Asset Purchases, Limited Asset Markets Participation and Inequality

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Abstract

This paper analyses the effects of quantitative easing (QE) on households' income and consumption inequality in the Euro Area. Using a SVAR with high frequency identification, I show that an identified QE shock is redistributive and expansionary. To rationalize the empirical findings, I build a New Keynesian DSGE model with household heterogeneity and financial frictions which explains the empirical results and provides insights on the inequality channel. Bond purchases increase aggregate demand and benefit financially restricted households more than investors, due to the dominance of QE's indirect effects and the foregoing term spread between bonds and reserves. Thus, income and consumption inequality decline in line with the evidence.

JEL classification: E44; E52; E58; E61

Keywords: Quantitative Easing; Inequality; Financial Participation; Heterogeneity; DSGE; SVAR; External Instrument

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1. Introduction

Asset purchase programmes following the Great Recession and the Covid-19 pandemic have been extensively employed to hold down long-term interest rates and stimulate aggregate demand. A question posed by policymakers (Yellen, 2016; Bernanke, 2015; Draghi, 2016), which has gained media attention, is whether these programs have contributed to an increase in inequality.[1] In this paper, I analyse the impact of quantitative easing (QE) on the macroeconomy and household income and consumption inequality in the Euro Area (EA). I employ a state-of-the-art DSGE model with financial frictions that incorporates household heterogeneity in financial holdings and an external instrument SVAR with high frequency identification. Both the empirical and structural specifications demonstrate that a QE program is expansionary and leads to a reduction in income and consumption inequality.

Figure 1 depicts the Gini index for the Euro Area, utilizing data from the Standardized World Income Inequality Database (henceforth SWIID), Solt (2020).[2] The Gini Index serves as a proxy for income inequality, with a higher value indicating greater income inequality. Income inequality in the Euro Area has exhibited a consistent upward trend since the establishment of the currency union, persisting until the end of 2016. However, in 2016, following the initiation of the European Central Bank's (ECB) Asset Purchase Programme (APP), a decline in income inequality was observed. This paper focuses on examining whether the ECB's Asset Purchase Programme program has contributed to the reduction of income inequality within the Euro Area.

I develop a New Keynesian DSGE model calibrated for the Euro Area with nominal rigidities, financial intermediaries, financially constrained and unconstrained households and a central bank that can purchase assets from banks and unconstrained households by issuing reserves. The QE framework follows Gertler and Karadi (2013) but a formal representation of reserves and the asset swap mechanism induced by the QE is developed. Households' Two Agents New Keynesian (TANK) specification borrows from Galí, López-Salido, and Vallés (2007) and banks are modelled similarly to Gertler and Kiyotaki (2010): a costly enforcement problem results in a leverage constraint on intermediaries. QE induces increased lending by relaxing the leverage constraint imposed on financial intermediaries, similarly to Sims and Wu (2021), by the exchange of banks' government bonds with reserves and thus stimulates aggregate demand.

A setting is developed in which central bank purchases of government bonds, financed by reserves, create direct and indirect effects that affect households differently based on their access to financial markets. In this setting, the existence of the banker's leverage constraint allows for QE-induced effects, as it eliminates the perfect substitutability of assets and leads to non-neutrality of quantitative easing.[3] I demonstrate

[1]Does Quantitative Easing Mainly Help the Rich? (CNBC), Debate rages on quantitative easing's effect on inequality (Financial Times), Quantitative easing helped vulnerable more than rich, says ECB (Financial Times).

[2]A detailed explanation of how I construct the index is provided in Section 2.

[3]Studies that show the neutrality of open market operations in frictionless settings originate from Wallace (1981), Sargent and Smith (1987).

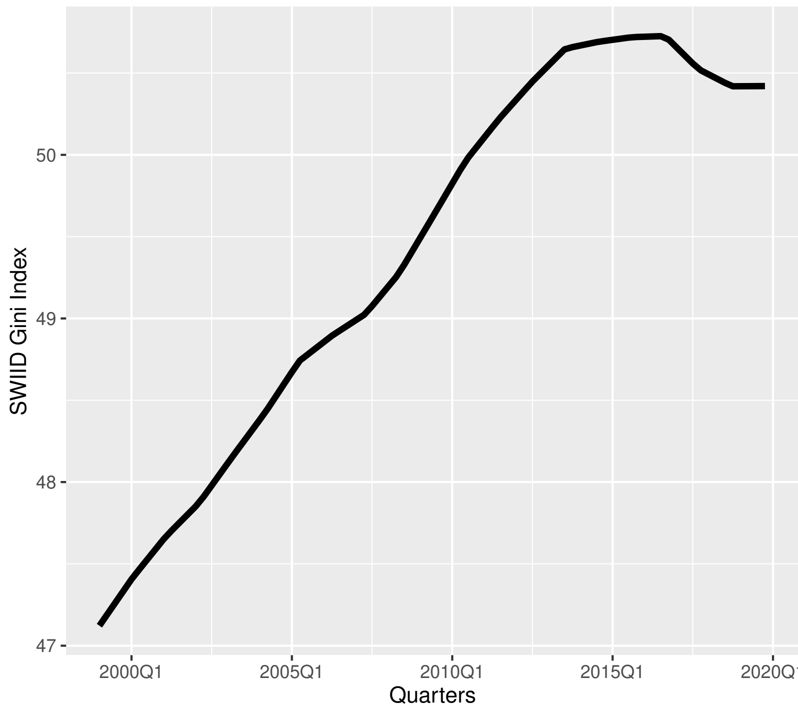

Fig. 1. Income Inequality Index for the the Euro Area

that the indirect effects (i.e general equilibrium) have a greater impact than the direct effects (i.e. asset price increase and reduction in credit and bonds spreads) for the two consumer types. As a result, income and consumption inequality are reduced.

To elaborate on the underlying mechanism, consider an economy with two distinct types of households: those with access to financial markets and those who face financial constraints and are hand-to-mouth agents. When the central bank increases its bond holdings, it leads to a rise in asset prices, benefiting bond holders. However, this action also has a negative impact on their portfolios due to the reduced interest returns on bonds. Furthermore, the interest rate received on reserves is considerably lower than that received on the risky assets they previously held. Through the present analysis, it is demonstrated that the primary channel of influence to income inequality is the unconstrained agents' income loss due to this interest rate differential channel. Savers experience a decline in income as a result of QE. Concurrently, there are indirect effects to consider, specifically through wage increases, which rise due to the labour income channel of QE. Financially constrained consumers, who rely solely on labour compensation, benefit from these wage increases and observe an increase in their income. As a result, the combination of these two channels, leads to a reduction in income and consumption inequality between the two income groups.

To offer a more detailed explanation of the adverse impact of QE on the income of asset holders, I present a breakdown of their income into its three key components: assets, profits, and labour. While both labour and profit income witness an increase, the income from assets experiences a decline as a result of the reduced coupon received on bonds. As shown, asset income forms a significant portion of the total income for asset holders. Therefore this reduction directly contributes to an overall decrease in their income and thus income inequality.

Bernanke (2020) provides a similar argument: the potential benefits to asset holders of higher asset prices are partially offset by the lower returns they can earn on their wealth. However, in this analysis, it is demonstrated that the benefits are not only offset but outweighed by the lower returns. Consequently, the responses of income and consumption inequality to a QE program are countercyclical. This is in line with the response of inequality after a policy rate cut, empirically studied by Coibion, Gorodnichenko, Kueng, and Silvia (2017) for the US and Samarina and Nguyen (2019) for the Euro Area. Lastly, Bilbiie, Kanzig, and Surico (2021) provide support for these findings in a simple model incorporating heterogeneity and capital.

Asset holdings heterogeneity in the model is introduced through limited asset markets participation (LAMP). This feature incorporates two relatively recent findings related to household asset composition and consumption smoothing. Empirical literature shows that a large fraction of households consumption plans can be tracked almost exclusively by their income.[4] Within the Euro Area, approximately 20% to 30% of the population can be classified as hand-to-mouth consumers. These individuals hold financial assets with a total value that is close to zero. In Appendix A, I present the distribution of financial assets among households utilising the Euro Area the Eurosystem Household Finance and Consumption Survey. A similar estimate is also provided by Almgren, Gallegos, Kramer, and Lima (2022).

To motivate the study's research question, I firstly investigate the relationship between QE and inequality empirically. This is done by the use of an external instrument SVAR with high frequency identification based on the work of Mertens and Ravn (2013) and Gertler and Karadi (2015). In order to identify QE policy surprises, the study employs the Euro Area Monetary Policy Event Study Database (EA-MPD) developed by Altavilla, Brugnolini, Gürkaynak, Motto, and Ragusa (2019) and uses the QE factor identified as an external instrument. By utilizing Euro Area data and the SWIID Gini of disposable income the study demonstrates that a QE shock has both expansionary effects on the macroeconomy and redistributive effects on inequality.

Lastly, the DSGE model is capable to capture the empirical responses from the SVAR and yields similar magnitudes of the responses in both inequality and macroeconomic variables to a QE shock. By combining empirical findings from the SVAR approach with the theoretical framework provided by the DSGE model, the study provides a comprehensive understanding of the effects of QE on both inequality and macroeconomic dynamics.

Related Literature. This study contributes to three areas within the literature on unconventional monetary policy: models of households heterogeneity with financial

[4] Recent studies on the households' wealth distribution, originating from Mankiw (2000) in the US, have shown the existence of a population share of 30-40% that does not smooth consumption across states and time. See also Krueger, Mitman, and Perri (2016). The authors find that 40% oh the households hold almost no net worth.

frictions, monetary policy and inequality, and the use of external instrument SVARs.

Galí et al. (2007) (GLV) firstly introduced a two-agents NK framework to study the effects of government spending on consumption. As demonstrated by Debortoli and Galí (2017), a two agents framework effectively captures differences in average consumption between constrained and unconstrained agents. However, it is less effective in characterizing consumption heterogeneity within the subset of unconstrained households, as in in Kaplan, Moll, and Violante (2018). Given that the primary focus of this paper is on the interactions between the two types of agents, it suffices to utilize a less complex setting of heterogeneity and build upon the GLV framework.[5]

The paper also draws from the financial frictions literature, which experienced a revival following the financial crisis, as initiated by Gertler and Kiyotaki (2010). Within this framework, the paper incorporates a costly enforcement problem that restricts the ability to arbitrage across deposit, bond, and credit markets.[6] To the best of my knowledge, this paper is the first to combine financial frictions in the spirit of Gertler and Karadi (2011) with a model featuring limited asset markets participation to analyse the real effects of QE on inequality and aggregate demand within this integrated framework. It also offers empirical evidence regarding the procyclicality of profits. This finding aligns with studies such as Broer, Harbo Hansen, Krusell, and Öberg (2020) and Cantore and Freund (2021), which highlight the significance of procyclical profits within a TANK modelling framework. Nominal wage rigidities inclusion ensures that the model's profits exhibit procyclicality, mirroring the findings observed in the data.

This paper is closely related to the literature on the distributional effects of monetary policy. Coibion et al. (2017) is a seminal work in this field, showing that inequality decreases after an interest rate cut. Similarly, empirical studies consistently find that the effects of QE tend to benefit the lower end of the income distribution, aligning with the results of this paper. Bilbiie et al. (2021) in a HANK model with capital, but without a banking sector, find also that income and consumption inequality are countercyclical. In line with the findings of this paper, empirical studies by Bunn, Pugh, Yeates et al. (2018) using UK data and Bivens (2015) also concur on the relatively stronger effect on lower income households. Additionally, Krenz and Tsiaras (2023) focus specifically on the variation in the level of households' financial asset holdings. Their study employs a local projection external instrument approach to analyse the effects of a common QE shock in the Eurozone on different member countries with varying degrees of asset market participation. The results highlight that the impact can vary significantly depending on the level of financial income.[7]

Related to this paper's empirical method there is a vast literature on SVARs using a set of different identification methods. A very comprehensive summary is included in Ramey (2016). Lenza and Slacalek (2022), in parallel work, employ a SVAR to assess the

[5]Other studies that adopt a TANK framework include Monacelli (2009), Bilbiie, Monacelli, and Perotti (2013), Colciago (2011), Ascari, Colciago, and Rossi (2017) and Galí, López-Salido, and Vallés (2004).

[6]For a similar financial frictions setting see also Carlstrom, Fuerst, and Paustian (2017) and Sims and Wu (2021) among others.

[7]For a literature review on macroeconomic models with heterogeneity and their distributional effects see Colciago, Samarina, and de Haan (2018).

aggregate and distributional effects of a QE shock, identified by means of external instruments, in a multi-country setting. Differently from the present paper's setting they distribute the aggregate effects estimated in the VAR across the individual households using data from Household Finance and Consumption Survey. Corrado and Fantozzi (2021) use as well the EA-MPD to identify a QE shock and show its distributional effects in the case of Italy. Both studies' outcomes are in line with the findings of this paper on the reduction of income inequality after a QE shock. The present study employs an external SVAR method similarly to Stock and Watson (2012) with the monetary policy surprises as in Altavilla et al. (2019) to identify the QE's impact in the Euro Area, using the income inequality measure of the Standardized World Income Inequality Database.

Cui and Sterk (2021) and Hohberger, Priftis, and Vogel (2019a) share similar research objectives and methodologies with this paper. Hohberger et al. (2019a) evaluate the effects of QE on consumption and income inequality in a standard NK setting with two agents and no financial intermediation. They show that consumption and income inequality decrease after a QE policy, in line with this paper's results. Cui and Sterk (2021) use a heterogeneous-agents model with liquid and partially liquid wealth, and nominal rigidities. They find that a QE policy reduces consumption and income inequality initially but increases both later on. The result originates from the increase in inequality considering mostly the liquid assets. In the present paper, this effect is absent since the rule of thumb income group holds zero liquid or illiquid assets, making inequality to decrease after a QE shock.

The present study stands apart from the aforementioned studies due to significant differences. It incorporates a financial sector, which plays a crucial role in facilitating the pass-through of QE to the real economy and consequently affects income inequality. The financial friction eliminates the perfect substitutability of assets and the QE neutrality. In contrast, the above papers achieve non-neutrality through the introduction of exogenous portfolio costs. To the best of my knowledge, there is no other study that combines a TANK model with financial frictions, an explicit framework for asset purchases by the central bank, and an examination of the effects of QE on consumption and income inequality. By incorporating these elements, the present study offers novel insights into the relationship between QE, consumption dynamics, income inequality, and the distributional implications of monetary policy.

The structure of the paper is as follows. Section 2 outlines the external instrument SVAR and provides the empirical responses to a QE shock. Section 3 describes the DSGE model while in section 4, I show the calibration and the quantitative results of the DSGE model for a QE shock. Finally, section 5 concludes.

2. Quantitative Easing and Inequality: SVAR Evidence

To motivate the research question, I present novel empirical evidence on the impact of an expansionary unconventional monetary policy shock on inequality and the macroeconomy. To investigate this relationship, I employ an external instrument SVAR model. The results demonstrate that QE not only stimulates the economy but also has a redistributive effect by reducing income inequality. The data employed is at the Euro Area aggregate level and an income inequality index for the Euro Area is constructed using the Gini coefficient from the Standardized World Income Inequality Database (henceforth SWIID) Solt (2020).

In order to overcome the challenges associated with identifying monetary shocks in the data, as elaborated in Ramey (2016), I adopt the proxy-SVAR approach introduced by Stock and Watson (2012). This approach provides a novel solution by utilizing external instruments to capture the structural shocks of interest. To identify external instruments for the QE shock I use and extend the Euro Area Monetary Policy Event Study Database (EA-MPD) constructed in Altavilla et al. (2019) (ABGMR hereafter), together with their methodology to extract the factors. The uniqueness of this approach lies in its ability to extract a QE factor directly from the data and employ it as an instrument.[8]

Data. I analyse quarterly data from 1999Q1 to 2019Q4, starting at the starting year of the Euro Area and leaving out of my sample the pandemic period. The baseline VAR has ten variables, including two policy indicators, a Euro Area income inequality index, the 10 year Euro Area benchmark bond rate and the the 3 month rate and seven economic and financial variables: the CPI, the real GDP, a EA stock prices index, the employment level, a measure for the wages, real consumption and real profits.[9] The selection of variables follows a similar specification by Slacalek, Tristani, and Violante (2020). The VAR has two lags based on the AIC criterion.

Data for the macro variables comes -mainly- from the Area Wide Model dataset originally constructed by Fagan, Henry, and Mestre (2001). The updated AWM database starts in 1970Q1 (for most variables) and is available until 2017Q4. To update the data further, I make use of publicly updated data from Eurostat, ECB and the OECD. To quantify income inequality, I utilize the Gini coefficient provided in the SWIID. Specifically, I focus on the Gini coefficient of equivalized household market income, which encompasses pre-tax and pre-transfer income. Additionally, I conduct analyses using the post-tax and post-transfer income specification, which yield similar results. To construct an income inequality index for the Euro Area, I aggregate the inequality data from all Euro Area countries weighting them by the respective country GDP weights.

To specifically analyze the effects of ECB's Asset Purchase Programme, the instrumental variable is employed for the period from 2014 until the end of the sample. This period aligns with the implementation of QE in the Euro Area. For estimating the lag coefficients and obtaining the reduced form residuals in equation (1) I utilize the entire sample from 1999Q1 to 2019Q4. Then I use the reduced form residuals for the period 2014 to 2019 to identify the impact of QE surprises.

[8] This methodology bears similarity to the high-frequency identification method of Gertler and Karadi (2015).

[9] For profits I make use of the gross operating surplus and mixed income, which is also used as a proxy for profits by Chen, Karabarbounis, and Neiman (2017). It is defined as gross output less the cost of intermediate goods and services to give gross value added, and less compensation of employees and taxes and subsidies on production and imports.

Estimation Methodology. The VAR has the following reduced form:

$$\mathbf{V_t} = c + \sum_{i=1}^{p} \mathbf{B_j} \mathbf{V_{t-1}} + \mathbf{u_t}, \quad (1)$$

where $\mathbf{u_t} = \mathbf{S}\epsilon_\mathbf{t}$ is the reduced form residuals, a function of the structural shocks $\epsilon_\mathbf{t}$.

We can partition the vector of structural shocks according to the structural shock of interest, in this case the QE shock, and the rest. That is

$$\epsilon_\mathbf{t} = \begin{bmatrix} \epsilon_t^{QE} & \epsilon_t^R \end{bmatrix}$$

Let s denote the column matrix of $\mathbf{S}$ which is associated with the impact of the reduced form residuals $\mathbf{u_t}$ of the structural shock of interest ϵ_t^{QE}. To compute the impulse responses of the system to this shock we have to estimate:

$$\mathbf{V_t} = c + \sum_{i=1}^{p} \mathbf{B_j} \mathbf{V_{t-1}} + \mathbf{s}\epsilon_t^{QE}$$

To compute the impulse responses specifically for a QE shock, it is not necessary to identify and make restrictions for the full matrix $\mathbf{S}$. Instead, the focus can be narrowed down to the column matrix s associated with the QE shock. At this stage we could proceed by applying the widely used timing or coefficient restrictions as is common in the SVAR literature (see for example the coefficient restrictions in Blanchard and Perotti (2002) or sign restrictions in Mountford and Uhlig (2009)) in order to identify the elements in s. As mentioned in Gertler and Karadi (2015), this is problematic for a VAR that includes financial variables, like the present one, in which the policy indicator has contemporaneous effect on financial variables. Therefore, I follow the work of Mertens and Ravn (2013) and Stock and Watson (2012) and use the proxy-SVAR method to obtain covariance restrictions from the use of an instrument which allows for no direct, hard-wired assumptions on the elements of s.

For a variable $\mathbf{Z_t}$ to be a valid the instrument for the QE shock, it needs to be correlated with the shock of interest, ϵ_t^{QE}, and to be orthogonal to the rest of the shocks ϵ_t^R. That is:

$$\mathbb{E}_t[\mathbf{Z_t}\epsilon_t^{QE}] = \Phi$$
$$\mathbb{E}_t[\mathbf{Z_t}\epsilon_t^{R}] = 0$$

where Φ is a scalar.

Identifying the QE surprises. The instrument used for the QE shock, $\mathbf{Z_t}$, is identified using high frequency changes in the yields of risk-free rates at different maturities, spanning one-month to ten-years, around the EA policy meetings. The data comes from the Altavilla et al. (2019) EA-MPD dataset.[10] Using tick data, they document the price

[10]The EA-MPD dataset reports median price changes around the time interval of past ECB monetary policy meetings for a broad class of assets and various maturities, including Overnight Index Swaps

changes about 10 minutes before and after the meeting and they estimate by principal components the factors that yield from the monetary policy changes. To extract monetary policy surprises that are economically interpretable the factors are rotated as in Gürkaynak (2005). The rotation is made such that the QE factor has no impact in the 1 month OIS rates and also has no impact in the pre-crisis period of the dataset 2002-2008 (the factor is restricted to have the smallest variance in that period).

I employ the identified QE factor as an external instrument for the QE surprises. Given that the rest of the VAR data is in quarterly frequency, I follow Slacalek et al. (2020) and sum all the intra-day surprises of the QE factor that occur in a quarter.

Results. Figure 2 shows the impulse responses of the 10 year benchmark rate of the Euro Area, the income inequality index, and other important macroeconomic variables after a QE shock. Using the external SVAR method, the QE shock can be identified up to a scaling constant. This constant has been set such as the shock reduces the ten-year rate by 95 bps on impact as has been documented the ECB's Asset Purchase Programme did.[11] The solid line shows the median responses after 50000 draws. The darker bands span the 16-84 percentiles of the draws distribution while the lighter band the 9-95 percentiles. In Appendix B, I show the impulse responses of all the variables used in this SVAR estimation together with the Cholesky identification of the VAR. Results remain qualitatively similar.

The responses of macroeconomic variables to a quantitative easing shock are in line with the evidence. Following a reduction of the ten-year rate by 95 bps output increases at its peak at 2 percentage points. Output's response gradually reduces after 10 quarters. A similar pattern is followed by the responses of wages, hours worked and stock prices; they peak at 2, 1 and 20 percentage points respectively after the QE shock. The delayed stock market response could be an outcome of the two different interpretations of a QE shock by the markets. The first, would be the conventional thought of a stimulative unconventional monetary policy shock which will increase the stock market index. The second would be the Delphic interpretation, the revelation of the economic outlook assessment by the policy makers on the state of the economy, leading to a contractionary stock market effect as shown by Jarociński and Karadi (2020) and Miranda-Agrippino and Ricco (2021) for monetary policy shocks. This is what happens in the stock market prices in the first quarters until reaching their peak on the fifth quarter. Consumption and profits are impacted positively by the shock while inflation's response (shown in Appendix) is positive but insignificant.

Income inequality is indeed influenced by the unconventional monetary policy shock. Following the shock, income inequality experiences a substantial and statistically sig-

(OIS), sovereign yields, stock prices, and exchange rates. ECB monetary meetings have a distinct sequence, firstly there is the press release at at 13.45 Central European Time where a policy decision in announced without further elaboration followed by the press conference at 14.30 where the monetary policy strategy and its details are explained more broadly.

[11]Given the recent analysis of Eser, Lemke, Nyholm, Radde, and Vladu (2019) on the APP's impact on the yield curve: "A 10 year term premium compression of around 50 bps was associated with the initial APP announcement in January 2015. With the expansion of the programme the yield curve impact has become more marked and is estimated to be around 95 bps in June 2018."

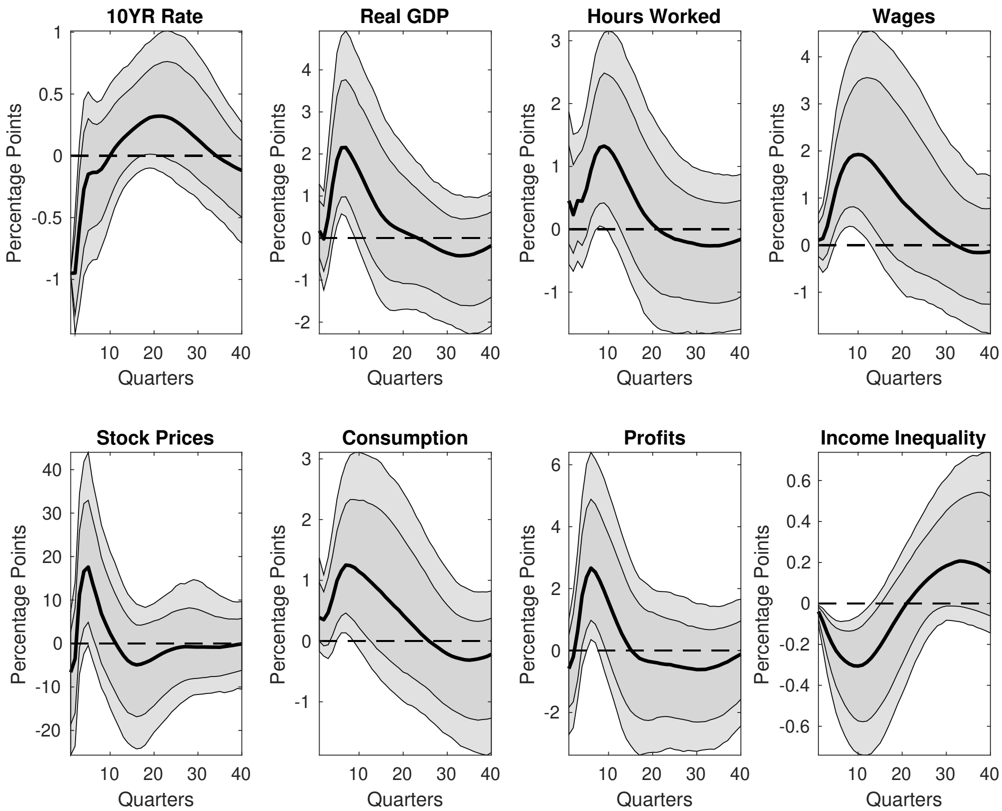

Fig. 2. Impulse Responses to a QE Shock. *Notes: The solid line shows the median responses after 50000 draws. The darker bands span the 16-84 percentiles of the draws distribution while the lighter band the 9-95 percentiles. The X axis shows the quarters while the Y axis the percent change.*

nificant decrease, amounting to nearly 0.3 percentage points. This negative response persists for a period of three years, remaining significant throughout. While the impact on income inequality is relatively small compared to the responses observed in other macroeconomic variables, it is still statistically significant. This suggests that income inequality exhibits a countercyclical pattern in response to a QE shock within the Euro Area.

3. The Model

The model economy is populated by two types of households: rule of thumb and optimising households that differ in their ability to participate in the assets market. A continuum of firms and financial intermediaries owned by the optimizers, labour wide unions that set the wages, capital goods producers and retailers, a monetary authority and the treasury complete the model economy. There is a moral hazard problem between the savers and the banks. In this setup, banks have the ability to abscond a fraction of their funds and return them to their families. This friction introduces an incentive constraint that banks must adhere to, which disrupts the neutrality of quantitative easing. Finally, the central bank operates under a Taylor rule as its conventional monetary policy framework and it can also engage in asset purchases and compensate investors by issuing newly created reserves of equivalent value.

3.1. Households - The Two Agents Framework

All households are assumed to have identical preferences, given by

$$\mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \left[\ln(C^s_{t+i}) - \frac{\chi}{1+\epsilon} L^{1+\epsilon,s}_{t+i} \right], \tag{2}$$

C^s_{t+i} denotes the per capita consumption of the household members and L^s_{t+i} the supply of labour. The super-index $s \in [o, r]$ specifies the household type (o for "optimizers" or r for "rule of thumb"). $\beta \in [0, 1]$ is the discount factor. Due to the stochastic setting, households make expectations for the future based on what they know in time t and $\mathbb{E}_t$ is the expectation operator at time t. Finally, ϵ is the inverse Frisch elasticity of labour supply and χ is the relative utility weight of labour.

Optimizers. Optimizers account to a measure of $(1-\lambda)$ of the economy's population. Their portfolio includes one period government bonds B^o_t, bank deposits D^o_t and firm shares S^o_t. They can freely adjust their deposit holdings. However, they are not experts in trading bonds and shares. Transactions above or below a frictionless level $\bar{S}^o_t$ and $\bar{B}^o_t$ for shares and bonds respectively require broker expertise and this induces costs. Costs equal to $\frac{1}{2}\kappa(S^o_t - \bar{S}^o_t)^2$ for shares and $\frac{1}{2}\kappa(B^o_t - \bar{B}^o_t)^2$ for bonds deviating from their respective frictionless level.[12]

Optimizing households budget constraint then is

$$\begin{aligned} C^o_t + T^o_t + D^o_t + q_t[B^o_t + \frac{1}{2}\kappa(B^o_t - \bar{B}^o)^2] + Q_t[S^o_t + \frac{1}{2}\kappa(S^o_t - \bar{S}^o)^2] \\ = W_t L^o_t + \Pi_t + R_{d,t} D^o_{t-1} + R_{b,t} q_{t-1} B^o_{t-1} + R_{k,t} Q_{t-1} S^o_{t-1}, \end{aligned} \tag{3}$$

Total deposits D^o_t are the sum of households' private deposits and deposits created by the exchange of securities with reserves when the central bank purchases those during a QE. They are remunerated at the risk-free rate $R_{d,t}$. $R_{b,t}$ and $R_{k,t}$ are the gross returns for the bonds and shares respectively in period t. W_t is the real wage that both types of households take as given. T^o_t are taxes (or transfers if negative) that optimizing households pay every period. Finally, optimizers receive income Π_t from the ownership of both non-financial firms and financial intermediaries.

[12] This is similar to Gertler and Karadi (2013). Another interpretation following Kaplan et al. (2018) is that bonds and stocks are illiquid assets and thus have adjustment costs while deposits are liquid assets.

The problem of the optimizing household is to choose $C_t^o, L_t^o, D_t^o, B_t^o, S_t^o$ in order to maximize its expected utility (2) subject to the budget constraint (3) at every period. Let $u_{c,t}^o$ denote the marginal utility of consumption and $\Lambda_{t,t+1}$ denote the optimizing household's stochastic discount factor (the intertemporal marginal rate of substitution)

$$\Lambda_{t,t+1} \equiv \beta \frac{u_{c^o,t+1}}{u_{c^o,t}}. \tag{4}$$

Maximizing optimizers' utility with respect to deposits yields their intertemporal optimality condition

$$\mathbb{E}_t \Lambda_{t,t+1} R_{d,t+1} = 1. \tag{5}$$

The choices for private securities and government bonds are given by:

$$\begin{aligned} S_t^o &= \bar{S}_t^o + \frac{\mathbb{E}_t \Lambda_{t,t+1}(R_{k,t+1} - R_{t+1})}{\kappa} \\ B_t^o &= \bar{B}_t^o + \frac{\mathbb{E}_t \Lambda_{t,t+1}(R_{b,t+1} - R_{t+1})}{\kappa} \end{aligned} \tag{6}$$

Households' demand for extra units of assets is increasing in the excess returns relative to the respective curvature parameter that governs the marginal transaction cost κ. As marginal transaction costs go to zero, excess returns disappear: there is frictionless arbitrage between the two assets and all assets' interest rates are equalized. On the other hand, when marginal transaction costs go to infinity, households' asset demands go to their respective frictionless capacity values.

Rule of Thumb. Rule of thumb households account for a λ measure of households. Their participation in financial markets is restricted. They cannot smooth consumption either by trading securities or by acquiring bank deposits. They consume their net income at every period which is their labour income net of taxes. Their budget constraint is:

$$P_t C_t^r = P_t W_t L_t^r + P_t T_t^r. \tag{7}$$

C_t^r, L_t^r, T_t^r denote, respectively, consumption, hours worked and taxes (or transfers).

Rule of thumb agents maximize their utility subject to their budget constraint. Accordingly, the level of consumption will equate labour income specified by (7).

Rule of thumb agents' taxation is the only fiscal variable that matters for the model's fiscal allocation as is shown in Proposition 1. Optimizing agents internalize the government budget constraint through their government bond holdings. On the other hand, a change in the tax rate (or transfer) of the rule of thumb consumers implies a change in their taxes today or in the future.[13] I study two transfer schemes for the rule of thumb consumers: a no-redistribution scheme where transfers to rule of thumb agents are zero and a fiscal rule that taxes the profits of the optimizing households and rebates them to hand to mouth consumers.

[13] Similar results are obtained for the TANK model in Bilbiie et al. (2013).

3.2. *Wage Setting*

It is assumed that wage decisions are delegated to a continuum of labour unions. This creates nominal wage rigidities. Apart from its realism, it supports the existence of procyclical profits in a NK model due to the smaller variation in the marginal costs compared to a textbook flexible wage NK model.

Hours are determined by firms taking the wages set by unions as given.[14] Households supply the hours required by the firms given the wage set by unions. Firms are also indifferent to the type of household they employ. Therefore, all households types supply the same working hours $L_t^o = L_t^r = L_t$. Labour supply L_t is a composite of heterogeneous labour services

$$L_t = \left(\int_0^1 L_{h,t}^{\frac{\epsilon_w - 1}{\epsilon_w}} dh \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \tag{8}$$

where $L_{h,t}$ is the supply of labour service h and ϵ_w is the elasticity of substitution between labour and consumption.

At each period there is a probability $1 - \xi_\omega$ that the wage for each particular labour service $W_{h,t}$ is set optimally. The union buys homogeneous labour at nominal price $W_{h,t}$, repackages it by adding a mark-up and chooses the optimal wage W_t^* to maximize the objective function where labour income of the two types is weighed by their marginal utilities of consumption.

$$\lambda \left[u_{c,t}^r W_{h,t} L_{h,t} - \frac{\chi}{1+\epsilon} L_t^{1+\epsilon} \right] + (1-\lambda) \left[u_{c,t}^o W_{h,t} L_{h,t} - \frac{\chi}{1+\epsilon} L_t^{1+\epsilon} \right] \tag{9}$$

.

Aggregation. Aggregate variables are given by the population weighted average of the corresponding variables of each household type.

$$C_t \equiv (1-\lambda) C_t^o + \lambda C_t^r \tag{10}$$

$$L_t \equiv (1-\lambda) L_t^o + \lambda L_t^r \tag{11}$$

$$T_t \equiv (1-\lambda) T_t^o + \lambda T_t^r$$

The H superscript denotes the total asset holdings of households.

$$S_t^H \equiv (1-\lambda) S_t^o$$

$$B_t^H \equiv (1-\lambda) B_t^o$$

$$D_t^H \equiv (1-\lambda) D_t^o$$

[14]For a detailed exposition on wage setting see Appendix C.

3.3. *Financial Frictions*

Banks. Banks are funded with deposits, extend credit to non-financial firms, buy bonds from the government and hold reserves. QE works by exchanging the assets purchased by the central bank with reserves. Each bank j allocates its funds to buying a quantity $s_{j,t}$ of financial claims on non-financial firms at price Q_t and government bonds $b^B_{j,t}$ at price q_t. Banks' liabilities are made up from households' deposits $d^H_{j,t}$. When the central bank proceeds in securities' purchases ($Q_t s_t$ or $q_t b_t$) it pays back the bank with an equivalent value of reserves $m_{j,t}$.[15] Finally, $n_{j,t}$ is the capital equity accumulated. Formally, the bank's balance sheet is:

$$Q_t s^B_{j,t} + q_t b^B_{j,t} + m^B_{j,t} = n_{j,t} + d^H_{j,t}. \tag{12}$$

To limit bankers' ability to save and eventually overcome their financial constraint by using own funds, following Gertler and Kiyotaki (2010) it is assumed that each period, a fraction $1-\sigma_B$ of bankers, exit and give retain earnings to their household. An equal number of new bankers enter at the same time. They begin with a start up fund of ξ given to them by their household.

The bank's net worth evolves as the difference between interest gains on assets and interest payments on liabilities.

$$n_{j,t+1} = R_{k,t+1} Q_t s^B_{j,t} + R_{b,t+1} q_t b^B_{j,t} + R_{m,t+1} m^B_{j,t} - R_{t+1} d^H_{j,t}.$$

Let Z_t be the net period income flow to the bank from a loan that is financing to a firm and δ the depreciation rate of capital being financed. Then the rate of return to the bank on the loan, $R_{k,t+1}$, is given by:

$$R_{k,t+1} = \frac{Z_t + (1-\delta) Q_{t+1}}{Q_t}. \tag{13}$$

Long-term bond is a perpetuity that pays one euro per period indefinitely. The real rate of return on the bond $R_{b,t+1}$ is given by:

$$R_{b,t+1} = \frac{1/P_t + q_{t+1}}{q_t}.$$

Central bank reserves bear a zero weight in the banks' constraint and, as it will be shown momentarily, have a gross return $R_{m,t}$ equal to the risk-free rate R_t. It follows that banks have no incentive to hold reserves in equilibrium.

The bankers' objective at the end of period t, is to maximize the expected present value of future dividends. Since the banks are owned by the optimizing households,

[15] We can think $m^B_{j,t}$ as the sum of reserves a bank receives from the purchases not only of its own securities but also from the ones the households listed to the bank hold. The bank will transfer the exact same amount to the household's deposit account (see McLeay, Radia, and Thomas (2014)), keeping the balance sheet constraint intact.

their stochastic discount factor Λ_{t+1} is used as the discounting measure.

$$V_{j,t} = \mathbb{E}_t \sum_{j=1}^{\infty} (1-\sigma_B)\sigma_B^{j-1}\Lambda_{t+1} n_{j,t+1}. \tag{14}$$

To motivate a limit on the banks' ability to obtain deposits, a costly enforcement constraint is introduced in the same fashion as in Gertler and Kiyotaki (2010). A banker can abscond a fraction of her assets and transfer them back to her household members, depositors can force the bank into bankruptcy and get the remaining fraction of assets. It is assumed that the banker can divert loans easier than diverting bonds and reserves.

The depositors continue providing funds to the bank as long as the following incentive constraint is not violated:

$$V_{j,t} \geqslant \theta[Q_t s_{j,t}^B + \Delta q_t b_{j,t}^B + \omega m_{j,t}^B]. \tag{15}$$

where θ is the fraction of assets that the banker may divert and $\Delta \in (0,1)$ and $\omega \in (0,1)$ are the ratios of how many bonds and how much reserves the banker can divert. On the left of (15) is the franchise value of the banker, which is what the banker would lose from diverting, while on the right are the banker's gains from diverting, which is a fraction θ of her assets.

The value of the bank at the end of period $t-1$ must satisfy the Bellman equation:

$$\begin{aligned} V_{j,t-1}(s_{j,t-1}^B, b_{j,t-1}^B, m_{j,t}^B, d_{j,t}^H) &= E_{t-1}\Lambda_{t-1,t}\sum_{i=1}^{\infty}\{(1-\sigma_B)n_{j,t} \\ &+ \sigma_B \max_{d_{j,t}}[\max_{s_{j,t}^B, b_{j,t}^B, m_{j,t}^B} V_t(s_{j,t}^B, b_{j,t}^B, m_{j,t}^B, d_{j,t}^H)]\}. \end{aligned} \tag{16}$$

Banker's problem is to maximize (14) subject to the balance sheet (12) and their constraint (15).

A solution to the banker's dynamic program is

$$V_{j,t}(s_{j,t}^B, b_{j,t}^B, d_{j,t}^H, m_{j,t}^B) = A_{j,t}^B n_t;$$

and the marginal value of the banker's net worth A^B solves:

$$A_{j,t}^B = \mu_t^s \phi_t + \nu_{d,j,t}.$$

μ_t^s is the stochastic spread between the loan and the deposit rates, ϕ_t is the maximum leverage and $\nu_{d,j,t}$ is the marginal loss from deposits. For the solution see Appendix D.

We can rewrite the incentive constraint using the linearity of the value function as:

$$\frac{A_{j,t}^B}{\theta} \geqslant \frac{[Q_t s_{j,t}^B + \Delta q_t b_{j,t}^B + \omega m_{j,t}^B]}{n_t} = \phi_t. \tag{17}$$

The adjusted leverage of a banker cannot be greater than $A_{j,t}^B/\theta$. The right hand side shows that as the net worth of the banker decreases the constraint is more likely to bind.

The maximum adjusted leverage ratio of the bank after the solution of the bank's problem (see Appendix D) yields:

$$\phi_t = \frac{\mathbb{E}_t \Lambda_{t,t+1} R_{t+1}}{\theta - \mathbb{E}_t \Lambda_{t,t+1}(R_{k,t+1} - R_{t+1})}. \tag{18}$$

Maximum adjusted leverage ratio depends positively on the marginal cost of the deposits and on the excess value of bank assets. As the credit spread increases, banks' franchise value V_t increases and the probability of a bank diverting its funds declines. On the other hand, as the proportion of assets that a bank can divert, θ increases, the constraint binds more.

Importantly, the maximum adjusted leverage ratio does not depend on any individual bank characteristics, therefore the heterogeneity in the bankers' holdings and net worth, does not affect aggregate dynamics. Hence, it is straightforward to express individual financial sector variables in aggregate form.

Aggregation. Let S_t^B be the total quantity of loans that banks intermediate, B_t^B the total number of government bonds they hold, M_t^B the total quantity of reserves and N_t their total net worth. Furthermore, by definition, total deposits acquired by the households D_t^H are equal with the total deposits of the banking sector. Using capital letters for the aggregate variables, the banks' aggregate balance sheet becomes

$$Q_t S_t^B + q_t B_t^B + M_t^B = N_t + D_t^H. \tag{19}$$

Since the leverage ratio (18) does not depend on factors associated with an individual bank's characteristics we can sum up across banks and get the aggregate bank constraint in terms of the total net worth in the economy:

$$Q_t S_t^B + \Delta q_t B_t^B + \omega M_t^B = \phi_t N_t. \tag{20}$$

The equation presented represents the aggregate demand for loans, $Q_t S_t$. In the presence of a binding incentive constraint, the demand for assets, including loans, is limited by the net worth of the bank adjusted by its leverage. During the implementation of QE, it is important to consider the impact on the bank's leverage constraint. Regardless of the specific type of security purchased by the central bank, the weights assigned to these securities are higher than the weight assigned to reserves (represented as $1 > \Delta > \omega$). As a result, when the central bank exchanges securities for reserves, the constraint faced by the bank is relaxed, stimulating lending to the non-financial sector. Conversely, if the constraint was not binding, the returns on all three types of assets (securities, reserves, and loans) would be equal to the deposit rate. In this scenario, the effectiveness of QE would be limited since there would be no differential impact on asset returns.

Aggregate net worth is the sum of the new bankers' and the existing bankers' equity: $N_{t+1} = N_{y,t+1} + N_{o,t+1}$. Young bankers' net worth is the earnings from loans multiplied by ξ_B which is the fraction of asset gains that being transferred from households to the new bankers

$$N_{y,t+1} = \xi[R_{k,t}Q_{t-1}S_{t-1}^{B} + R_{b,t}q_{t-1}B_{t-1}^{B} + R_{m,t}M_{t-1}^{B}]$$

and the net worth of the old is the probability of survival for an existing banker multiplied by the net earnings from assets and liabilities

$$N_{o,t+1} = \sigma[R_{k,t}Q_{t-1}S_{t-1}^{B} + R_{b,t}q_{t-1}B_{t-1}^{B} + R_{m,t}M_{t-1}^{B} - R_tD_t^{H}].$$

3.4. Central Bank, Asset Purchases and the Treasury

Central Bank. The central bank can utilise two policy tools. Firstly, it adjusts the policy rate according to the Taylor rule specified momentarily. Secondly, it can engage in asset purchases from households and banks.

At the state of QE, the central bank acquires securities from banks and households. These securities can take the form of private assets, S_t^G, or bonds, B_t^G. The central bank makes payments for the assets purchased based on their respective prices, denoted as Q_t and q_t. To finance these asset purchases, the central bank creates electronic reserves, M_t:

$$Q_tS_t^G + q_tB_t^G = M_t.$$

It is assumed that the central bank turns over any profits to the treasury and receives transfers to cover any losses. The central bank's budget constraint is:

$$T_t^{CB} + R_tM_{t-1} + Q_tS_t^G + q_tB_t^G = R_{b,t}q_{t-1}B_{t-1}^G + R_{s,t}Q_{t-1}S_{t-1}^G + M_t \tag{21}$$

where T_t^{CB} are transfers of the central bank to the treasury.

Conventional monetary policy is characterised by a Taylor rule. It sets the nominal interest rate, $R_{n,t}$, such as to respond to deviations of inflation, Π_t, and output,Y_t from its steady state level:

$$\log\left(\frac{R_{n,t}}{R_n}\right) = \rho_m \log\left(\frac{R_{n,t-1}}{R_n}\right) + \kappa_\pi \log\left(\frac{\Pi_t}{\Pi}\right) + \kappa_y \log\left(\frac{Y_t}{Y}\right) + \epsilon_{m,t} \tag{22}$$

where R_n is the steady state level of the nominal interest rate, variables without time subscript denote their steady state value and $\epsilon_{m,t}$ an exogenous monetary policy shock. The relation between nominal and real interest rates is given by the Fisher equation:

$$R_{n,t} = R_{t+1}\frac{P_{t+1}}{P_t}.$$

The market clearing conditions for bonds and shares are as follows:

$$S_t = S_t^B + S_t^H + S_t^G \tag{23}$$

and for the bonds:

$$B_t = B_t^B + B_t^H + B_t^G. \tag{24}$$

If we combine the clearing conditions and insert them into the leverage constraint of the banks, we obtain the following expression:

$$Q_t S_t \leqslant \phi N_t + Q_t S_t^H + Q_t S_t^G + \Delta(q_t B_t^G + q_t B_t^H - q_t B_t) \tag{25}$$

The above mentioned constraint implies that when the central bank purchases loans or bonds, it effectively eases the leverage constraint faced by the banking sector. This is particularly beneficial during periods of financial stress, as it can reduce excess returns and stimulate the overall economy. However, when this constraint is not binding and the inequality holds, shares or bond purchases made by the central bank have a neutral effect, a setting similar to Wallace (1981).

Equation (25) offers further insight into the mechanism of asset purchases. It suggests that buying loans or bonds does not have an equal impact on the relaxation of the banks' leverage constraint. Specifically, when the central bank purchases loans, which have a 100% absconding fraction, it relaxes the constraint to a greater extent compared to purchasing bonds, where the coefficient Δ is less than 100%. Intuitively, the acquisition of government bonds by the central bank frees up less bank capital than acquiring an equivalent amount of private loans.

It is now easier to understand when the irrelevance theorem holds. Since the central bank creates as many reserves as the value of the bonds purchased ($M_t = q_t B_t^G$), then in the case of frictionless arbitrage between the existing assets ($R_{s,t} = R_{b,t} = R_t$), the market operations are indeed irrelevant. But since the financial frictions included in the model disrupt the frictionless arbitrage, asset purchases have an effect on the real economy.

In the subsequent analysis, our focus will be on bond purchases conducted by the central bank, as opposed to share purchases. The share of the total bonds that is purchased by the central bank is assumed to follow a second order stochastic process.[16] Specifically,

$$B_t^G = \phi_{b,t} B_t.$$

$\phi_{b,t}$ follows a second order stochastic process.

Treasury. The treasury collects lump sum taxes $T_t = \lambda T_t^r + (1-\lambda)T_t^o$ to finance its public expenditures which are fixed relative to output, $\bar{G} = \gamma^G Y^{ss}$. It also targets a constant real level of long-term debt, denoted by $\bar{B}$. It collects taxes at rate τ_{pr} from non-financial firms' profits and redistribute them back to the hand to mouth households, $T_t^r = \tau_{pr} Prof_t$.

The treasury's budget constraint is:

$$\bar{G} + q_{t-1} R_{b,t} \bar{B} = q_t \bar{B} + T_t + T_t^{CB}. \tag{26}$$

.

Proposition 1. Fiscal policy matters only through the impact of taxes (transfers) on

[16] As is shown in the calibration section, an AR(2) is the best way to simulate the ECB's Asset Purchase Program schedule.

hand to mouth agents. Therefore, the only fiscal variable that needs to be defined is the hand to mouth transfers (or taxes).

Proof. I make use of the optimizers budget constraint (3), the bank's -owned by optimizing agents- balance sheet (12), the taxes aggregator and the treasury and central bank's budget constraints (21), (26). Substituting the latter four equations in the optimizers' budget constraint and using the financial variables aggregator, the aggregate resource constraint yields:

$$C_t^R + \frac{\bar{G}}{1-\lambda} - \frac{\lambda}{1-\lambda} T_t^K + adj\{B,S\} = W_t L_t^R. \tag{27}$$

Where $adj\{B,S\}$ are the adjustment costs for bonds and shares that households have to pay, defined in (3). Taxes on optimizers and any short of government bond decision do not matter for the allocation. □

3.5. *Non-Financial Firms and Nominal Price Rigidities*

The non-financial firms are separated into three types: intermediate, final goods firms (retailers) and capital goods producers. To allow for nominal price rigidities, I assume that the differentiated intermediate goods i produced by a continuum of monopolistically competitive intermediate goods firms are subject to Calvo price stickiness.

The final output composite is a CES composite of all indeterminate goods i: $Y_t = \left(\int_0^1 Y_t(i)^{\frac{\zeta-1}{\zeta}}\right)^{\frac{\zeta}{\zeta-1}}$ where ζ denotes the elasticity of substitution across intermediate goods. Each period there is a fixed probability $1-\gamma$ that a firm will adjust its price. Each firm chooses the reset price P_t^* subject to the price adjustment frequency constraint. Firms can also index their price to the lagged rate of inflation with a price indexation parameter γ_p. The goods are then sold and used as inputs by a perfectly competitive firm producing the final good. Finally, the capital goods producers create new capital under investment adjustment costs and sell it to goods producers at a price Q_t. The non-financial sector problem is described in detail in Appendix E.

Capital stock evolves according to the law of motion of capital

$$K_{t+1} = I_t + (1-\delta)K_t. \tag{28}$$

The intermediate good $i \in [0,1]$ is produced by a monopolist who uses a constant returns to scale production function combining capital and labour:

$$Y_t(i) = A_t K_t(i)^\alpha L_t(i)^{1-\alpha}. \tag{29}$$

A_t is the total factor productivity. It finances its capital needs each period by obtaining funds from banks and households. To acquire the funds to buy capital, the firm issues $S_t(i)$ claims equal to the number of units of capital acquired $K_{t+1}(i)$ and prices each claim at the price of a unit of capital $Q_t(i)$. Then by arbitrage: $Q_t(i)S_t(i) = Q_t(i)K_{t+1}(i)$.

The funds acquisition between goods firms and its lenders is under no friction. Firm's lenders can perfectly monitor the firms and there is perfect information.

Resource Constraint. Final output may be either transformed into consumption good, invested subject to investment adjustment costs or used by the government for government spending:

$$Y_t = C_t + I_t[1 + \tilde{f}\Big(\frac{I_t}{I_{t-1}}\Big)] + G_t.$$

4. Quantitative Analysis

This section presents the calibration of the model using Euro Area data, followed by the model's results on the effects of QE on both the macroeconomy and household inequality.

4.1. Calibration

The model's calibration is performed in order the model to match specific Euro Area stylized facts. It is divided in the calibration of conventional and banking parameters. The parameters of the model are set such as their values in the steady state equilibrium are in line with the Euro Area data long run averages. The values of the conventional parameters are in line broadly with the updated version of the New Area-Wide Model (NAWM), (Christoffel, Coenen, and Warne (2008), Coenen, Karadi, Schmidt, and Warne (2018)), the DSGE model of the ECB which shares a number of similarities with this study. A small set of parameters regarding the NK part of the model is set to the values of the NAWM. One period in the model is one quarter. All the calibrated values are presented in Table 1.

Financial parameter values are chosen in order to match specific Euro Area banking averages: banks' leverage, lending spread and planning horizon. There are three key parameters that characterize the behaviour of the financial sector in the model: the absconding rate, θ, the fraction of initial capital fund for entering bankers, ξ_B, and the steady-state value of the survival rate, σ_B. To calibrate these parameters, I match certain steady-state moments with the data reported in Coenen et al. (2018) for the Euro Area.

Firstly, the steady-state leverage of the banks is set to 6, which corresponds to the average asset-over-equity ratio of monetary and other financial institutions, as well as non-financial corporations. The weights are based on their share of assets in the total assets between 1999Q1 and 2014Q4, according to the Euro Area sectoral accounts. Secondly, the steady-state spread between the lending rate and the risk-free rate is set to 2.17 percentage points. This value represents the average spread between the long-term cost of private-sector borrowing and the EONIA rate from 2003Q1 to 2014Q4. The banks' planning horizon is set to 5 years, aligning with the related studies in the literature. Additionally, the fraction of bonds that can be absconded, Δ, is set to 50%, targeting a steady-state bond spread that is half of the lending spread. The absconding rate of reserves, ω, is set to zero, reflecting the assumption that reserves are fully

Parameters	Value	Definition
		Households
β	0.998	Discount rate
χ	4.152	Relative utility weight of labour
λ	0.20	Share of rule of thumb agents
ϵ	2	Inverse Frisch elasticity of labour supply
$\bar{S}^R/S$	0.500	Proportion of shares of the optimizers
$\bar{B}^R/B$	0.750	Proportion of bond holdings of the optimizers
κ	1	Portfolio adjustment cost parameter
		Banks
θ	0.20	Absconding rate
Δ	0.5	Absconding fraction for bonds
ω	0	Absconding fraction for reserves
ξ_B	0.0014	Entering bankers initial capital
σ_B	0.950	Bankers' survival rate
		Intermediate and Capital Goods Firms
δ	0.025	Depreciation of capital
α	0.36	Capital share
η	5.77	Inverse elasticity of net investment to the price of capital
		Wage and Price Setting
ζ	2.540	Elasticity of substitution between goods
γ	0.890	Probability of keeping the price constant
γ_p	0.480	Price indexation parameter
ζ^W	4.340	Elasticity of labour substitution
γ^W	0.720	Probability of keeping the wages constant
γ_p^W	0.417	Wage indexation parameter
		Treasury Policy
γ^G	0.20	Steady state fraction of government expenditures to output
τ_{pr}	0%	Optimizers' profit tax rate
		Monetary Policy
κ_π	1.860	Inflation coefficient in the Taylor rule
κ_y	0.147	Output gap coefficient in the Taylor rule
ρ_m	0.860	Interest-rate smoothing
ρ_1	1.700	First AR coefficient of the bond purchase shock
ρ_2	-0.730	Second AR coefficient of the bond purchase shock
ψ	0.015	Initial asset purchase shock

Table 1: Parameter Values

recoverable by depositors in the event of bankruptcy. This assumption is in line with Sims and Wu (2021), and it emphasizes that reserves essentially represent central bank money, which the central bank has full control over.

The long term target of the real bonds supply is set to 70% of GDP. The fraction of bonds held by banks in steady state is 25% which is consistent with the sovereign debt holdings of the banking sector in the Euro Area. It is assumed that the central bank holds no bonds in steady state. This leaves the rest 75% of the bond holdings to the optimizing households. In terms of shares, it is assumed that optimizing households hold 50% of the shares available in the market.

The value of β is assigned to 0.998, chosen to be consistent with an annualised equilibrium real interest rate of 2%. The relative utility weight of labour χ is chosen to ensure a level of labour close to $1/3$ in steady state, a fairly common benchmark in the literature (see Corsetti, Kuester, Meier, and Müller (2014)). The values for the share of capital α and the depreciation rate δ are chosen to 0.36 and 0.025 respectively following the estimation results of Christoffel et al. (2008). The parameter of the inverse Frisch elasticity of labour supply ϵ is one difficult to identify. In the NAWM, this parameter is not estimated and is set a to 2 which is the one I employ as well.

The government spending as a fraction of the GDP is set to 20% also following other studies for the Euro Area. The elasticity of substitution between goods ζ and the capital adjustment costs follow the NAWM and set to 2.54 and 5.77 respectively. The same holds for the wage setting parameters and the retail firms parameters. Regarding monetary policy, the inflation and output coefficients in the Taylor rule and the interest rate smoothing parameter are also set in line with the NAWM.[17]

The share of rule of thumb consumers is set to $\lambda = 0.20$. This is calibrated utilising data from the Eurosystem Household Finance and Consumption Survey. As outlined in the introduction, the bottom 20% of the Euro Area households' distribution hold essentially no net worth. This parameter value is in line with the estimates of Slacalek et al. (2020) and Almgren et al. (2022).[18] The profits' tax rate in the baseline scenario are assumed to be 0%.[19]

Finally, the bond purchase (QE) shock is modelled as an AR(2) process.[20] The AR(2) process in contrast with an AR(1) captures the expectation of the further expansion of central bank purchases in the future, which is the case in the ECB's APP started in 2015Q1. Purchases for the first year are constant to 60 billion euro, then in 2016 increase to 80 billion for four quarters to eventually go back to 60 billion and fade out. Relative to 2015 GDP purchases increase from a 2% to almost 4% at their peak. To

[17]Given that the main quantitative exercise of the model consists of a QE shock impulse response analysis, and the similarity of the model with the estimated model of Coenen et al. (2018), the full information estimation with Bayesian techniques can be left for future work which would require an estimation by Bayesian maximum likelihood, e.g. for welfare evaluation of central bank policies.

[18]The same parameter value is also used by a similar study for the EA with LAMP Hohberger, Priftis, and Vogel (2019b).

[19]Results remain qualitatively similar under any reasonable tax rate ranging from 0% to 40%.

[20]This follows similar studies that conclude that the ECB's QE program is characterised by a AR(2) process (see Andrade, Breckenfelder, De Fiore, Karadi, and Tristani (2016), Hohberger et al. (2019b)).

illustrate this pattern, the first AR coefficient is chosen to 1.700 and the second being -0.730 while the initial shock is chosen to 0.015. To achieve a direct comparison between the QE and the conventional monetary policy shock, I calibrate the magnitude of the latter such as it provides the same increase in GDP with the one of the QE shock.

4.2. Impulse Response Analysis

I proceed with a quantitative analysis to investigate the impact of the ECB's APP on the following points: i) the assessment of the APP's impact on the macroeconomy, ii) the evaluation of the APP's effects on consumption and income inequality. iii) the comparison of the APP's impact with that of an accommodative monetary policy shock, assuming the absence of the effective lower bound constraint. Additionally, I provide a decomposition of the optimizing agents' income response to gain insights into the specific effects of the APP on their income dynamics. The model is solved non-linearly following Lindé and Trabandt (2019).

Central Bank Bond Purchases and Conventional Monetary Policy. The dynamics of macro variables under a bond purchasing program similar to the APP and an expansionary monetary policy shock that generates a comparable increase in output are depicted in Figure 3. The figure illustrates the responses of output, consumption, investment, inflation, hours worked, wages profits, interest rates and spreads. The monetary policy shock is set such that it produces the same increase in output to that of the QE shock, of about 2.5%, which is translated to a 60 bps reduction in the policy rate. In the case of the QE shock the nominal interest rate is set constant for the first four quarters and then it is let freely to follow the Taylor rule specification. This simulates the inability of the central bank to use conventional monetary at times it is forced to use unconventional measures.[21] In the Appendix, I provide robustness analysis which shows that results hold for the case of i) fully flexible rate and ii) constant rate for eight quarters. In bold lines, the responses of a bond shock reflect the responses of a conventional interest rate reduction.

Bond purchases, as depicted in Figure 3, have a stimulative effect on the economy, leading to an increase in output. In the case of the QE shock, the mechanism works mainly through the loosening of the banks' leverage constraint. Central bank purchases raise asset prices Q_t resulting in an increase in banks' valuation and net worth. This, in turn, triggers standard financial accelerator effects, leading to a further boost in the prices of capital and overall economic activity. The reduction in excess returns is more substantial in the case of QE compared to the conventional monetary policy shock. This is primarily because the QE shock directly impacts the banks' financial constraint, leading to a more significant reduction in both spreads. Higher investment leads to higher demand for employment and therefore wage and hours worked increase. The presence of nominal wage rigidities dampens the variability of marginal costs, allowing profits to respond procyclically, contrary to the simple New Keynesian frameworks where prof-

[21] ECB after the initiation of its APP programme in 2015Q1 kept its main refinancing operations interest rate constant for a year.

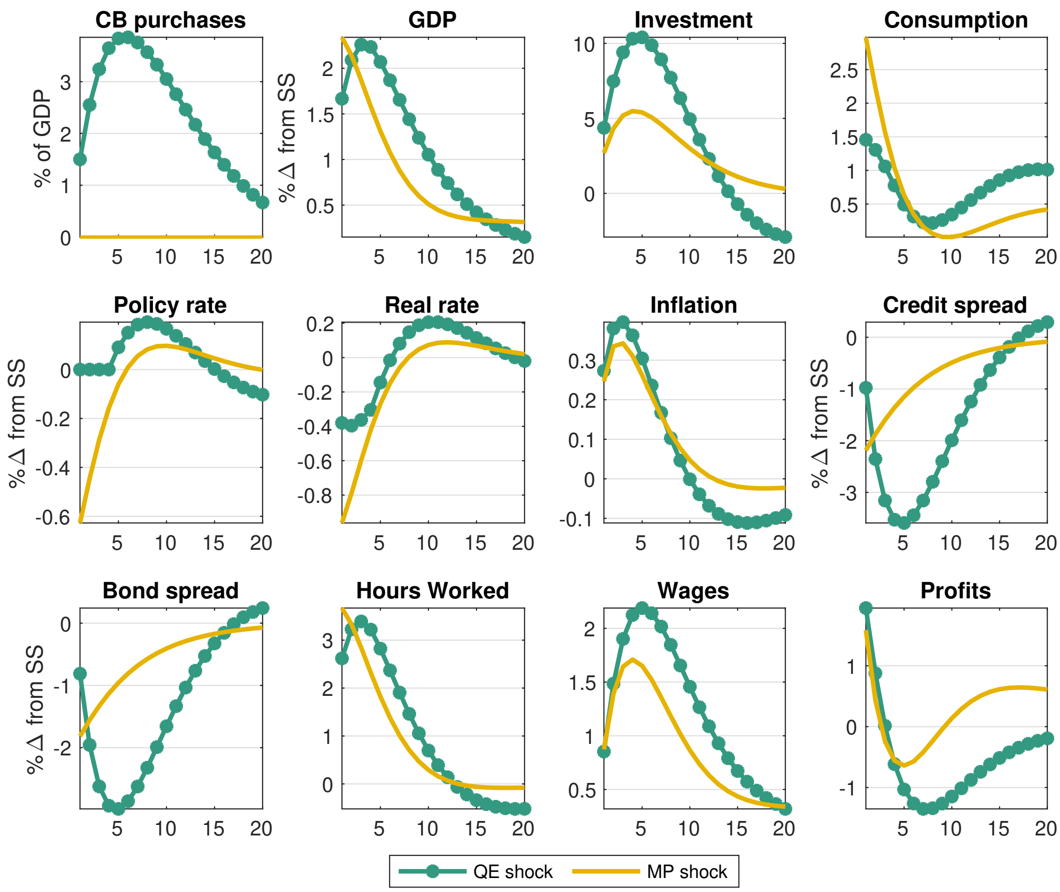

Fig. 3. Government Asset Purchase Shock and Conventional Monetary Policy Shock

its are typically countercyclical. Additionally, both shocks result in a decline in the real interest rate, although the reduction is more pronounced in the case of the monetary policy shock. This, combined with the expansionary effects of the shocks, contributes to a positive response in aggregate consumption.

Overall, responses are qualitatively similar for both conventional and unconventional monetary policy shocks. Nevertheless, excess returns on the bonds and loans decrease substantially more in the QE case leading to a higher impact on inequality measures shown next.

Income and Consumption Inequality. Figure 4 presents the responses of income and consumption for the two income groups, as well as the relative inequality measure for both variables following a QE and MP shock. Consumption (income) inequality is defined as the optimizers' consumption (income) divided by the aggregate consumption (income).

After an expansionary monetary shock, both types of agents experience an increase in consumption. Rule of thumb agents' consumption follows closely the labour income

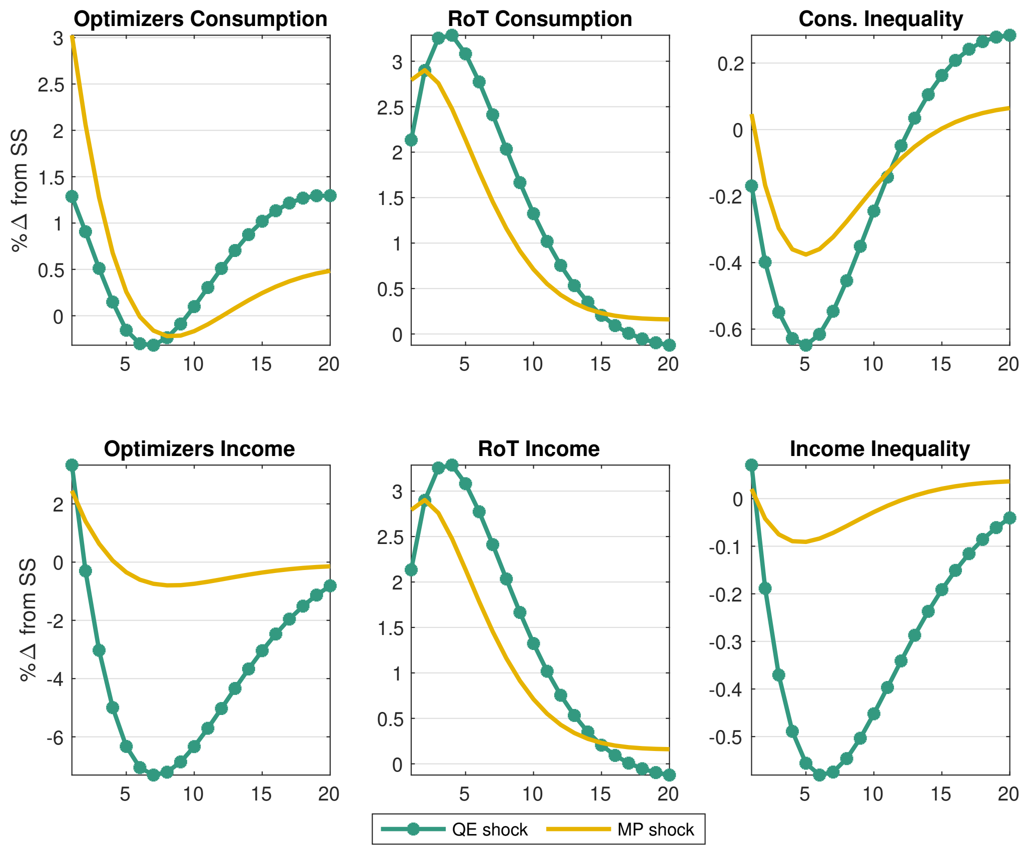

Fig. 4. Government Asset Purchase Shock and Conventional Monetary Policy Shock: Inequality

schedule which rises due to the increased demand for labour resulting from the shock. Optimizers' consumption increases on impact but consequently falls due to intertemporal substitution channel. It is important to note that the constant nominal interest rate assumption for the first four periods has an impact on the consumption behaviour of the optimizing agents. If nominal interest rates were not held constant for the first four quarters, following the Taylor rule specification, the optimizing agents' consumption would have decreased. This is because higher nominal interest rates would lead to a decline in consumption through the standard intertemporal substitution mechanism. The response of consumption for both types of agents leads to a reduction in consumption inequality between the two income groups. This finding aligns with the well established fact that hand to mouth consumers tend to have a higher marginal propensity to consume than the financially unconstrained agents (Auclert (2019), Kaplan et al. (2018) among others).

Rule of thumb agents' income, following the labour income path, increases which leads to a rise in their consumption schedule. In contrast, the optimizing agents experience a decline in income, with the effect being more pronounced in the case of the QE shock. The reason for this lies in the response of the optimizing agents to the QE shock. As shown in their demand function for bonds (6), optimizing agents reduce their bond holdings when excess bond returns decrease. This has a negative impact on their asset income since they lose from the *interest rate differential* between the bond and the risk-free rate on top of the real rate reduction that they receive in their deposits and reserves. Their income loss is explained by two factors: the exchange of a fraction of their bonds bonds to reserves that pay a lower interest rate, but also the coupon receivable reduction due to the QE shock. Therefore, the income reduction is much more amplified in the case of the QE shock relative to the conventional monetary policy shock. Consequently, the income responses of the two types of agents lead to a decrease in income inequality under both accommodative policies. However, the reduction in income inequality is more significant in the case of the QE shock due to the higher loss in excess returns experienced by the optimizing agents.

To investigate the reduction in income for permanent agents following the QE shock and demonstrate that it is primarily driven by a decline in asset income, Figure 5 presents the income component responses (left column) and the relative contribution of each component to their total income (right column). This analysis is conducted for both the QE and MP shocks. As can be seen on the left column, for both shocks the labour income of optimizing agents increases, along with a rise in profits on impact. However, the asset income component shows distinct dynamics between the two shocks. In the case of the QE shock, asset income initially increases due to the price valuation effect of the assets. Nevertheless, it subsequently drops significantly, reaching a level approximately 8% below its steady-state value. This reduction in asset income is primarily driven by the lower coupon returns and the exchange of bonds with risk-free reserves. In contrast, under the MP shock, asset income initially increases due to the valuation effect, but then declines as the price of assets returns to its steady-state level and the interest rates are still low.

To quantify the contribution of each income component to the total income of the agents, the right column of Figure 5 presents the decomposition of the optimiser's income response to its three components: asset, labour and profit income.[22] The decomposition analysis shows how income would deviate from its steady-state value if only the specific income component shown in the graph were reacting endogenously, while the other components remained at their steady-state levels. In both cases, the analysis reveals that the optimizing agents' income is primarily determined by variations in asset income, with smaller contributions from labour and profit income. This indicates that a reduction in asset income is the main driver behind the decline in total income for the optimizing agents, particularly in the case of the QE shock where the effect is more pronounced. These findings emphasize that the reduction in total income for optimizing agents is mainly caused by the decrease in asset income.

The finding that the income of asset holders and non-asset holders moves in oppo-

[22]The decomposition of the income to each component's contribution is implemented similarly to Kaplan et al. (2018).

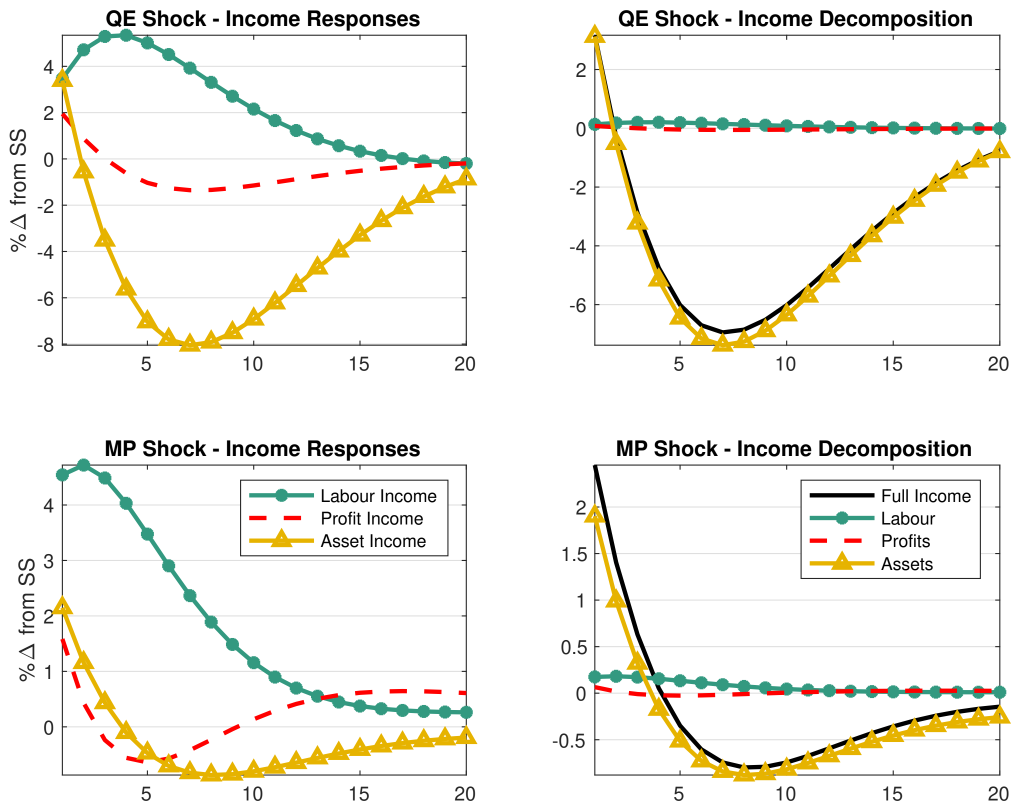

Fig. 5. Optimisers' Income Components Responses and Income Decomposition

site directions in response to a QE shock is also supported by studies such as Hohberger et al. (2019a) who conduct a similar study in a standard NK setting with two agents. This is also in line with Ampudia, Georgarakos, Slacalek, Tristani, Vermeulen, and Violante (2018); they show that a QE shock benefits substantially more the households at the lower part of the income distribution due to the expansionary income effect and decreases income inequality. In the Euro Area, Lenza and Slacalek (2022) also find similar patterns in response to a QE shock. They show that the income of the lower part of the income distribution increases substantially while the income of the right end decreases on impact, similarly to this study, but then remains mostly unchanged. It is important to note that their analysis incorporates the housing channel, which is not explicitly modelled in this study but could be a potential avenue for future research. An increase in house prices as a result of a QE shock could stimulate asset income and alleviate any loss of the financial asset income. Therefore, leaving the income of the optimizers unchanged or declining by a smaller amount. Nevertheless, this would lead to a reduction in income inequality between the two groups given the relative income increase of the hand to mouth consumers. Therefore, the income response estimates of this study can be considered as a lower bound of the optimisers' income response.

5. Conclusion

The extensive implementation of asset purchase programs following the Great Recession and the recent Covid-19 pandemic has highlighted the need to examine the consequences of QE on the macroeconomy and households' inequality. In this paper, I answer this question by providing novel evidence, using both a structural and an empirical specification for the Euro Area. I build and calibrate a state of the art New Keynesian DSGE model with limited assets market participation, financially constrained banks and price and wage rigidities. To motivate my research question, I employ an external instrument SVAR using an instrument for the QE shock identified with a high frequency approach. Results from the empirical specification and the DSGE model show that QE is stimulative and reduces income and consumption inequality in the EA. Through the lens of the model, the indirect effects of QE are found to be more substantial than the direct effects and due to this, agents who do not own financial assets benefit relatively more from QE, leading to a reduction in inequality.

In an economy with two types of households, namely optimizers and hand-to-mouth households, an increase in the bond holdings of the central bank through QE has both direct and indirect (i.e. general equilibrium) effects. This study demonstrates that following a QE shock there are two channels leading to the reduction of income inequality between the two income groups. Optimisers' asset income decreases due to the exchange of bonds to reserves and the foregone *interest rate differential* between the bond and the risk-free rate together with the real rate reduction that they receive in their deposits and new reserves. At the same time, the general equilibrium effects of a bond purchase programme are stronger than the the asset price valuation effects and benefit relatively more the hand-to-mouth households through the *labour income channel* and the higher labour income they receive. This leads to a reduction of income and consumption inequality.

Arguably, a substantial limitation of the present model is the absence of housing, which has been left out to reduce the model's complexity. Slacalek et al. (2020) provide a characterization of Euro Area households based on their holdings of liquid and illiquid assets. They can be broadly divided into optimizers, wealthy hand to mouth and poor hand to mouth. Differently to this model, optimizers and wealthy hand to mouth hold housing in addition to their other assets which, importantly, are very similar in volume. Therefore, including housing in the present study, accommodative monetary policy would have had the same positive price to income effect on the wealthy hand to mouth and the optimizers, leaving, at least qualitatively, the inequality results of this paper between the two groups intact. This could be a potentially future research project.

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Appendix A Hand to Mouth Evidence

To examine the distribution of financial and real asset holdings among Euro Area households, I focus on the first wave of the Eurosystem Household Finance and Consumption Survey data. This wave was mainly conducted in 2009 and 2010, allowing us to isolate the effects of the 2008 financial crisis. Importantly, this survey was conducted well before the initiation of the ECB's QE program in March 2015. However, it is worth noting that the subsequent waves of the survey yield similar results. The data used in this analysis is derived from a sample of over 62,000 households across 15 Euro Area member states. It provides a comprehensive picture of the distribution of financial and real asset holdings within the Euro Area.

Figure 6 presents the distribution of financial and real asset holdings among Euro Area residents.[23] Approximately 20-30% of the Euro Area households hold a total value of financial assets that is close to zero (green bar). In contrast all percentiles of Euro Area households hold substantial values of real assets (yellow bar).

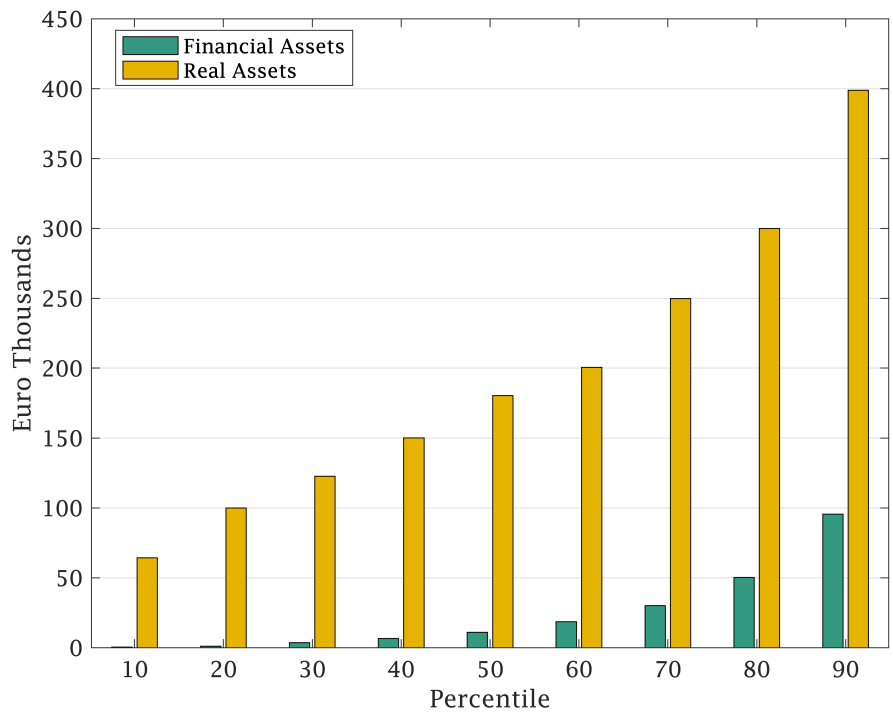

Fig. 6. Total Financial and Real Assets among EA Households

[23]Financial assets include deposits (sight and saving accounts), mutual funds, bonds, shares, money owed to the households, value of voluntary pension plans and whole life insurance policies of household members and other financial assets item - which includes private non-self-employment businesses, assets in managed accounts and other types of financial assets. Real assets include the value of household's main residence.

Appendix B SVAR Figures and Cholesky Identification

Figure 7 shows the impulse responses to a QE shock of all variables used in the SVAR estimation.

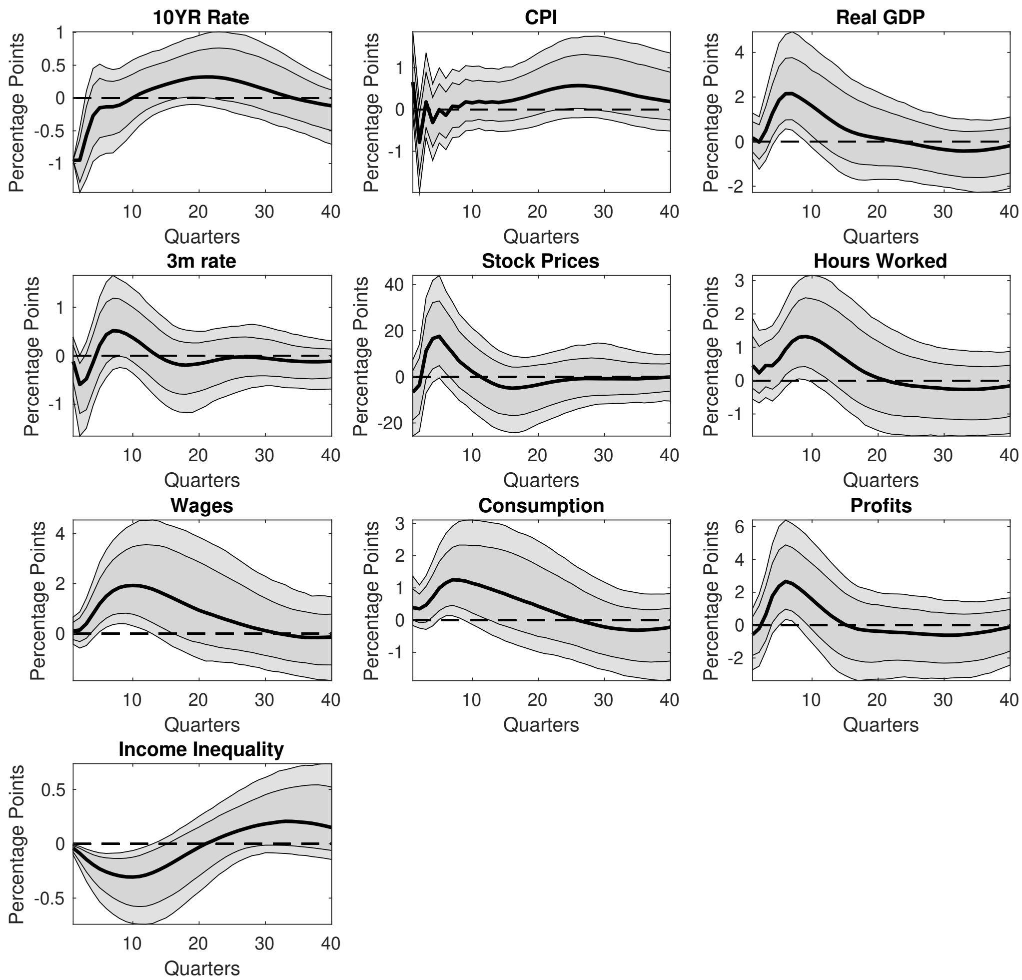

Fig. 7. Impulse Responses to a QE Shock: All Variables.
Notes: The solid line shows the median responses after 50000 draws. The darker bands span the 16-84 percentiles of the draws distribution while the lighter band the 9-95 percentiles. The X axis shows the quarters while the Y axis the percent change.

Figure 8 presents the impulse responses to a QE shock using the standard Cholesky identification. The shock is normalised such as to produce a 95 bps drop in the ten-year rate. In comparison with the impulse responses using the external instrument approach, the two methods provide similar results. All variables are responding as expected after an accommodative monetary shock with the exception of the price index. The CPI drops for the first 10 quarters and then increases though insignificantly.

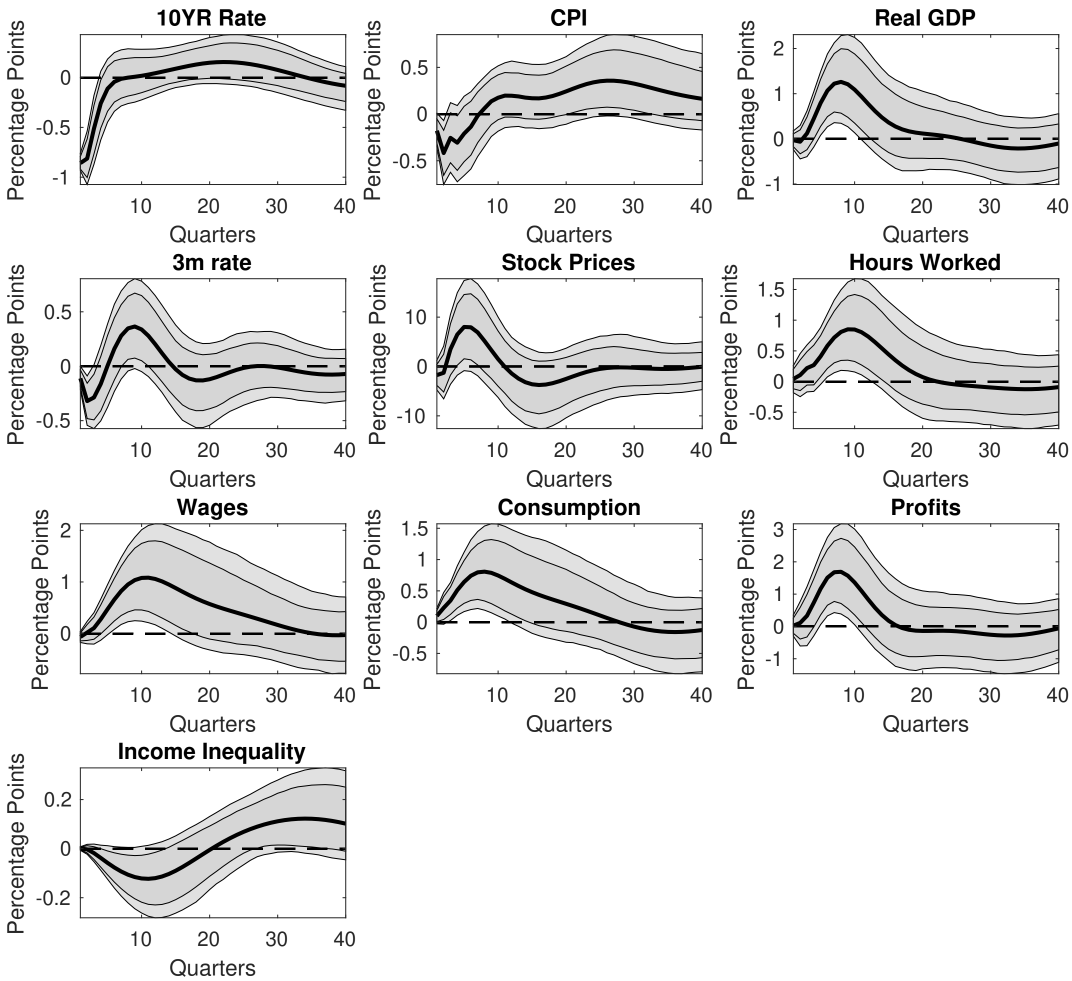

Fig. 8. Impulse Responses to a QE Shock with Cholesky Identification.
Notes: The solid line shows the median responses after 50000 draws. The darker bands span the 16-84 percentiles of the draws distribution while the lighter band the 9-95 percentiles. The X axis shows the quarters while the Y axis the percent change.

Appendix C Wage-Setting by Unions

The problem of the labour union is to maximize its objective function (in the main text).

$$\lambda \left[u^r_{c,t} W_{h,t} L_{h,t} - \frac{\chi}{1+\epsilon} L_t^{1+\epsilon} \right] + (1-\lambda) \left[u^o_{c,t} W_{h,t} L_{h,t} - \frac{\chi}{1+\epsilon} L_t^{1+\epsilon} \right]$$

.

subject to

$$L_{h,t} = \left(\frac{W_{f,t}}{W_t^*} \right)^{-\epsilon_w} L_t$$

The first order condition yields:

$$\left(\frac{\lambda}{u^r_{c,t} u^r_{l,t}} + \frac{1-\lambda}{u^o_{c,t} u^o_{l,t}} \right) W_t = \mu^W$$

where $\mu^W = \frac{\epsilon_w}{\epsilon_w - 1}$ and $u^j_{c,t} u^j_{l,t}$ is the marginal rate of substitution of agent of type j.

Appendix D Bank's Problem

This Appendix describes the method used for solving the banker's problem. I solve this, with the method of undetermined coefficient in the same fashion as in Gertler and Kiyotaki (2010). I conjecture that a value function has the following linear form:

$$V_t(s_{j,t}, d_{j,t}, b^B_{j,t}, m^B_{j,t}) = \nu_{l,j,t} s_{j,t} + \nu_{b,j,t} b^B_{j,t} + \nu_{m^B,j,t} m^B_{j,t} - \nu_{d,j,t} d_{j,t} \tag{D.1}$$

where $\nu_{s,j,t}$ is the marginal value from credit for bank j, $\nu_{d,t}$ the marginal cost of deposits, $\nu_{m^B,j,t}$ the marginal value from the central bank reserves and $\nu_{b^B,j,t}$ the marginal value from purchasing one extra unit of sovereign bonds. The banker's decision problem is to choose $s_{j,t}, b^B_{j,t}, m^B_{j,t}, d_{j,t}$ to maximize $V_{j,t}$ subject to the incentive constraint (15) and the balance sheet constraint (12). Using (12) we can eliminate $d_{j,t}$ from the value function. This yields:

$$V_{j,t} = s_{j,t}(\nu_{s,t} - \nu_{d,t} Q_t) + b^B_{j,t}(\nu_{b,j,t} - \nu_{d,j,t} q_t) + m^B_{j,t}(\nu_{m,j,t} - \nu_{d,j,t}) + \nu_{d,t} n^B_{j,t}.$$

Let $\mathcal{L}$ be the Lagrangian of the maximization problem and λ_t the Lagrange multiplier.

$$\mathcal{L} = V_t + \lambda_t [V_t - \theta(Q_t s_{j,t} + \Delta q_t b^B_{j,t} + \omega m^B_{j,t})] = (1+\lambda_t) V_t - \lambda_t \theta (Q_t s_{j,t} + \Delta q_t b^B_{j,t} + \omega m^B_{j,t}).$$

The first order and Kuhn-Tucker conditions for the maximization problem are:

$$\frac{\theta \mathcal{L}}{\theta s_{j,t}} : (1+\lambda_t)(\frac{\nu_{s,j,t}}{Q_t} - \nu_{d,j,t}) = \lambda_t \theta \tag{D.2}$$
$$\frac{\theta \mathcal{L}}{\theta b^B_{j,t}} : (1+\lambda_t)(\frac{\nu_{b^B,t}}{q_t} - \nu_{d,j,t}) = \Delta \lambda_t \theta \tag{D.3}$$
$$\frac{\theta \mathcal{L}}{\theta m^B_{j,t}} : (1+\lambda_t)(\nu_{m^B,t} - \nu_{d,j,t}) = \omega \lambda_t \theta \tag{D.4}$$

The Kuhn-Tucker condition yields:

$$KT : \lambda_t[s_{j,t}(\nu_{s,j,t} - \nu_{d,t}Q_t) + b^B_{j,t}(\nu_{b^B,j,t} - \nu_{d,j,t}q_t) + m^B_{j,t}(\nu_{m^B,j,t} - \nu_{d,j,t}) \\ + \nu_{d,j,t}n^B_{j,t} - \theta(Q_t s_{j,t} + \Delta q_t b^B_{j,t} + \omega m^B_{j,t})] = 0. \tag{D.5}$$

I define the excess value of bank's financial claim holdings as

$$\mu^s_t = \frac{\nu_{s,j,t}}{Q_t} - \nu_{d,j,t}. \tag{D.6}$$

The excess value of bank's bond holdings relative to deposits

$$\mu^b_t = \frac{\nu_{b^B,t}}{q_t} - \nu_{d,j,t},$$

and the excess value of bank's reserve holdings relative to deposits

$$\mu^m_t = \nu_{m^B,j,t} - \nu_{d,j,t}.$$

Then from the first order conditions we have:

$$\mu^b_t = \Delta \mu^s_t. \tag{D.7}$$

Setting the fraction of the absconding rate for reserves ω to 0%, the reserves first order condition (D.4) implies that

$$\nu_{m^B,t} = \nu_{d,j,t}. \tag{D.8}$$

This relationship implies that the gain from one extra unit of reserves is exactly the same with the cost of raising one extra unit of deposits. This helps us to show that when reserves is a strictly riskless asset, the bank is not taking them into account when the optimization problem is formulated. From (D.5) and (D.7) when the constraint is binding ($\lambda_t > 0$) we get:

$$
\begin{aligned}
s_{j,t}(\nu_{s,t} - \nu_{d,t}Q_t) + b^B_{j,t}(\nu_{b^B,j,t} - \nu_{d,j,t}q_t) + m^B_{j,t}(\nu^B_{m,j,t} - \nu_{d,j,t}) + \nu_{d,t}n_{j,t} &= \theta(Q_t s_{j,t} + \Delta q_t b^B_{j,t} + \omega m^B_{j,t}) \\
s_{j,t}(\mu^s_t Q_t) + b^B_{j,t}(\mu^b_t q_t) + m^B_{j,t}(\mu^m_t) + \nu_{d,t}n_{j,t} &= \theta(Q_t s_{j,t} + \Delta q_t b^B_{j,t} + \omega m^B_{j,t}) \\
Q_t s_{j,t}(\mu^s_t - \theta) + q_t b^B_{j,t}(\Delta\mu^s_t - \Delta\theta) + m^B_{j,t}(\omega\mu^s_t - \omega\theta) + \nu_{d,t}n_{j,t} &= 0 \\
Q_t s_{j,t}(\mu^s_t - \theta) + \Delta q_t b^B_{j,t}(\mu^s_t - \theta) + \omega m^B_{j,t}(\mu^s_t - \theta) + \nu_{d,t}n_{j,t} &= 0
\end{aligned}
$$

and by rearranging terms, we get equation the adjusted leverage constraint:

$$
Q_t s_{j,t} + \Delta q_t b^B_{j,t} + \omega m^B_{j,t} = \frac{\nu_{d,t}n_{j,t}}{\theta - \mu^s_t} \tag{D.9}
$$

which gives the bank asset funding. It is given by the constraint at equality, where ϕ_t is the maximum leverage allowed for the bank. The constraint limits the portfolio size to the point where the bank's required capital is exactly balanced by the fraction of the weighted measure of its assets. Hence, in times of crisis, where a deterioration of banks' net worth takes place, supply for assets will decline.

Now, in order to find the unknown coefficients I return to the guessed value function

$$
V_{j,t} = Q_t s_{j,t}(\mu^s_t) + q_t b^B_{j,t}(\mu^b_t) + m^B_{j,t}(\mu^m_t) + \nu_{d,t}n^B_{j,t}. \tag{D.10}
$$

Substituting (D.9) into the guessed value function yields:

$$
\begin{aligned}
V_t &= (n_{j,t}\phi_t - \Delta q_t b^B_{j,t} - \omega m^B_{j,t})\mu^s_t + q_t b^B_{j,t}(\mu^b_t) + m^B_{j,t}(\mu^m_t) + \nu_{d,t}n^B_{j,t} \Leftrightarrow \\
V_t &= (n_{j,t}\phi_t)\mu^s_t + q_t b^B_{j,t}(\mu^b_t - \Delta\mu^s_t) + m^B_{j,t}(\mu^m_t - \omega\mu^s_t) + \nu_{d,t}n^B_{j,t}
\end{aligned} \tag{D.11}
$$

and by (D.7) the guessed value function (D.11) becomes:

$$
V_t = \phi_t\mu^s_t n_{j,t} + \nu_{d,j,t}n_{j,t}
$$

Given the linearity of the value function we get that

$$
A^B_t = \phi_t\mu^s_t + \nu_{d,j,t}.
$$

The Bellman equation (16) now is:

$$
\begin{aligned}
V_{j,t-1}(s_{j,t-1}, x_{j,t-1}, d_{j,t}, m_{j,t-1}) = \mathbb{E}_{t-1}\,\Lambda_{t-1,t}\sum_{i=1}^{\infty}\{(1-\sigma_B)n^B_{j,t} \\
+ \sigma_B(\phi_t\mu^s_t + \nu_{d,j,t})n^B_{j,t}\}.
\end{aligned} \tag{D.12}
$$

By collecting terms with $n_{j,t}$ the common factor and defining the variable Ω_t as the marginal value of net worth:

$$
\Omega_{t+1} = (1-\sigma_B) + \sigma_B(\mu^s_{t+1}\phi_{t+1} + \nu_{d,t+1}). \tag{D.13}
$$

The Bellman equation becomes:

$$\begin{aligned} V_{j,t}(s_{j,t}, b^B_{j,t}, m^B_{j,t}, d_{j,t}) &= E_t\Lambda_{t,t+1}\Omega_{t+1}n^B_{t+1} = \\ &= E_t\Lambda_{t,t+1}\Omega_{t+1}[R_{k,t}Q_{t-1}s_{j,t-1} + R_{b,t}q_{t-1}b^B_{j,t-1} + R_t m^B_{j,t} - R_t d_{j,t}]. \end{aligned} \tag{D.14}$$

The marginal value of net worth implies the following: Bankers who exit with probability $(1-\sigma_B)$ have a marginal net worth value of 1. Bankers who survive and continue with probability σ_B, by gaining one more unit of net worth, they can increase their assets by ϕ_t and have a net profit of μ_t per assets. By this action they acquire also the marginal cost of deposits $\nu_{d,t}$ which is saved by the extra amount of net worth instead of an additional unit of deposits. Using the method of undetermined coefficients and comparing (D.1) with (D.14) we have the final solutions for the coefficients:

$$\begin{aligned} \nu_{s,j,t} &= E_t\Lambda_{t,t+1}\Omega_{t+1}R_{k,t+1}Q_t \\ \nu_{b^B,j,t} &= E_t\Lambda_{t,t+1}\Omega_{t+1}R_{b,t+1}q_t \\ \nu_{m^B,j,t} &= E_t\Lambda_{t,t+1}\Omega_{t+1}R_{t+1} \\ \nu_{d,j,t} &= E_t\Lambda_{t,t+1}\Omega_{t+1}R_{t+1} \\ \mu^s_t &= \frac{\nu_{s,j,t}}{Q_t} - \nu_{d,j,t} = E_t\Lambda_{t,t+1}\Omega_{t+1}[R_{k,t+1} - R_{t+1}] \\ \mu^b_t &= \frac{\nu_{b,j,t}}{Q_t} - \nu_{d,j,t} = E_t\Lambda_{t,t+1}\Omega_{t+1}[R_{b,t+1} - R_{t+1}] && \text{(D.15)} \\ \mu^m_t &= \nu_{m,j,t} - \nu_{d,j,t} = E_t\Lambda_{t,t+1}\Omega_{t+1}[R_{t+1} - R_{t+1}] = 0 && \text{(D.16)} \end{aligned}$$

Appendix E Price Setting

Final-Good Firms.— The profit maximization problem of the retail firm is:

$$\max_{Y_t(j)} P_t \left(\int_0^1 Y_t(i)^{\frac{\zeta-1}{\zeta}}\right)^{\frac{\zeta}{\zeta-1}} - \int_0^1 P_t(i)Y_t(i)di.$$

The first order condition of the problem yields:

$$P_t\frac{\zeta}{\zeta-1}\left(\int_0^1 Y_t(i)^{\frac{\zeta-1}{\zeta}}\right)^{\frac{\zeta}{\zeta-1}-1}\frac{\zeta-1}{\zeta}Y_t(i)^{\frac{\zeta-1}{\zeta}-1} = P_t(i).$$

Combining the previous FOC with the definition of the aggregate final good we get:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\zeta} Y_t.$$

Nominal output is the sum of prices times quantities across all retail firms i:

$$P_t Y_t = \int_0^1 P_t(i) Y_t(i) di.$$

Using the demand for each retailer we get the aggregate price level:

$$P_t = \left(\int_0^1 P_t(i)^{1-\zeta} di \right)^{\frac{1}{1-\zeta}}.$$

Intermediate-Good Firms.— Intermediate good firms are not freely able to change prices each period. Following the Calvo price updating specification each period there is a fixed probability $1-\gamma$ that a firm will be able to adjust its price.

The problem of the firm can be decomposed in two stages. Firstly, the firm hires labour and rents capital to minimize production costs subject to the technology constraint (29). Thus, it is optimal to minimize their costs which are the rental rate to capital and the wage rate for labour:

$$\min_{K_t(i), L_t(i)} P_t W_t l_t(i) + P_t Z_t K_t(i)$$

subject to

$$A_t K_t(i)^\alpha L_t(i)^{1-\alpha} \geqslant \left(\frac{P_t(i)}{P_t} \right)^{-\zeta} Y_t.$$

The problem's first order conditions are:

$$W_t = \frac{P_{m,t}^{nom}(i)}{P_t} (1-\alpha) A_t \frac{Y_t(i)}{L_t(i)}, \tag{E.1}$$

$$Z_t = \frac{P_{m,t}^{nom}(i)}{P_t} \alpha A_t \frac{Y_t(i)}{K_t(i)}. \tag{E.2}$$

$P_{m,t}^{nom}$ is the Lagrange multiplier of the minimization problem and the marginal cost of the firms with $P_{m,t} = \frac{P_{m,t}^{nom}(i)}{P_t}$ being the real marginal cost. Standard arguments lead to that marginal cost is equal across firms. Solving together the above equations we find an expression for the real marginal cost $P_{m,t}$ which is independent of each specific variety:

$$P_{m,t} = \left(\frac{1}{1-\alpha} \right)^{1-\alpha} \left(\frac{1}{\alpha} \right)^\alpha W_t^{1-\alpha} Z_t^\alpha.$$

In the second stage of the firm's problem, given nominal marginal costs, the firm chooses its price to maximize profits. Firms are not freely able to change prices each period. Each period there is a fixed probability $1-\gamma$ that a firm will adjust its price. Each firm chooses the reset price P_t^* subject to the price adjustment frequency constraint. Firms can also index their price to the lagged rate of inflation with a price indexation parameter γ_p. They discount profits s periods in the future by the stochastic discount factor $\Lambda_{t,t+s}$ and the probability that a price price chosen at t will remain the same for some periods γ^s. The second stage of the updating firm at time t us to choose $P_t^*(i)$ to maximize discounted real profits:

$$\max_{P_t^*(i)} \mathbb{E}_t \sum_{s=0}^{\infty} \gamma^s \Lambda_{t,t+1} \left(\frac{P_t^*(i)}{P_{t+s}} - P_{m,t+s} \right) Y_{t+s}(i)$$

subject to

$$Y_{t+s}(i) = \left(\frac{P_t^*(i)}{P_{t+s}} \prod_{\kappa=1}^{s} (1 + \pi_{\tau+\kappa-1})^{\gamma_p} \right)^{-\zeta} Y_{t+s}.$$

where π_t is the rate of inflation from $t-i$ to t. The first order condition of the problem is:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \gamma^s \Lambda_{t,t+1} \left(\frac{P_t^*(i)}{P_{t+s}} \prod_{\kappa=1}^{s} (1 + \pi_{\tau+\kappa-1})^{\gamma_p} - P_{m,t+s} \frac{\zeta}{\zeta - 1} \right) Y_{t+s}(i) = 0.$$

Using the constraint and rearranging we get:

$$P_t^*(i) = \frac{\zeta}{\zeta - 1} \frac{\mathbb{E}_t \sum_{s=0}^{\infty} \gamma^s \Lambda_{t,t+1} P_{m,t+s} P_{t+s}^{\zeta} Y_{t+s}}{\mathbb{E}_t \sum_{s=0}^{\infty} \gamma^s \Lambda_{t,t+1} P_{t+s}^{\zeta-1} \prod_{\kappa=1}^{s} (1 + \pi_{\tau+\kappa-1})^{\gamma_p} Y_{t+s}}.$$

Since nothing on the right hand side depends on each firm i, all updating firms will update to the same reset price, P_t^*. By the law of large numbers the evolution of the price index is given by:

$$P_t = [(1-\gamma)(P_t^*)^{1-\zeta} + \gamma(\Pi_{t-1}^{\gamma_p} P_{t-1})^{1-\zeta}]^{\frac{1}{1-\zeta}}.$$

Capital Goods Producers.— Capital goods producers produce new capital and sell it to goods producers at a price Q_t. Investment on capital (I_t) is subject to adjustment costs. Their objective is to choose $\{I_t\}_{t=0}^{\infty}$ to solve:

$$\max_{I_\tau} \mathbb{E}_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left\{ Q_t I_t - [1 + \tilde{f}\left(\frac{I_\tau}{I_{\tau-1}} \right) I_\tau] \right\}.$$

where the adjustment cost function $\tilde{f}$ captures the cost of investors to increase their capital stock:

$$\tilde{f}\left(\frac{I_\tau}{I_{\tau-1}} \right) = \frac{\eta}{2} \left(\frac{I_\tau}{I_{\tau-1}} - 1 \right)^2 I_\tau.$$

η is the inverse elasticity of net investment to the price of capital. The solution to the decision problem of the investors yields the competitive price of capital:

$$Q_t = 1 + \Big(\eta \frac{I_\tau}{I_{\tau-1}} \Big(\frac{I_\tau}{I_{\tau-1}} - 1 \Big) + \frac{\eta}{2} \Big(\frac{I_\tau}{I_{\tau-1}} - 1 \Big)^2 - \eta \Lambda_{t,\tau} \frac{I_{\tau+1}^2}{I_\tau^2} \Big(\frac{I_\tau}{I_{\tau-1}} - 1 \Big) \Big).$$

Profits. Firms' nominal profits are: $Prof_t(i) = P_t(i)Y_t(i) - W_tP_tL_t(i) - Z_tP_tK_t(i)$. Using (E.1) and (E.2) we get $W_tP_tL_t(i) = P^{nom}_{m,t}(i)(1-\alpha)A_tY_t(i)$ and $Z_tP_tK_t(i) = P^{nom}_{m,t}(i)\alpha A_tY_t(i)$, We then can write real profits as: $\frac{Prof_t(i)}{P_t} = \frac{P_t(i)}{P_t}Y_t(i) - P_{m,t}Y_t(i)$.[24]

Aggregation. Total profits of non financial firms are equal to the sum of profits earned by intermediate good firms:

$$Prof_t = \int_0^1 Prof_t(i)di.$$

Under standard arguments and using that supply should equal demand in all markets: $\int_0^1 N_t(i)di = N_t$, $\int_0^1 K_t(i)di = K_t$, we get that total profits of the firms are:

$$Prof_t = Y_t - W_tL_t - Z_tK_t. \tag{E.3}$$

Appendix F Robustness: Effect of Policy Rate Specification

This section enhances the robustness of the policy rate specification discussed in Section 4.2 for the main results presented. It demonstrates that the findings from the main text, where the nominal rate remains constant for four quarters, hold under two alternative specifications: a free floating rate and a constant policy rate for eight periods. In the main text, Figures 3 and 4 illustrate the impact of QE shocks on aggregate economic variables and inequality measures when the policy rate is unchanged for four periods. This approach captures the fact that central banks refrain from adjusting the policy rate during QE due to the effective lower bound. Consequently, the consumption of optimizers increases immediately after a QE shock, influenced by intertemporal substitution effects resulting from this particular specification.

Figure 9 presents the responses of the same variables as in Figure 3 for the two policy rate specifications. When the policy rate is flexible, in contrast to the main text, it rises due to the increase in inflation and output. The direction of the variables' responses is qualitatively similar to Figure 3, except for aggregate consumption, which decreases as the real rate increases in this case. Output peaks at below 2% increase, compared to 2.5% in the main text, due to the contractionary effect of the policy rate. The responses of the remaining variables are also more moderate than in the policy rate specification used in the main text. In the second case, where the policy rate does not follow the Taylor rule for eight quarters instead of four, the stimulative effects of QE are reinforced, as evidenced by the increase in output and investment after the QE shock.

Figure 10 complements the analysis presented in Figure 4 of the main text by illustrating the consumption and income responses of the two agents under the two policy

[24] In Gertler and Karadi (2011) firms derive revenues from selling their good and selling the undepreciated portion of the physical capital back to the capital producers. Therefore profits are $Prof_t = P_t(i)Y_t(i) + Q_t(i)(1-\delta)K_t(i) - W_tP_tL_t(i) - R_{k,t}Q_{t-1}(i)K_t(i)$. Substituting $R_{k,t}$ from (13) we get the same equation for aggregate real profits as in (E.3).

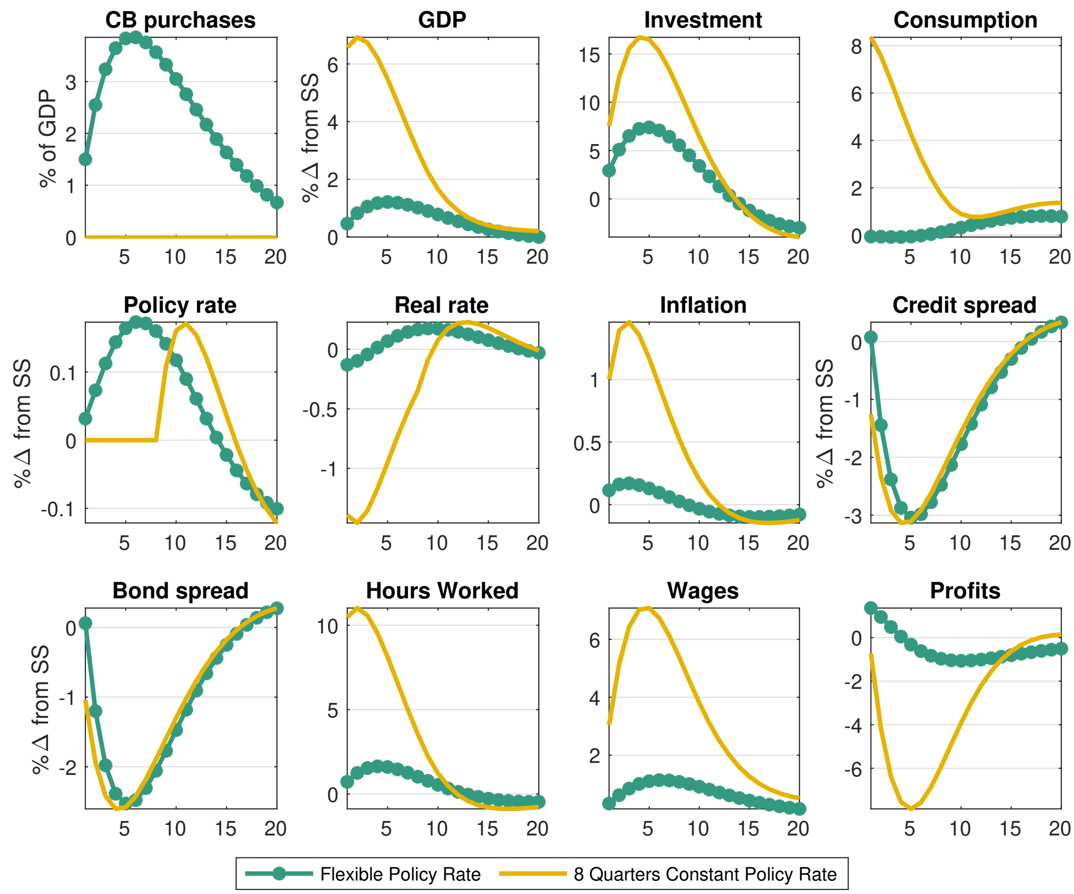

Fig. 9. Government Asset Purchase Shock. Flexible and Constrained Policy Rate

rate specifications discussed earlier. In the case of a flexible policy rate, the notable difference from the main text is that, as a result of the policy rate increase, the consumption of optimizers now decreases on impact due to intertemporal substitution effects. This reduction in savers' consumption would further contribute to a decrease in consumption inequality. However, the increase in consumption by rule-of-thumb agents is smaller compared to the main text, resulting in a similar magnitude of reduction in consumption inequality. Regarding consumption and income inequality, the responses exhibit the same directionality as in the main text. In the second case, where the constant policy rate is maintained for a longer period, the stimulative effects of the lower real rate lead to increased consumption and income for a longer duration, resulting in a more pronounced reduction in consumption and income inequality.

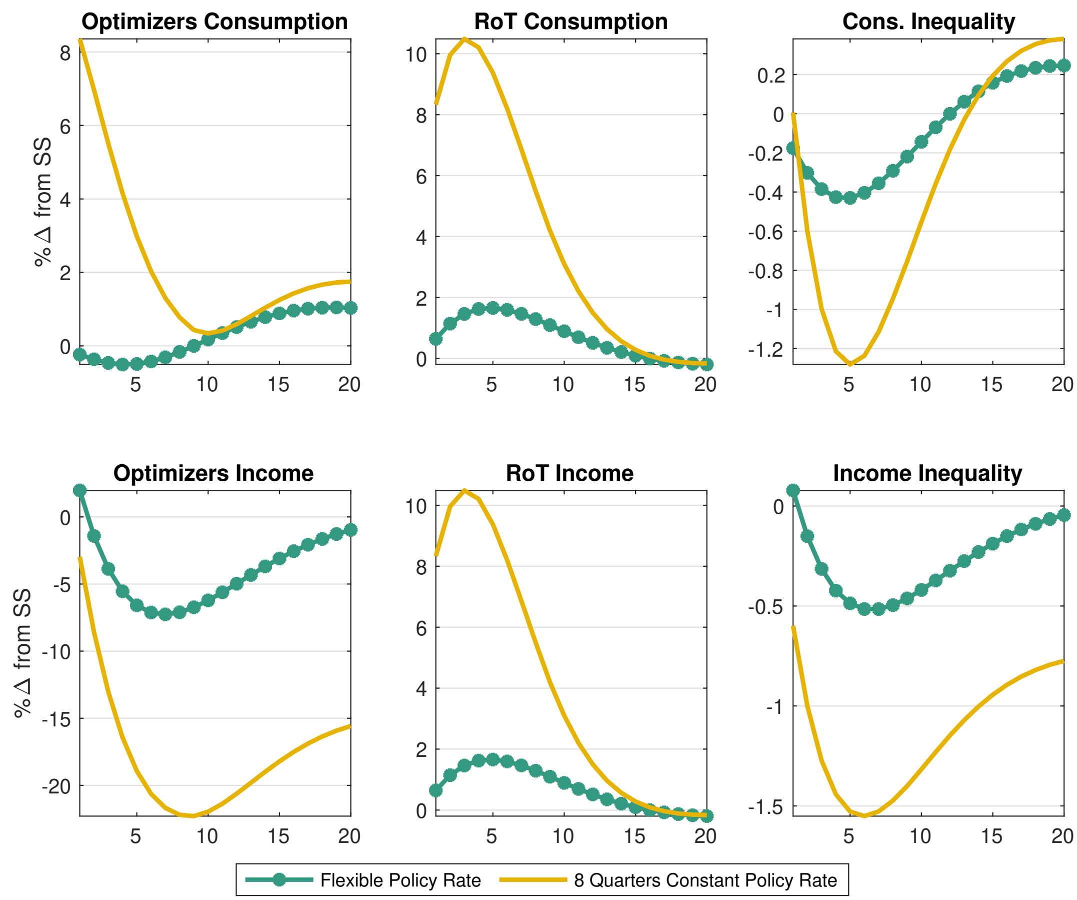

Fig. 10. Government Asset Purchase Shock. Flexible and Constrained Policy Rate