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# The transmission of monetary policy through redistributions and durable purchases☆

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ABSTRACT

Using a tractable OLG model with government debt, we study a redistribution channel for the transmission of monetary policy. Expansionary open-market operations generate a negative wealth effect, increasing households' incentives to save and pushing down the real interest rate. This leads to a substitution towards durables, generating a temporary boom in the durable-good sector. With search and matching frictions, the fall in interest rates causes an increase in labor demand, raising aggregate employment. The model mimics the empirical responses of key macroeconomic variables to monetary policy interventions. The fiscal policy stance plays a key role in the transmission mechanism.



## 1. Introduction

A central question in monetary economics is how monetary policy interventions transmit to the real economy. This paper contributes to the literature by studying a redistribution channel for the transmission of monetary policy. Using a tractable quantitative model building on Gertler (1999), the paper shows that this channel can account for a significant fraction of the empirical responses of key macroeconomic aggregates to monetary policy interventions.

An important element for the transmission channel we emphasize is the rather uncontroversial assumption (applicable to the United States and other industrialized countries) that the government is a big net debtor in the economy, while the

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private sector as a whole is a net creditor.[1] Overlapping generations of households consume durable and non-durable goods and work and save for retirement through bonds, money holdings, and durable goods. A temporary expansion in monetary policy carried out through open market operations (OMO), whereby the central bank purchases government bonds, pushes down the nominal interest rate and leads to a temporary increase in inflation. This price adjustment, needed to close the gap between money supply and demand, causes a downward revaluation of the government debt, generating a negative wealth effect for the private sector.[2] The fall in private wealth induces households to save a larger fraction of their income, as they seek to restore their retirement savings, pushing down the real interest rate. This in turn leads to a substitution towards durable goods, generating a boom in the durable good sector. With search and matching frictions in the labor market, job vacancies are a form of productive investment, as they create durable employment matches. The decline in the real interest rate thus increases the demand for both durables and productive investment, leading to an increase in aggregate employment and output.

The emphasis on durable goods in the model is motivated by the empirical finding that the response of activity to monetary policy is largely driven by the durable goods sector. The introduction of search and matching frictions, while not necessary for the qualitative results, adds realism and generates significant persistence in the responses of economic variables to monetary policy, in line with the empirical evidence. (For expositional clarity, we study versions of the model with and without search and matching frictions.)

The redistributive channel in our model is motivated by Doepke and Schneider's (2006a) empirical study, which shows that inflationary episodes can cause significant revaluations of assets and redistributive effects from wealthy, middle age, and old households towards the government (the main debtor) and poor, young households. Similar evidence is documented by Adam and Zhu (2018) for European countries and Canada. Despite the stark empirical findings, most DSGE models used for quantitative monetary policy analysis rely on a representative agent formulation and thus abstract from redistributional effects. In this paper, we show that these redistributive effects can have a sizeable impact on real macroeconomic aggregates.

We proceed in two steps. First, building on Gertler and Karadi's (2015) identification strategy, we show that following an unexpected monetary policy expansion, the real value of public debt falls and the price level increases. The results indicate a swift and significant response of the aggregate price level, without the so called "price puzzle" resulting from other identification strategies. These, in themselves, are novel findings that motivate the exploration of revaluation effects. Furthermore, we corroborate that the durable-good sector is the key driver of the response of real activity to monetary policy expansions, and show that nondurables and services display a relatively mild response. In the second step, we develop a tractable model to quantitatively study the aggregate effects caused by the revaluation of government liabilities due to monetary policy interventions. We show that the model can quantitatively account for most of the increase in durable expenditures, and a substantial part of the response in non-durables following a monetary policy expansion. A crucial element in the model is the presence of a government sector; despite playing a passive role, its presence is relevant as it leads to a redistribution of wealth away from the private sector—as well as across households—causing a fall in the real interest rate and a boom in durables.

An open issue is of course what the government does with its windfalls.[3] Following standard assumptions in the literature, the government in our model is a passive agent; in particular, the model abstracts from government consumption and assumes that the Treasury follows a balanced-budget policy, using the increased net income flows to finance a persistent reduction in (non-distortionary) taxes. While these tax cuts help to compensate households for their wealth losses, they do not undo the redistributive effects. In particular, retirees emerge as the biggest losers from the operation whereas future (unborn) generations benefit the most. In between these extremes are agents who are in the working phase of their lives when the shock hits. They suffer a negative revaluation of their retirement savings but do not receive full compensation from the Treasury once they retire. So, on net, living agents lose and this breakdown of the Ricardian equivalence (Barro, 1974) leads to the non-neutrality of money.

Our model highlights that the real effects of open market operations can be sharply different from the effects of "helicopter drops" , that is, tax cuts financed by an increase in the money supply, even though the effects of the two policies on nominal interest rates and prices are similar. Indeed, we show that an expansionary helicopter drop causes a counterfactual fall in durables and a decline in output and hours. The difference, as will become clear, is driven by the distributional effects that the two policies generate. Our analysis takes Doepke and Schneider's (2006a) results one step further to show that the macroeconomic effects stemming from the revaluation of wealth will critically depend on how the policy is implemented.

We conclude by stressing that our model complements the standard New Keynesian (NK) paradigm, by highlighting a transmission channel that is omitted by construction when assuming a representative household, and which operates even under flexible prices. We also complement an important literature following Iacoviello (2005), who studies how endogenous

[1] US households tend to hold bank deposits, while banks hold government bonds; we implicitly assume that competitive banks fully pass through their losses to households and accordingly, in the model, we merge the household and banking sectors.

[2] Though the intervention redistributes wealth from retired towards working-age households, we argue that the dominant effect is the redistribution away from the household sector and to the government.

[3] An expansionary OMO improves the financial position of the government via two channels. First, an increase in prices reduces the real value of government debt. Second, the operation increases the Central Bank's bonds holdings and consequently its stream of interest revenues, which are transferred to the Treasury as they are accrued. In the data, these remittances amount to an average of two percent of government expenditures per year, with high variability over time.

collateral constraints affect the transmission of (monetary policy) shocks. His propagation mechanism operates via persistent changes in the relative price of durables vis-à-vis non-durables, from which we abstract.[4] Finally, our redistributional channel and associated non-Ricardian effects bring the interplay between monetary and fiscal policy to the forefront of the analysis. Empirically, we provide evidence of such interaction by documenting a substantial response of public debt to a monetary policy shock. In the model, we find that the response of real activity is magnified considerably once we match the empirical path of the public debt following a monetary policy shock.

*Relation to the literature.* As emphasized by Woodford (2012), in standard modern, general-equilibrium, frictionless asset pricing models, open market purchases of securities by Central Banks have no effect on the real economy. This result, which goes back to Wallace's (1981) seminal article, is at odds with the widely held view that open market operations (OMO) by Central Banks affect interest rates—and at odds indeed with the very practice of Central Banks. The "irrelevance" or neutrality of OMO is easiest to see in the context of a representative agent model, as explained by Woodford (2012); however, Wallace's (1981) widely cited result applies to a more general setting with heterogeneous agents. A key premise for Wallace's irrelevance result, however, is that OMO by the Central Bank are accompanied by fiscal transfers that ensure no change in the income distribution following the monetary policy intervention. In other words, by construction, distributional effects of OMO are muted by fiscal transfers that neutralize distributional changes—and hence preclude any change in individuals' decisions following the intervention.[5]

In contrast with Wallace (1981), OMO have real effects in our model economy because we allow for redistributional effects. Indeed, the goal of this paper is to study the effects of monetary policy interventions when, realistically, OMO are not accompanied by neutralizing fiscal transfers—nor is there a complete set of state-contingent securities that would ensure an unchanged income distribution following the policy intervention.[6]

The paper connects with a growing branch of the literature that seeks to study alternative channels for the transmission of monetary policy, which can complement the standard channel based on nominal rigidities.[7] More quantitative analyses can be found in Doepke and Schneider (2006b), Meh et al. (2010), Algan et al. (2012) and Gottlieb (2015). Like us, they numerically analyze the effects of monetary policy and/or inflation in a flexible price economy with aggregate dynamics and heterogeneous-agents. However, none of these papers models o pen market operations or consumer durables, both key elements of the transmission mechanism we highlight. More crucially, they do not consider the critical role played by the government as net debtor, which leads to the negative wealth effect in the private sector.[8] Finally, our model is solved quickly using standard linearization methods, allowing for a straightforward comparison to VARs as well as New-Keynesian DSGE models. To achieve this, we follow a simple stochastic ageing structure introduced in Gertler (1999), but differently from Gertler (1999), we work out a computational strategy that allows for standard preferences.[9]

Our paper also relates to recent work by Auclert (2015) and Kaplan et al. (2018). Auclert (2015) focuses on the redistribution of wealth across agents with different marginal propensities to consume and different exposure to interest rate changes. Kaplan et al. (2018) study a setting with heterogenous agents in a NK framework with price rigidities (see also Werning (2015) and Gornemann et al. (2012) for related analyses). While we abstract from price rigidities, our model shares with Kaplan et al. (2018) the property that the fiscal response to monetary policy shocks plays a crucial role in the transmission mechanism.

The remainder of this paper is organized as follows. Section 2 presents and discusses the main empirical facts that motivate key features of our model. Section 3 introduces a simple version of the model and discusses the basic mechanisms at play. Section 4 presents the full model with labor market frictions, which both add realism to the model and increase the persistence of the responses of key macroeconomic aggregates to monetary policy interventions; the section then studies the extent to which the model can quantitatively account for the empirical evidence. Section 5 offers concluding remarks.

[4] We have verified that our empirical results are robust to controlling for the relative price of durables.

[5] Wallace (1981) refers to this condition as "unchanged fiscal policy." An unchanged fiscal policy in that context is one in which there is no change in government consumption and no change in the income or wealth distribution. To implement Wallace's OMO without the redistributional effects, a Central Bank needs to rely on the Treasury to adjust transfers and taxes in a particular way to keep the income distribution unchanged. An alternative way of obtaining this result would be to have a complete set of contingent securities that would undo any change in the income distribution.

[6] The motivation is necessarily a practical one. When researchers estimate the causal effects of monetary policy interventions, they do not (cannot) abstract from or control for the distributional effects they cause—and there is no accompanying fiscal policy that undoes them in practice. Hence, to understand the effects of those interventions on activity, researchers need to take into account the potential impact of the redistribution caused by the policy intervention and any interaction with the fiscal policy in place.

[7] Examples in this literature are Grossman and Weiss (1983), Rotemberg (1984), and Alvarez and Lippi (2014), who study the role of segmentation in financial markets and the redistributive effects caused by monetary policy. Lippi et al. (2015) provide a general characterization of optimal monetary policy in a setting with heterogeneous agents and incomplete markets.

[8] The qualitative effects are also different: Doepke and Schneider (2006b) and Meh et al. (2010) generate a contraction in activity following a monetary policy expansion, whereas our model generates a boom in activity driven by the durable good sector.

[9] Gertler's approach requires the utility function to be in a class of nonexpected utility preferences, excluding for example standard CRRA utility functions, whereas our model is instead compatible with the latter.

## 2. Empirical evidence

In this section, we first revisit the empirical evidence on the effects of monetary policy shocks on the macroeconomy, highlighting the role of durables and the government debt. We do so by estimating a structural VAR model using Gertler and Karadi (2015, GK)'s identification strategy. Details on this can be found in Appendix A1. For earlier VAR evidence on the effects of monetary policy on durables, see e.g. Erceg and Levin (2006) and Monacelli (2009).

Following GK, we use monthly data starting in July 1979, when Paul Volcker took office as chairman of the Federal Reserve System, and end the sample in July 2012. Also following GK, we include twelve lags of data and use the one-year rate on government bonds as the policy indicator. The non-policy variables in the system include the seasonally adjusted Consumer Price Index (CPI) in (log) levels, as well as expenditures on durables and non-durables, both seasonally adjusted and deflated with the CPI. Further, we control for the Gilchrist and Zakrajšek (2012) excess bond premium, following GK. Finally, we include total public debt, deflated by the CPI, which is relevant for the monetary transmission mechanism that we study. This data series has been retrieved manually from the Monthly Statements of Public Debt of the United States, available online via www.treasurydirect.gov.

Our approach to identifying monetary policy shocks follows GK, who use the methodology of Mertens and Ravn (2013). A key element of the approach is the use of an instrumental variable which is correlated with the monetary policy shock, but not with the other macroeconomic shocks. The instrument used is the change in the three-month ahead futures rate during a 30 minute window around announcements by the Federal Open Market Committee (FOMC).[10] We scale the Impulse Response Functions (IRFs) such that the one-year rate declines by a maximum of 75 basis points.

The estimated IRFs are depicted in Fig. 1, together with 95 percent confidence bands. The monetary expansion triggers an increase in inflation. On an *annualized* basis, the monthly inflation rate increases by more than two percentage points on impact. Thus, our results do not exhibit a "price puzzle". On the contrary, inflation swiftly increases, even though the increase is short-lived. The inflation response implies that the price level (not plotted) increases peristently, by about 0.5 percent.[11] Further, there is a large, somewhat gradual increase in durables expenditures, up to about 2 percent. By contrast, the increase in non-durables expenditures is much smaller. On impact, non-durables even decline substantially. Furthermore, real public debt shows a large and significant decline.[12] Fig. 1 also displays responses from our full quantitative model. We discuss these responses in Section 5. For now, we simply highlight that the model responses fall largely within the empirical confidence bands.

While our identification strategy follows (Gertler and Karadi, 2015), we include a different set of variables in the VAR. In the Appendix, we directly compare the responses of the one-year interest rate and the CPI level, as implied by our VAR, to those reported in Gertler and Karadi (2015). It turns out that the response of inflation is very similar: the CPI displays a sharp and temporary increase, which will be mimicked by our model.

*Redistributive effects of monetary policy.* A main goal of our paper is to study the redistributive effects of monetary policy and their impact on aggregate variables in a quantitative model. A number of recent empirical papers substantiate our motivation. In particular, Doepke and Schneider (2006a) document significant wealth redistributions in the US economy following (unexpected) inflationary episodes. Their analysis is based on detailed data on assets and liabilities held by different segments of the population, from which they calculate the revaluation effects caused by inflation. The authors find that the main winners from a monetary expansion are the government as well as poor, young households, whereas the losers tend to be richer, middle age and older households (in their forties or above). Note that households as a whole are net creditors and the government is a net debtor in the US economy. Adam and Zhu (2018) document similar patterns for Euro area countries and Canada, and update the results for the United States. As for the US economy, in most euro-area countries, the household sector is a net creditor and the government is a net debtor.

Our model embeds these redistributive revaluation effects and brings two additional considerations to the analysis. The first consideration is how these redistributive effects alter the various demographic groups' incentives to work, consume, and save in different types of assets, the hiring decision of firms, and finally, how these changes affect the macroeconomy. The second consideration is how the Treasury redistributes the higher revenues stemming from an expansionary monetary policy intervention. These higher revenues consist of (i) higher value of remittances received from the Central Bank as a result of the interest on bonds earned by the Central Bank; and (ii) gains from the revaluation of government debt—assuming the government is a net debtor. The revaluation gains by the government can be large, as Doepke and Schneider's (2006a) calculations illustrate. The remittances are also considerable, amounting to an average of two percent of total government revenues during our period of analysis, with significant volatility. We assume that these remittances are rebated to the working-age agents, as in practice the taxation burden tends to fall on the working population. However, the framework can be adjusted to allow for different tax-transfer configurations.

An additional empirical paper motivating our analysis is Coibion et al. (2017), who find that unexpected monetary contractions as well as permanent decreases in the inflation target lead to an increase in inequality in earnings, expenditures,

[10] The data series for the instrumental variable is taken from GK, who convert the surprises to a monthly frequency using a weighting procedure which accounts for the precise timing of each FOMC within the month. The instruments are available over the period 1990–2012.

[11] For other VAR approaches that avoid the price puzzle, see e.g. Bernanke et al. (2005) and Castelnuovo and Surico (2010).

[12] There is also a decline in the excess bond premium (not plotted), which is in line with the results of GK (given the size and the sign of the shock).

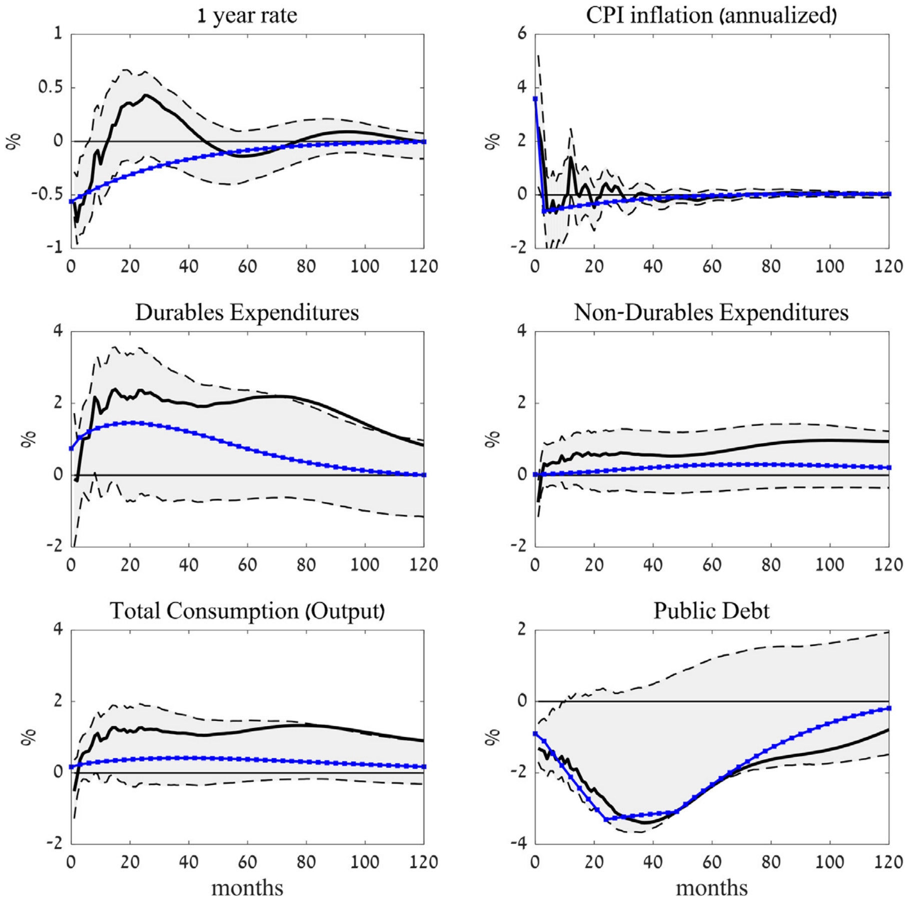


**Fig. 1.** Responses to an expansionary monetary policy shock. *Note:* The figure shows the model and estimated empirical impulse responses to an expansionary monetary policy shock, together with the 95 percent confidence bands for the empirical responses. The model responses correspond to the full model, as described in Section 5. The empirical responses are scaled to imply a maximum decline in the one-year nominal government bond rate of 75 basis points. The model responses are scaled such that the impact decline in the one-year rate coincides with the empirical point estimate. Model responses are plotted in blue and indicated with square markers.

and consumption. Their results rely on the CEX survey, and thus exclude top income earners. The authors however argue that their estimates provide lower bounds for the increase in inequality following monetary policy contractions. This is because individuals in the top one-percent of the income distribution receive a third of their income from financial assets—a much larger share than any other segment of the population; hence, the income of the top one-percent likely rises even more than for most other households following a monetary contraction.

Consistent with these findings, in our model, monetary policy expansions cause a redistribution of income from retirees, who rely more heavily on their nominal wealth as a source of finance for consumption, to working agents and future tax payers. The consumption of goods by working agents increases relative to that of retired agents following a monetary expansion. These results are more directly examined by Wong (2015), who finds that total expenditures by the young increase relatively to those of older people following a monetary policy expansion, the latter identified through a recursive VAR assumption.

## 3. Monetary policy shocks in a simple heterogeneous-agent model

We study the dynamic effects of monetary policy shocks in a general equilibrium model that embeds overlapping generations and a parsimonious life-cycle structure with two stages: working life and retirement. Transitions from working life to retirement and from retirement to death are stochastic but obey fixed probabilities, as in Gertler (1999). Financial markets are incomplete in the sense that there exists no insurance against risks associated with retirement and longevity. As a result, agents accumulate savings during their working lives, which they gradually deplete once retired. These savings can take the form of money, bonds, and durable consumption goods.

The money supply is controlled by a Central Bank, who implements monetary policy using open market operations, that is, by selling or buying bonds. Realistically, we assume that the Central Bank transfers its profits to the Treasury. The

Treasury in turn balances its budget by setting lump-sum transfers to households. In this environment we study the dynamic effects of persistent monetary policy shocks. We contrast our benchmark model with an alternative economy in which the Central Bank uses “helicopter drops” of money rather than OMO to implement monetary policy.

We solve the model using a standard numerical method.[13] This may seem challenging given the presence of heterogeneous households and incomplete markets. In particular, the presence of aggregate fluctuations implies that a time-varying wealth distribution is part of the state of the macroeconomy. To render the model tractable, we introduce a government transfer towards newborn agents which eliminates inequality among working agents. (Wealth inequality among retired agents, as well as between working-age and retired agents, is preserved in our framework.) We show that aggregation then becomes straightforward and only the distribution of wealth between the group of working-age agents and retirees is relevant for aggregate outcomes. At the same time, our setup preserves the most basic life-cycle savings pattern: working-age agents save for retirement and retired agents gradually consume their wealth.

We consider two versions of the model. The simple version does not incorporate any form of product or labor market friction. It highlights the source of the transmission mechanism due exclusively to the redistributive effect of the intervention. The simplest version has very limited persistence when compared to the empirical responses (a result that is also true in a simple NK framework). To add persistence and amplification, we incorporate search and matching frictions in the labour market. This is done in Section 5, where we quantitatively study a more realistic model to gauge the extent to which the proposed mechanism can quantitatively account for the VAR evidence.

*Agents and demographics.* We model a closed economy which consists of a continuum of households, a continuum of perfectly competitive firms and a government, which is comprised of a Treasury and a Central Bank. In every period a measure of new working agents is born. Working-age agents retire and turn into retirees with a time-invariant probability $\rho_R \in [0, 1)$ in each period. Upon retirement, agents face a time-invariant death probability $\rho_x \in (0, 1]$ in each period, including the initial period of retirement. The population size and distribution over the age groups remains constant over time and the total population size is normalized to one. The fraction of working-age agents in the economy, denoted $\nu$, can be solved for by exploiting the implication that the number of agents retiring equals the number of deaths in the population, i.e. $\rho_R \nu = \rho_x(1-\nu+\rho_R\nu)$.

The life-cycle status of an agent is denoted by a superscript $\mathbf{s} \in \{\mathbf{N}, \mathbf{W}, \mathbf{R}\}$, with $\mathbf{N}$ denoting a newborn agent ready to work, $\mathbf{W}$ a pre-existing working agent, and $\mathbf{R}$ a retiree. Households derive utility from non-durables, denoted $c \in \mathbb{R}^+$, a stock of durables, $d \in \mathbb{R}^+$, and real money balances, denoted $m \in \mathbb{R}^+$. They can also invest in nominal bonds, the real value of which we label $b \in \mathbb{R}$. Bonds pay a net nominal interest rate $r \in \mathbb{R}^+$. Working-age agents, including the newborns, supply labor to firms in a competitive labor market whereas retirees are no longer productive. Durables depreciate at a rate $\delta \in (0, 1)$ per period and are produced using the same technology as non-durables. Because of the latter, durables and non-durables have the same market price. All agents take laws of motion of prices, interest rates, government transfers, and idiosyncratic life-cycle shocks as given. We describe the decision problems of the agents in turn.

*Retired agents.* Agents maximize expected lifetime utility subject to their budgets, taking the law of motion of the aggregate state, denoted by $\Gamma$, as given. Letting primes denote next period's variables, we can express the decision problem for retired agents ($\mathbf{s}=\mathbf{R}$) recursively and in real terms as:

$$\begin{aligned}
&V^{\mathbf{R}}(a,\Gamma) = \max_{c,d,m,b} U(c,d,m) + \beta(1-\rho_x)\mathbb{E}V^{\mathbf{R}}(a',\Gamma') \\
&s.t. \qquad c+d+m+b = a+\tau^{\mathbf{R}}, \qquad c,d,m \geq 0, \\
&a' \equiv (1-\delta)d + \frac{m}{1+\pi'} + \frac{(1+r)b}{1+\pi'},
\end{aligned} \tag{1}$$

where $V^{\mathbf{R}}(a, \Gamma)$ is the value function of a retiree which depends on the aggregate state and the real value of wealth, denoted by $a$, $\mathbb{E}$ is the expectation operator conditional on information available in the current period, $\beta \in (0, 1)$ is the agent's subjective discount factor, and $\pi \in \mathbb{R}$ is the net rate of inflation. $U(c, d, m)$ is a utility function and we assume that $U_j(c, d, m) > 0$, $U_{jj}(c, d, m) < 0$ and $\lim_{j\to 0} U_j(c,d,m) = \infty$ for $j = c, d, m$. Finally, $\tau^{\mathbf{s}} \in \mathbb{R}$ is a transfer from the government to an agent with age status $\mathbf{s}$, so $\tau^{\mathbf{R}}$ is the transfer to any retired agent.

The budget constraint implies that retirees have no source of income other than the interest stemming from previously accumulated wealth. Implicit in the recursive formulation of the agent's decision problem is a transversality condition $\lim_{t\to\infty} \mathbb{E}_t \beta^t (1-\rho_x)^t U_{c,t} x_t = 0$, where $x = d, m, b$ and where $U_{c,t}$ denotes the marginal utility of non-durable consumption. Finally, we assume that agents derive no utility from bequests and that the wealth of the deceased agents is equally distributed among the currently working-age agents.

*Working agents.* Working-age agents supply labor in exchange for a real wage $w \in \mathbb{R}^+$ per hour worked. The optimization problem for newborn agents ($\mathbf{s}=\mathbf{N}$) and pre-existing working-age agents ($\mathbf{s}=\mathbf{W}$) can be written as:

$$V^{\mathbf{s}}_{\mathbf{s}=\mathbf{N},\mathbf{W}}(a,\Gamma) = \max_{c,d,m,b,h} U(c,d,m) - \zeta\frac{h^{1+\kappa}}{1+\kappa} + \beta(1-\rho_R)\mathbb{E}V^{\mathbf{W}}(a',\Gamma') + \beta\rho_R(1-\rho_x)\mathbb{E}V^{\mathbf{R}}(a',\Gamma')$$

[13] Specifically, we use first-order perturbation, exploiting its certainty-equivalence property. See the appendix for details.

$$s.t. \qquad c + d + m + b = a + wh + \tau^{bq} + \tau^{\mathbf{s}}, \qquad c, d, m \geq 0, \tag{2}$$
$$a' \equiv (1-\delta)d + \frac{m}{1+\pi'} + \frac{(1+r)b}{1+\pi'},$$

where working-age agents too obey transversality conditions. The term $\zeta\frac{h^{1+\kappa}}{1+\kappa}$ captures the disutility obtained from hours worked, denoted $h$, with $\zeta > 0$ being a scaling's parameter and $\kappa > 0$ being the Frisch elasticity of labor supply. Bequests from deceased agents are denoted $\tau^{bq}$; as before, $\tau^{\mathbf{s}}$ is a lump-sum transfer from the government. When making their optimal decisions, working agents take into account that in the next period they may be retired, which occurs with probability $\rho_R(1-\rho_x)$, or be deceased which happens with probability $\rho_R\rho_x$. We thus allow the possibility that upon retirement, agents may be immediately hit by a death shock.

*Firms.* Goods are produced by a continuum of perfectly competitive and identical goods firms. These firms operate a linear production technology: $y_t = h_t$. Profit maximization implies that $w_t = 1$, that is, the real wage equals one.

*Central bank.* Although we do not model any frictions within the government, we make a conceptual distinction between a Central Bank conducting monetary policy and a Treasury conducting fiscal policy. We make this distinction for clarity and in order to relate the model to real-world practice.

The Central Bank controls the nominal money supply, $M_t \in \mathbb{R}^+$, by conducting open market operations. In particular, the Central Bank can sell or buy government bonds. We denote the nominal value of the bonds held by the Central Bank by $B_t^{\mathbf{CB}} \in \mathbb{R}$. The use of open market operations implies that in every given period the change in bonds held by the Central Bank equals the change in money in circulation, that is, $B_t^{\mathbf{CB}} - B_{t-1}^{\mathbf{CB}} = M_t - M_{t-1}$. The Central Bank transfers its accounting profit—typically called seigniorage—to the Treasury.[14] The real value of the seigniorage transfer, labeled $\tau_t^{\mathbf{CB}} \in \mathbb{R}$, is given by $\tau_t^{\mathbf{CB}} = \frac{r_{t-1}b_{t-1}^{\mathbf{CB}}}{1+\pi_t}$.

The above description is in line with how Central Banks conduct monetary policy, as well as with the typical arrangement between a Central Bank and the Treasury. By contrast, many models of monetary policy assume monetary policy is implemented using "helicopter drops," that is, expansions of the money supply that are not accompanied by a purchase of assets but instead by a fiscal transfer equal to the change in the money supply. Modern monetary models are often silent on how monetary policy is implemented and directly specify an interest rate rule. In our framework, however, the specific instruments used to implement monetary policy are critical, since the associated monetary-fiscal arrangements pin down redistributive effects and hence the impact of changes in monetary policy on the real economy. When we implement the model quantitatively, we simulate exogenous shocks to monetary policy. We do so by specifying a stochastic process that affects the growth rate of the money supply $M_t$. The change in $M_t$ is implemented through open market operations.

*Treasury.* The Treasury conducts fiscal policy. For simplicity, we abstract from government purchases of goods and assume that the Treasury follows a balanced budget policy. The government has an initial level of bonds $B_{t-1}^{\mathbf{G}}$ which gives rise to interest income (or expenditure if the government has debt) on top of the seigniorage transfer from the Central Bank. To balance its budget, the government makes lump-sum transfers to the households, which can be either positive or negative. The government's budget policy satisfies:

$$\nu\rho_R\tau_t^{\mathbf{N}} + \nu(1-\rho_R)\tau_t^{\mathbf{W}} + (1-\nu)\tau_t^{\mathbf{R}} = \frac{r_{t-1}b_{t-1}^{\mathbf{G}}}{1+\pi_t} + \tau_t^{\mathbf{CB}}. \tag{3}$$

Here, the left-hand size denotes the total transfer. In particular, $\nu\rho_R\tau_t^{\mathbf{N}}$ is the total transfer to the newborns, $\nu(1-\rho_R)\tau_t^{\mathbf{W}}$ is the transfer to pre-existing working agents and $b_t^{\mathbf{G}}$ is the real value of government bonds. The right-hand side denotes total government income.

For tractability we also assume that the government provides newborn agents with an initial transfer that equalizes their wealth levels with the average after-tax wealth among pre-existing agents, that is, $\tau_t^{\mathbf{N}} = a_t^{\mathbf{W}} + \tau_t^{\mathbf{W}}$, where $a_t^{\mathbf{W}} \equiv \int_{i:\mathbf{s}=\mathbf{W}} a_{i,t}di$ is the *average* wealth among pre-existing working agents (before transfers). Since before-tax wealth is the only source of heterogeneity among working agents, all working agents make the same decisions and what arises is a representative agent. This implication makes the model tractable. Note that although we eliminate heterogeneity among working agents by assumption, the framework preserves the heterogeneity between working and retired agents, as well as the heterogeneity among retired agents.

Finally, we assume that only productive agents are affected by transfers or taxes, that is, we set $\tau_t^{\mathbf{R}} = 0$. This assumption is motivated by the observation that the majority of the tax burden falls on people in their working life, due to the progressivity of tax systems.Note, however, that the framework is highly flexible and can be used to analyze more complex fiscal settings.

[14] We abstract from operational costs incurred by the central bank.

**Table 1**
Parameter values for the simple model and the full model (see Section 5).

| | Simple | Full | Description | Motivation |
|---|---|---|---|---|
| $\beta$ | 0.9745 | 0.9770 | Subjective discount factor | 3% s.s. annual interest rate |
| $\eta$ | 0.31 | 0.31 | Durables preference param. | 20% s.s. spending on durables (NIPA) |
| $\mu$ | 0.0069 | 0.0048 | Money preference param. | 1.8 s.s. M2 velocity $\left(\frac{y}{m}\right)$ (FRB/NIPA) |
| $\sigma$ | 1 | 1 | Coef. rel. risk aversion | Convention literature |
| $\epsilon$ | 1 | 1 | Intratemp. elast. of subst. | Convention literature |
| $\kappa$ | 1 | – | Inv. elasticity labour supply | Convention literature |
| $\zeta$ | 0.5781 | – | Disutility of labor | Normalize agg. output to one |
| $\rho_R$ | 0.0063 | 0.0063 | Retirement probability | Avg duration working life 40 years |
| $\rho_x$ | 0.0125 | 0.0125 | Death probability | Avg duration retirement 20 years |
| $\delta$ | 0.04 | 0.04 | Depreciation rate durables | Baxter (1996) |
| $b_0^{\mathbf{G}}$ | −3.2 | −3.2 | Initial bonds Treasury | Government debt 80% of ann. output |
| $b_0^{\mathbf{CB}}$ | 0 | 0 | Initial bondsCentral Bank | No initial central bank debt/bonds |
| $\xi$ | 0.1 | 0.1 | Coefficient monetary rule | Persistence nominal interest rate |
| $\chi_0$ | – | $1.84e^{-4}$ | Variable hiring cost | s.s. hiring cost 0.5% of output |
| $\chi_1$ | – | $3.68e^{-3}$ | Fixed hiring cost | $\chi_1/\chi_0$= 20 (Pissarides, 2009) |
| $\alpha$ | – | 0.5 | Matching function elasticity | Convention search literature |
| $w$ | – | 1.049 | Real wage | 5% s.s. unemployment rate |
| $\bar{g}$ | – | 0.7 | Scaling matching function | Vacancy filling probability 0.74 |

*Market clearing and equilibrium.* Aggregate non-durables and durables are given, respectively, by $c_t = \nu c_t^{\mathbf{W}} + (1-\nu)c_t^{\mathbf{R}}$, and $d_t = \nu d_t^{\mathbf{W}} + (1-\nu)d_t^{\mathbf{R}}$, where superscripts **W** and **R** denote the averages among working and retired agents, defined analogously to the definition of $a_t^{\mathbf{W}}$.[15] Clearing in the markets for goods, money and bonds requires, respectively, $c_t + d_t = \nu h_t^{\mathbf{W}} + (1-\delta)d_{t-1}$, $m_t = \nu m_t^{\mathbf{W}} + (1-\nu)m_t^{\mathbf{R}}$, and $0 = b_t^{\mathbf{G}} + b_t^{\mathbf{CB}} + \nu b_t^{\mathbf{W}} + (1-\nu)b_t^{\mathbf{R}}$. Finally, the size of the bequest received per working-age agent is given by: $\tau_t^{bq} = \frac{\rho_x a_t^{\mathbf{R}} + \rho_R \rho_x a_t^{\mathbf{W}}}{\nu}$. In Appendix A2, we define the equilibrium. Moreover, in Appendix A2 we show that in the equilibrium of a representative-agent version of the model, obtained by setting $\rho_x = 1$, wealth effects are absent.

### 3.1. The dynamic effects of open market operations

We now analyze the effects of open market operations in our simple model using numerical simulations. Before doing so, we specify the details of household preferences and the monetary policy rule, as well as parameter values.

*Functional forms and parameter values.* We assume that the utility function is a CES basket of non-durables, durables and money, nested in a CRRA function:

$$U(c_{i,t}, d_{i,t}, m_{i,t}) = \frac{x_{i,t}^{1-\sigma} - 1}{1-\sigma}, \text{ where } x_{i,t} \equiv \left[c_{i,t}^{\frac{\epsilon-1}{\epsilon}} + \eta d_{i,t}^{\frac{\epsilon-1}{\epsilon}} + \mu m_{i,t}^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}},$$

where $\epsilon, \sigma, \eta, \mu > 0$. Here, $\epsilon$ is the elasticity of substitution between non-durables, durables and money, $\sigma$ is the coefficient of relative risk aversion, and $\eta$ and $\mu$ are parameters giving utility weights to durables and money, respectively. Computation of the dynamic equilibrium path seems complicated due to the high dimensionality of the aggregate state $\Gamma_t$. In the Appendix we show that solving the model using a standard first-order perturbation (linearization) method is nonetheless straightforward under the above preference specification.[16]

The Central Bank is assumed to set the money supply according $M_t/M_{t-1} = 1 + z_t$, where $z_t$ is an shock process to the rate of nominal money growth, assumed to be of the following form:

$$z_t = \xi(\overline{m} - m_{t-1}) + \varepsilon_t, \ \xi \in (0,1), \tag{4}$$

where $\varepsilon_t$ is an i.i.d. shock innovation and $\overline{m}$ is the steady-state value of real money balances. A positive shock increases the money supply on impact. The above feedback rule implies that this increase is gradually reversed in subsequent periods when $\xi \in (0, 1)$.[17]

The model period is set to one quarter and parameter values are presented in Table 1, in the column labeled "simple". The subjec tive discount factor, $\beta$, is set to 0.9745 which implies an annual real interest rate of about 3 percent in the deterministic steady state. The durable preference parameter $\eta$ is chosen to target a steady-state consumption spending

[15] Due to the transfer to newborns $c_t^{\mathbf{W}} = c_t^{\mathbf{N}}$, $d_t^{\mathbf{W}} = d_t^{\mathbf{N}}$, $b_t^{\mathbf{W}} = b_t^{\mathbf{N}}$ and $m_t^{\mathbf{W}} = m_t^{\mathbf{N}}$.

[16] In particular, we exploit the properties of first-order perturbation and show that the implied certainty equivalence with respect to the aggregate state allows us to express the decision rules of retired agents as linear functions of their wealth levels. This in turn implies that aggregation is straightforward and that only the distribution of wealth between *between* retired and working agents is relevant for aggregate outcomes.

[17] In equilibrium, both real an nominal money balances increase following the shock. Also, the rule implies that the net rate of inflation is zero in the steady state.

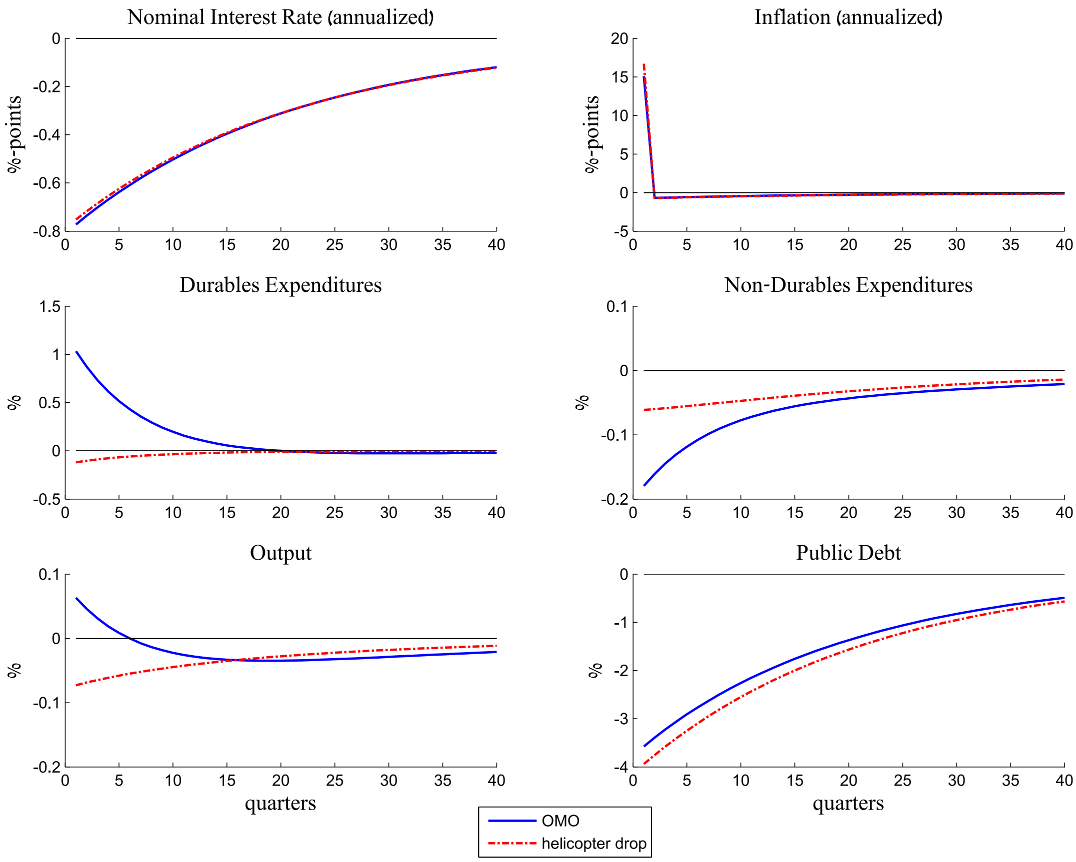


**Fig. 2.** Responses to an expansionary monetary policy shock in the simple model. *Note:* The figure shows the simple model's impulse responses to an annualized 75 basis point decline in the quarterly nominal interest rate, when policy is implemented, correspondingly, through OMO or helicopter drops. The model responses correspond to the simple model without search and matching frictions. Horizontal axes denote quarters after the shock.

ratio of 20 percent on durables. To set the money preference parameter, we target a quarterly money velocity, defined as $\frac{y}{m}$, of 1.8. The intratemporal elasticity of substitution between non-durables, durables and money, $\epsilon$, is set equal to one, as is the coefficient of relative risk aversion, $\sigma$. These two parameter settings imply that money and consumption enter the utility function additively in logs. Hence, our benchmark results are not driven by non-separability of money and consumption in the utility function. In the simple model, we set the Frisch elasticity of labor supply $\kappa$ equal to one following many macro studies. (We shut down the labour supply response in the extension.) The parameter scaling the disutility of labor, $\zeta$, is set so as to normalize aggregate quarterly output to one.

Life-cycle transition parameters are set to imply a life expectancy of 60 years, with an expected 40 years of working life and expected 20 years of retirement. Accordingly, we set $\rho_R = 0.0063$ and $\rho_x = 0.0125$ which imply $\nu = 0.6677$. The depreciation rate of durables, $\delta$, is set to 0.04 following (Baxter, 1996). The initial level of government debt is set to eighty percent of annual output. For simplicity we assume that the Central Bank starts off without any bond holdings or debt. The parameter $\xi$, which governs the persistence of the shock process, is set to 0.1. Section 5 further discusses this parameter.

*Responses to a monetary policy shock under OMO.* Fig. 2 presents the responses to an expansionary monetary policy shock in the simple model. We first study the responses under the (realistic) premise that monetary policy is implemented using open market operations. These responses are indicated by the blue solid lines. The magnitude of the shock is scaled to imply a reduction in the nominal interest rate of about 75 basis points on impact. For now, we focus on the qualitative effects of the shock. In the next section, we use the full model to evaluate the quantitative effects in light of the empirical evidence.

Following the monetary expansion, the inflation rate increases on impact, as the price level jumps up.[18] In the periods after the initial shock, the nominal interest rate and the price level gradually revert back to their initial levels, which hap-

[18] The intuition for the price increase is standard. As the central bank buys government bonds, it increases the amount of money in circulation. Since agents' utility is concave in real money holdings, they are induced to substitute some of the extra cash for consumption goods. The increased demand for goods in turn drives up prices, which dampens the demand increase as it reduces the real value of money holdings.

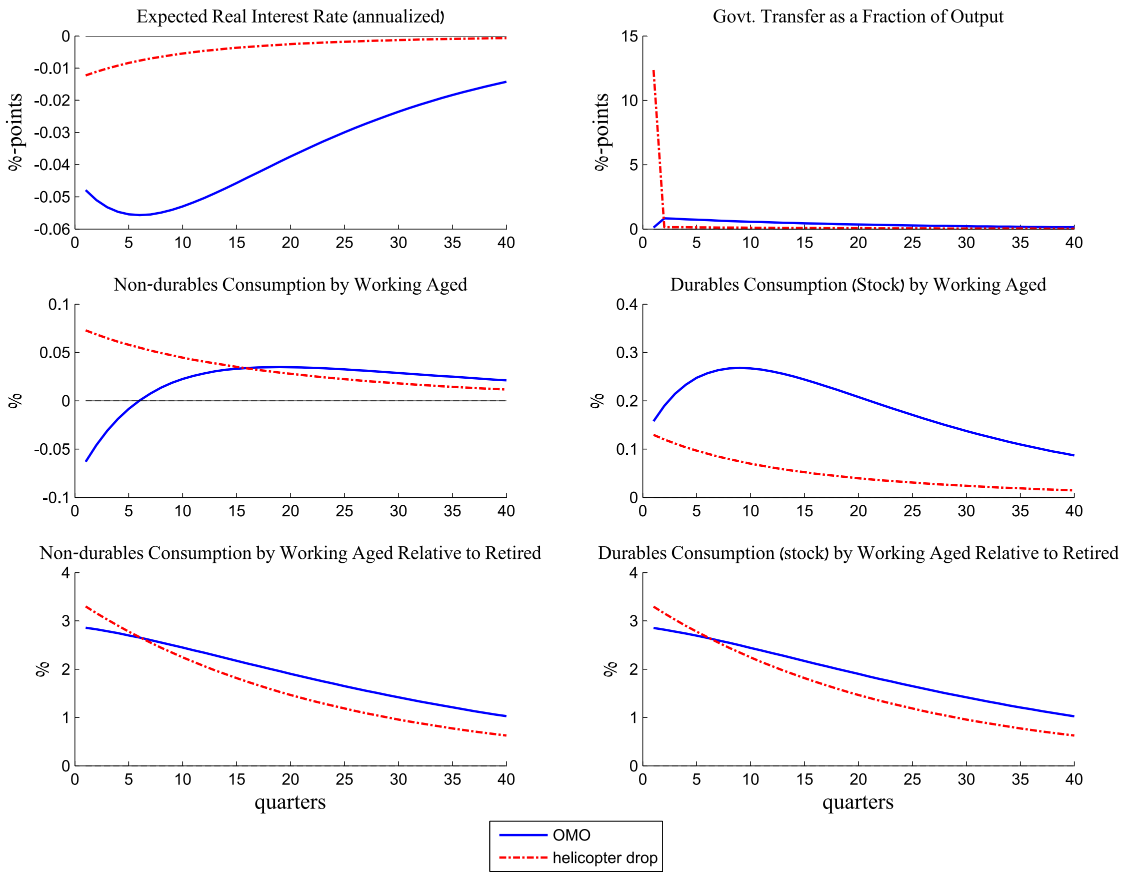


**Fig. 3.** Responses to an expansionary monetary policy shock in the simple model. *Note:* The figure shows the simple model's impulse responses to an annualized 75 basis point decline in the quarterly nominal interest rate, when policy is implemented, correspondingly, through OMO or helicopter drops. The model responses correspond to the simple model without search and matching frictions. Horizontal axes denote quarters after the shock.

pens as a result of the reversion in the monetary policy rule. During this period, inflation is slightly negative and the price level gradually reverts back to its initial level before the shock.

The monetary expansion increases aggregate output on impact. The responses of durables and non-durables make clear that this increase in output is entirely driven by an increase in expenditures on durables. Non-durables decline on impact, although the magnitude of the response is much smaller than the response of durables. Finally, there is a decline in the real value of public debt (i.e. debt issued by the Treasury), which mirrors the response of the price level and which reflects a financial gain for the government at the expense of the public due to a revaluation of its debt.[19]

Fig. 3 plots several variables that provide insight into the impact of monetary policy shocks, as well as into their endogenous propagation over time. Consider again the model version in which monetary policy is implemented using open market operations (indicated by blue solid lines). The real interest rate, plotted in the upper left panel, declines, reflecting an increased desire to save. The top right panel plots the transfer to the working households as a fraction of output, which on impact increases by about 0.8 percent, after which it gradually reverts back to the steady state.[20] Thus, the government gradually remits its financial gains from the monetary expansion back to the households.

The middle two panels show the responses of consumption by working agents, whereas the bottom panels show the consumption responses of working agents vis-à-vis retired agents. Relative to the retirees, consumption of durables and non-durables by working agents increases. All households face a reduction in their real wealth due to the increase in prices, but the retirees are not compensated by an increase in transfers; hence, they lose relative to working agents.[21] In absolute

[19] A second financial gain for the government stems from a downward revaluation of the outstanding stock of money, which is a liability to the government alongside debt.

[20] This response is in line with empirical evidence in Tenreyro and Thwaites (2016), who show that the tax-to-GDP ratio *increases* following a *contractionary* monetary policy shock.

[21] Additionally, for retired agents wealth is the only source of income, whereas working agents also receive wage income, which in real terms is not directly affected by inflation. This is another reason why working agents are less vulnerable to inflation.

terms, consumption of durables by working agents increases as well. The response of non-durables expenditures by working agents is negative on impact.

To understand the effects of monetary policy on real activity more deeply, note that the increase in prices creates a negative wealth effect to the households as it reduces the real value of their money and bond holdings. These losses are only partly compensated for by an increase in (expected) government transfers. Thus, the policy shock reduces the households' permanent income levels. Furthermore, households become less well insured against idiosyncratic shocks after a decline in the value of their assets. These effects induce the households to consume less and enjoy less leisure, that is, to work more, in order to re-build their savings. However, as the aggregate resource constraint makes clear, in equilibrium it is not possible for the household sector as a whole to reduce all consumption expenditures and work more, since the additional labour effort generates more output. Thus, while the household sector desires to save a larger fraction of the real income that it generates through production, it is not possible to increase its aggregate holdings of bonds since the economy is closed and the government's financial position is determined by its policies. However, it is possible for households to save more by accumulating more durables, which are partly consumption goods and partly assets. This implies a substitution from non-durables expenditures towards durables expenditures. Thus, the negative wealth effect triggered by a monetary expansion induces households to work more and save more for retirement, which leads to an expansion in output and a substitution of consumption towards durables. In the next section, however, we will show that the labor supply response is not crucial for the effect, as we obtain similar results in a model version in which labor is fully demand determined.

*Helicopter drops.* We now contrast the effects of open market operations to the effects of shocks in a version of the simple model in which monetary policy is implemented using "helicopter drops" of money. By a helicopter drop, we mean an expansion in the money supply that is not accompanied by an increase in Central Bank bond holdings, but rather by an outright transfer to the Treasury.[22] It then follows that the total transfer from the Treasury to the households is given by its interest earnings on bond holdings (which can be negative) plus the change in the money supply. In real terms, the transfer to the households becomes:

$$m_t - \frac{m_{t-1}}{1+\pi_t} + \frac{r_{t-1} b^{\mathbf{G}}_{t-1}}{1+\pi_t} = \nu \rho_R \tau_t^{\mathbf{N}} + \nu (1-\rho_R) \tau_t^{\mathbf{W}}, \tag{5}$$

We assume again that helicopter drops are gradually reversed after the initial shock, following the same feedback rule as used in the economy with market operations.[23]

The red dashed lines in Figs. 2 and 3 plot the responses for the economy with helicopter drops. Note first that the response of the nominal interest rate is virtually the same as it is in the case of OMO. The figures show that although response of prices to the helicopter drop is comparable to the one in our economy with OMO, the effects on real economic outcomes are very different. In particular, with helicopter drops, output and durable expenditures *decline* following an expansion of the money supply, whereas in the decline in the real interest rate is much more muted than under OMO. Thus, the transmission of monetary policy depends importantly on the operating procedures of the Central Bank and the associated monetary-fiscal arrangements.

The response of government transfers, plotted in the lower right panel, reveals why the effects of a monetary expansion are so different when helicopter drops are used. Upon impact, there is a large one-time positive transfer to working households, whereas transfers in later periods are negligible. Thus, a helicopter drop creates mostly a redistribution between *current* generations, favoring currently working agents, who receive the government transfer, at the expense of the retirees. Future generations are largely unaffected. As a result of their wealth gains, working agents increase consumption of both types of goods and reduce their labor supply, the latter creating a drop in output. By contrast, in the economy with OMO the transfers are spread out over time. As a result, future generations gain at the expense of the current generations (both working and retired agents), who face net losses of wealth. These losses induce working agents to increase labor supply, which generates an increase in output. As a result, the transmission mechanism is essentially reversed when helicopter drops are used.

## 4. Full model and quantitative exploration

Before we compare the model's predictions directly to the data, we add two more ingredients. First, we introduce search and matching frictions in the labor market. Second, we enrich the model's description of fiscal policy.

*Adding search and matching frictions.* In the simple model described above, fluctuations in aggregate output due to monetary policy shocks arise from labour-supply effects. To appreciate this point, recall that labour is the only input in production and note that the working households' first-order condition for labour can be written as $w_t \lambda_t = \zeta h_t^{\kappa}$, where $\lambda_t$ is the Lagrange multiplier on the working households' budget constraint, which measures the marginal utility of wealth. After a negative shock to wealth, $\lambda_t$ increases, which pushes up aggregate labour supply and therefore aggregate output. Vice versa, any

[22] Consequently, $b_t^{\mathbf{CB}}$ remains zero at all times.

[23] For comparability, we do not re-scale the magnitude of the shock relative to the benchmark model.

increase in aggregate output following a monetary expansion derives from an increase in labour supply.[24] Various empirical studies indicate that reductions in wealth can depress labour supply, see e.g. (Imbens et al., 2001). However, at high frequency and for small shocks, the labour supply response may not be strong.

We verify robustness of our transmission mechanism in an environment in which the labour supply channel is suppressed completely. The new assumptions we introduce are arguably more realistic and in line with the macro-labour literature. Specifically, we introduce search and matching frictions in the labour market. Workers inelastically supply labour if they have a job and firms hire workers by posting costly vacancies. Operational firms make positive profits and hence firm equity is a valuable asset, which is a form of savings to households alongside money, bonds, and consumer durables.

We introduce matching frictions following the approach of Diamond, Mortensen, and Pissarides, see e.g. Pissarides (1990). Working-age agents can be either unemployed or matched with a firm.[25] A separation between a worker and a firm takes place if the worker retires at the end of the period. If the worker does not retire, the match dissolves with an exogenous probability $\rho_S$. The overall separation rate, denoted $\widetilde{\rho}_S$, is therefore given by $\widetilde{\rho}_s = \rho_R + (1-\rho_R)\rho_S$. Newborn agents enter the workforce as unemployed. It follows that the number of job searchers in the economy, which we denote $s_t$, is given by $s_t = \rho_R \nu + (1-\rho_R)\rho_S n_{t-1}$. Hiring takes place at the beginning of the period, after aggregate and individual shocks have realized, but before production takes place. The evolution of the employment rate among working-age agents, denoted $n_t$, is given by $n_t = (1-\widetilde{\rho}_S)n_{t-1} + g_t$, where $g_t$ denotes the number of new hires in period $t$. We assume that there is full income sharing among working-age agents, following Merz (1995) and many others. Hence, we preserve our setup without heterogeneity among working-age agents.

Firms are either matched with a worker or are inactive. The equity value of an active firm is given by:

$$V_t = \theta - w_t + (1-\widetilde{\rho}_S)\mathbb{E}_t \Lambda_{t,t+1} V_{t+1}, \tag{6}$$

where $w_t$ is the real wage, $\theta$ is worker productivity, and $\Lambda_{t,t+1}$ is the stochastic discount factor of the owner of the firms. Inactive firms may search on the labor market for a worker after posting a vacancy, which comes at a flow cost $\chi_0$ per period. If the firm is successful in finding a worker, the firm pays a fixed cost $\chi_1$ to hire the worker. The latter cost represents all hiring costs that are not proportional to the duration of the vacancy, such as training costs, see Pissarides (2009).[26] Creating an inactive firm is costless which gives rise to the following free-entry condition $\frac{\chi_0}{\lambda_t} + \chi_1 \leq V_t$, where $\lambda_t \in [0,1]$ is the probability of filling a vacancy. The free-entry condition states that the total (expected) cost of activating a firm cannot exceed the equity value. We calibrate the model such that the condition holds with equality at all times. Given a number of vacancies and a number of searchers, the total number of new matches follows from an aggregate matching function given by $g_t = \bar{g} s_t^{\alpha} v_t^{1-\alpha}$, where $v_t$ is the aggregate number of vacancies, $\bar{g}$ is a scaling's parameter and $\alpha$ is the elasticity of the number of new matches with respect to the number of searchers. The probability of filling vacancy is given by $\lambda_t = \frac{g_t}{v_t}$. We assume the real wage is fixed, i.e. $w_t = w < \theta$. Further, we assume that firms use the working-age agents' stochastic discount factor.[27],[28]

*Fiscal policy rule.* The second modification we make relative to the simple model is the introduction of a more general fiscal policy rule. The motivation for this is essentially empirical. Recall that in the simple model, the government follows a balanced budget policy and transfers any income to the households, period-by-period. This implies that, following a monetary expansion, real public debt declines as the price level increases. Subsequently, however, debt reverts back to the mean, as the price level recovers. In the VAR, however, we observe that real public debt further declines in the two years after the shock. (See Fig. 1.)

Given that public debt plays a key role in the transmission mechanism, we devise a fiscal rule which mimics the behavior of real public debt in the VAR. We achieve this by allowing the government to transfer its income to the household with some delay. Realistically, such delays can arise from the fact that it takes time for a government to adjust tax rates.

Specifically, we generalize fiscal policy to imply a period-by-period Treasury Budget constraint of the following form:

$$\nu \rho_R \tau_t^{\mathbf{N}} + \nu(1-\rho_R)\tau_t^{\mathbf{W}} = \sum_{i=0}^{\infty} \gamma_i \left( \frac{r_{t-i-1} b_{t-i-1}^{\mathbf{G}}}{1+\pi_{t-i}} + \tau_{t-i}^{\mathbf{CB}} \right)$$

The above equation simply states that the total transfer tot the households (the left-hand side) equals a weighted combinations of government income in the past. We impose a long-run balanced budget by imposing that $\sum_{i=0}^{\infty} \gamma_i = 1$, that is, all

[24] Recall that $w_t = 1$, so any increase in $h_t$ must be accompanied by an increase in $\lambda_t$.

[25] We set $\zeta = 0$ in this model version, i.e. there is no disutility from work. We do not model unemployment benefits.

[26] As emphasized by Pissarides (2009), the presence of fixed component in vacancy creation helps to alleviate the well-known problem that search and matching models tend generate much smaller unemployment fluctuations than those observed in the data. Similarly, in our model, the fixed component helps to align the model response in output with the one observed in the VAR.

[27] Thus, the firms' discount factor is given by $\Lambda_{t,t+1} = \beta(1-\rho_R)\frac{U^{\mathbf{W}}_{c,t+1}}{U^{\mathbf{W}}_{c,t}} + \beta\rho_R(1-\rho_x)\frac{U^{\mathbf{WR}}_{c,t+1}}{U^{\mathbf{W}}_{c,t}}$ This assumption simplifies the analysis but is not very restrictive since it can be shown that the stochastic discount factor of all households is the same to a first-order approximation.

[28] Consistent with this assumption we assume that agents sell off all firm their equity upon retirement. The budget constraint of a working-age household becomes: $c_t + d_t + m_t + b_t + V_t(x_t - (1-\widetilde{\rho}_S)x_{t-1}) = a_t + (\theta - w_t)x_t + wn_t + \tau^{bq} + \tau^{\mathbf{s}}$,where $x_t$ is the amount of firm equity held by the household. The aggregate supply of firm equity is equal to $n_t$.

government income will be transferred to households at some point in time. When we set $\gamma_0 = 1$ and $\gamma_i = 0$ for any lag $i > 0$, we obtain the fiscal rule of the simple model. In the full model, we set $\gamma_0 = -1.15$, $\gamma_1 = -1$, $\gamma_8 = 2$, and $\gamma_{16} = 1.15$. Below we will show that, with these parameter values, the model can mimic the debt response in the VAR reasonably well.

*Calibration.* The calibration of the full model targets the same steady-state values for the interest rate, the durables spending ratio, and money velocity as the simple model. Accordingly, $\beta$, $\eta$ and $\mu$ are set to, respectively, 0.9770, 0.31 and 0.0048. The labour utility parameters $\kappa$ and $\zeta$ are irrelevant in the search and matching version. Instead, five parameter pertaining to the labour market frictions are calibrated: $\alpha$, $\chi_0$, $\chi_1$, $w$ and $\zeta$. The matching function elasticity, $\alpha$, is set to 0.5, a conventional value in the search and matching literature. The ofther parameters are set to hit four steady-state targets. The first target is a steady-state unemployment rate of 5 percent. Second, we target the average hiring cost to be 0.5 percent of the quarterly output generated by a worker. Third, we target the ratio of the vacancy cost to the fixed cost of hiring, $\chi_1/\chi_0$, equal to 20, which is at the upper end of the range considered by Pissarides (2009). Finally, set we set $\zeta$ to 0.7, which delivers a vacancy filling probability of 0.74, in line with Den Haan et al. (2000). The parameter $\theta$ is normalized to 1.05, in order to imply an aggregate output level of roughly one in the steady state. Finally, the persistence parameter, $\xi$, is set to 0.1, in order to obtain a degree of persistence in the nominal interest rate similar to the VAR. We further modify the fiscal policy rule as described above. All other parameter values are the same as in the simple model.

*Model vis-à-vis empirical evidence.* We now compare the model's predictions to the VAR. The blue lines in Fig. 1 plot the impulse responses to an expansionary monetary policy shock in the full model. Recall that the black lines in Fig. 1 are the point estimates obtained from the VAR. Two aspects of the model's parametrization are chosen to directly match the VAR by construction. First, as it is standard, the size of the shock is chosen to match the decline of the one-year nominal interest rate, plotted in the top left panel. Second, and as discussed above, the parameters of the fiscal policy rule are chosen to match the dynamics of real public debt, plotted in the bottom right panel.

The remaining four panels inform on the model's quantitative performance vis-à-vis the empirical VAR estimates. The top right panel shows that the inflation dynamics predicted by the model is similar to the VAR, although the initial spike in the model is somewhat larger than the VAR's point estimate. The middle left panel shows that the model can account for much of the increase in durables expenditures. Like the VAR, the model predicts a hump-shaped increase in durables expenditures. Compared to the predictions of the simple model, displayed in Fig. 2, the full model predicts a much more persistent increase in durables expenditures, due to the introduction of search and matching frictions. The responses of non-durables consumption and total consumption expenditures in the model are also in line with the VAR evidence: although the model responses are quantitatively smaller than the point estimates, they fall comfortably within the 95-percent confidence bands. We conclude that the model can quantitatively mimic, to a large extent, the empirical responses obtained from the estimated VAR.[29]

Finally, let us elaborate on how the presence of search and matching frictions affects the impact of monetary policy shocks on the real economy. In the full model, the labour supply channel is absent and aggregate output is determined by firms' hiring decisions. In this economy, the household sector can increase real savings not only through consumer durables, but also via investment in firm equity. An increased desire to save among households pushes up the market value of the firms, which encourages vacancy posting and boosts employment.[30] Thus, in this version of the model aggregate output increases because of an increase in labor demand rather than in labor supply. Furthermore, aggregate output dynamics are governed by the employment rate, which is a slow-moving state variable that adds to the degree of endogenous persistence in the model.

## 5. Concluding remarks

We study the redistributive and aggregate effects of monetary policy in an economy in which the government is a large net debtor. An expansionary open market operation causes a downward revaluation of public debt and a negative wealth effect for the private sector as a whole, as households' revaluation losses are not fully compensated by fiscal rebates. Households respond to the fall in wealth by increasing their saving rate, which pushes down the real interest rate. Lower interest rates generate a substitution towards durable goods, causing a boom in the durable good sector. In the simple model, aggregate hours worked increase due to a labour supply effect. With search and matching frictions, aggregate hours increase as firms post more vacancies. In all, the expansionary OMO causes an increase in output driven by the durable good sector. This response, together with the redistributive effects embedded in the model, is consistent with the empirical evidence on the effects of monetary interventions in the US economy. In this respect, our paper provides new evidence that that following an unexpected monetary policy expansion, the real value of public debt falls and the price level increases.

[29] Both Figs. 1 and 2 are consistent with the VAR evidence provided by Uhlig (2005) who follows an agnostic identification approach and emphasizes that his empirical evidence is consistent with either an increase, a decrease, or no change in output following a monetary shock.

[30] From Eq. (6) it can be seen that an increase in the discount factor, $\Lambda_{t,t+1}$, leads to an increase in the firm value, $V_t$. The free-entry condition dictates that an increase in $V_t$ must be offset by a decline in $\lambda_t$, the rate at which vacancies are filled. From the matching function it the follows that hiring increases.

Our model thus offers a setting consistent with (i) the way in which Central Banks affects the policy rate; (ii) empirical estimates on how such changes affects the macroeconomy and more specifically, the durable good sector and the real value of public debt; and (iii) empirical evidence on the distributional effects of monetary policy. Our results address the challenge posed by Barsky et al. (2007), who pointed out a challenge in generating positive co-movement between durables and non-durables in a standard sticky-price model. The mechanism emphasized in our model can thus be used to complement the workhorse New Keynesian model in monetary policy analyses. We further complement monetary propagation mechanisms which via collateral constraints and changes in relative prices, following (Iacoviello, 2005). Integrating our redistribution channel into these frameworks is an important avenue for future research.

We stress that in economies with a largely indebted government sector, monetary policy can have significant fiscal repercussions and it is hence important to take them into account to fully understand the effect of monetary interventions. In other words, fiscal policy, even if passive, can play a critical role on how monetary policy affects the macroeconomy. Understanding how the government redistributes its losses or windfalls through spending, investment, and taxes is important and we plan to study this second round of redistributions in future work.

## Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.jmoneco.2018.07.003.

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