in the labor force:

$$\sum \Delta l_{i,t} = -\frac{\psi}{W} (\beta R)^{t-2} s \Big(\overbrace{\sum_{i|b_1^* \leq b_{i,0} < b_0^*} \eta(T_i, T_i')(1-f_i) b_{i,0} \frac{R}{1-\gamma}}^{\text{Temporary constrained}} + \underbrace{\sum_{i|T_i>0 \,\cup\, T_i'>0} \eta(T_i, T_i') \beta R b_{i,0}}_{\text{employed at t=0}} \Big) \quad \forall\, t > 1$$

A.8 Optimality conditions for the general equilibrium model

Household optimality conditions FOCs with respect to $l_{i,t}$ and $b_{i,t+1}$

$$l_{i,t} = \max\left\{0, 1 - \frac{\psi}{(1-\tau_{soc}) W_t z_{i,t}} c_{i,t}\right\} \text{ if } z_{i,t} > 0, \text{ else } l_{i,t} = 0, \tag{A.9}$$

$$\frac{1}{c_{i,t}} = \beta E_t \frac{1}{c_{i,t+1}} \left(\frac{R_t^b + \zeta}{\pi_{t+1}} \mathbf{1}_{b_{i,t}<0} + R_t^s \mathbf{1}_{b_{i,t}>0} \right) + \lambda_{i,t}(R_t^b + \zeta), \tag{A.10}$$

where $\lambda_{i,t}$ is the Lagrange multiplier associated with the borrowing constraint.

There is a unique threshold that makes a household indifferent between renting and owning over the next period for a potential buyer (current renter) and potential seller (current owner), respectively:

$$\begin{aligned} \tilde{\xi}^{buy}(w,z) &= v^{op}(w, h=0, z) - v^{rp}(w, h=0, z), \\ \tilde{\xi}^{sell}(w,z) &= v^{rp}(w, h=1, z) - v^{op}(w, h=1, z). \end{aligned}$$

Due to bounds of the distribution on ξ, the fractions of households that buy and sell are given by $\hat{\xi}^{buy}(w,z) = \min\{1, \max\{0, \frac{\tilde{\xi}^{buy}(w,z)}{\bar{\xi}})\}\}$ and $\hat{\xi}^{sell}(w,z) = \min\{1, \max\{0, \frac{\tilde{\xi}^{sell}(w,z)}{\bar{\xi}}\}\}$, respectively.

This implies that value functions can be expressed as:

$$\begin{aligned} V^r(w,z) &= (1-\hat{\xi}^{buy}(w,z))v^{rp}(w,h,z) + \hat{\xi}^{buy}(w,z)v^{op}(w,h,z) \\ V^o(w,z) &= \hat{\xi}^{sell}(w,z)v^{rp}(w,h,z) + (1-\hat{\xi}^{sell}(w,z))v^{op}(w,h,z). \end{aligned}$$

Investment fund The FOC w.r.t. k_t gives

$$R_t^b = \frac{r_{t+1}^k + (1-\delta)q_{t+1}^k}{q_t^k}. \tag{A.11}$$

Goods production Intermediate producer j maximizes the stream of profits:

$$\max_{n_{j,t},P_{j,t}} \sum_{t=0}^{\infty} E_t\left(\Lambda_{0,t}\frac{\Pi_{j,t}}{P_t}\right), \tag{A.12}$$

subject to (2.7) and (2.9). Profits are distributed to households in a lump-sum fashion $T_{i,t} = \Pi_{j,t}/P_t$, where $\Lambda_{0,t}$ is the aggregate stochastic discount factor. We use the real interest rate as the discount factor, i.e.,

$$\Lambda_{0,t} = \prod_{s=0}^{t} \frac{\pi_{s+1}}{r_s^b}. \tag{A.13}$$

Period t profits are given by

$$\frac{\Pi_{j,t}}{P_t} = \frac{P_{j,t}}{P_t}y_{j,t} - W_t n_{j,t} - r_t k_{j,t-1} - \frac{\kappa}{2}\left(\frac{P_{j,t}}{\pi^* P_{j,t-1}} - 1\right)^2 y_t + m_{j,t}\left(a_t k_{j,t-1}^{\alpha} n_{j,t}^{1-\alpha} - y_{j,t}\right) \tag{A.14}$$

or alternatively

$$\frac{\Pi_{j,t}}{P_t} = \frac{P_{j,t}}{P_t}y_{j,t} - W_t n_{j,t} - r_t^k k_{j,t-1} + (1-\delta)\,k_{j,t-1} - \frac{\kappa}{2}\left(\frac{P_{j,t}}{\pi^* P_{j,t-1}} - 1\right)^2 y_t + m_{j,t}\left(a_t k_{j,t-1}^{\alpha} n_{j,t}^{1-\alpha} - y_{j,t}\right), \tag{A.15}$$

where π^* is the inflation target and where the price stickiness is due to quadratic adjustment costs. The FOC w.r.t. $n_{j,t}$ gives

$$\begin{aligned} W_t &= (1-\alpha)\,m_{j,t}\frac{y_t}{n_{j,t}}, \\ r_t^k &= \alpha m_{j,t}\frac{y_t}{k_{j,t-1}}, \end{aligned}$$

which gives

$$m_{j,t} = \frac{1}{a_t}\left(\frac{r_t}{\alpha}\right)^{\alpha}\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}, \tag{A.16}$$

where $m_{j,t}$ is the Lagrange multiplier of the production function and can be interpreted as real marginal costs. Combining the above equations, we can get:

$$\begin{aligned} W_t &= (1-\alpha)\left(m_{j,t} a_t \left(\frac{r_t}{\alpha}\right)^{-\alpha}\right)^{\frac{1}{1-\alpha}}, \\ y_t &= \frac{W_t n_{j,t}}{m_{j,t}(1-\alpha)}. \end{aligned}$$

The FOC w.r.t. $P_{j,t}$ is given by:

$$\begin{aligned} \Lambda_{0,t}\left[(1-\varepsilon)\left(\frac{P_{j,t}}{P_t}\right)^{-\varepsilon}\frac{y_t}{P_t} - \kappa\left(\frac{P_{j,t}}{\pi^* P_{j,t-1}} - 1\right)\frac{y_t}{P_{j,t-1}\pi^*} + m_{j,t}\varepsilon\left(\frac{P_{j,t}}{P_t}\right)^{-\varepsilon-1}\frac{y_t}{P_t}\right] & \\ + E_t \Lambda_{0,t+1}\kappa\left(\frac{P_{j,t+1}}{\pi^* P_{j,t}} - 1\right)\frac{y_{t+1}P_{j,t+1}}{P_{j,t}^2 \pi^*} &= 0. \end{aligned}$$

Since goods producers are facing a symmetric problem, in equilibrium, there is no price dispersion. Imposing $P_{j,t} = P_t$ and $m_{j,t} = m_t$ in the above FOC, we can rewrite it to get the New Keynesian Phillips curve:

$$\left(\frac{\pi_t}{\pi^*} - 1\right)\frac{\pi_t}{\pi^*} = E_t \frac{\Lambda_{0,t+1}}{\Lambda_{0,t}}\left(\frac{\pi_{t+1}}{\pi^*} - 1\right)\frac{\pi_{t+1}}{\pi^*}\frac{y_{t+1}}{y_t} + \frac{\varepsilon}{\kappa}\left(m_t - m^*\right), \tag{A.17}$$

where $m^* = \frac{\varepsilon-1}{\varepsilon}$ and $\frac{\Lambda_{0,t+1}}{\Lambda_{0,t}} = \frac{\pi_{t+1}}{r_t}$.

Capital producers The FOC w.r.t. i_t is given by:

$$z_t^k q_t^k = 1 + z_t^k \kappa^k \left[\frac{1}{2}\left(\frac{x_t}{x_{t-1}} - 1\right)^2 + \frac{x_t}{x_{t-1}}\left(\frac{x_t}{x_{t-1}} - 1\right)\right] + q_{t+1}^k \frac{\pi_{t+1}}{R_t^b} z_{t+1}^k \left(\frac{x_{t+1}}{x_t}\right)^2 \kappa^k \left(\frac{x_{t+1}}{x_t} - 1\right). \tag{A.18}$$

B Additional figures

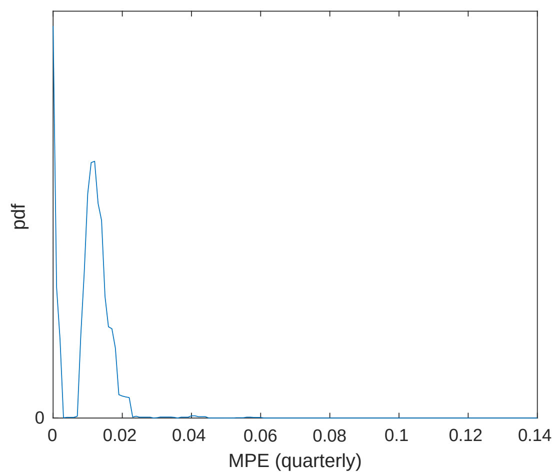

Figure 14: Distribution of marginal propensity to earn (MPE) in the model. Quarterly MPE are the negative of the response of earned income to a one-time, unexpected small payment in the same period. The mass point at zero corresponds to retired and unemployed households.

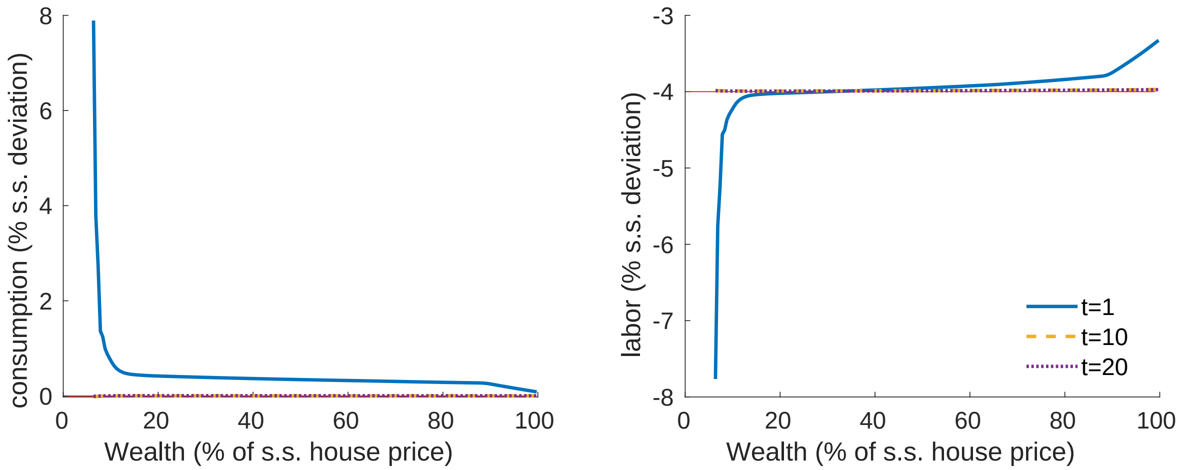

Figure 15: Consumption and labor supply responses conditional on wealth dissipate quickly. We report the deviations of consumption and labor supply responses for a given wealth level of working borrowers. On impact all households increase consumption. This is especially true for borrowers close to the borrowing constraint, who also lower their labor supply. Wealthier borrowers increase their labor supply despite higher consumption due to higher wages. In periods 10 and 20 there is no significant response of consumption and labor supply for any wealth level.

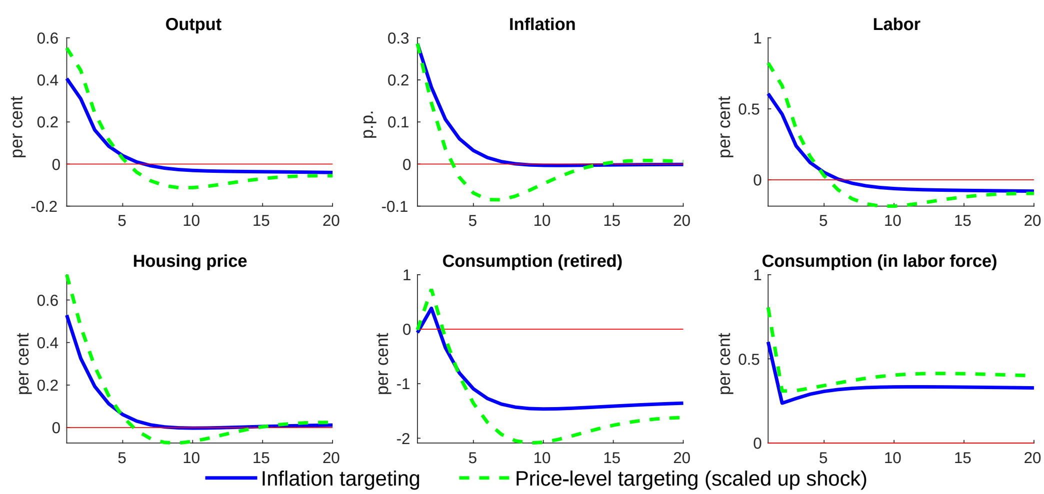

Figure 16: Comparison of monetary policy regimes: impulse responses to monetary easing under IT and PLT, when the shock size is larger under PLT to equalize the inflation response between the two regimes.

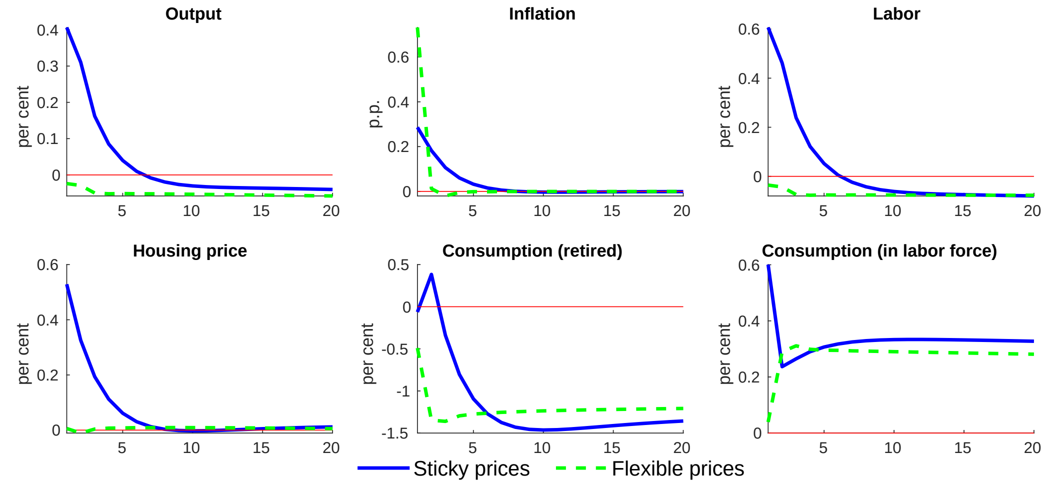

Figure 17: Comparison of monetary policy easing effects in the benchmark model with sticky prices and in a model with flexible prices. The persistence is similar in both models, suggesting that output over the medium term is driven by lower potential.

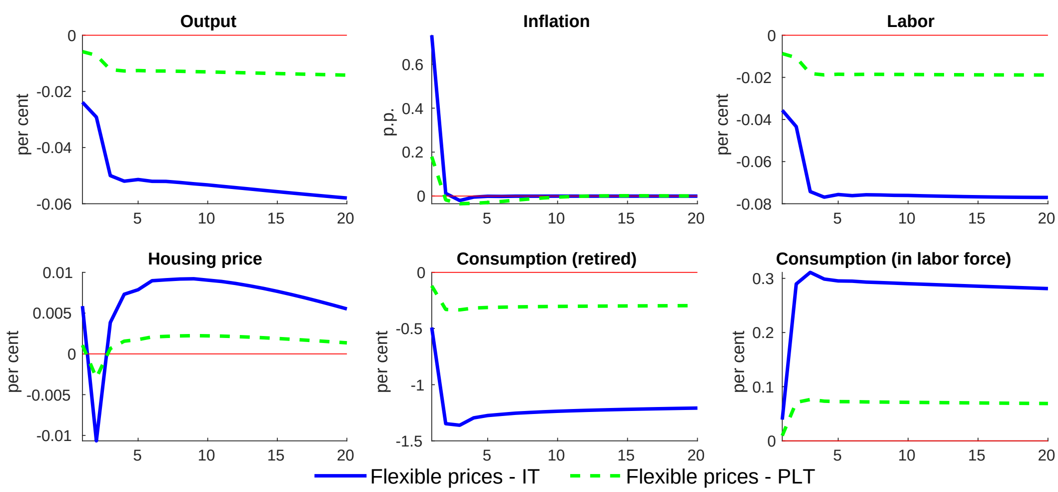

Figure 18: Comparison of monetary policy easing under IT and PLT under flexible prices. The short-term monetary stimulus is absent, but PLT implies a stronger drop in output than IT, similar to the case with sticky prices.

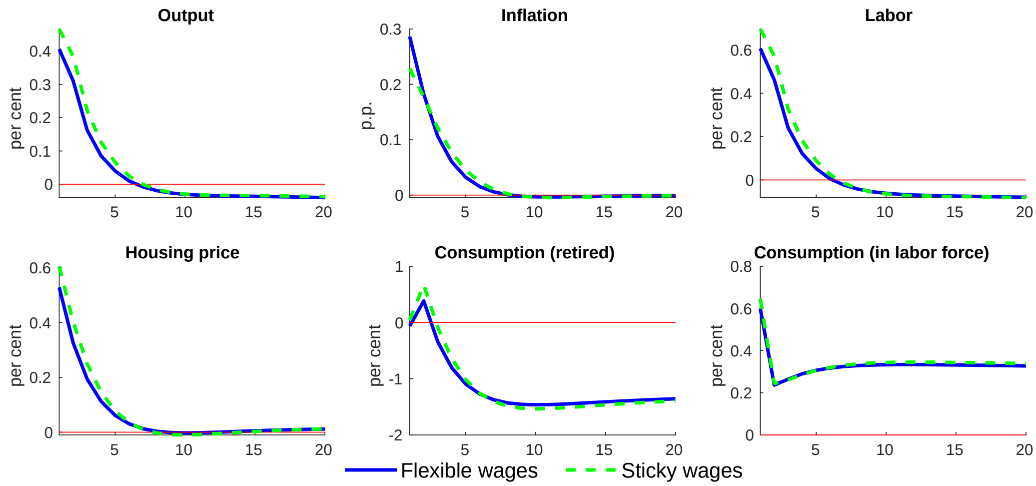

Figure 19: Comparison of monetary policy easing under flexible and sticky wages. When wages are sticky, they do not increase as much, resulting in less inflation pressure, more demand for labor and higher output in the short run. However, the medium-term negative effects on output are unchanged.

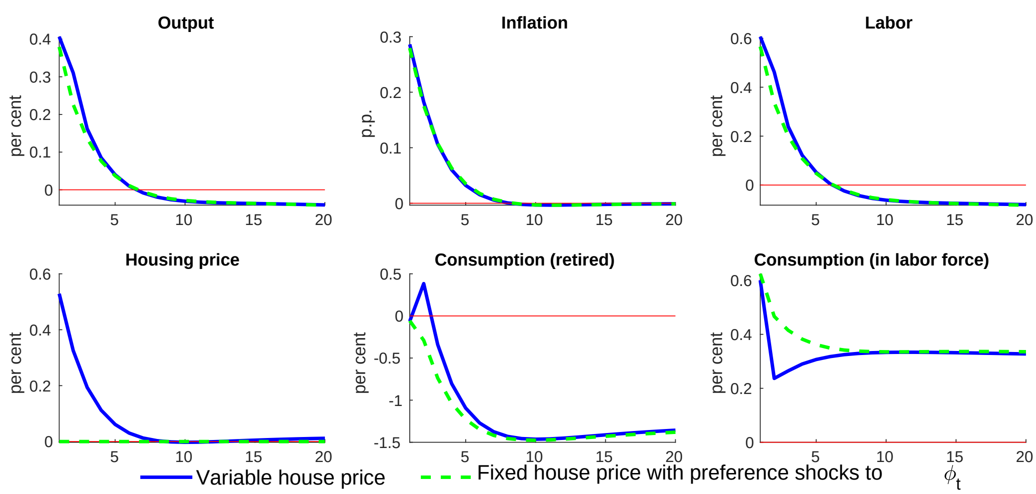

Figure 20: Effect of a fixed house price. We fix the housing price to the steady-state value with a series of negative shocks to the utility of housing services ϕ_t. This does not have sizable medium-term effects. It only temporarily increases the consumption of households in the labor force, reduces their labor supply and output and depresses consumption of retired households.

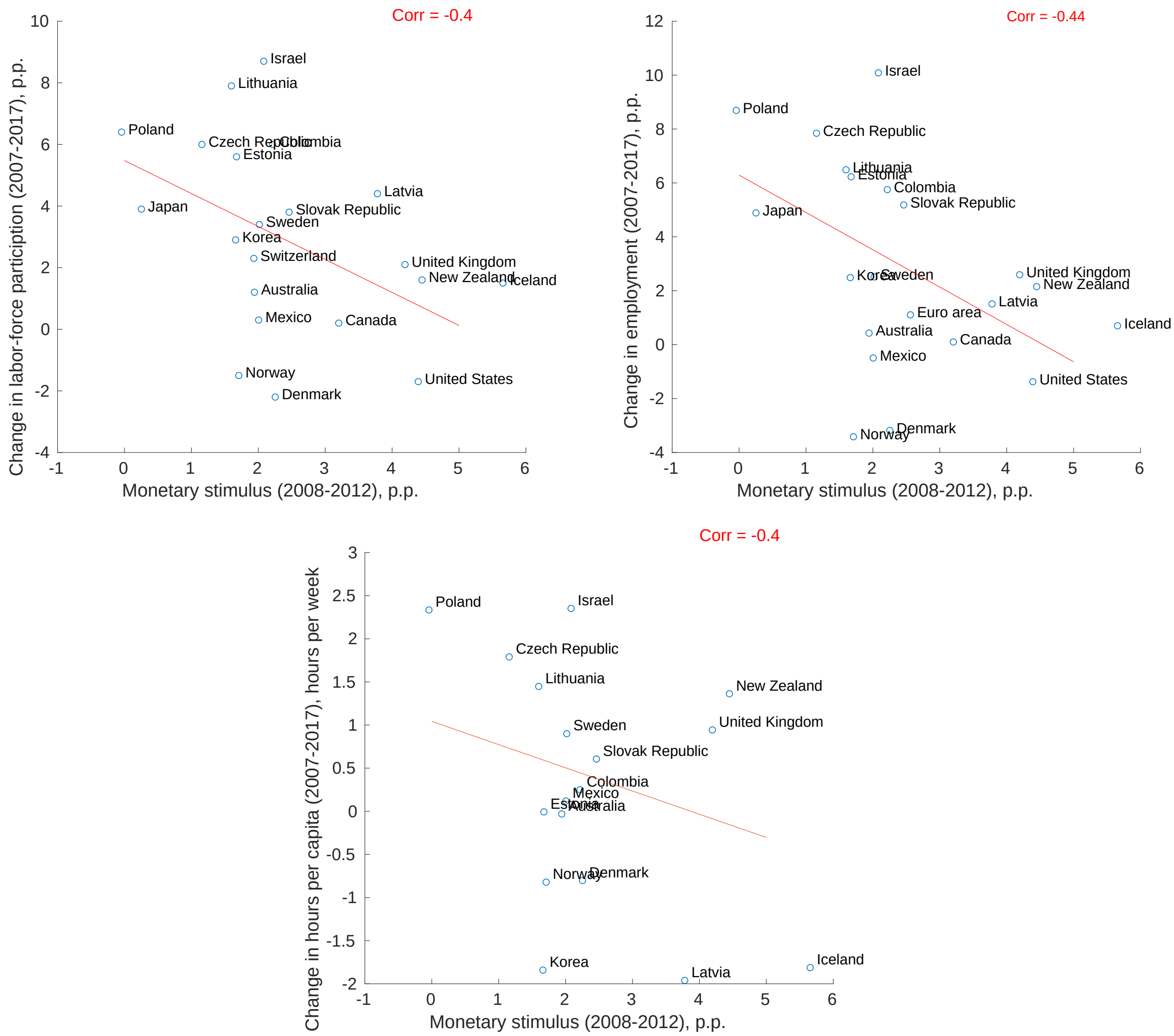

Figure 21: Monetary stimulus after the crisis is negatively correlated with labor supply. We report the correlation coefficient, and the red line represents the regression. Monetary stimulus is measured as the average short-term nominal rate over 2008-2012 relative to the average level in 2007. The labor supply change is measured as the level at the end of 2017 relative to the level at the end of 2007. We report the change in the labor participation rate, employment rate and the hours per person in the age group 25 to 65 years of age. We include all countries available in the database of the Organisation for Economic Co-operation and Development (OECD) while excluding member countries of the euro area in 2007 as these by definition receive the same stimulus. We will include the euro area once aggregate data are available. Source: OECD.