Distributional consequences of conventional and unconventional monetary policy[*]

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Abstract

This paper uses a life-cycle model with a rich asset structure, and standard nominal and real rigidities, to investigate the distributional consequences of traditional monetary policy and communication about its future course (forward guidance). The model is calibrated to the euro area using both macroeconomic aggregates and microeconomic evidence from the Household Finance and Consumption Survey. We show that the life-cycle profiles of income and asset accumulation decisions are important determinants of redistributive effects of both anticipated and unanticipated monetary shocks. Even though house prices respond strongly to monetary policy easing, hurting young households, their distributional effects are dwarfed by changes in returns on nominal assets and labor market revival that work in the opposite direction. Both anticipated and unanticipated policy easing hence redistribute welfare from older to younger generations. The scale of this redistribution is larger for forward guidance if it is announced in the period when nominal interest rates are expected to remain fixed.

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1 Introduction

It is fairly well known that there are bilateral linkages between monetary policy and asset distribution: central bank policy has distributional consequences and asset distribution affects monetary transmission. For instance, by raising interest rates, monetary policy can benefit rich households who earn more on interest bearing assets, but is usually harmful for poorer households, who rely more on labor income and credit. Regarding the impact of wealth distribution on the transmission of monetary policy, a relatively large proportion of credit constrained households can lower its effectiveness as these agents cannot fully adjust their consumption in response to monetary policy changes. This paper deals with the former part of this two-way relationship, and a detailed discussion of the main findings from the literature is presented in Section 2. However, as will become obvious, the existing literature mainly relies either on a purely empirical approach or on structural models where heterogeneity arises from idiosyncratic shocks affecting agents as introduced in a seminal paper by Bewley (1977). Interestingly, life-cycle models, which introduce another very important dimension of heterogeneity, have very rarely been used in the debate so far. Moreover, the bulk of existing evidence refers to the effects of traditional policy instruments, while much less has been written about the distributional consequences of nonstandard policy measures that have become popular after in the last decade, of which a prominent example is central bank communication on the future path of the policy rate.

Our paper tries to fill some of these gaps. To this end, we construct a life-cycle model with a rich asset structure and new-Keynesian features that allow for studying the effects of both unanticipated monetary shocks and policy announcements. The model features three types of assets – housing, nominal and real financial assets. Using the categories introduced by Kaplan et al. (2018), this allows us to analyze in detail the direct effects of monetary policy shocks, while the presence of nominal and real rigidities ensures a realistic representation of indirect effects. The model is calibrated to the euro area using standard macroeconomic data and microeconomic evidence collected in the Household Finance and Consumption Survey (HFCS). Its aggregate implications are consistent with the empirical evidence on the effects of unanticipated monetary shocks identified in standard vector autoregressions.

We next use the model to simulate the effects of conventional and nonstandard monetary policy, the latter defined as forward guidance (FG) on the future adjustments in the policy rate. We are particularly interested whether FG has different redistributive consequences as compared with traditional monetary policy. We choose a life-cycle framework as it generates a natural environment where agents differ in many key economic characteristics, including asset positions, labor market participation, the extent of being credit constrained, or propensity to consume. As a consequence, households of different age are not only affected by monetary policy to a different degree, but also adjust their consumption, housing and financial savings

differently. Focusing on the age dimension and abstracting from other sources of household heterogeneity allows us to include in the model a fairly rich set of frictions that have been found key in ensuring empirical fit according to the representative agent DSGE literature, especially in the context of dynamic responses to monetary shocks.

The effects of FG in our overlapping generations economy differ considerably from those obtained under the representative household assumption. In the latter case, FG is often found to have even stronger effects than a regular monetary policy shock, see e.g. Del Negro et al. (2012). The presence of mortality risk and finite planning horizon help overcome this forward guidance puzzle, and an additional assumption of imperfect communication borrowed from Campbell et al. (2019) significantly reduces the model reactions to policy announcements on impact.

Overall, our model simulations show that the life-cycle profiles of income and asset accumulation decisions are important determinants of redistributive effects of both anticipated and unanticipated monetary policy shocks. We show how our modeling framework allows to decompose these effects into a few sources, and evaluate their relative importance. We find that the distributional effect via changes in house prices is of relatively minor importance, since what matters is not the housing wealth per se, but rather the housing transaction flows. This means that appreciation of house prices following a monetary expansion hurts young households that are in the process of accumulating housing. However, what turns out to be much more impactful are changes in returns on nominal assets. By lowering them, monetary easing benefits young borrowers and this effect dwarfs the effect of house price changes. Additionally, the working population benefit from expansion in labor market. The net impact of all these effects is welfare redistribution from older to younger generations for both conventional monetary easing and its announcement. The forward guidance can lead to larger redistribution compared with a standard monetary surprise only when implemented during the period when the policy rate is constrained by the effective lower bound (ELB).

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 lays out the model used in our analysis. Section 4 discusses the construction of aggregate and age-specific input data underlying our calibration strategy. Section 5 presents the empirical evidence from the euro area on the aggregate effects of conventional and unconventional policy. In Section 6 we explain a central bank communication technology that we use to model the forward guidance. Section 7 presents our main simulation results.Section 8 concludes.

2   Related literature

As mentioned above, the literature relating monetary policy and asset distribution has been growing dynamically over the recent years. Here we refer to the selected channels and studies

only, an extensive review of the existing literature is offered by Colciago et al. (2019). We divide the review into two parts. First, we deal with conventional monetary policy. Then we discuss the relatively scarce evidence on the impact of unconventional policies.

Inflation stands out as a prominent, and obviously related to monetary policy, driver of redistribution. When contracts are nominal, unexpected inflation benefits debtors at the expense of creditors. One immediate consequence is the impact of inflation on real money balances which redistributes wealth from cash holders to the government (Imrohoroglu, 1992). Since poor households hold a proportionally higher share of their wealth in cash, they are affected more than rich individuals. Holders of other nominally fixed assets (e.g. government bonds) are affected in a similar way. What ultimately maters for the impact of inflation on household wealth are net nominal asset positions (NNP). Doepke and Schneider (2006) offer a detailed analysis of household NNPs in the United States and conclude that rich households are hurt by unexpected inflation because of their large holdings of nominal bonds, while (usually younger) holders of mortgage debt gain.

Changes of real interest rates matter as well. The problem is analyzed in detail by Auclert (2019), who accentuates the role of unhedged interest rate exposures. In particular, Auclert (2019) points out that what matters for the impact of real interest rates on wealth is the difference between maturing assets (including income) and liabilities (including consumption), called the unhedged interest rate exposure (URE). An unexpected tightening of monetary policy raises real interest rates and hurts those households whose maturing liabilities are higher than maturing assets, since they will have to acquire new debt at a higher cost. Again, relating this theoretical concept to real world asset distributions reveals that, for instance, households with fixed rate mortgages have higher UREs than those with adjustable rate mortgages. As a consequence, the former gain and the latter lose from tighter monetary policy.

Another important channel of potential redistribution works indirectly, via macroeconomic effects of monetary policy actions. A monetary tightening results in an economic slowdown. As a consequence, wages decline and unemployment increases. This hurts people disproportionally, with relatively poor and credit constrained agents being affected more severely. Furceri et al. (2018) show that the impact of monetary policy shocks on inequality is larger the higher are the labor shares. This finding seems in line with the more general result of Heathcote et al. (2010), who find that labor income of the poor fluctuates most over the business cycle.

All in all, monetary policy seems to have statistically and economically significant consequences for income distribution and inequality. Several studies investigated not only the selected channels described above, but also aggregate effects of central bank policy on economic inequality. Coibion et al. (2017) used data from the US Consumer Expenditure Survey and find that contractionary monetary policy shocks increase several measures of inequality.

Similar results are found by Guerello (2018), who analyzes the impact of monetary policy on income dispersion in the euro area, by Mumtaz and Theophilopoulou (2017) who investigate the case of UK monetary policy and by Furceri et al. (2018) who investigate a panel 32 countries.

It needs to be noted that the bulk of evidence refers to standard monetary policy measures. Much less is known about unconventional instruments, such as FG or quantitative easing (QE). This is not surprising given the relatively low amount of data from the unconventional monetary policy episodes. Overall, the results from the few existing studies seem inconclusive (Colciago et al., 2019). For instance, Saiki and Frost (2014) show that expansionary unconventional policy of the type conducted in Japan increases inequalities. In contrast, Colciago et al. (2019) find that a QE-type monetary expansion has an equalizing effect on incomes in the euro area. Ampudia et al. (2018) use data for the euro area and find that the ECB asset purchase program benefited most households and did not contribute to increased asset or consumption heterogeneity. Finally, Inui et al. (2017) analyze Japanese data and find that expansionary unconventional policy pursued by the Bank of Japan increased economic inequality before 2000, but had no significant distributional impact afterwards.

3   Model

To analyze in detail the distributional effects of monetary policy, we construct a New Keynesian model with overlapping generations of finitely-lived households. The households face age-dependent mortality risk and have access to housing and two types of financial assets. As it is standard in the New Keynesian literature, nominal rigidities encompass both price and wage stickiness. The model economy is also populated by two types of producers, investment funds, and a monetary authority. The problems that the agents solve are described below. While denoting prices, we employ the convention of using upper case for nominal values and lower case for their ratio to the aggregate price index P_t.

3.1   Households

Each household consists of a single agent, who is assumed to enter the model at age 20 and is assigned age index $j = 1$. The maximum lifespan of a household is 99 years ($j = J = 80$) and at each year the household faces age-dependent mortality risk ω_j. Thus at each time period there are 80 cohorts of overlapping generations, with their sizes denoted with $N_{j,t}$. Within a cohort, households differ only the amount of supplied labor due to staggered wage contracts. However, we assume that idiosyncratic wage risk can be perfectly insured so that all other allocations chosen by agents in the same cohort are identical.

3.1.1 Optimization problem

A j-aged household ι maximizes its expected remaining lifetime utility that depends on consumption $c_{j,t}$, owned housing stock $\chi_{j+1,t+1}$ and hours worked $h_{j,t}$ according to

$$U_{j,t}(\iota) = \mathbb{E}_t \sum_{s=0}^{J-j} \beta^s \frac{N_{j+s,t+1}}{N_{j,t}} \left(\log\left(c_{j+s,t+s} - \varrho\bar{c}_{j+s,t+s-1}\right) + \psi_{j+s} \log \chi_{j+s+1,t+s+1} - \phi_{j+s} \frac{h_{j+s,t+s}(\iota)^{1+\varphi}}{1+\varphi} \right)$$

(1)

where β is the subjective discount factor, the ratio $N_{j+s,t+1}/N_{j,t}$ represents the probability of surviving for at least s more years, ψ_j and ϕ_j are the age-dependent parameters regulating preference for housing and leisure, φ is the inverse of the Frisch elasticity of labor supply, and ϱ controls the strength of external habits, expressed relative to average consumption of the same age group in the previous period.

Households face the following budget constraint

$$P_t c_{j,t} + P_{\chi,t}[\chi_{j+1,t+1} - (1-\delta_\chi)\chi_{j,t}] + P_t a_{j+1,t+1} = W_t(\iota)z_j h_{j,t}(\iota) + R^a_{j,t}P_{t-1}a_{j,t} + P_t beq_t + P_{\chi,t}beq_{\chi,t} + \Xi_t(\iota)$$

(2)

where P_t denotes the aggregate price level, $P_{\chi,t}$ denotes the price of housing, δ_χ is the annual housing depreciation rate, $a_{j,t}$ stands for the beginning-of-period t real stock of financial assets that are managed by investment funds and that yield the gross nominal rate of return $R^a_{j,t}$ (where the rate of return is age-specific, see below), W_t is the nominal wage per effective hour, z_j represents age-specific labor productivity, and Ξ_t collects net payments from the wage insurance scheme and firm profits.

Our model features exogenous retirement upon reaching the age of 64 ($j = JR = 45$), and hence we set $z_j = 0$ for all $j \geq JR$. Since most agents die before reaching the maximum age, they leave unintentional bequests in form of financial assets and housing. Both are redistributed equally across all agents that are at least five years before retirement in form of lump-sum transfers beq_t and $beq_{\chi,t}$, respectively.[1]

3.1.2 Wage stickiness

The differentiated labor services of households are bundled up by competitive aggregators who then transform them into standardized labor services

$$h_t = \left[\int_0^1 h_{j,t}(\iota)^{1/\mu_w} \, d\iota \right]^{\mu_w}$$

(3)

where μ_w captures the imperfect substitutability of differentiated labor services and is equal to households' markup over the competitive wage level.

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[1]The upper age limit on receiving bequests is consistent with typical assumptions in the literature, see e.g. De Nardi and Yang (2014).

Each household sets its own nominal wage independently from others and, as in the Calvo scheme, can reoptimize its level only if it receives a signal to do so, which arrives with probability $1-\theta_w$. Households who do not receive the signal index their wages fully to steady state inflation.

3.1.3 Age-specific rates of return

There are two financial assets traded in the model economy: claims on physical capital and bonds, the latter representing nominal debt contracts between borrowers and savers. These two assets will hence be also referred to as real and nominal financial assets, respectively. The age-specific shares of bonds in portfolio are denoted with

$$s_{j,t} = \frac{b_{j,t}}{a_{j,t}} \tag{4}$$

where $b_{j,t} \leq a_{j,t}$ stands for real bond holdings of a representative j-aged household. The gross nominal age-specific rates of return in household's budget constraint are thus given by

$$R_{j,t}^a = s_{j,t}R_{t-1} + (1 - s_{j,t})R_t^a \tag{5}$$

where R_t is the gross interest on bonds, which we assume to be risk-free in nominal terms (i.e. determined ex ante), and R_t^a is the gross return on capital.

Rather than modeling age-specific portfolio choices by agents, we assume that real bond holdings by age $b_{j,t}$ are constant over time, and set at values such that their steady state shares in household assets match the age profiles from the data exactly. It has to be stressed that, while this makes the financial asset portfolio of households exogenous, it is innocuous for the types of model simulations that we perform in this paper, see section 4.4 for more discussion.

3.1.4 Demographics and aggregation

In our model, the relative sizes of cohorts are determined by mortality risk ω_j and the growth rate of the number of youngest agents, both of which are assumed to be exogenous. Then, the total number of living agents N_t and the population growth rate n are given by

$$N_t = \sum_{j=1}^{J} N_{j,t} \quad \text{and} \quad n_t = \frac{N_{t+1}}{N_t} - 1 \tag{6}$$

where the number of agents in each cohort evolves according to

$$N_{j+1,t+1} = (1 - \omega_j)N_{j,t} \tag{7}$$

Since we allow population growth in the steady state to differ from zero, the number of households within each cohort becomes nonstationary, and it is useful to define the size of cohorts relative to that of the youngest one (which are then time-invariant)

$$N_{j,t}^{rel} = \frac{N_{j,t}}{N_{1,t}} \tag{8}$$

and the growth rate of youngest agents n_1

$$n_1 = \frac{N_{1,t+1}}{N_{1,t}} - 1 \tag{9}$$

This allows us to rewrite equations (6) and (7) in relative terms

$$N^{rel} = \sum_{j=1}^{J} N_j^{rel} \quad \text{and} \quad n = n_1 \tag{10}$$

$$N_{j+1}^{rel} = \frac{(1 - \omega_j)N_j^{rel}}{1 + n_1} \tag{11}$$

where we omitted the time subscripts as both mortality risk and the growth rate of youngest agents are assumed to be constant.

The aggregate allocations over all living households can be then expressed in per capita terms as follows

$$c_t = \sum_{j=1}^{J} \frac{N_j^{rel} c_{j,t}}{N^{rel}} \tag{12}$$

$$h_t = \sum_{j=1}^{J} \frac{N_j^{rel} z_j h_{j,t}}{N^{rel}} \tag{13}$$

$$\chi_{t+1} = \sum_{j=1}^{J} \frac{N_j^{rel} \chi_{j+1,t+1}}{N^{rel}(1 + n)} \tag{14}$$

$$a_{t+1} = \sum_{j=1}^{J} \frac{N_j^{rel} a_{j+1,t+1}}{N^{rel}(1 + n)} \tag{15}$$

$$beq_t = \sum_{j=1}^{J} \frac{\left[N_{j-1}^{rel} - N_j^{rel}(1 + n)\right] R_t^a a_{j,t}}{N^{rel}(1 + n)\pi_t} \tag{16}$$

$$beq_{\chi,t} = \sum_{j=1}^{J} \frac{\left[N_{j-1}^{rel} - N_j^{rel}(1 + n)\right] \chi_{j,t}}{N^{rel}(1 + n)} \tag{17}$$

where $\pi_t \equiv P_t/P_{t-1}$ is gross inflation.

3.2 Firms

There are four types of firms in our model economy – final goods producers, intermediate goods producers, capital producers and investment funds. Except for intermediate goods producers, which are monopolistically competitive, all firms operate under perfect competition. Consistently with demographic processes in the household sector, the mass of each type of firms is tied to the size of population. Whenever firms generate period profits or losses, they are equally distributed across households.[2]

3.2.1 Final goods producers

Final goods producers purchase intermediate inputs $y_t(i)$, where i indexes intermediate goods producers, and produce a homogeneous final good y_t according to the following CES aggregator

$$y_t = \left[\frac{1}{N_t} \int_0^{N_t} y_t(i)^{\frac{1}{\mu}} \mathrm{d}i \right]^{\mu} \tag{18}$$

where μ controls the degree of substitutability between intermediate inputs and can be interpreted as gross markup. The solution to a representative final goods producer's profit maximization problem implies the following demand function for intermediate goods

$$y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{\frac{\mu}{1-\mu}} y_t \tag{19}$$

and the associated aggregate price index is given by

$$P_t = \left[\frac{1}{N_t} \int_0^{N_t} P_t(i)^{\frac{1}{1-\mu}} \mathrm{d}i \right]^{1-\mu} \tag{20}$$

3.2.2 Intermediate goods producers

Intermediate goods producers hire capital k_t and labor l_t, and produce differentiated output according to the Cobb-Douglas production function

$$y_t(i) = k_t(i)^{\alpha} h_t(i)^{1-\alpha} - \Phi \tag{21}$$

where Φ is a fixed cost of production ensuring zero profits in the steady state. They face demand schedules given by equation (19), and set their prices subject to the Calvo friction, with θ representing the probability of not receiving the reoptimization signal, in which case prices are fully indexed to steady state inflation π. Intermediate goods producers are risk

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[2]Final goods producers and investment funds earn zero profits every period while intermediate goods producers and capital producers generate zero profits on average. In the latter case, period profits are small and hence their distribution across households does not matter quantitatively for our main results.

neutral, i.e. they use the nominal risk-free rate R_t to discount expected future profit flows. The reoptimizing firms hence maximize

$$\mathbb{E}_t \sum_{s=0}^{\infty} \left(\prod_{l=0}^{s} R_{t+l} \right)^{-1} \theta^i \left[P_{t+s}(i)\pi^s - P_{t+s}m_{t+s} \right] y_{t+s}(i) \tag{22}$$

where m_t is real marginal cost consistent with production function (21).

3.2.3 Capital producers

Capital producers purchase investment goods i_t at price P_t and combine them with existing undepreciated capital purchased at price Q_t to produce new capital, subject to flow investment adjustment costs. The resulting law of motion for aggregate capital per capita in the economy is

$$(1+n)k_{t+1} = (1-\delta)k_t + \left[1 - S_k \left(\frac{i_t}{i_{t-1}} \right) \right] i_t$$

where δ is the capital depreciation rate and $S_k(\cdot)$ describes the investment adjustment costs. We use the following functional form

$$S_k \left(\frac{i_t}{i_{t-1}} \right) = \frac{S_1}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \tag{23}$$

where $S_1 \geq 0$, which ensures that adjustment costs are zero in the steady state.

3.2.4 Investment funds

Investment funds intermediate nominal assets between borrowing and saving households, and manage physical capital that they rent to intermediate goods producers at nominal rate R_t^k. Since investment funds are assumed to be risk-neutral, their portfolio choices imply equalization of ex ante rates of return on capital and bonds

$$\mathbb{E}_t \frac{R_{t+1}^k + (1-\delta)Q_{t+1}}{Q_t} = R_t \tag{24}$$

Ex post returns earned by investment funds are transferred to households according to their age-specific portfolio composition described before.

3.3 Monetary authority

The monetary authority sets the nominal interest rate according to a Taylor-like rule that takes into account the zero lower bound constraint

$$R_t = \begin{cases} R_t^{cb} & \text{if } R_t^{cb} > 1 \\ 1 & \text{if } R_t^{cb} \le 1 \end{cases} \tag{25}$$

where

$$\frac{R_t^{cb}}{R} = \left(\frac{R_{t-1}}{R} \right)^{\gamma_R} \left[\left(\frac{\pi_t}{\pi} \right)^{\gamma_\pi} \left(\frac{y_t}{y_{t-1}} \right)^{\gamma_y} \right]^{1-\gamma_R} \exp(\varepsilon_t^R) \tag{26}$$

where the coefficients γ_R, γ_π and γ_y control, respectively, the degree of interest rate smoothing, the response to deviations of inflation from the target, and the response to the per-capita output growth rate, and ε_t^R is a monetary policy innovation. We assume that this innovation can be a pure shock, reflecting a conventional monetary policy intervention, or imperfectly communicated to agents in advance, in which case it can be interpreted as forward guidance. See section 6 for details.

3.4 Market clearing conditions

The model is closed with a standard set of market clearing conditions. We assume that the per-capita housing stock is fixed and the housing market clears

$$\chi_t = \chi$$

Equilibrium on the final goods market implies

$$y_t = c_t + i_t + \delta_\chi p_{\chi,t} \chi \tag{27}$$

The market clearing conditions for capital and labor can be written as

$$\frac{1}{N_t} \int_0^{N_t} k_t(i) = k_t \tag{28}$$

$$\frac{1}{N_t} \int_0^{N_t} h_t(i) = h_t \tag{29}$$

This allows us to write the aggregate production function as

$$y_t \Delta_t = k_t^\alpha h_t^{1-\alpha} - \Phi \tag{30}$$

where

$$\Delta_t \equiv \frac{1}{N_t} \int_0^{N_t} \left(\frac{P_t(i)}{P_t} \right)^{\mu/(1-\mu)} \mathrm{d}i \tag{31}$$

measures the price dispersion across intermediate goods.

Finally, we assume that bonds are in zero net supply so that

$$\sum_{j=1}^{J} N_j^{rel} b_{j,t} = 0 \tag{32}$$

4   Calibration and model solution

The model is calibrated for the euro area, using annual time frequency. The asset structure, both at the aggregate level and how it varies over the life cycle, can be expected to play a key role in our analysis. Therefore, we calibrate it with utmost care and precision. Most detailed information about the age profiles of various types of assets in the euro area can be derived from the Household Finance and Consumption Survey (HFCS). Since aggregate quantities from this survey do not line up with aggregate data from national account statistics (see e.g. Hammer, 2015), we proceed as follows. We calibrate the standard macroeconomic parameters and match the key aggregate steady state proportions, including those describing the aggregate asset structure, on the basis of national account data. The age profiles, on the other hand, are taken from the HFCS.

4.1   Aggregate structural parameters and macroeconomic proportions

We calibrate the economy-wide structural parameters using standard values from the literature, to match the key macroproportions, or using econometric estimates performed outside of the model. The chosen values are reported in Table 1.

We calibrate the age-invariant discount factor of households at 0.988 to get the average real interest rate of 0.8%, observed in the euro area over the years 1997-2012. We cut the sample at 2012 as this was the last year during which the ECB monetary policy was not constrained by the effective lower bound. The Frisch elasticity of labor supply is set at 0.5, which is a conventional value in the business cycle literature. We calibrate both the price and wage markups at a standard value of 1.2, see e.g. Coenen et al. (2008). The Calvo parameters governing price and wage reoptimization probabilities set such that they imply the average contract duration of 3 and 5 quarters, respectively, which translates into the values of 0.19 and 0.41. We also impose a relatively high (though still within the range of estimates reported in the DSGE literature) degree of habit persistence in consumption of

0.65 and slope of investment adjustment cost of 4. These are the only parameters that are used to make our model responses to standard monetary shocks better aligned with VAR evidence that we present in the next section.

We use the balance sheets of financial and nonfinancial assets[3] for the euro area countries to calibrate the steady state stock of housing, non-residential fixed capital and loans. Our empirical counterpart of the first category is dwellings owned by households and its ratio to GDP is 1.4.[4] Our empirical measure of non-residential capital is total fixed assets in the economy less dwellings owned by households, and its ratio to GDP is 1.9. We use these two ratios to pin down the capital share in output (set at 0.3) and residential capital depreciation rate (set at 1.5% annually). As a proxy for aggregate loans, we take financial liabilities of the household sector, which amount to 66% of GDP in the data. We will use this target later to complement the calibration of the composition of net financial assets. By calibrating the physical capital depreciation rate at 12% annually we are able to match the ratio of investment to GDP observed in the euro area.

The parametrization of the monetary policy feedback rule is based on the econometric estimation of a log-linearized version of the monetary policy feedback rule (26), using euro area data over the period 1981-2012 from the AWM database, converted to annual frequency. Prior to estimation, all series are detrended using the Hodrick-Prescott filter with the smoothing parameter set to 100, which is a conventional value used for annual data. Subtracting trends from the data is aimed to capture the time variation in the natural interest rate, potential output, and the implicit inflation target.

4.2 Demographic variables

We use Eurostat data for the euro area to construct the age-dependent mortality risk and the rate of growth of 20-year olds.[5] In our calibration we use averages for the time period 1999-2018. For years where mortality rates were not documented for the oldest cohorts, we employ exponential extrapolation. Since the population structure in the model's steady state is stationary by construction, which also means that the 20-year olds and total population grow at the same rate, we have set the rate of growth of the youngest cohorts to 0.1% annually, which corresponds to the average growth rate in total EA population. Figure 1 depicts the profiles of mortality rates and the implied stationary population structure.

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[3]Eurostat data codes: nasa_10_f_bs and nama_10_nfa_bs.

[4]As in our model we abstract from government spending, we subtract government expenditures from GDP while calculating this and the following empirical ratios.

[5]Population data and age-specific death rates come from the demo_pjan and demo_mlifetable series, respectively.

4.3 Life-cycle profiles

Finally, we use the HFCS data to extract the steady state age profiles for labor income, hours worked, housing, total net financial assets and net interest-bearing nominal assets at the household level. Labor income is the sum of wage employment and self-employment, while hours worked are defined as time spent working at the main job. Housing is the sum of the household's main residence and other real estate property not for business activities. Total financial assets consist of household's business wealth, value of non self-employment private business, publicly traded shares, bonds and mutual funds. The interest bearing assets, which is a subset of total financial assets, equal the value of deposits net of mortgage and non-mortgage debt. We use the second wave of this survey, conducted in 18 euro area countries between 2012 and 2014. See the appendix (TBA) for more detailed definitions and HFCS codes, and Jablonowski (2018) for the method used to extract the age profiles.

The age of the household is determined by the age of the household head. Since our model does not explicitly account for changes in the household composition or the family size, the extracted age profiles are next divided by the square root of the number of household members, which is one of the equivalence scales used while working with household level data, see Fernandez-Villaverde and Krueger (2007) and OECD (2008). The thus obtained profiles are next smoothed using fourth-order polynomials and extrapolated for age cohorts not represented in the HFCS, subject to the model-consistent assumption that assets of the youngest and oldest cohort are zero.

While calibrating the model, we choose to match the steady state age profiles for labor income and hours worked exactly to their empirical counterparts. We achieve this by setting the age-specific productivity parameters z_j to a ratio of labor income to hours worked from the empirical profiles. Similarly, the age-specific weights on labor disutility ϕ_j are chosen such that at the steady state the model-implied hours worked match exactly the empirical age profile for this variable. Rather than matching the age profile for housing exactly using housing weights in utility ψ_j, we assume that they increase linearly until retirement, and then stay flat. As we show below, choosing appropriately the intercept and slope over the pre-retirement period for this set of parameters is sufficient to obtain a very good fit of the housing profile.

Given other structural parameters, the age profile of total net financial assets is generated endogenously in the model, but its composition between nominal (interest-bearing) and real assets varies exogenously with age. We match it using the HFCS profiles for net interest-bearing assets in the following way. For households under the age of 57, who are net borrowers, we use the empirical profiles directly, scaling them such that the ratio of their sum to output matches 66% obtained from the national accounts data as described above. For the remaining age groups, which hold positive net nominal assets, we adjust the empirical

profiles such that, consistently with the model construction (and roughly in line with the national accounts data), their net supply is zero. Moreover, as we do not have observations for households older than 80 from the HFCS, we assume that after this age all financial assets are held in form of nominal assets. Naturally, this restriction is not innocuous for how the monetary shocks affect these old individuals. However, given the empirical demographic input described above, their implied share in total population is small, and hence their economic situation does not have significant impact on the remaining cohorts. Also, while presenting our main findings, we drop the last 20 cohorts from the analysis.

Figure 2 presents the profiles which we match exactly. The wage profile follows the well-documented pattern, increasing up to the late middle age of a household head, and then declining. As regards hours worked, they are almost flat, with some increase at a young age and a drop close to retirement. The nominal assets are negative for young cohorts, who finance their consumption and accumulation of housing by borrowing from old agents (who own positive nominal assets).

Figure 3 shows two key asset profiles that our model generates endogenously. The model reproduces very well the increasing pattern of housing and then its gradual decumulation. It is also quite successful at matching total net financial assets. In the HFCS data, households are net debtors until the age of 40 and have highest indebtedness around the age of 30. After that, they accumulate assets until about retirement, and then start running them down. The model captures the timing of these episodes in asset accumulation very well, although the peak net financial asset position is somewhat higher than in the data.

4.4   Solution method

We simulate the model in its non-linear form, also taking into account the possible presence of the effective lower bound on the nominal interest rate (ELB). More precisely, we use the extended path method developed by Fair and Taylor (1983), replacing the conditional expectations showing up in the model equilibrium conditions with their conditional means obtained from a deterministic simulation. The method hence ignores the effect of uncertainty on agents' decisions in a way similar to standard first-order perturbation techniques that rely on the certainty equivalence assumption.[6] As in the case of linearized DSGE models, this solution feature does not allow for solving a portfolio problem within the model, hence justifying our strategy to fix the composition of financial assets within a cohort exogenously, as explained in section 3.1.3.

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[6]We have also experimented with a stochastic version of the extended path method, using Gaussian quadrature to take into account the effects of future uncertainty one or two periods ahead. The results turned out to be very similar to those presented below.

5 Aggregate evidence from high-frequency identification

Before discussing the model simulations, we present some empirical evidence on how conventional and forward guidance shocks affect key macroeconomic variables in the euro area. To this end, we construct a monetary VAR model and apply a structural decomposition in the spirit of Gürkaynak et al. (2005), Mertens and Ravn (2012) and Gertler and Karadi (2015), based on high frequency identification of monetary policy shocks to simulate relevant impulse responses. This approach uses surprises to financial asset prices evaluated in small time windows around announcements of monetary policy decisions as exogenous instruments that allow to identify monetary policy shocks. To that purpose, we use factors calculated by Altavilla et al. (2019) – one that reflects surprises related to FG shocks, and two factors related to conventional policy surprises (called respectively Forward Guidance, Target and Timing factors in the original paper). Unfortunately, the factors are available only since 2002, which is too short a period to estimate a quarterly VAR model. For this reason, we proceed as Hafemann and Tillmann (2017) and estimate the model on monthly data. In line with most standard information criteria, we allow for four lags. The obtained monthly impulse responses are transformed to annual figures to facilitate comparison with our model that operates at the latter frequency. The details of the data preparation and structural identification are presented in the Appendix.

The first column of Figure 4 presents the impulse responses of inflation and GDP growth to a typical conventional expansionary monetary policy shock identified in the VAR model. In line with most of the existing literature on monetary transmission, an expansionary policy shock generates a boost in output and raises inflation. Since a standard monetary surprise can be mapped into our structural model in a fairly straightforward way, we also use this shock to validate it. More specifically, the model-based responses are generated using the unexpected component in the Taylor rule (26), and setting the shock size such that it generates the same interest rate response on impact as the VAR. The reactions implied by our model are very well aligned with the VAR evidence, giving us confidence that it is consistent with the empirical evidence on the conventional monetary transmission.

We next move to the forward guidance. We cannot unfortunately present a direct impulse response comparison between the VAR and the structural model in this case. First, the interest rate maturity differs substantially between the two models. Second, by necessity the VAR shows evidence for a period that was partly subject and partly not subject to the ELB, while the structural model differentiates between these episodes. Yet another complication is lack of precise information about forward guidance horizon in our dataset. The second column of Figure 4 shows the reactions to an average monetary shock of this type as identified in the VAR model. As this policy is typically designed to affect maturities longer than one

year, this time we use the 5-year interest rate in estimation. One interesting observation is that a standard FG shock generates expansions of economic activity and inflation that are similar to those following a standard conventional monetary shock, both in terms of magnitude and the shape of reactions. We view this evidence as indicating that this type of central bank interventions is empirically relevant in the euro area.

6 Imperfect communication

Before we use our model to address the distributional consequences of conventional and unconventional monetary policy, we have to define them properly. As regards the former, we will follow the bulk of the literature by considering a standard expansionary monetary policy shock, unanticipated to all agents, and defined as before, i.e. as unexpected deviation from the monetary policy rule. The latter aims to capture signals about the policy deviation of the same magnitude, but concerning the future. We assume that the signal is first issued two years before the planned monetary intervention, then repeated in the next period, and finally implemented as initially announced. This scenario is aimed to mimic Odyssean forward guidance, in which the central bank commits to certain policy interventions ahead of their implementation. A typical motivation for this kind of actions is to substitute for conventional monetary easing at times when the latter is not feasible because of the binding ELB: lowering the policy rate is replaced by a promise to deviate negatively from a systematic interest rate adjustment (e.g. postulated by a feedback rule used in normal times) at some point in the future (two years ahead in our case) when the ELB no longer constrains the monetary policy conduct.

It is well known that, when signals issued by the monetary authority are assumed to be fully credible, the efficiency of such defined FG as predicted by a standard New Keynesian setup is very high. This prediction is widely considered questionable, and several solutions to the so-called forward guidance puzzle have been proposed in the literature (see e.g. Del Negro et al., 2012; Gabaix, 2016; McKay et al., 2016). In this paper we follow the approach proposed by Campbell et al. (2019), which highlights imperfect central bank communication. Since our approach is perfectly aligned with their setup, we present below only its main ingredients, referring the reader to the source paper or its discussion by Bielecki et al. (2019).

In a standard New Keynesian model, a central bank's promise to change monetary policy parameters however far in the future is always treated as fully credible by all agents. The imperfect communication approach assumes instead that the central bank can only issue a noisy signal about future deviations form its policy rule. Let us denote this signal as $\boldsymbol{s_t} = \boldsymbol{\varepsilon_t^R} + \boldsymbol{v_t}$, where $\boldsymbol{\varepsilon_t^R} = [\varepsilon_t^R, ..., \varepsilon_{t+H}^R]'$ is a vector of deviations from the rule given by equation (26) from period t until $t + H$, and $\boldsymbol{v_t} = [v_t, ...v_{t+H}]'$ is a corresponding vector of noise. In practical terms, the latter can be either interpreted as miscommunication between

the central bank and the public or the occurrence of important, unforeseen events that make the central bank deviate from its earlier promise.

Agents observe the signals as well as past and current period policy deviations, and hence know how frequently the central bank deviated from its promises in the past. Assuming Gaussian shocks, they can use the Kalman filter to form (or update) their expectations about the vector of policy deviations

$$E_t \boldsymbol{\varepsilon}_t^R = E_{t-1} \boldsymbol{\varepsilon}_t^R + \boldsymbol{\kappa} \left(\boldsymbol{s_t} - E_{t-1} \boldsymbol{\varepsilon}_t^R \right)$$

where $\boldsymbol{\kappa}$ is the $(H{+}1){\times}(H{+}1)$ Kalman gain matrix which effectively determines what weight agents attach to the signals sent by the central bank. In particular, when past communication has been noisy, agents will attach a relatively low weight to new signals. We calibrate the on-diagonal parameters of $\boldsymbol{\kappa}$ to approximate the dynamic accumulation of knowledge about the future policy deviations as estimated by Campbell et al. (2019).[7] With this procedure we arrive at

$$\boldsymbol{\kappa} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0.6 & 0 \\ 0 & 0 & 0.2 \end{bmatrix}$$

where setting $\kappa_{1,1} = 1$ reflects the assumption that the current period policy shock is observed without noise.

As a result of this communication and learning technology, when the monetary authority announces its plans to deviate from its normal feedback rule in two years, agents will adjust their plans taking into account only about one-fifth of the issued signal. If the signal is repeated next year, agents will believe more than a half of it. This means that, when the policy is actually implemented in the following year as previously announced, it will still have a sizable surprise component.

In our simulations we will use a forward guidance scenario sketched out above in two versions. As this policy is typically considered particularly useful when the short-term rate hits the ELB, while implementing FG we will first assume that this constraint is binding and hence the policy rate is constant until the announced deviation is implemented. Note that the central bank signals concern the policy deviations $\boldsymbol{\varepsilon}_t^R$ and not directly the policy rate itself. Consistently with formulas (25)-(26), this means that the binding ELB is not subject to imperfect communication, i.e. this constraint is perfectly understood by all agents. In the second variant of FG, we will let the short-term rate endogenously respond to changes in inflation and economic activity generated by the signal about future policy deviations,

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[7]Their estimates also suggest that noise associated with policy announcements for a horizon exceeding two years is so large that they are virtually ignored by agents. This substantiates our choice of $H = 2$.

which may better describe this type of intervention implemented in normal times, i.e. when the ELB is not binding.

7   Model simulations

We are now ready to use our model to address several important questions about the distributional consequences of conventional and unconventional monetary policy. We start by showing the impulse responses of key macroeconomic aggregates, including asset prices and labor market variables, to these two types of policy. We next present how net worth of households of different age is affected by these two shocks at the moment they hit. We further discuss the impact of the monetary shocks on the allocations of the living cohorts over their remaining life span. This finally allows us to assess the direction and magnitude of redistribution associated with anticipated and unanticipated policy shocks.

7.1   Aggregate effects

To understand the redistributive effects of monetary policy across different age cohorts, we need essentially two ingredients, i.e. the life-cycle profiles for income and asset positions, which we have already discussed in the Section 4, and the reaction of key macroaggregates to policy shocks, which we present now in Figure 5. Let us first focus on the comparison of conventional monetary policy with forward guidance in normal times, i.e. in the latter case we allow the policy rate to respond endogenously to macroeconomic developments during the two years before the announced shock is realized. Since the the central bank communicates a monetary expansion, this means that the nominal interest rate actually increases on impact and further in the next year (reacting to higher output and inflation), only to fall sharply when the policy intervention is implemented.

Comparing the outcomes for conventional and such defined unconventional policy shocks, the following observations can be made. First of all, both policies lead to a boom in aggregate output, which supports an increase in labor income, and hence allows for higher aggregate consumption spending. However, while the strongest effect of conventional policy occurs already in the first year, it is much weaker on impact for the forward guidance, reflecting imperfect communication and endogenous adjustment in the policy rate. Also, in the latter case the peaks are postponed by two years, i.e. by the announcement horizon. Importantly, they are roughly of the same size for real allocations, or even smaller for inflation and house prices. This is a marked difference to standard medium-sized DSGE models with a representative agent, in which the forward guidance puzzle, i.e. excessive reaction to anticipated policy shocks, is more severe. For example, in a similarly designed experiment using the FRBNY model, Del Negro et al. (2012) document a response of output of roughly

the same size on impact for a contemporaneous and 2-year ahead policy shock, and a peak response about two times bigger for the latter, while this amplification is even stronger for inflation and occurs already on impact. This better performance of our life-cycle model in this kind of exercise is due to the finite planning horizon and mortality risk faced by households, which increases the effective rate at which they discount the future, and also due to imperfect communication by the central bank, which additionally postpones the culmination of the shock.

For the redistributive outcomes that we will discuss later, it is important to comment on the differences between the reactions of returns on the two types of financial assets. Note that these differences can be observed only on impact for conventional policy, and only over the initial three periods for forward guidance since, absent surprises, the returns on all financial assets are the same in our model by construct. For the conventional policy easing, the response of the return on non-housing capital is strongly positive on impact, reflecting an appreciation of stock prices, while the real return on nominal assets falls following an inflation surprise. In contrast, under forward guidance, the stock market peak is delayed until the policy easing is actually implemented and the negative response of bond returns is also much muted. All of this suggests that wealth redistribution associated with nominal versus real asset holdings will be much stronger for conventional monetary policy.

Turning to the forward guidance scenario with a binding ELB, the reactions at the moment of policy announcement are now much stronger than in normal times, but still weaker compared to a conventional policy easing for all relevant variables. As regards the peak responses, they are much higher for real allocations and inflation, even compared to standard surprise monetary easing. This amplification is not actually surprising since this scenario can be interpreted as equivalent to a sequence of three expansionary monetary shocks in normal times, of which the first two correspond to the central bank refraining from reacting to a boom created by its signal before it materializes.

7.2   Income and wealth redistribution on impact

We now turn to the main topic of this paper, which is the redistributive effects of monetary policy across the age cohorts. To understand the effects associated with changes in asset prices, it is useful to recall their distribution over the life cycle. We summarize it in Figure 6, which combines and normalizes the age profiles for the three type of assets that we include in our model, and which we plotted in Figures 2 and 3.

It is instructive to start with how monetary policy affects households' wealth and income on impact, and we present these effects in Figure 7, normalizing all presented gains by per capita output. Given the profile of housing over the lifetime and reaction of house prices discussed before, the outcomes for housing wealth are straightforward. For both conventional

and unconventional policies, the gains follow a hump shape that peaks around the age of 65, and are positive for all cohorts as each of them holds some housing. Since house prices respond much more on impact to unanticipated monetary shocks than to their announcement, the effects are significantly lower in the latter case, especially when the ELB is not binding. The gain related to financial wealth is a sum of two effects. First of all, we have redistribution associated with nominal asset holdings that has been well documented in the literature, and which arises from unexpected inflation. Given our profiles for nominal assets, it benefits households aged 58 or less, with most gains accruing to households in their 30s as they are most heavily indebted, while the remaining cohorts lose. Second, we have gains associated with higher stock prices, the holdings of which rise sharply until the age of around 60, and then decline. The strength of these two effects differs for conventional and unconventional monetary policy, especially if the latter is carried out in the non-ELB regime as the reactions of asset prices is then much weaker. A relatively stronger reaction of real asset returns in response to conventional monetary policy has a significant impact on the threshold age separating winners and losers from financial asset holdings. While unanticipated monetary policy shocks have a positive impact on financial wealth of agents until the age of 74, forward guidance becomes harmful to individuals already around 70 (with binding ELB) or even in mid 60s (without ELB).

Asset price revaluation is only a part of the story as monetary policy has also indirect effects, operating mainly through the labor market. An expansion in economic activity increases employment and real wages, which benefits the working population proportionally to their working time and productivity. As Figure 7 reveals, the size of this effect is a non-negligible factor, especially for younger individuals, even when we consider only the first period reaction to monetary shocks. Overall, putting all of these effects together shows that conventional monetary policy and forward guidance at the ELB boosts resources available for spending for all age groups that we consider in our analysis, with most gains accruing to households aged around 60 as their housing and real assets positions, as well as labor income, peak around this age. If the monetary authority endogenously responds to a boom generated by its announcements, the gains are positive for individuals in their mid 60s, but these gains and even more so losses for older cohorts are very small.

7.3   Income and wealth over the remaining lifetime

Naturally, the analysis presented above does not give us the full answer on who really gains and loses from monetary policy easing. One obvious reason is that monetary shocks have persistent effects on the economy, and, from the household perspective, especially on labor income and (to lesser extent) on real returns on assets. An additional and often neglected argument is related to asset prices in the presence of life cycle decisions. Whether and to

what extent an individual in fact benefits from an increase in asset prices depends not only on the current net exposition, but also on whether she is in the process of accumulating or decumulating this particular type of assets. For example, a household with a lot of housing might not necessarily gain from house price appreciation if it is still accumulating this asset due to life cycle motives, because the planned increase in housing becomes more costly. A similar argument applies to accumulation of financial assets before retirement and their decumulation during the remaining lifetime.[8]

To take into account these channels, we now offer an evaluation that, for each household, takes into account her expected remaining lifetime and the associated choices over this horizon. To isolate the effect of house price changes on different cohorts due to monetary policy shocks, we will calculate, for each period of their remaining lifetime, the additional financial gain that the change in house prices generate, holding other prices and allocations, including real housing choices over the life cycle, at the steady state level. Our measure of house price effect is then defined as the discounted sum of these gains, where the discounting uses the subjective rate of time preference corrected for mortality risk. More formally, we have

$$\Gamma^{\chi}_{j,t} = \mathbb{E}_t \sum_{i=0}^{J-j} \beta^i \frac{N_{j+i}}{N_j} (p_{\chi,t+i} - p_{\chi}) [(1 - \delta_{\chi})\chi_{j+i} - \chi_{j+i+1}] \tag{33}$$

where variables without time subscripts denote the steady state values. Similarly, we can isolate the effect of changes in returns on financial assets by defining

$$\Gamma^a_{j,t} = \mathbb{E}_t \sum_{i=0}^{J-j} \beta^i \frac{N_{j+i}}{N_j} \left(\frac{R^a_{j+i,t+i}}{\pi_{t+i}} - \frac{R^a_{j+i}}{\pi} \right) a_{j+i} \tag{34}$$

which can be further split in a straightforward way between components associated with nominal and real assets. Finally, we also apply a similar measure to calculate the gains associated with improvement on the labor market

$$\Gamma^w_{j,t} = \mathbb{E}_t \sum_{i=0}^{JR-1-j} \beta^i \frac{N_{j+i}}{N_j} (w_{t+i}z_{j+i}h_{j+i,t+i} - wz_{j+i}h_{j+i}) \tag{35}$$

Figure 6 plots the three effects together with their sum, after normalizing them by the present value of expected future consumption streams in the steady state, defined as

$$\Gamma^c_j = \sum_{i=0}^{J-j} \beta^i \frac{N_{j+i}}{N_j} c_{j+i} \tag{36}$$

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[8]This kind of considerations are related to a debate on whether and when housing is net wealth, see e.g. Buiter (2010). A recent formalization of these arguments, though not directly referring to life cycle choices, can be found in Auclert (2019).

The following observations can be made. First, after a conventional monetary policy easing, the housing effect is negative for all cohorts before the age of 65, after which it turns positive and starts increasing sharply with age. This comes from the fact that, roughly until retirement, households want to accumulate housing, and hence an increase in house prices makes execution of this plan more costly. The effect becomes positive for those cohorts who are in the process of decreasing their housing stock. The gains rise fast with age because the process of decumulation in the late stages of life is faster than its accumulation when young, and because the expected remaining life time shrinks with age, and hence the average house prices over the remaining lifetime are higher. Except for turning positive two years earlier, the age profile of the house price effect after forward guidance in normal times is very similar. When FG is combined with fixing the nominal interest rate before policy implementation, the house price effect is more negative for young and middle-aged households, and then rises at a steeper pace. These differences can be traced back to the impulse response functions shown in Figure 5, according to which forward guidance leads to a delayed, and with the presence of ELB also more persistent increase in real house prices.

The remaining lifetime effect of changes in financial asset returns also paints a picture that is very different from the instantaneous effects discussed in the previous subsection. First of all, they are positive only for the cohorts in their late 50s, roughly compensating the negative house price effects for this group of households, and then turn significantly negative. These financial effects are mainly due to surprise inflation, which benefits borrowers and hurts nominal asset holders, additionally amplified by a constant nominal interest rate (and hence low returns on nominal assets) in the case of FG at the ELB. The redistribution induced by changes in real asset returns works in the opposite direction: younger cohorts lose as accumulation of claims on capital becomes more expensive while older households benefit from the ability to sell their stocks at a higher price. Overall, the effects associated with nominal assets clearly dominate over those arising from real asset holdings. Moreover, the strongest redistribution is observed for forward guidance with no endogenous policy response before implementation due to its most persistently depressing impact on the return on nominal assets.

Turning to the labor income effect, the results are intuitive knowing the responses of the labor market to monetary easing shown in Figure 5. The remaining lifetime gains apply only to working households and peak for the cohorts approaching the age 60 for conventional policy easing, and for households four years younger for unconventional monetary policy shocks. Higher gains in the case of forward guidance comes from the fact that the labor market revives already at the time of policy announcement, and its peak response is larger, especially in the times of binding ELB.

Finally, we merge all three effects in the last panel of Figure 8. Despite the differences between the analyzed components, the total income and asset price effects for the working

population are almost identical for conventional policy and forward guidance conducted in normal times, and larger if the latter is combined with the ELB. This difference can be mainly attributed to stronger indirect effects associated with labor income. For all policies, the winners are households aged 60 or less, while the older cohorts loose. These losses are mainly due to low ex post returns on nominal financial assets, which constitute the dominant vehicle to save for retirement. Interestingly, announcing a policy easing during the periods of a binding ELB can be more harmful for the old generations than a fully unanticipated decrease in the policy rate, but the opposite holds true in normal times.

7.4   Effect on consumption and welfare

In reaction to the direct effects of monetary shocks associated with asset prices, and indirect ones coming from general equilibrium reactions of other prices, and wages in particular, households modify their allocations. Figure 9 shows how different cohorts adjust their consumption, while Figure 10 plots the responses of housing. These reactions are consistent with the estimated remaining lifetime gains described in the previous section. In particular, following a monetary policy easing, younger and middle-aged households can increase consumption and accumulate more housing, while older generations are forced to cut down on their spending and speed up running down their assets.

Having discussed all key effects and adjustments of allocations, we are finally ready to summarize our findings. A natural summary measure in a model like ours is expected welfare over the remaining lifetime, defined as in equation (1), and we picture it in Figure 11. One of the advantages of this measure is that it also takes into account the fact that labor market expansion leads to higher hours worked, which increases labor disutility for the working population. As the picture reveals, the redistributive effects captured by the expected remaining lifetime welfare are qualitatively similar to the ones derived in the previous section – young generations gain while older ones lose, with the threshold age separating winners and losers equal to about 60. The size of the welfare redistribution is largest for forward guidance at the ELB and lowest for that in normal times, with conventional policy effects somewhere in between.

More generally, the similarity between the welfare-based measure and the remaining lifetime income and wealth effects considered before suggests that the latter is a good approximation to evaluating the redistributive effects of monetary policy, while looking only at the effects on impact can be very misleading. Note that, to derive the former measure in the previous section, we held the asset profiles fixed, and despite that we arrived at conclusions consistent with welfare. All of this can be taken as indicative of an important role of life cycle motives in determining who gains and who loses from monetary policy adjustment.

8   Conclusions

In this paper we have investigated the redistributive effects of both unanticipated and anticipated monetary policy shocks in an economy where households differ by age. We have calibrated the model economy to match the salient features of the euro area economy and have paid considerable attention to replicate the asset structure of European households.

Our contribution to the literature is twofold. First, while the distributional effects of traditional monetary policy have received some attention in the extant literature, relatively little is known of the distributional effects of non-standard monetary policy actions. Second, instead of investigating these effects in economies with either ex-ante identical agents subject to idiosyncratic risk or with a streamlined age structure following the Blanchard-Yaari approach, we employ a full life-cycle model, where, depending on their current age, agents differ significantly in their net worth and composition of their asset portfolios. This gives rise to a natural quantitative environment where both conventional and unconventional monetary policy affect households through multiple channels.

Our results therefore extend those obtained by Auclert (2019), who shows that the distributional effects of monetary policy depend on the current holdings of portfolio assets, introducing the notion of unhedged interest rate exposure. What we find is that the life-cycle paths of consumption and asset accumulation decisions are an important determinant of this exposure. By exploiting the life-cycle heterogeneity we can also credibly assess the redistributive effects over the remaining lifetime of agents, and decompose them into few sources. We find that the distributional effect via changes in house prices is of relatively minor importance, since what matters is not the housing wealth per se but rather the housing transaction flows. Much more impactful are changes in nominal financial asset returns and labor market flows. The net impact of all these effects is redistribution from older to younger generations for both conventional and unconventional monetary easing, with the magnitudes not dramatically different, especially if the latter policy is conducted in normal times.

Admittedly, our account of the effects of unconventional monetary policy shocks is limited, as we consider only forward guidance. Since the breakout of the 2007-2009 financial crisis, central banks worldwide have employed also other policy tools, including various asset purchase programs, mostly aimed at affecting the slope of the yield curve. Considering such measures would require introducing nominal assets with different maturities and adding further frictions limiting the arbitrage along the yield curve, like e.g. in Chen et al. (2012). We leave such an extension for future research.

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# Tables and figures

Table 1: Calibrated structural parameters

Parameter	Value	Description
β	0.988	Discount factor
φ^{-1}	0.5	Frisch elasticity of labor supply
ϱ	0.8	Habit persistence
δ_χ	0.015	Housing depreciation rate
δ	0.12	Capital depreciation rate
α	0.3	Capital share in output
S_1	4	Investment adjustment cost curvature
μ	1.2	Product markup
θ	0.2	Calvo probability (prices)
Φ	0.04	Intermediate goods producers fixed cost
μ_w	1.2	Wage markup
θ_w	0.32	Calvo probability (wages)
π	1.02	Inflation target
γ_R	0.41	Interest rate smoothing
γ_π	1.97	Reaction to inflation
γ_y	0.42	Reaction to GDP growth

Figure 1: Population structure and mortality risk by age
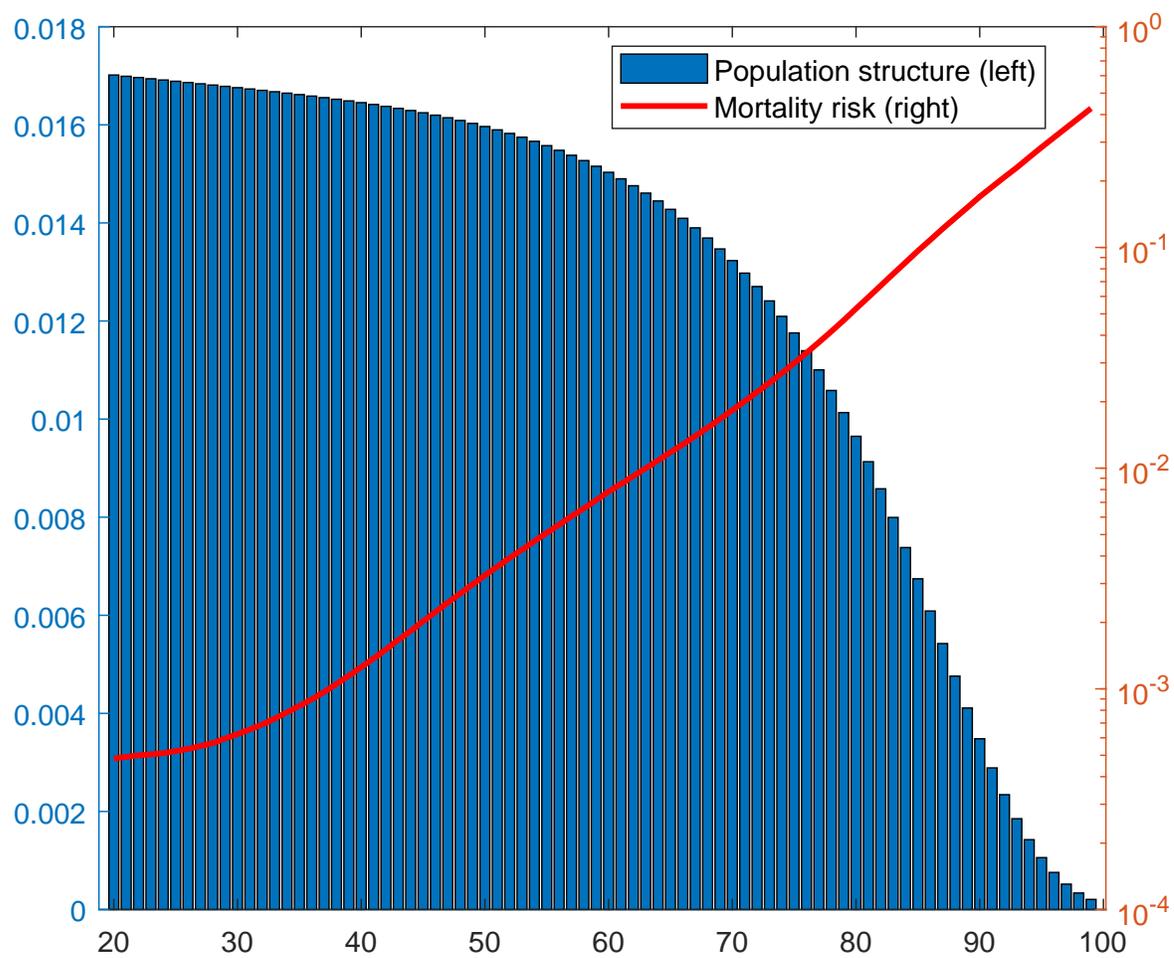
Note: Mortality risk is calculated as the death probability, taken from the Eurostat and averaged over the period 1999-2018. The population structure is the stationary distribution given constant mortality rates and annual growth of total population equal to 0.5%.

Figure 2: Age profiles imposed exogenously
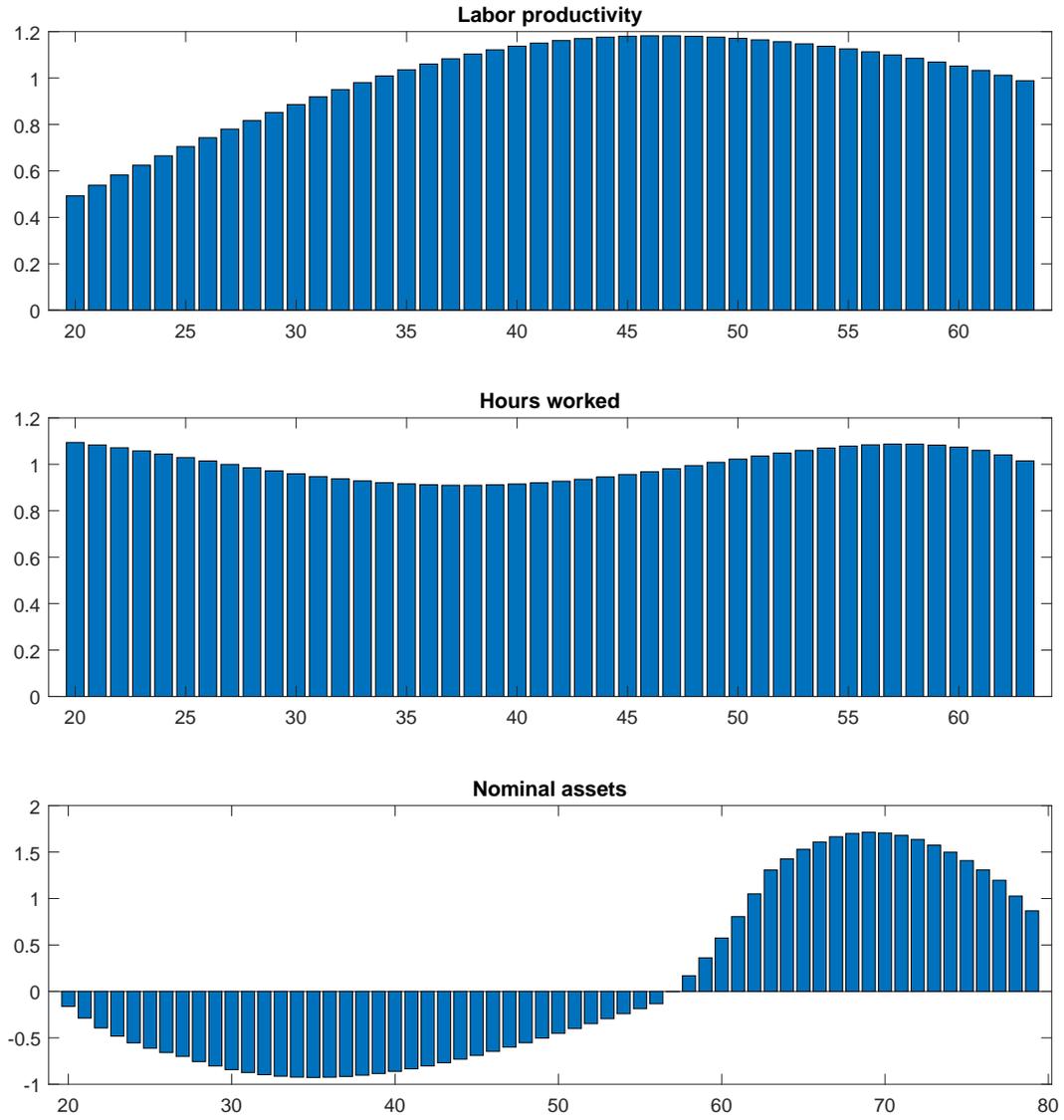
Note: The age profiles for labor productivity and hours worked are normalized by their average values over the working age. The nominal assets are expressed relative to the mean of the total net financial assets position.

Figure 3: Age profiles for housing and net financial assets
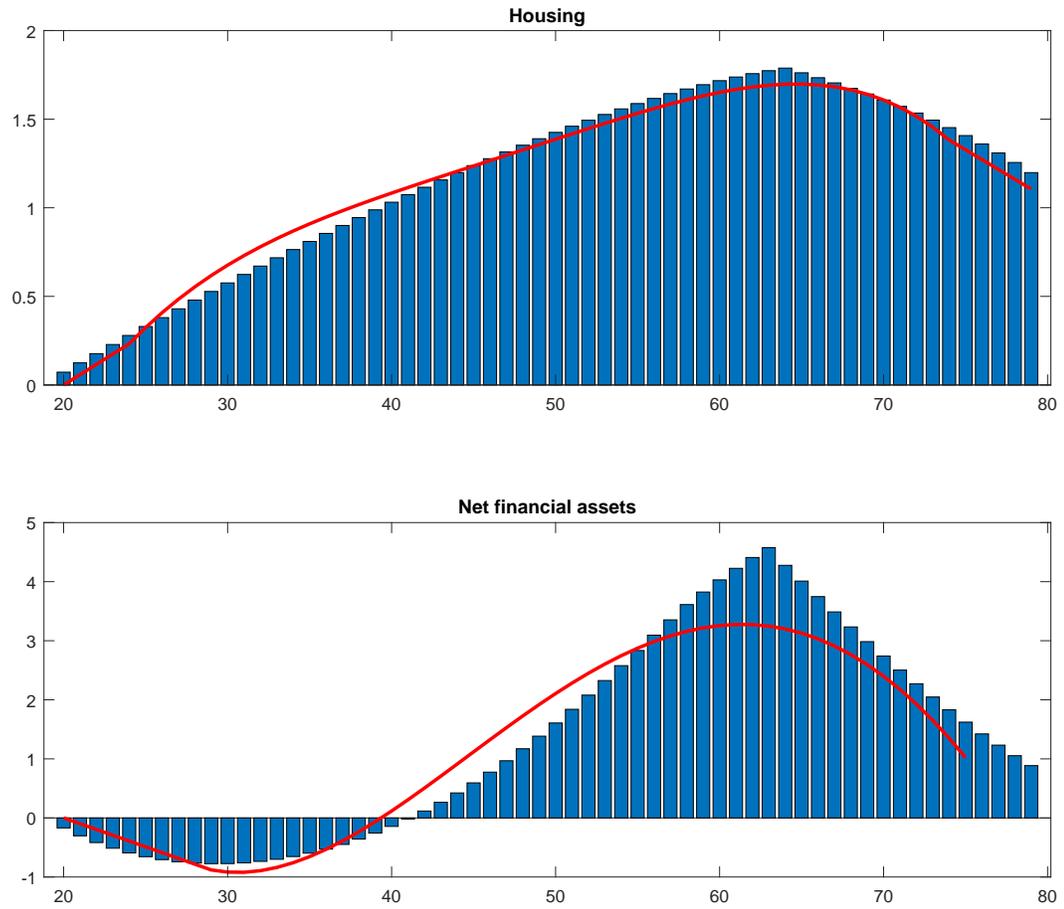
Note: The figure compares the age profiles from the HFCS data (red lines) to those implied by the baseline model (blue bars). All age profiles are expressed relative to their mean values over the life cycle.

Figure 4: VAR evidence on monetary transmission
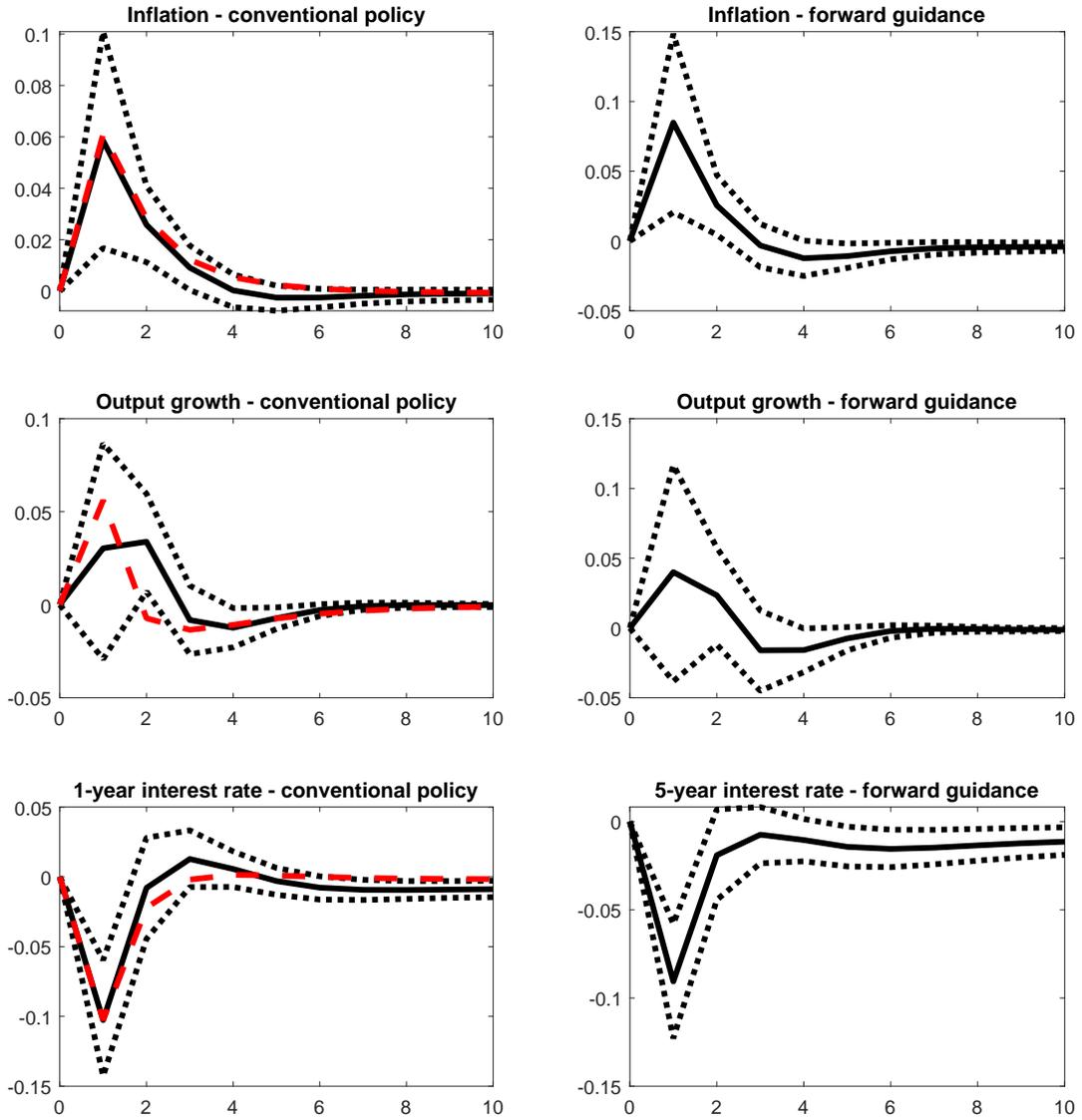
Note: The mean annual VAR impulse responses are presented as black solid lines, dotted lines denote +/- one standard deviation based on 5000 bootstrap repetitions. Red dashed lines plot the responses from the life-cycle model. All variables are in percent.

Figure 5: Aggregate responses to conventional and unconventional monetary policy
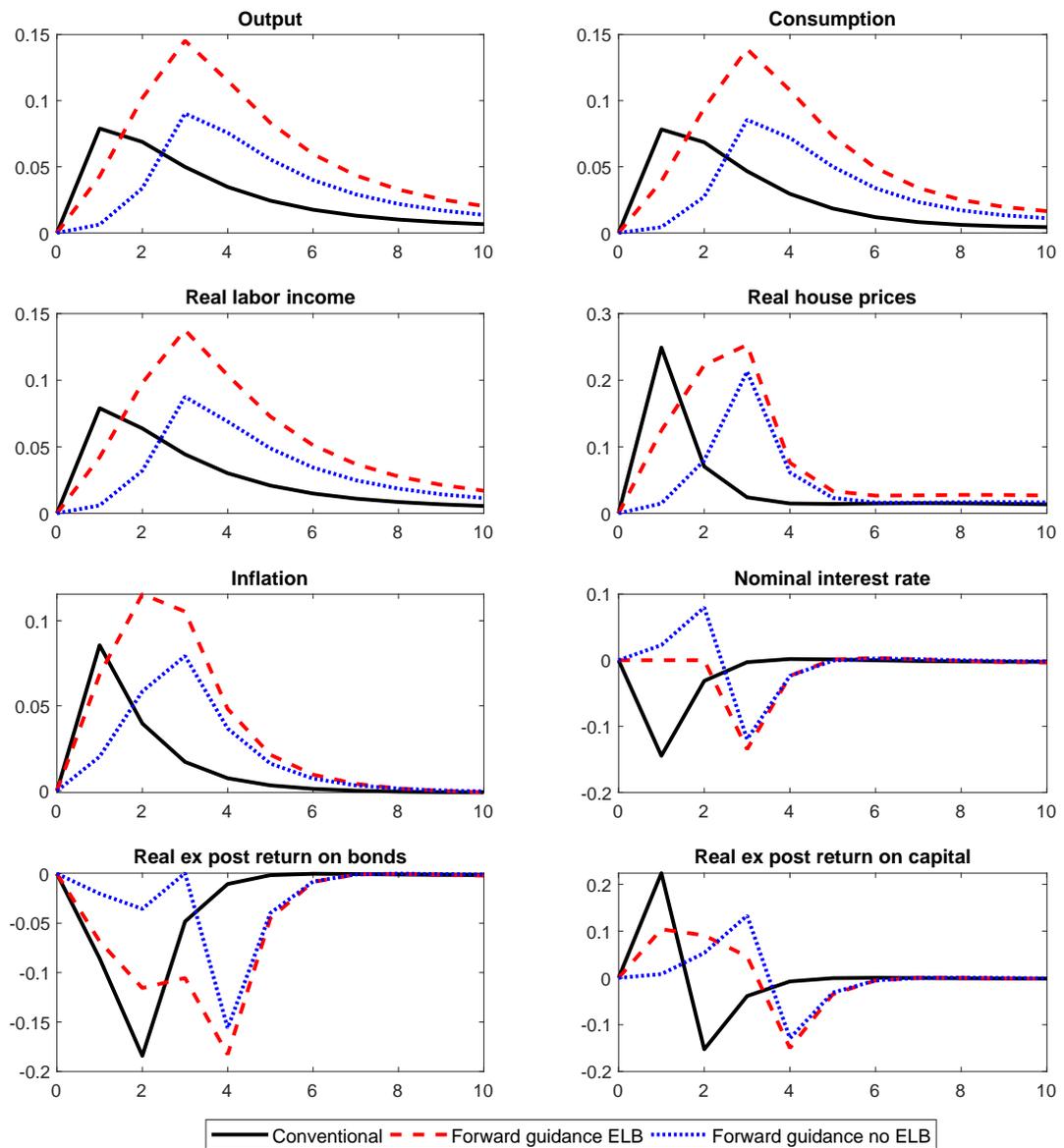
Note: The figure shows the reactions in response to a contemporaneous (conventional) and 2 year ahead (forward guidance) monetary policy shock of 25 basis points, the latter either with or without imposing a binding constraint on the nominal interest rate in the two years before the shock materializes. All variables are in percent deviations from the steady state.

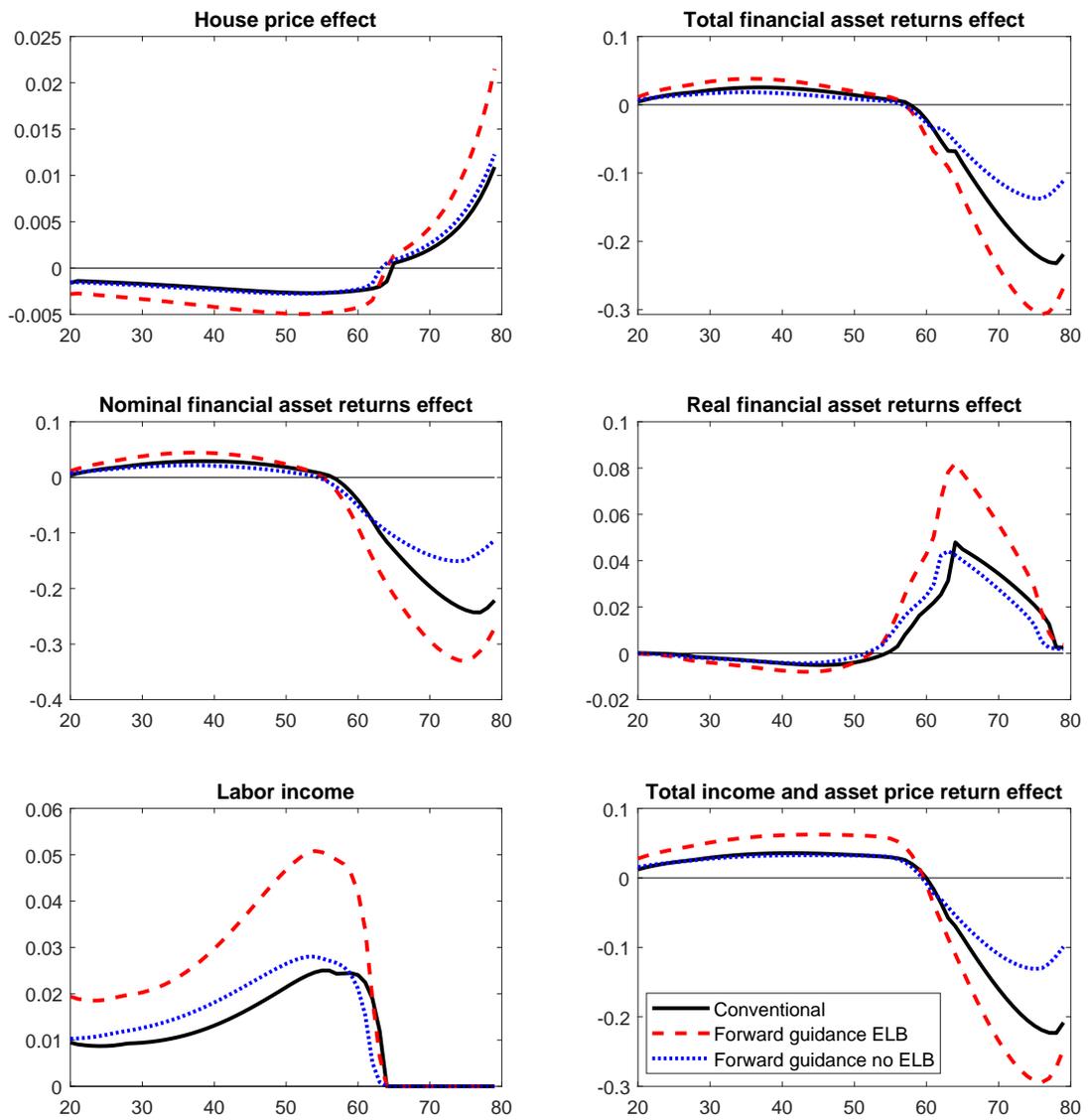Figure 6: Model-implied age profiles of assets
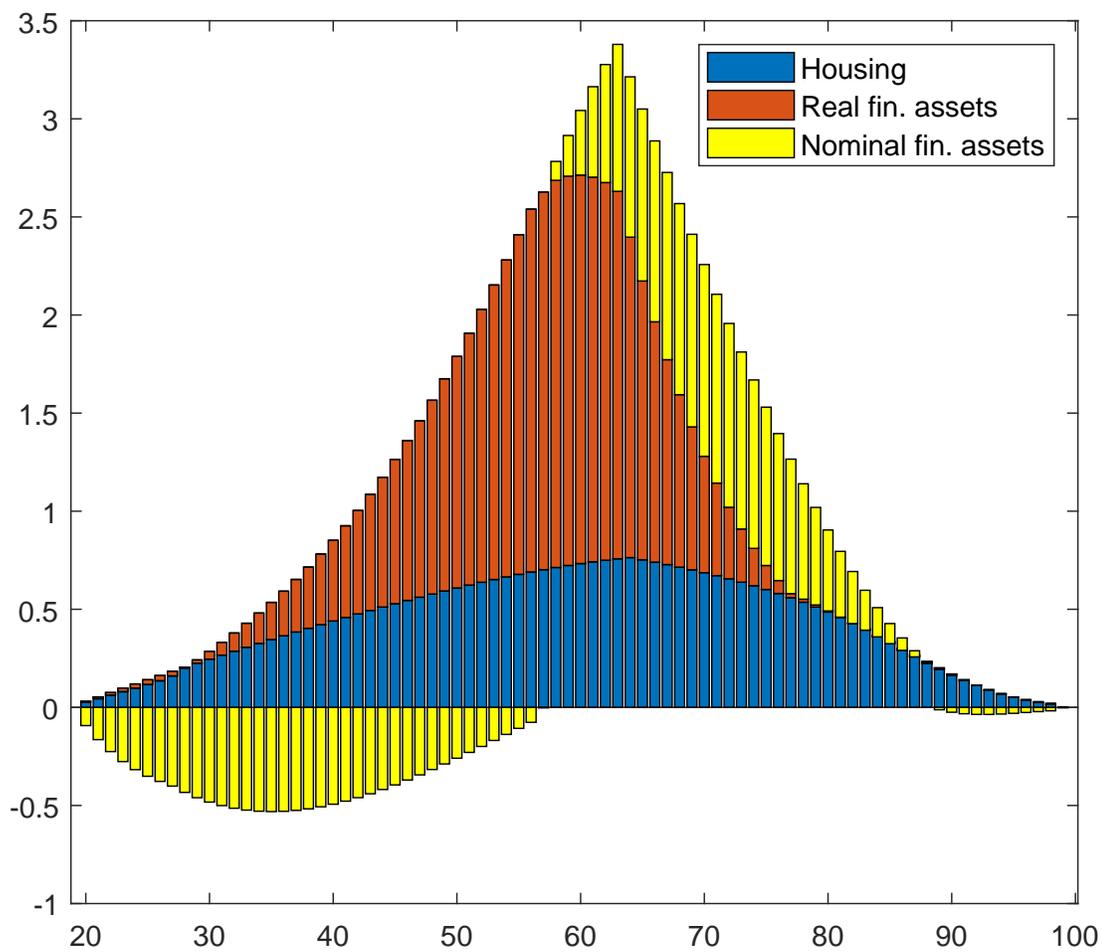
Note: The age profiles are expressed relative to the mean value of total assets over the life cycle.

Figure 7: Redistributive effects of monetary policy on impact
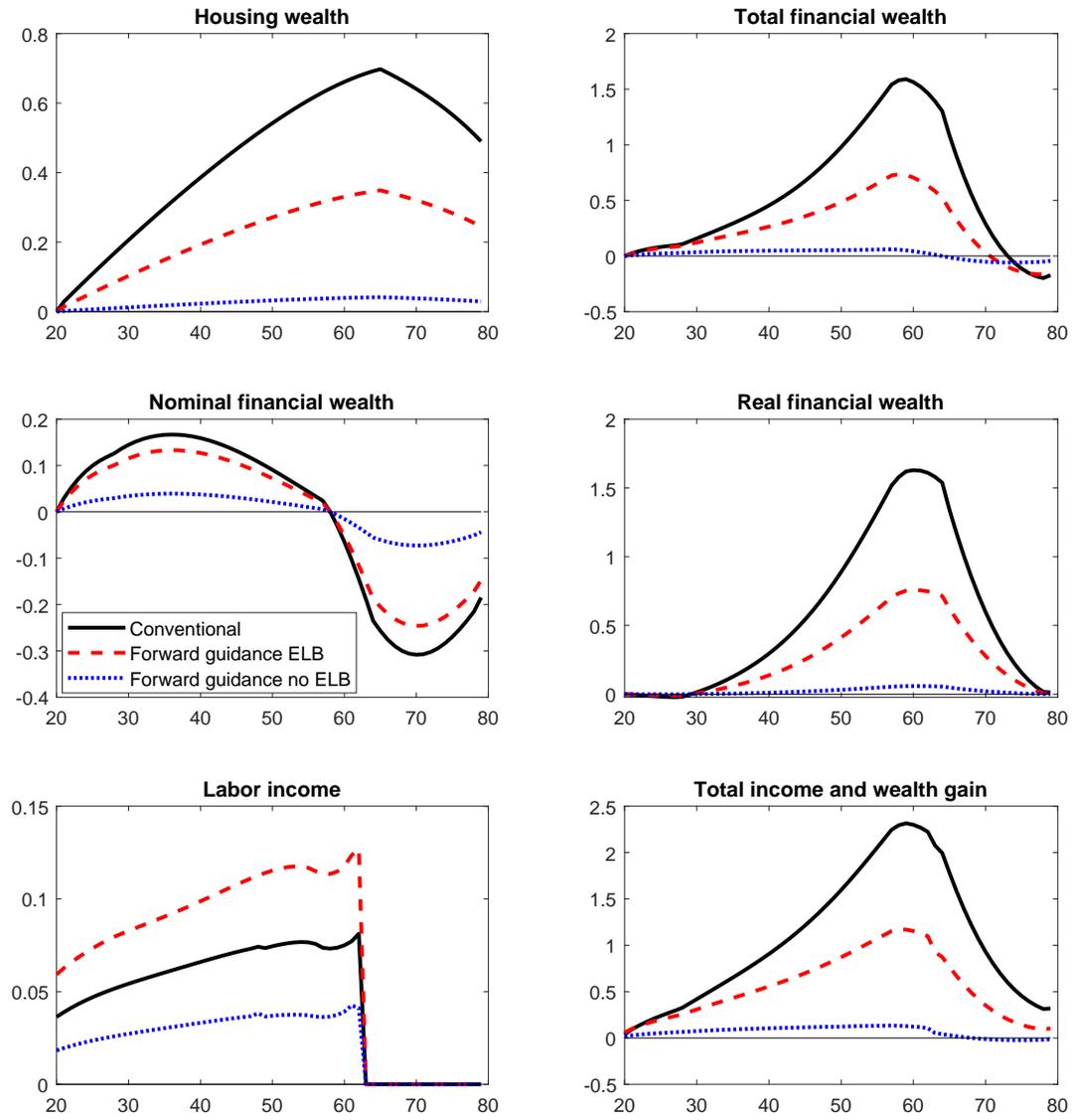
Note: All gains are expressed as percent of per capita output.

Figure 8: Redistributive effects of monetary policy over remaining lifetime

Note: All gains are expressed in percent of present value of steady state consumption streams over the remaining lifetime.

Figure 9: Impulse responses of consumption to monetary shocks by cohort

Conventional

Forward guidance with ELB

Forward guidance without ELB
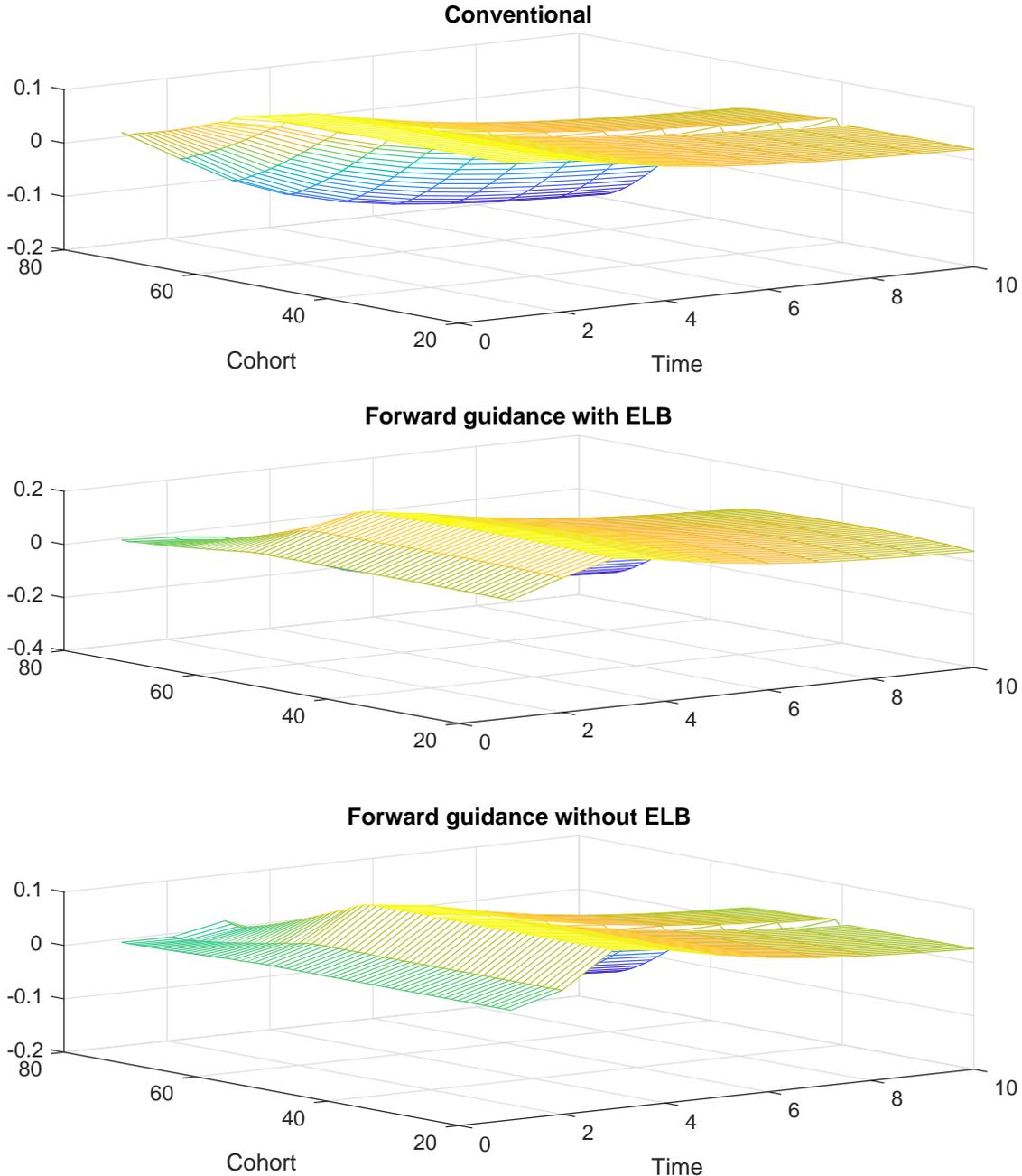
Note: The responses are presented in percent deviations from the steady state.

Figure 10: Impulse responses of housing to monetary shocks by cohort

Conventional

Forward guidance with ELB

Forward guidance without ELB
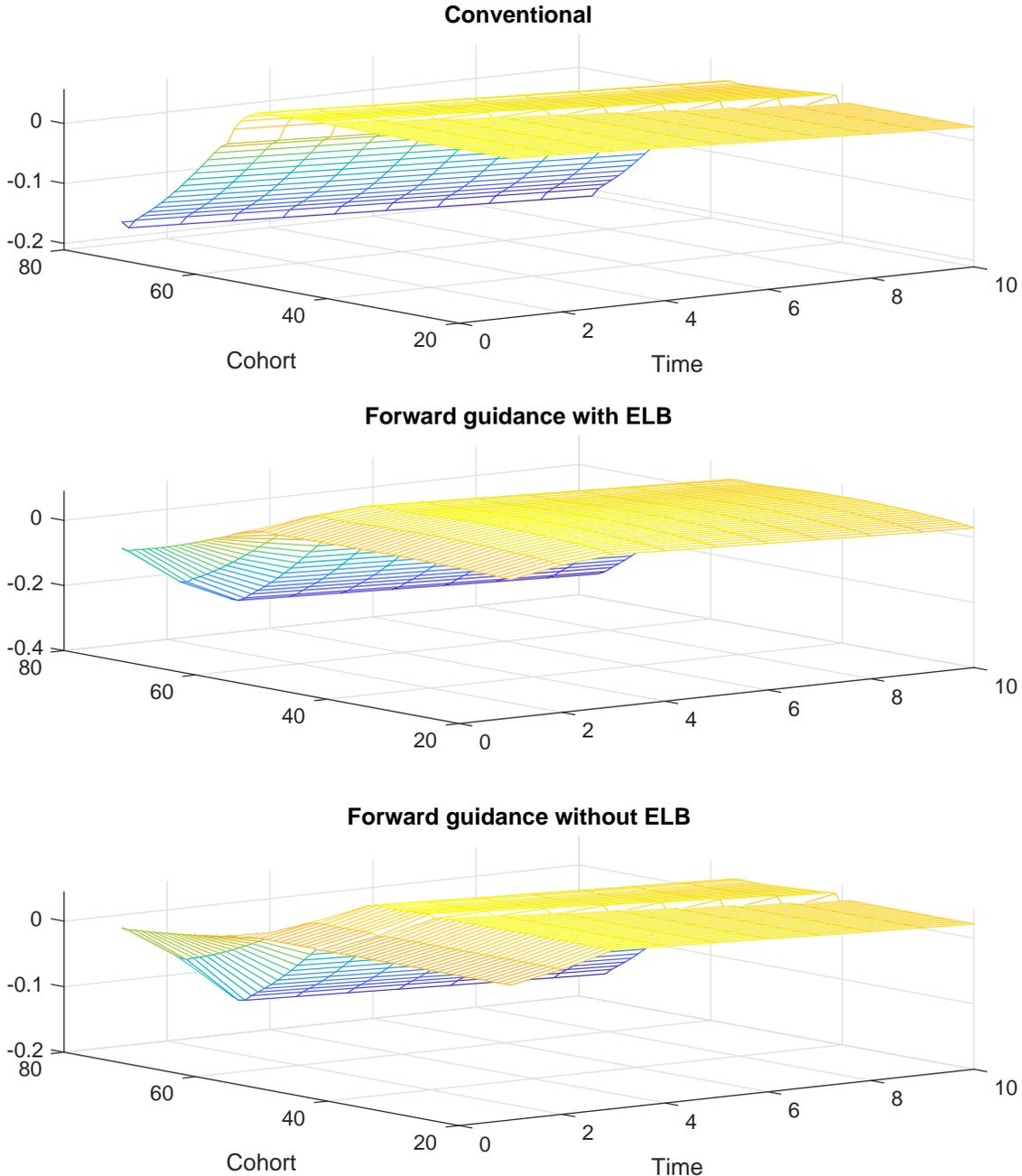
Note: The responses are presented in percent deviations from the steady state.

Figure 11: Welfare effects by cohort
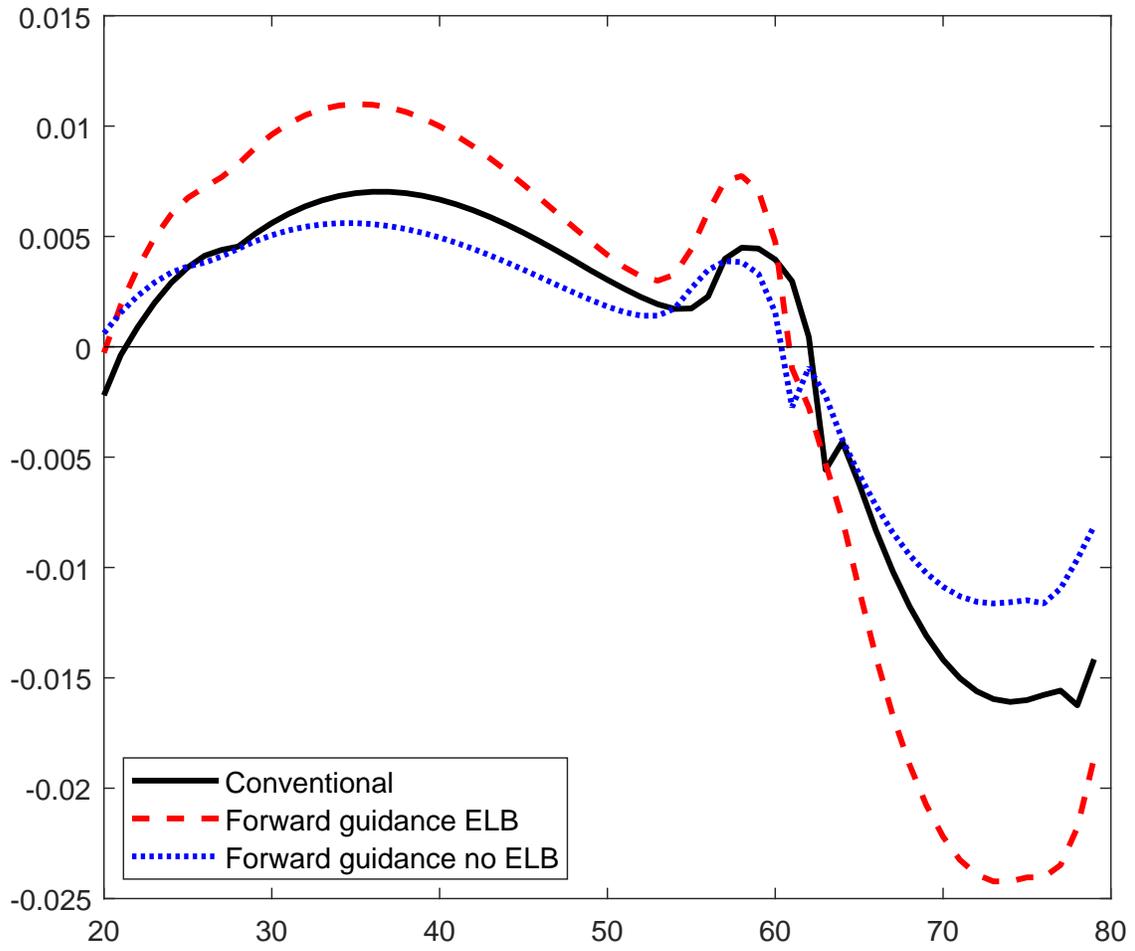
Note: For each cohort, the welfare gains correspond to the expected remaining lifetime.

Appendix

A.1 HFCS definitions

The table below maps our definitions of life-cycle variables to the categories and their codes from the Household Finance and Consumption Survey.

Category in the paper	HFCS name	HFCS code
Labor income	= Employee income	DI1100
	+ Self-employment income	DI1200
Hours worked	= Hours working a week - main job	PE0600
Housing stock	= Value of household's main residence	DA1110
	+ Value of other real estate property not for business activities	DA1122
Real financial assets	= Business wealth	DA1200
	+ Mutual funds	DA2102
	+ Bonds	DA2103
	+ Value of non self-employment private business	DA2104
	+Shares, publicly traded	DA2105
Nominal financial assets	= Deposits	DA2101
	- Outstanding balance of mortgage debt	DL1100
	- Outstanding balance of other, non-mortgage debt	DL1200

A.2 VAR model and the structural decomposition

A.2.1 Data

The VARs are estimated with monthly euro area data for the period 01.2002 - 09.2018. We estimate two separate models to identify the impact of conventional policy and of forward guidance. The former model consists of three endogenous variables: the log of the harmonized index of consumer prices (HICP, source Eurostat), log of GDP, the 3-month money market interest rate[9] and two exogenous instruments (target and timing factors from Altavilla et al. (2019)). In the forward guidance model we use HICP and GDP as well. However, the interest rate is the yield on 5-year benchmark euro government bonds (euro-denominated fixed-rate government bonds from France and Germany, source Bloomberg) and there is only one exogenous instrument - the forward guidance factor from the same paper. Altavilla

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[9]Given possible considerations related to the presence of the lower bound on interest rates we also tried various government bond rates instead of the money market rate, but the results remained similar.

et al. (2019) have shown that their policy surprise factors affect a wide range of asset prices including interest rates of various maturities. However, while the impact of the target and timing factors is strongest on maturities up to 12 months, the forward guidance factor affects most strongly 2 and 5 year rates. This motivates our choice of interest rates in the VARs. Additionally, both models contain the log of oil prices as exogenous variable.

Regarding the real-economy variable, it is common to use industrial production in monetary VAR models estimated on monthly frequency. However, our structural model does not have such a variable, so that impulse responses could not be compared. To allow for comparison along these lines we generate a GDP series of monthly frequency by interpolating quarterly GDP using industrial production as an indicator variable for the Chow and Lin (1971) procedure (source for both series Eurostat).

A.2.2 Identification of shocks

The implementation of the high-frequency identification approach follows Ouliaris et al. (2018) and will be presented in detail for the forward guidance model. Let $\boldsymbol{y_t} = \left[p_t, gdp_t, i_t^{5y}, fg_t\right]'$ be the vector of endogenous variables and the surprise factor. The variables denote HICP, GDP, the interest rate and the forward guidance factor respectively. Our SVAR model can be written in matrix notation as follows

$$\boldsymbol{Ay_t = B(L)Ly_t + Cx_t + D\varepsilon_t}$$

where $\boldsymbol{\varepsilon_t} = \left[\varepsilon_{1,t}, \varepsilon_{2,t}, \varepsilon_{3,t}, \varepsilon_{4,t}\right]'$ is a vector of shocks, $\boldsymbol{x_t} = \left[oil_t\right]$ the exogenous variable (oil price) and L denotes the lag operator. Matrix $\boldsymbol{A}$ describes the contemporaneous interactions between variables, matrices $\boldsymbol{B(L)}$ the impact of lagged variables, $\boldsymbol{C}$ the impact of the exogenous variable and $\boldsymbol{D}$ the impact of disturbances. Identification via external instruments relies on instruments correlated with the identified shock and uncorrelated with all other shocks. In our case this implies $E\left(fg_t\varepsilon_{3,t}\right) \neq 0$, $E\left(fg_t\varepsilon_{i,t}\right) = 0$ for $i = 1, 2$. In contrast to the Cholesky identification scheme we allow for the policy variable to affect contemporaneously prices and GDP. Hence

$$\boldsymbol{A} = \begin{bmatrix} 1 & 0 & a_{1,3} & 0 \\ a_{2,1} & 1 & a_{2,3} & 0 \\ a_{3,1} & a_{3,2} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

and

$$D = \begin{bmatrix} \sigma_{1,1} & 0 & 0 & 0 \\ 0 & \sigma_{2,2} & 0 & 0 \\ 0 & 0 & \sigma_{3,3} & 0 \\ 0 & 0 & \sigma_{4,3} & \sigma_{4,4} \end{bmatrix}$$

The oil price is assumed not to affect the surprise factor (the last row of matrix C contains zeros) and the factor is assumed not to be correlated neither over time nor with other variables (the last rows and columns of matrices $B(L)$ contain zeros). With six restriction the system is just-identified and estimated via maximum likelihood.

The case of conventional policy is similar, the main difference being that there are two exogenous instruments, both are assumed to be correlated with the monetary policy shock only.