Asset Purchases, Limited Asset Markets Participation and Inequality

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May 2023

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

*Corresponding email: stylianos.tsiaras@epfl.ch. I would like to thank Cristiano Cantore, Edouard Challe, Andrea Colciago, Russel Cooper, Martin Kaae Jensen, Luisa Lambertini, Paul Levine, David Levine, Ramon Marimon, Ricardo Nunes, Romanos Priftis and Morten Ravn for their valuable feedback and discussions and also participants of the T2M 2022, CRETE 2022, Conference in honor of Ramon Marimon at EUI, Econometric Society Winter Meetings 2020 & 2021, the EEA - ESEM Congress in 2021, the Spring Meeting of Young Economists 2021 and seminar participants at the HEC Lausanne, University of Alicante, Ecole Polytechnique Fédérale de Lausanne, Bank of Latvia and the Joint Research Centre at Ispra.

1. Introduction

Asset purchase programmes following the Great Recession and the ongoing 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) and which has gained the media attention is whether and to what extent these programmes have contributed to an increase in inequality.[1] In this paper, I analyse the impact of QE on households' inequality empirically and also using a state of the art quantitative macro model with household heterogeneity in financial holdings and financial frictions. Both the empirical and the structural specifications show that a QE programme is expansionary and reduces inequality in the Euro Area (EA).

Figure 1 shows the income inequality index for the the Euro Area using data from the Standardized World Income Inequality Database (henceforth SWIID), Solt (2020).[2] The income inequality is proxied by the Gini Index. The higher the value of the index, the higher the income inequality. Income inequality in the Euro Area has been growing steadily since the beginning of the currency union, until the end of 2016. In 2016, a year after the Asset Purchase Programme by the ECB had been initiated, income inequality declined. In this paper, I am looking on whether the ECB's QE programme has contributed to the reduction of income inequality in the EA.

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) (GLV hereafter) and banks are modelled similarly to Gertler and Kiyotaki (2010): a costly enforcement problem creates a leverage constraint on the intermediaries. QE induces more lending through relaxing the leverage constraints of the 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 where central bank purchases of government bonds financed by reserves create direct and indirect effects for the households affecting differently those with and without access to financial markets. QE-induced effects are possible in this setting due to the existence of the banker's leverage constraint which eliminates the perfect substitutability of assets and leads to QE non-neutrality.[3]

I show that the indirect (i.e general equilibrium) effects outweigh the direct effects

[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). See also Sargent and Smith (1987); Chamley and Polemarchakis (1984); Eggertsson and Woodford (2003); Curdia and Woodford (2010).

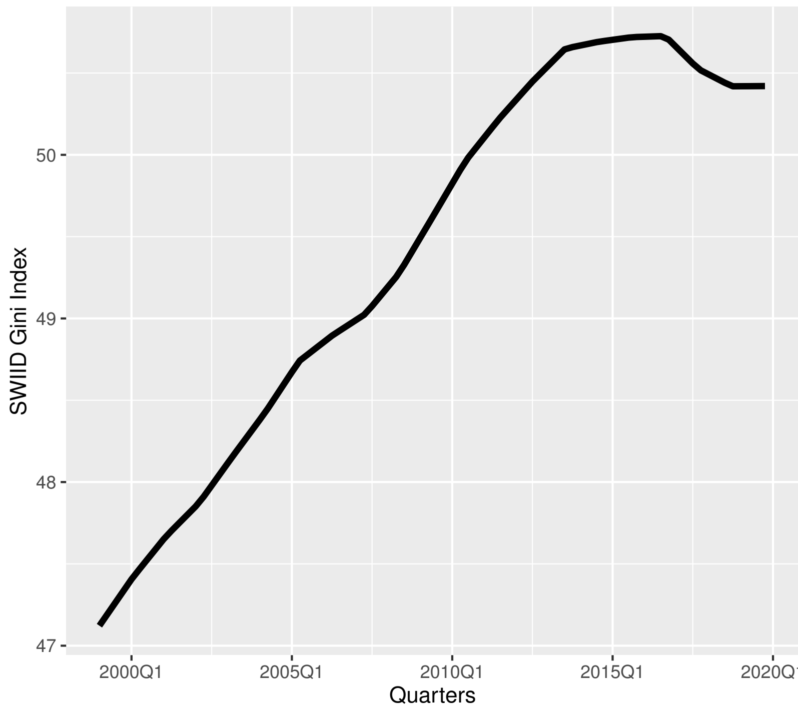

Fig. 1. Income Inequality Index for the the Euro Area

(i.e. asset price increase and reduction in credit and bonds spreads) for the two consumer types, leading to a reduction in income and consumption inequality. Consider an increase in the bond holdings of the central bank in an economy with two types of consumers, agents with a multi-asset portfolio and hand to mouth, financially constraint, consumers. A following increase in asset prices benefits the bond holders but the reduced interest returns harm their portfolios. Furthermore, reserves' interest rate receivable would be much lower than the risky assets they held. I show that the interest rate differential channel dominates and savers' income falls after a QE policy. At the same time, the indirect effects from wage increases post-QE benefit the hand to mouth consumers whose income is their labour compensation. This leads to a reduction in income and consumption inequality between the two income groups.

To elaborate more on the asset holders' income negative response, I provide the decomposition of their income to its three components: assets, profits and labour. While labour and profit income increase, asset income reduces due to the lower coupon received. Given the asset income's substantial contribution to the total income, it makes the income to decrease substantially and leads to an lower 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. Here, I show that the benefits are not only offset but outweighed by the lower returns. Therefore, income and consumption inequality responses, due a QE programme, are countercyclical. This is in line with the response of inequality after a policy rate cut, empirically examined by Coibion, Gorodnichenko, Kueng, and Silvia (2017) for the US and Samarina and Nguyen (2019) for the Euro Area. Bilbiie, Kanzig, and Surico (2021) in a simple model with heterogeneity and capital also agree with these findings.

Asset holdings heterogeneity in the model is introduced by limited asset markets participation (LAMP). This incorporates two relatively recently explored data facts on the asset composition and the consumption smoothing of the households. Empirical literature shows that a large fraction of households consumption plans can be tracked almost exclusively by their income.[4] In the Euro Area, about 20% to 30% of the population can be characterized as hand to mouth consumers; they hold a total value of financial assets that is close to zero. In Appendix A, I present, using the Eurosystem Household Finance and Consumption Survey, the EA households' financial assets distribution that verify this number. Almgren, Gallegos, Kramer, and Lima (2022) provide a similar estimate.

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). To identify the QE policy surprises, I make use of the Euro Area Monetary Policy Event Study Database (EA-MPD) by Altavilla, Brugnolini, Gürkaynak, Motto, and Ragusa (2019) and use the QE factor as external instrument. Using Euro Area data and the SWIID Gini of disposable income, I show that a QE shock is expansionary and redistributive. The DSGE model manages to capture competently the empirical responses from the SVAR providing a similar magnitude of the inequality and macroeconomic variables' responses to a QE shock.

Related Literature. This study contributes to the fast-growing literature of unconventional monetary policy; precisely to three strands: on models of households heterogeneity with financial frictions, on impact effects of QE to inequality and on the external instrument SVARs.

Galí et al. (2007) (GLV) firstly introduced a two-agents NK framework to study the effects of government spending on consumption. More recently, Kaplan, Moll, and Violante (2018), develop Aiyagari-type heterogeneous agent frameworks with New Keynesian nominal rigidities (HANK) making the characterization and study of the full income and wealth distribution feasible.[5] As shown by Debortoli and Galí (2017), a two agents framework is able to identify differences in average consumption *between* the constrained and unconstrained agents but is less effective in characterising consumption heterogeneity *within* the subset of unconstrained households. Since the main focus of this paper is on the interactions between the two types of agents, it suffices to use a less rich setting of heterogeneity and build on the GLV framework.[6]

[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.

[5]See also McKay and Reis (2016), Acharya and Dogra (2020) and Ravn and Sterk (2021).

[6]Studies using a TANK framework also include Monacelli (2009), Bilbiie, Monacelli, and Perotti (2013), Colciago (2011), Ascari, Colciago, and Rossi (2017) and Galí, López-Salido, and Vallés (2004).

The paper borrows also from the financial frictions literature. A post-crisis revival was originated by Gertler and Kiyotaki (2010).[7] A costly enforcement problem limits the ability to arbitrage across the deposit, bond and credit markets.[8] This paper, to my knowledge, is the first one that adds financial fictions à-la Gertler and Karadi (2011) in a model with limited asset markets participation and analyses the real effects of QE on inequality and aggregate demand.

The present paper provides also empirical evidence on the procyclicality of profits. Broer, Harbo Hansen, Krusell, and Öberg (2020) and Cantore and Freund (2021) are two studies that identify the importance of the procyclicality of profits in a TANK model. In the modelling part, I include nominal wage rigidities such that profits in the model are procyclical as shown in the data.

This paper is also closely related to the literature on the distributional effects of monetary policy. The seminal paper in this fast growing literature, Coibion et al. (2017), focuses on the impact of conventional monetary policy in the US and shows that inequality decreases after an interest rate cut. Most empirical studies agree that the QE effects benefit mostly the lower end of income distribution in line with this paper's results. Bilbiie et al. (2021) in a HANK model with capital, but without a banking sector, find also that income and consumption inequality are countercyclical. Empirical studies by Bunn, Pugh, Yeates et al. (2018) using UK data and Bivens (2015) also concur on the relatively greater effect on lower income households. Lastly, focusing on the variation in the level of financial asset holdings Krenz and Tsiaras (2023) use a SVAR to analyse the effect of a common Euro Area QE shock to the different members of the Eurozone that differ in their asset market participation. Results can vary substantially depending on the level of financial income.[9]

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 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 agree with the present paper towards the reduction of income inequality after an identified 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) are the studies this

[7]For a comprehensive literature review see Brunnermeier, Eisenbach, and Sannikov (2013).

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

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

paper is more closely related to. Hohberger et al. (2019a) conduct a similar study where they evaluate the effects of QE on consumption and income inequality in a standard NK setting with two agents. They show that consumption and income inequality fall 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 aforementioned papers differ in many characteristics with the present study. This study is enriched with a financial sector that is the key to the QE pass-through to the real economy and thus to inequality. QE relaxes the leverage constraint of the financial intermediaries. Furthermore it is what eliminates the perfect substitutability of assets and the QE neutrality in contrast with the above papers which this occurs through exogenous portfolio costs. Lastly, this study explores the effects asset market participation heterogeneity on QE effects in two different labour market settings. To my knowledge there is no other study employing a TANK model with financial frictions and an explicit framework for asset purchases by the central bank that measures the QE effects on consumption and income inequality and the impact financial asset holdings heterogeneity has on the QE.

The plan 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 my research question, I begin by providing novel empirical evidence on identifying the impact of an expansionary unconventional monetary policy shock on inequality and the macroeconomy. I implement this in an external instrument SVAR model. Results show that QE is stimulative and redistributive by decreasing income inequality. The data is for the Euro Area aggregate level and I construct the income inequality index for the EA using the Gini coefficient reported in the Standardized World Income Inequality Database (henceforth SWIID) Solt (2020).

I employ the proxy-SVAR approach as introduced by Stock and Watson (2012). Due to the difficulty of identifying monetary shocks in the data as elaborated in Ramey (2016), this approach provides a novel way that makes use of external instruments for 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 novelty of this approach is that a QE factor can be extracted from the data and be used directly as an instrument. Using the QE factor, my methodology also resembles the high frequency identification method of Gertler and Karadi (2015).

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. 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.[10] The selection of variables follows a similar specification by Slacalek, Tristani, and Violante (2020). The VAR has two lags based on the AIC criterion.

The income inequality data comes from the Gini coefficient reported in the SWIID. I use the Gini of equivalized household market (pre-tax, pre-transfer) income. Results hold with also the post-tax, post-transfer specification. I construct an income inequality index for the Euro Area by combining all Euro Area countries' inequality data from the SWIID dataset and weighting them by the respective country GDP weights.

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.

Given that the analysis is focused on the Quantitative Easing, the instrument is used for the period 2014 to the end of the sample, which is the period QE took place in the Euro Area. I thus use the full sample 1999Q1 to 2019Q4 to estimate the lag coefficients and obtain the reduced form residuals in equation (1). Then I use the reduced form residuals for the period 2014 to 2019 to identify the impact of QE surprises (i.e the vector $\mathbf{S}$).

Estimation Methodology. The VAR has the following reduced form:

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

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 re-

[10]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.

sponses of the system to this shock we have to estimate:

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

Since I am interested to compute the impulse responses of a QE shock only, we do not need to identify and make restrictions for the full matrix $\mathbf{S}$ but only the column matrix s which is 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. I construct the instrument used for the QE shock, $\mathbf{Z_t}$, using changes in the yields of risk-free rates at different maturities, spanning one-month to ten-years, around the EA policy meetings. Data comes from the Altavilla et al. (2019) EA-MPD dataset that is continuously updated and covers the period 2002 to 2020. 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 (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.

Using tick data, they document the price 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). Based on the risk free assets' maturity type those factors load, four factors are identified: the "Target" that loads only on the short rates, "Timing",

”Forward Guidance” and the ”QE” factor that loads only in the longer-term rates.

ABGMR have estimated the factors up to 2018. I proceed by updating the monetary policy factors until 2020 using the up to date EA-MPD dataset and following the work of Gürkaynak, Sack, and Swanson (2007) and the procedures of ABGMR described above, I estimate and rotate the latent factors in the same fashion. Naturally, in my VAR exercise I use the QE factor as an external instrument for the QE surprises. Given that the rest of the dataset 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.

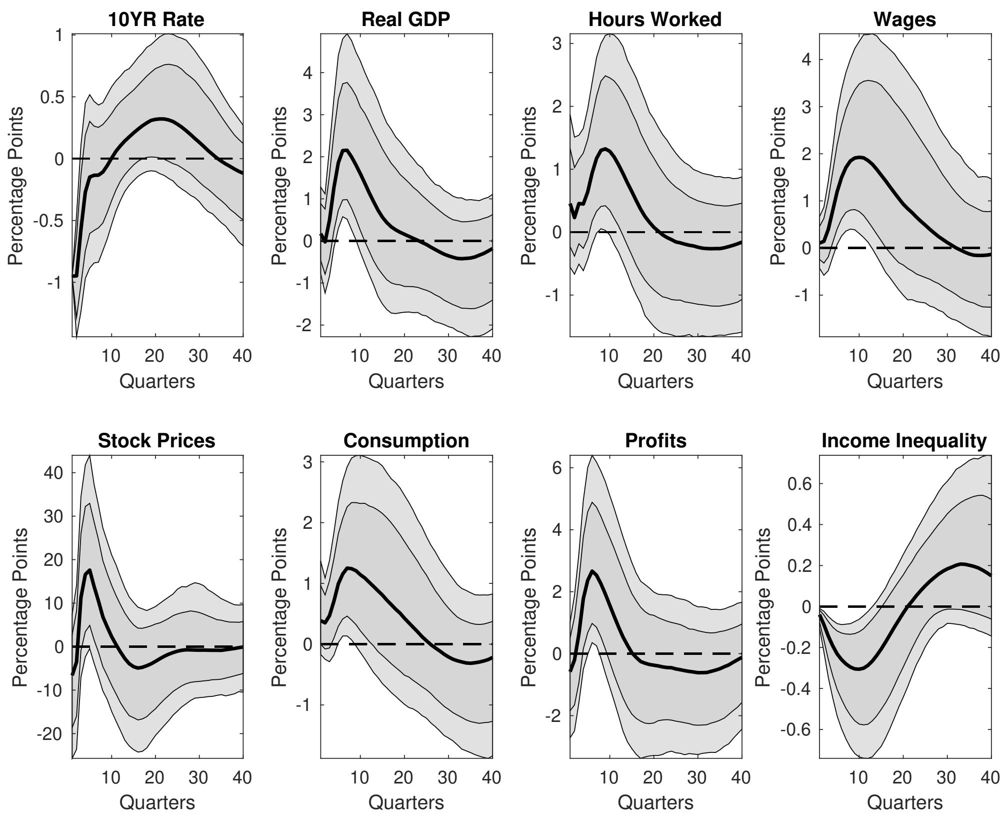

Fig. 2. Impulse Responses to a QE Shock. *Notes: The solid line shows the median responses after 50000 draws. The darker bands span the 16-84 percentiles of the draws distribution while the lighter band the 9-95 percentiles. The X axis shows the quarters while the Y axis the percent change.*

Results. Figure 2 shows the impulse responses of the 10 year benchmark rate of the Euro Area and the income inequality index, 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. For robustness, the same exercise using the Cholesky identification has been performed and is also presented in Appendix B.

The responses of macroeconomic variables to a quantitative easing shock are in line with the evidence on the topic. Following a reduction of the ten-year rate by 95 bps output increases at its peak at 2 percentage points. Output's response gradually dies out 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) in positive but insignificant.

Income inequality is affected by the unconventional monetary policy shock. After the shock, it decreases significantly by 0.3 percentage points. The response remains negative and statistically significant for two years. Then the response becomes positive but is insignificant. In terms of magnitude, the impact on income inequality is small relative to the other macroeconomic variable responses but nevertheless statistically significant. Therefore, the evidence suggests that income inequality is countercyclical after a QE shock for the Euro Area.

3. The Model

The 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. Banks can steal a fraction of their funds and return them to their families. This problem introduces an incentive constraint to be followed by the banks which eliminates the QE neutrality. Finally, the central bank performs its conventional

[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."

monetary policy under a Taylor rule, but can also engage in asset purchases and pay the investors back the same value in newly created reserves.

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.

The problem of the optimizing household is to choose $C^o_t, L^o_t, D^o_t, B^o_t, S^o_t$ in order to maximize its expected utility (2) subject to the budget constraint (3) at every period. Let $u^o_{c,t}$ denote the marginal utility of consumption and $\Lambda_{t,t+1}$ denote the optimizing

[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.

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 long-term government bonds are given by:

$$S_t^o = \bar{S}_t^o + \frac{\mathbb{E}_t \Lambda_{t,t+1}(R_{k,t+1} - R_{t+1})}{\kappa}$$

$$B_t^o = \bar{B}_t^o + \frac{\mathbb{E}_t \Lambda_{t,t+1}(R_{b,t+1} - R_{t+1})}{\kappa} \tag{6}$$

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.

I consider two labour market specifications. Under the first setting the labour market is competitive and each household chooses the quantity of hours supplied given the market wage W_t. In the second case wages are set by a labour union. Hours are demand driven by firms taking the wages as given by the union, households are ready to supply as many hours as required by the firms given the wage. Both wage specifications are analysed in section 3.2.

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

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

and a fiscal rule that taxes the profits of the optimizing households and rebates them to hand to mouth consumers.

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.

$$C_t \equiv (1-\lambda) C_t^o + \lambda C_t^r \tag{10}$$
$$L_t \equiv (1-\lambda) L_t^o + \lambda L_t^r \tag{11}$$
$$T_t \equiv (1-\lambda) T_t^o + \lambda T_t^r \tag{12}$$

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 and buy bonds from the government. 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:

$$Q_t s^B_{j,t} + q_t b^B_{j,t} + m^B_{j,t} = n_{j,t} + d^H_{j,t}. \tag{13}$$

To limit bankers' ability to save and eventually overcome their financial constraint by using own funds, following Gertler and Kiyotaki (2010) we assume the following: 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:

$$R_{k,t+1} = \frac{Z_t + (1-\delta)Q_{t+1}}{Q_t}. \tag{14}$$

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 inventive 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.

$$V_{j,t} = \mathbb{E}_t \sum_{j=1}^{\infty} (1-\sigma_B)\sigma_B^{j-1}\Lambda_{t+1} n_{j,t+1}. \tag{15}$$

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:

$$V_{j,t} \geqslant \theta[Q_t s_{j,t}^B + \Delta q_t b_{j,t}^B + \omega m_{j,t}^B]. \tag{16}$$

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 (16) 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:

$$\begin{aligned} V_{j,t-1}(s_{j,t-1}^B, b_{j,t-1}^B, m_{j,t}^B, d_{j,t}^H) = E_{t-1}\Lambda_{t-1,t} \sum_{i=1}^{\infty} \{(1-\sigma_B) n_{j,t} \\ + \sigma_B \max_{d_{j,t}} [\max_{s_{j,t}^B, b_{j,t}^B, m_{j,t}^B} V_t(s_{j,t}^B, b_{j,t}^B, m_{j,t}^B, d_{j,t}^H)]\}. \end{aligned} \tag{17}$$

Banker's problem is to maximize (15) subject to the balance sheet (13) and their constraint (16).

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:

$$\frac{A_{j,t}^B}{\theta} \geqslant \frac{[Q_t s_{j,t}^B + \Delta q_t b_{j,t}^B + \omega m_{j,t}^B]}{n_t} = \phi_t. \tag{18}$$

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:

$$\phi_t = \frac{\mathbb{E}_t \Lambda_{t,t+1} R_{t+1}}{\theta - \mathbb{E}_t \Lambda_{t,t+1}(R_{k,t+1} - R_{t+1})}. \tag{19}$$

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

$$Q_t S_t^B + q_t B_t^B + M_t^B = N_t + D_t^H. \tag{20}$$

Since the leverage ratio (19) 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:

$$Q_t S_t^B + \Delta q_t B_t^B + \omega M_t^B = \phi_t N_t. \tag{21}$$

The above equation gives the overall demand for loans $Q_t S_t$. When the incentive constraint is binding, the demand for assets is constrained by the net worth of the bank adjusted by the leverage. We can get some intuition here for what changes in the bank's constraint during the QE. No matter the security the central bank purchases, since their weights are higher than the weight of reserves ($1 > \Delta > \omega$), the exchange of securities with reserves relaxes the constraint and stimulates lending to the non-financial sector. If the constraint does not bind, then all three types of assets would have the same returns, equal to the deposit rate and QE would be ineffective.

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

$$N_{o,t+1} = \sigma[R_{k,t}Q_{t-1}S^B_{t-1} + R_{b,t}q_{t-1}B^B_{t-1} + R_{m,t}M^B_{t-1} - R_tD^H_t].$$

3.4. Central Bank, Asset Purchases and the Treasury

Central Bank. The central bank uses two policy tools. Firstly, it adjusts the policy rate according to the Taylor rule specified here below. Secondly, it can engage in risky asset purchases from households and banks. When balance sheet constraints are tight, excess returns rise. Central bank purchases relax the incentive constraint of the banks and increase aggregate demand, thus driving up asset prices.[16]

Under a QE operation, the central bank buys securities from banks and households. These can be either private assets S^G_t or bonds B^G_t. It does this by paying the assets purchased by their respective price Q_t and q_t. To finance those purchases it creates electronically reserves M_t that pay back purchases from households and banks:

$$Q_tS^G_t + q_tB^G_t = M_t.$$

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:

$$T^{CB}_t + R_tM_{t-1} + Q_tS^G_t + q_tB^G_t = R_{b,t}q_{t-1}B^G_{t-1} + R_{s,t}Q_{t-1}S^G_{t-1} + M_t \tag{22}$$

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

Monetary policy is also characterised by a simple Taylor rule. It sets the nominal interest rate i_t such as to respond to deviations of inflation and output from its flexible price equilibrium level Y^*:

$$i_t = i + \kappa_\pi \pi + \kappa_y(Y - Y^*) + \epsilon_{m,t},$$

where i is the steady state level of the nominal interest rate and $\epsilon_{m,t}$ an exogenous monetary policy shock. The relation between nominal and real interest rates is given by the Fisher equation:

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

With the addition of the central bank in the model, three agents can hold assets or bonds: Optimizing households, banks and the central bank. The total quantity of loans therefore is decomposed as:

$$S_t = S^B_t + S^H_t + S^G_t \tag{23}$$

and for the bonds:

$$B_t = B^B_t + B^H_t + B^G_t. \tag{24}$$

[16]See Araújo, Schommer, and Woodford (2015) for a same intuition under a different setting.

If we combine these identities and insert them into the balance sheet constraint of the banks we have:

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

The above constraint implies that when government purchases either loans or bonds it relaxes the balance sheet constraint of the banking sector. This can, in financial stress periods, reduce the excess returns and stimulate the economy. When this constraint does not bind and the inequality holds, asset or bond purchases made by the government are neutral. This happens due to frictionless arbitrage that characterizes the economy when the banks has no binding constraint. Wallace (1981) in his seminal paper has made use of that assumption for the neutrality theorem of the open market operations.

Equation (25) gives another insight into the asset purchase mechanism. Buying loans or bonds does not have the same impact to the loosening of the banks' balance sheet constraint. In fact, since loans have an absconding fraction of 100%, purchases of loans by the central bank relaxes the constraint more than the purchase of bonds with a coefficient $\Delta < 100\%$. Intuitively, the central bank acquiring government bonds frees up less bank capital than does the acquisition of a similar amount of private loans.

It is now easier to understand when the irrelevance theorem holds. Since the government creates as many reserves as the value of the assets purchased ($M_t = q_t B_t^G + Q_t S_t^G$), 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.

The share of the total assets that is purchased by the government follows a second order stochastic process.[17] Specifically,

$$S_t^G = \phi_{s,t} S_t,$$

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

$\phi_{b,t}$ and $\phi_{s,t}$ obey 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:

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

.

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

Proposition 1. Fiscal policy matters only through the impact of taxes (transfers) on 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 (13), the taxes aggregator and the treasury and central bank's budget constraints (22), (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 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

In this section I present the model's calibration with the Euro Area data and the results of the model regarding the impact of QE on the macroeconomy and households's 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 characteristics namely the mean of banks' leverage, lending spread and planning horizon. There are three parameters that characterise the behaviour of the financial sector in the model. This is the absconding rate θ, the fraction of entering bankers initial capital fund ξ_B , and the steady-state value of the survival rate, σ_B. I calibrate these parameters to match certain steady-state moments following the moments reported in Coenen et al. (2018) for the Euro Area. The steady-state leverage of the banks is set equal to 6, which corresponds to the average asset-over-equity ratio of monetary and other financial institutions as well as non-financial corporations, with weights equal to their share of assets in total assets between 1999Q1 and 2014Q4 according to the Euro Area sectoral accounts. Second, the steady-state spread of the lending rate over the risk-free rate, $R^k_t - R_t$ is set to 2.17 percentage points at the steady state, which is 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 equal to 5 years. These parameters are also in line with the related studies in the literature. Finally I set the fraction of bonds that can be absconded Δ to 50% targeting a steady state bond spread half to the lending spread. The absconding rate of reserves ω is set to zero. Similarly to

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%-40%	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

Sims and Wu (2021) I assume that they are fully recoverable by depositors in the event of bankruptcy. Since they are in essence central bank money, the central bank has full control on them.

Regarding the bond market, the long term target of the real bonds supply is set to 70% of GDP. The fraction of long-term bonds held by banks is 25% which is consistent with the sovereign debt holdings of the banking sector in the Euro Area. This leaves the rest 75% of the bond holdings to the optimizers' portfolio. The fraction of shares held by optimizing households is 50%.

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 here as well. ϵ has a crucial role on the results of the paper following next.

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. Finally, monetary policy parameters: the inflation and output gap coefficients in the Taylor rule and the interest rate smoothing parameter are also set in line with the NAWM.[18]

Given the data from the Eurosystem Household Finance and Consumption Survey, the share of rule of thumb consumers is set to $\lambda = 0.20$. As outlined in the introduction, the bottom 20% of the Euro Area households' distribution hold essentially no net worth at all. This parameter value is in line with the estimates of Slacalek et al. (2020) and Almgren et al. (2022).[19] The profits' tax rate in the baseline scenario are assumed to be 0%. In the Appendix, I show the results when the parameter takes values from 0% to 40%.[20]

Finally, the bond purchase (QE) shock is modelled as an AR(2) process.[21] 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

[18] 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.

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

[20] Results remain qualitatively similar under any reasonable tax rate.

[21] 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)).

out. Relative to 2015 GDP purchases increase from a 2% to almost 4% at their peak. To 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 exercise on identifying i) what was the impact of the ECB's APP programme on the macroeconomy, ii) its impact on consumption and income inequality and iii) what is the difference with an accommodative monetary policy shock, assuming that the economy is not at the effective lower bound. Finally, I provide a decomposition of the permanent agents income response to shed light on the effects of APP on their income. For high levels of asset markets participation, as it occurs in the calibrated model, the two specifications offer qualitatively similar results. The model is solved non-linearly following Lindé and Trabandt (2019).

Central Bank Bond Purchases and Conventional Monetary Policy. How do a bond purchasing programme similar to the APP and an expansionary monetary policy shock that produces a similar output increase affect the main macro variables? Figure 3 plots these dynamics for output, consumption, investment, inflation, hours worked, profits and a series of interest rates and spreads. The bond purchase shock is modelled as a second-order autoregressive process, similarly to Gertler and Karadi (2013), calibrated to mimic the APP programme of the ECB. The monetary policy shock is set such that it produces the same increase in output 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 to follow the Taylor rule of the central bank. This simulates the inability of the central bank to use conventional monetary at times is forced to use unconventional measures.[22] In the Appendix, I provide robustness analysis which shows that results hold for the case of i) fully flexible and ii) constant for eight quarters. In bold lines, the responses of a bond shock reflect the responses of a conventional interest rate reduction.

Bond purchases stimulate the economy and increase output as Figure 3 shows. In the case of QE the main mechanism works through the loosening of the banks' leverage constraint. Central bank intermediation increases asset prices Q_t and this leads to an increase in banks' valuation (net worth). Standard financial accelerator effects lead to a further increase of capital price and an economic upturn. An increase in the bonds' prices drives banks to buy more assets which leads to an increase in assets' prices. Excess returns reduce for both securities as can be seen in the graph and it is much more substantial for the QE case. This is because it directly affects the banks' financial constraint. The economic upturn also affects the real economy due to the higher demand for employment and therefore wage and hours worked increase. Nominal wage rigidi-

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

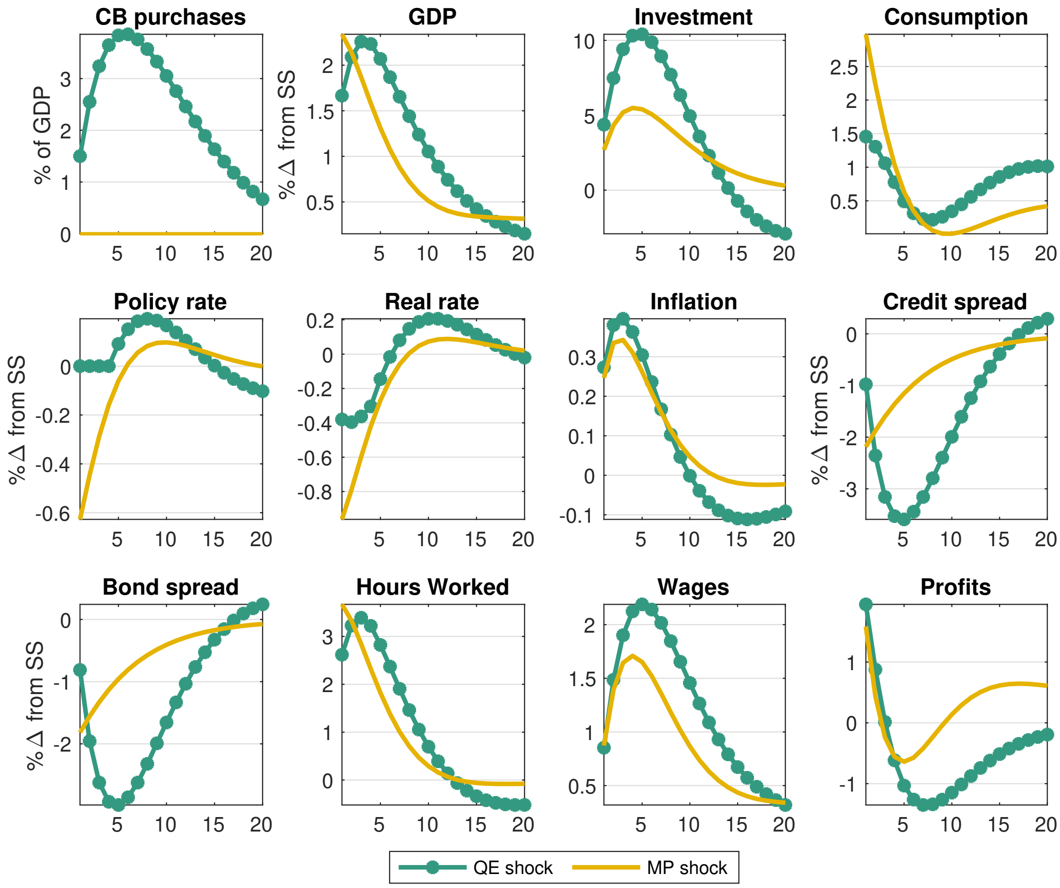

Fig. 3. Government Asset Purchase Shock and Conventional Monetary Policy Shock

ties reduce the variability of the marginal costs and after the expansionary shocks and induce profits to respond procyclically similarly to the empirical evidence on section 2 and in contrast with the simple NK frameworks where profits are countercyclical. Finally, in both cases, the real rate drops while in the monetary policy shock case it does by much more. This, together with the expansionary effect of the shocks induces a positive response of the aggregate consumption.

Overall, responses are qualitatively similar for both conventional and unconventional monetary policy shocks. Excess returns of the bonds and loans decrease more in the QE and this has an impact on the inequality measures shown next.

Income and Consumption Inequality. Figure 4 shows the responses of income and consumption of the two income groups as well as the relative inequality measure for both variables after a QE and MP shock. Consumption (income) inequality are defined as the optimizers' consumption (income) over aggregate consumption (income).

After an expansionary monetary shock, consumption increases for both agents. Rule of thumb agents' consumption strictly follows the labour income path which in both

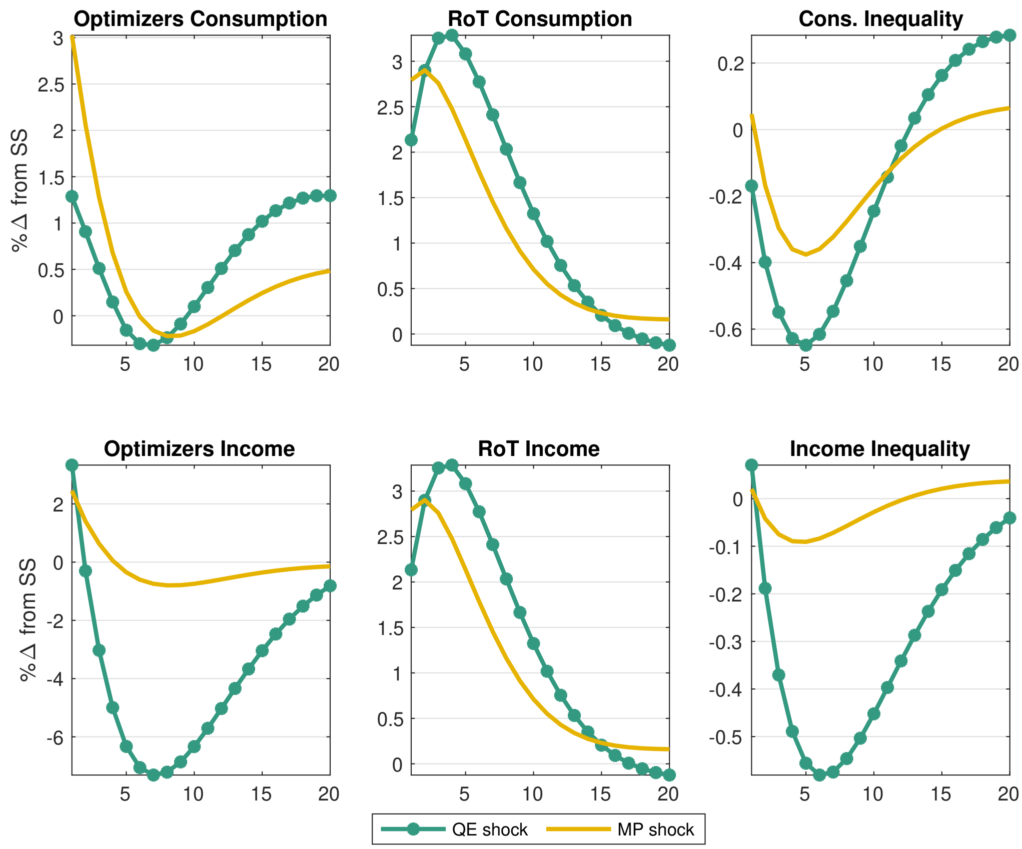

Fig. 4. Government Asset Purchase Shock and Conventional Monetary Policy Shock: Inequality

cases it goes up due to the increased demand for labour. Optimizer's consumption increases on impact but responds also through the intertemporal substitution channel. Notice that were the nominal interest not constant for the first four periods, consumption of the optimizing agents would have been decreasing (see Appendix) since nominal interest rates would go up following the Taylor rule specification. Through the standard intertemporal substitution mechanism the optimizing agents would have lowered their consumption. Both consumption responses lead to a reduction in consumption inequality between the two income groups. This is in line with the well established fact that hand to mouth consumers have a higher marginal propensity to consume than the financially unconstrained agents (Auclert (2019), Kaplan et al. (2018) among others).

The second row of Figure 4 shows the income responses of the two agents. Rule of thumb agents' income, following the labour income path, increases which leads to a rise in their consumption schedule. On the other hand, optimizers' income decline and the effect is much stronger in the case of the QE shock. The reasoning of the latter is the following: following a QE shock, optimizers reduce their bond holdings as shown in their demand function for bonds (6) as excess bond returns fall. This has a negative impact on their balance sheet since they lose from the *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. Due to the exchange of bonds to reserves, and not just the coupon receivable reduction as in the conventional monetary policy shock case, the income reduction is much more amplified in the case of the QE shock relative to the one of the conventional monetary policy shock. Therefore, the two agents' income responses lead to a fall in income inequality for both accommodative policies while it is more amplified in the QE case due to the higher excess returns loss.

The substantial reduction of the permanent agents income after the QE shock could also had been a result of a change in profit, labour or asset income. To demonstrate that it is due to the asset income reduction, figure 5 shows on its left column the income component responses and on its right column the relative contribution of each component to the total income. This is done for the cases of both QE and MP shocks. For both shocks, the labour income of the optimisers goes up while profits increase as well on impact. After the QE shock, the asset income case increases on impact due to the price valuation effect of the assets and it drops substantially at about 8% below it's steady state value due to the lower coupon returns and the exchange of bonds with risk-free reserves. At the case of the MP shock, the asset income increases due to the valuation effect and then drops as the price of the assets return to the steady state value but the interest rates are still low.

To quantify the contribution of each income component the right column of figure 5 shows the decomposition of the optimiser's income response to its components: asset, labour and profit income.[23] This shows how would income would deviate from its steady state if only the component shown was reacting endogenously and the rest were at their steady state value. For both cases the optimiser's income is mostly determined by the variations in the asset income with small contributions from the labour and profit income. Therefore, and with a must stronger effect in the case of the QE shock, a reduction in the asset income is the one that causes the reduction in the total income of the optimising agent.

Lastly, the fact that the income of asset holders and non assets holders move in opposite directions in response to a QE shock is also documented by 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. Lenza and Slacalek (2022) show that in response to a QE shock in the Euro Area the income of the lower part of the distribution increases substantially while the income of the right end of the income distribution decreases on impact, similarly to this study, but then remains mostly unchanged. This is most likely a result of the housing effect which is absent in this model, but present in their study, given the further com-

[23]The decomposition of the income to each component contribution is done similarly to Kaplan et al. (2018).

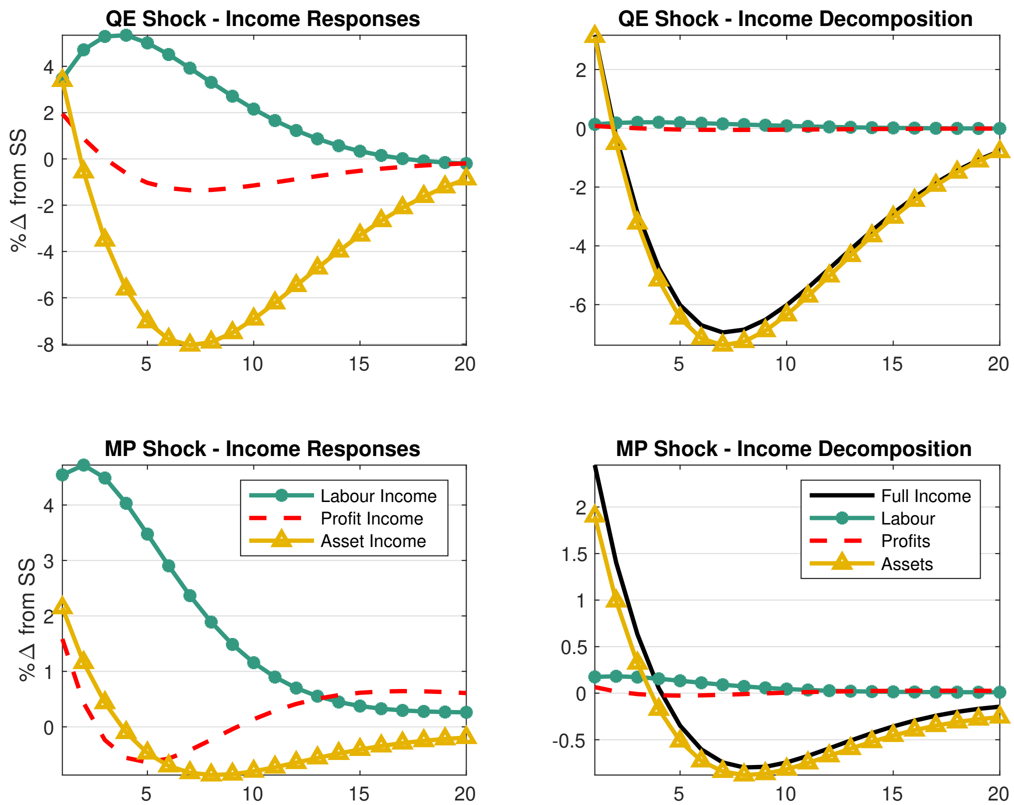

Fig. 5. Optimisers' Income Components Responses and Income Decomposition

plexity and could be considered in a future study. 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. Still, 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 estimate of this study can be thought as a lower bound of the optimisers' income response.

5. Conclusion

Asset purchase programmes following the Great Recession were employed extensively, while the recent Covid-19 pandemic urged central banks to expand further their balance sheets to ease the market turmoil. In this paper, I provide novel evidence, using both a structural and an empirical specification, on how QE affects inequality and the macroeconomy in the Euro Area. Results show that QE reduces inequality and it is expansionary. Overall, the indirect effects of QE outweigh the direct effects and agents that do not own financial assets benefit relatively more, leading to a reduction in inequality.

I build and calibrate a state of the art New Keynesian DSGE model for the Euro Area economy 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 through a high frequency approach. Results from the empirical specification and the DSGE model, that captures well the SVAR results, show that QE is stimulative and reduces income and consumption inequality in the EA.

The main economic intuition behind the inequality reduction is as follows. Consider an increase in the bond holdings of a central bank in an economy with two types of households, bond holders and hand to mouth. The outcome of this operation has direct and indirect effects. The direct effects, namely the reduction of the interest rates and the asset price increases would harm and benefit the bond holders respectively. On the other hand, the indirect or general equilibrium effects such as the employment level and real wage increases benefit both household types. I show that after a QE shock there are two reasons for 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. Together, the general equilibrium effects of a bond purchase scheme are stronger than the the asset price valuation effects and benefit relatively more the hand to mouth households. This leads to a reduction of income and consumption inequality.

Arguably, a substantial limitation of this 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 on top of 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

I restrict attention to the first wave of the Eurosystem Household Finance and Consumption Survey data conducted mainly in 2009 and 2010 in order to abstract from the effects of the 2008 financial crisis. Also, the survey was performed well before the start of ECB's QE in March 2015. Nevertheless, the results are similar for the subsequent waves. The data has been collected from 15 Euro Area member states for a sample of more than 62,000 households.

Figure 6 reports the distribution of financial and real asset holdings of the Euro Area residents.[24] As the Figure shows, 20-30% of the Euro Area households hold a total value of financial assets that is close to zero (green bar). In comparison all percentiles of Euro Area households hold substantial values of real assets (yellow bar). Naturally, this leads to the question on how QE will affect those that have financial asset holdings in comparison with those that do not.

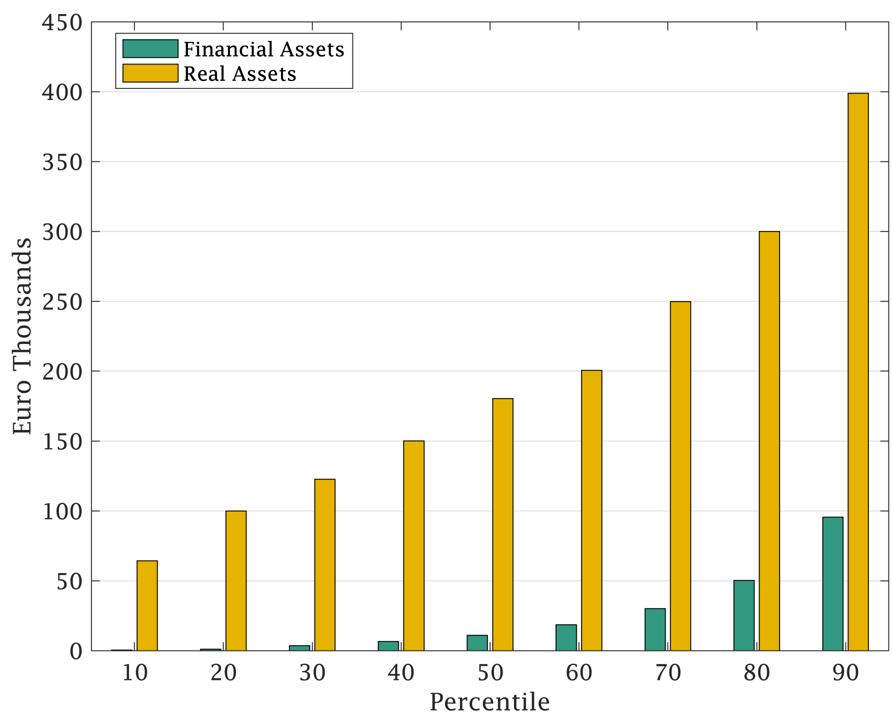

Fig. 6. Total Financial and Real Assets among EA Households

[24]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.

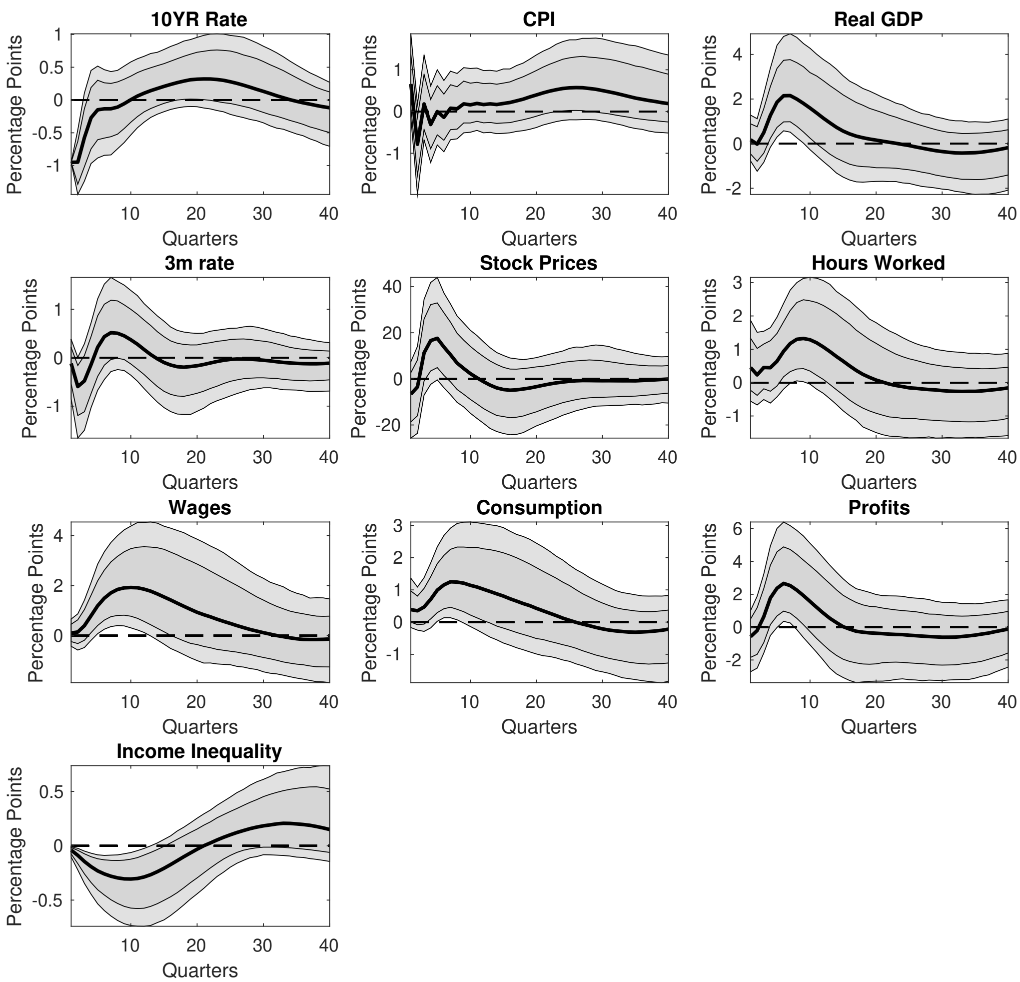

Fig. 7. Impulse Responses to a QE Shock: All Variables.
Notes: The solid line shows the median responses after 50000 draws. The darker bands span the 16-84 percentiles of the draws distribution while the lighter band the 9-95 percentiles. The X axis shows the quarters while the Y axis the percent change.

Figure 8 shows 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 give 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.

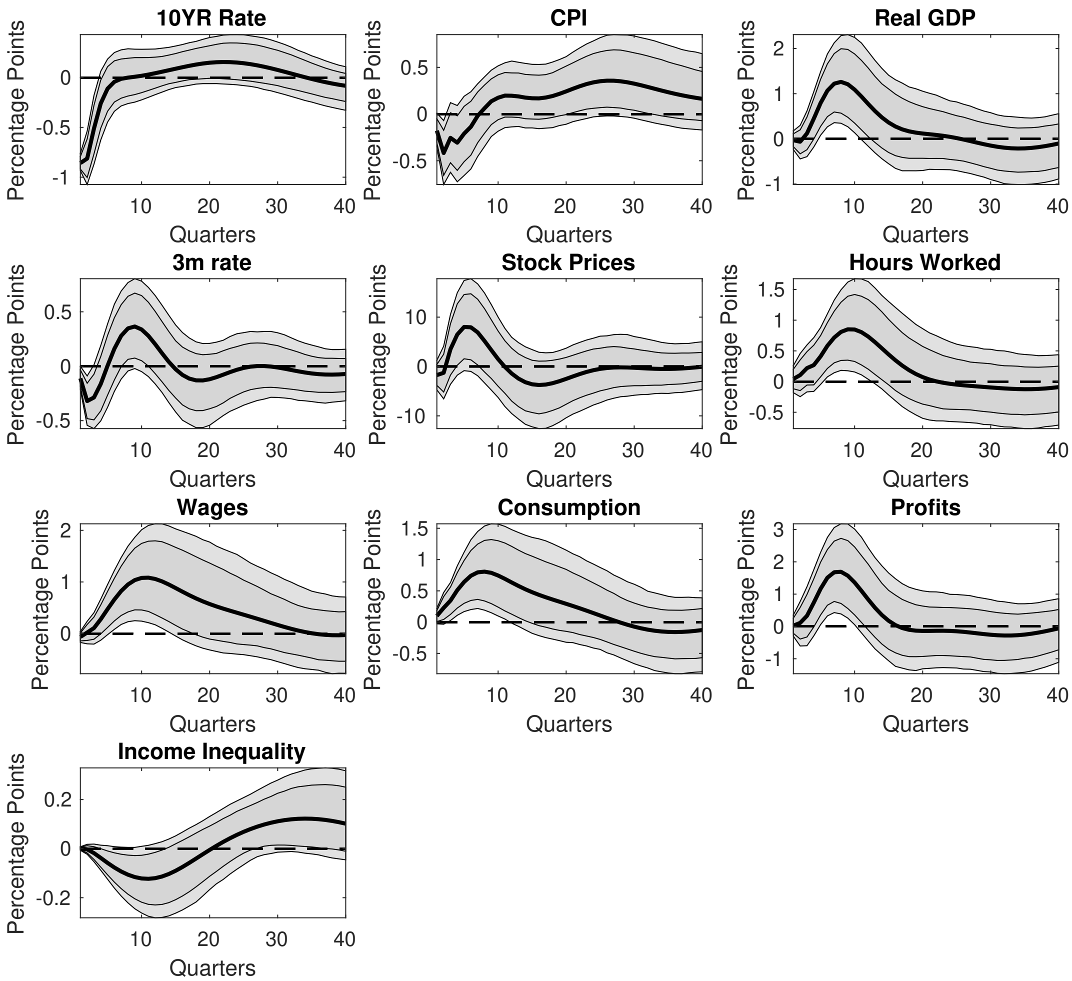

Fig. 8. Impulse Responses to a QE Shock with Cholesky Identification.
Notes: The solid line shows the median responses after 50000 draws. The darker bands span the 16-84 percentiles of the draws distribution while the lighter band the 9-95 percentiles. The X axis shows the quarters while the Y axis the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

Appendix C Wage-Setting by Unions

The problem of the 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 (16) and the balance sheet constraint (13). Using (13) 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.

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

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:

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

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 (17) 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:

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

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:

$$\min_{K_t(i),L_t(i)} P_tW_tl_t(i) + P_tZ_tK_t(i)$$

subject to

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

The problem's first order conditions are:

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

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

$P^{nom}_{m,t}$ is the Lagrange multiplier of the minimization problem and the marginal cost of the firms with $P_{m,t} = \frac{P^{nom}_{m,t}(i)}{P_t}$ 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: $\frac{Prof_t(i)}{P_t} = \frac{P_t(i)}{P_t}Y_t(i) - P_{m,t}Y_t(i)$.[25]

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 Steady State

As it is shown on the main text, the rule of thumb agents will always supply constant labour hours equal to and the first order condition for labour supply the rule of thumb agents:

$$L^r = \left(\frac{1}{\chi}\right)^{\left(\frac{1}{1+\epsilon}\right)}$$

From labour hours the aggregator (11) we get the labour hours supplied by the optimizing agents:

$$L^o = \frac{L - \lambda L^r}{1-\lambda}.$$

Rearranging the optimizing agents' first order condition for labour, utilizing the fact that $U^o_c = 1/C^o$, we can get an expression between consumption of the agents and labour supply:

$$C^o = \frac{W}{\chi(L^o)^\epsilon}.$$

Utilizing the above relation and the optimal consumption path of the rule of thumb agents, the consumption aggregator (10) becomes

$$C = \lambda WL^r + (1-\lambda)\frac{W}{\chi(L^o)^\epsilon}.$$

[25] 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 (14) we get the same equation for aggregate real profits as in (E.3).

After some algebraic manipulation we end up to the total consumption coming from the demand side of the economy:

$$C = W\left[\lambda L^r + (1-\lambda)^{1+\epsilon}\frac{(L-\lambda L^r)^{-\epsilon}}{\chi}\right] \tag{F.1}$$

In addition, from the resource constraint we have:

$$C = Y - I - G - \tau_b B^G - \tau_s S^G,$$

where in a steady state $B^G = S^G = 0$. Therefore:

$$C = L\left[(1-\gamma)\left(\frac{K}{L}\right)^{\alpha} - \delta\frac{K}{N}\right] \tag{F.2}$$

To get an expression of K/L we make use of the marginal product of capital (E.2):

$$\frac{L}{K} = (\frac{Z}{A\alpha})^{\frac{1}{1-\alpha}},$$

yielding

$$\frac{K}{L} = \left(\frac{\alpha\left(\frac{\epsilon-1}{\epsilon}\right)}{R_k-(1-\delta)}\right)^{\frac{1}{1-\alpha}}. \tag{F.3}$$

Thus, combining the expressions (F.1), (F.2), (F.3) we obtain an equation depending only on parameters, calibrated values ($spread_{Rk}$) and L^k and determines steady state hours L. Having found L, using the labour hours aggregator (11) we can easily find the labour hours worked by the rule of thumb agents L^o. Thus, consumption of the optimizing agents can be pinned down. Notice that an equation between optimizers' consumption and aggregate consumption can be found by combining the first order condition for labour supply and the demand side aggregate consumption equation (F.1) and solving for W. Then:

$$C^o = \frac{C(1-\lambda)^{\epsilon}/\chi}{\lambda L^o(L-\lambda L^o)^{\epsilon} + (1-\lambda)^{1+\epsilon}/\chi} \tag{F.4}$$

Appendix G 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.

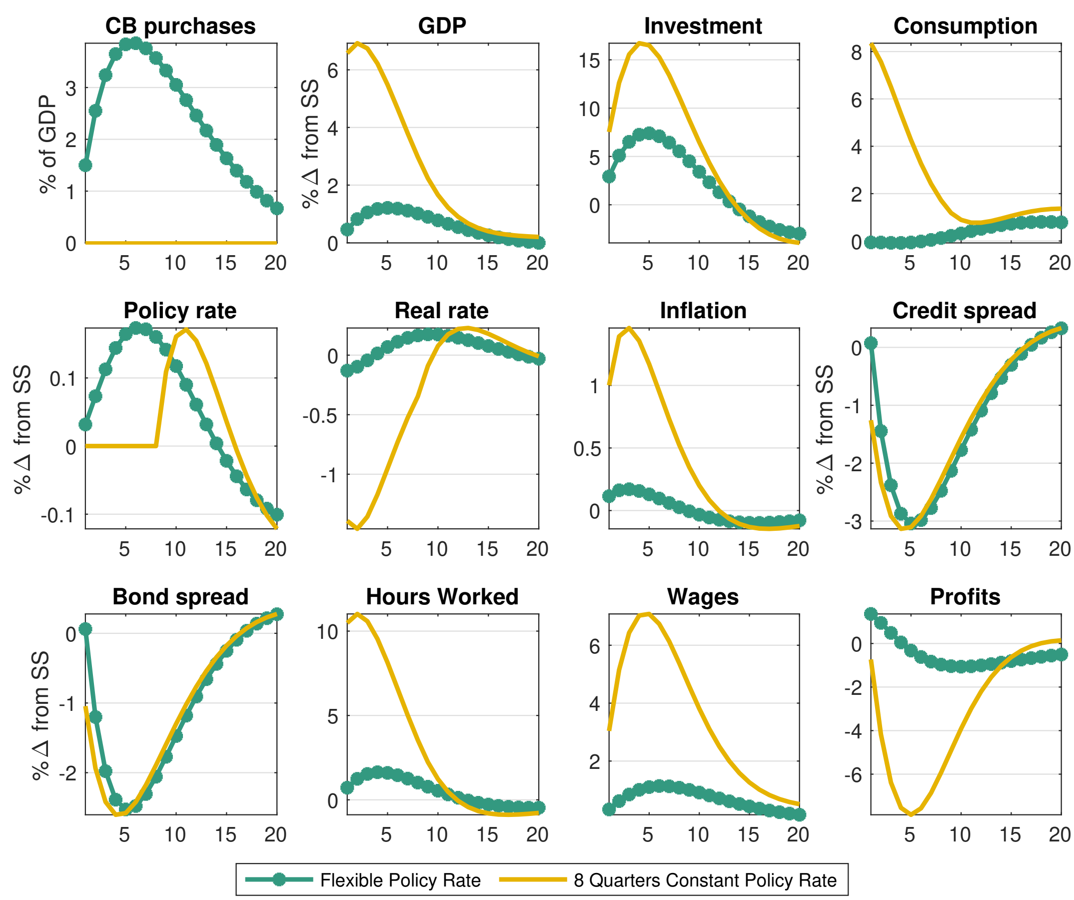

Fig. 9. Government Asset Purchase Shock. Flexible and Constrained Policy Rate

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 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.

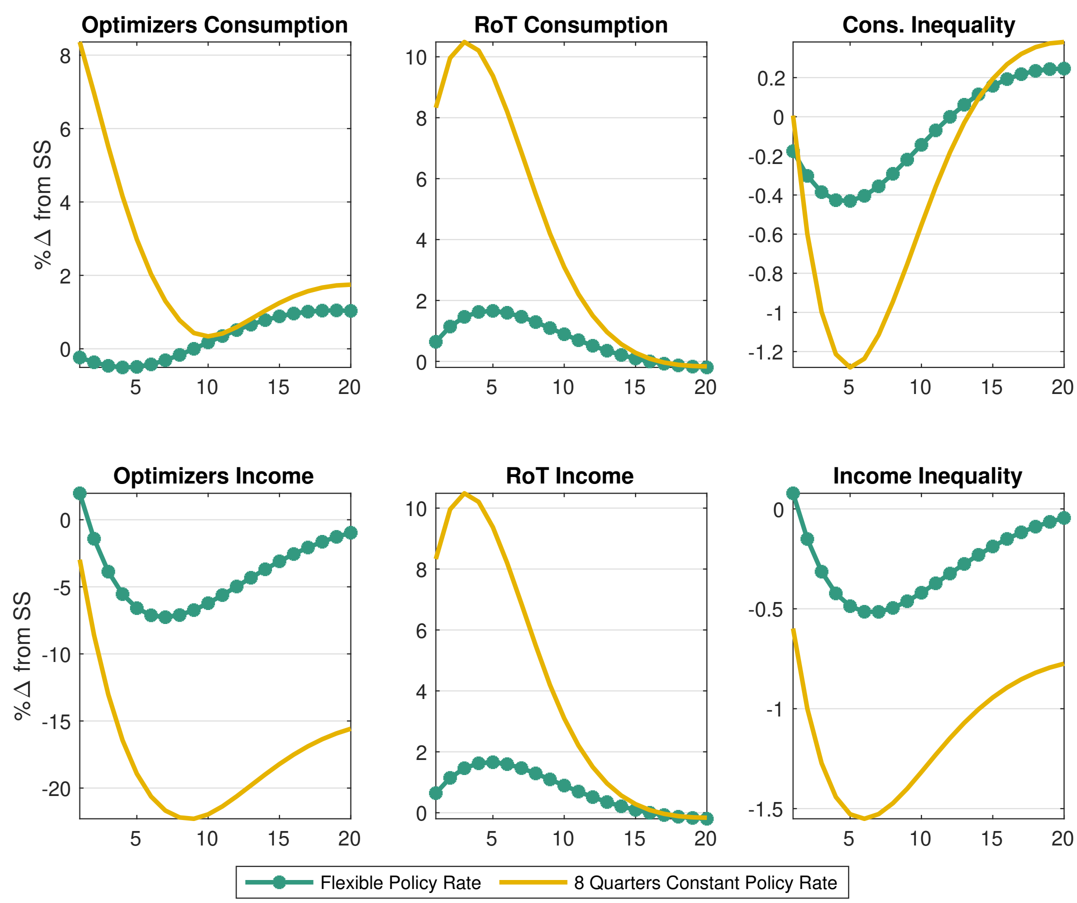

Fig. 10. Government Asset Purchase Shock. Flexible and Constrained Policy Rate