Demographic Trends and the Transmission of Monetary Policy

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Abstract

This paper studies the impact of demographic trends on the transmission of monetary policy through a novel channel: consumption heterogeneity. Older individuals devote a larger share of their consumption bundles to products with higher price rigidity, like services, so the aggregate price stickiness increases as the population ages. At the macro level, I confirm the positive relationship between U.S. states' population aging, service sector share, and sensitivity to monetary shocks. I rationalize these findings using a two-sector OLG New Keynesian model. Combining the model with population projections for the U.S., I find that demographic trends between 1980 and 2010 increased the contemporaneous response of output to monetary shocks by 6.5% and will increase it by 10% by 2050, whereas the effect on inflation is negligible. The proposed consumption heterogeneity channel alone accounts for up to 40% of the total increase in output responsiveness. Finally, age groups are heterogeneously affected by the rise in monetary policy pass-through, with younger households being the most exposed.

Keywords: Monetary policy, age structure, consumption heterogeneity
JEL classification: E31, E52, J11

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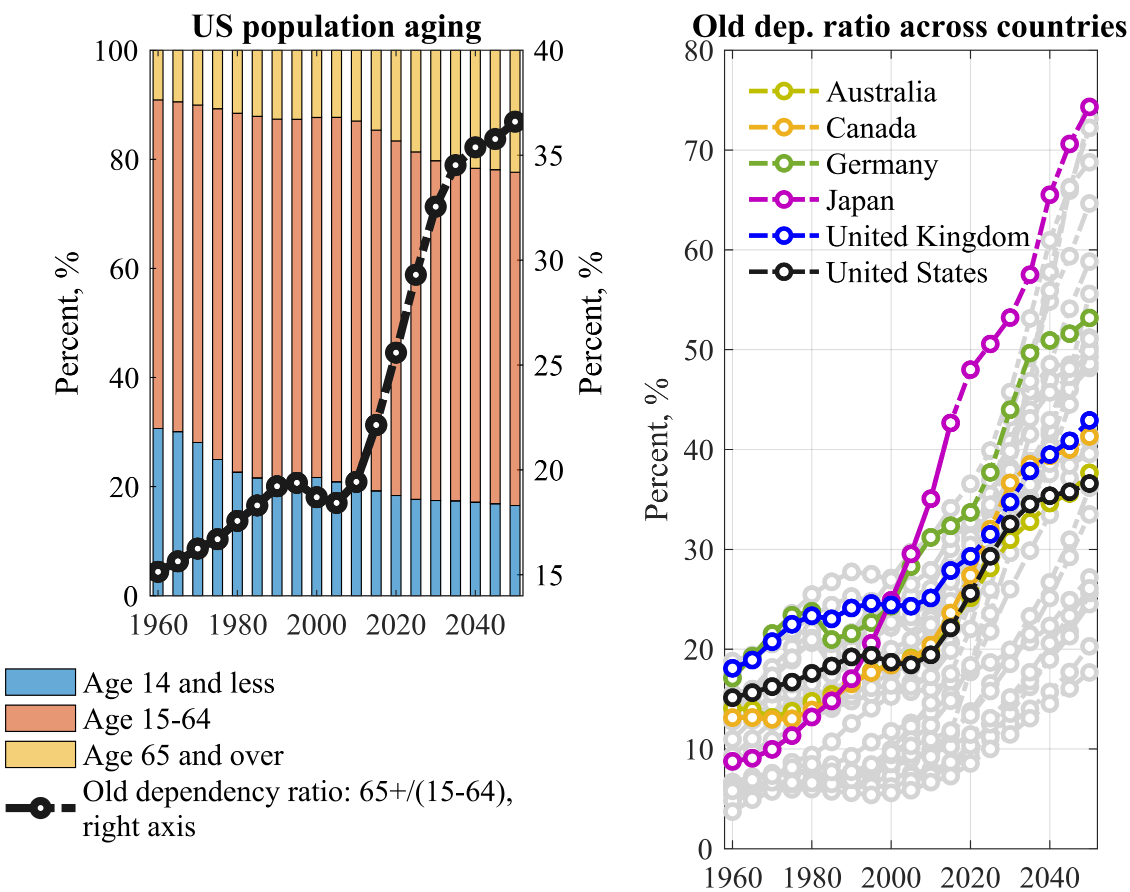
1 Introduction

The world population has aged rapidly over the past half-century. In the United States, lower fertility rates and longer life expectancies have already increased the share of retired people and reduced the size of the working population. As shown in the left panel of Figure 1, the ratio of these two groups, defined as the old-age dependency ratio, has significantly grown since 1960 and it is projected to rise even further in the following decades. The U.S. is not alone in this demographic transition. Every country is expected to experience similar demographic trends as the U.S. These trends influence many central aspects of the economy and are not limited to the pension system sustainability or labor market participation. Monetary authorities are also not immune to the effects of the changes in the population distribution. Given the magnitude and the increasing pace of these trends, it is of great importance for the monetary authorities to understand the extent to which demographic trends might affect their abilities to achieve their mandates.

Figure 1: Demographic trends



Notes: The left panel of the plot shows the age composition evolution over time for the U.S. population as well as the relative old-age dependency ratio from 1960 to 2050. The right panel compares the time series of the old-age dependency ratio across major economies. The source of the data is the World Bank Population Estimates And Projections.

This paper studies the impact of population aging on the effectiveness of monetary policy. I propose a novel channel to explain how the transmission of monetary policy might be influenced by demographic trends. Older individuals devote a larger share of their expenditures to services, and services tend to adjust their prices less often than goods. As the population ages, the relative importance of services rises leading to an increase in price stickiness. Since fewer firms can adjust their price in response to a monetary shock, output responds more strongly. Using household-level data for the U.S., I document that the negative relationship between age and the frequency of price adjustment of the consumption bundle is driven by significant differences in sectoral expenditure shares across age groups. In line with this micro evidence, I show that populating aging is accompanied by an increase in the relative size of the service sector and that the economic activity of older U.S. states is more responsive to monetary shocks. I then use a theoretical model to quantify how much of the change in the effectiveness of U.S. monetary policy from 1980 to 2050 can be accounted for by population aging.

To study the relationship between age and price stickiness, I combine household-level data from the U.S. Consumer Expenditure Survey (CEX) for the period 1982-2018 with the sectoral frequency of price adjustment computed by Nakamura and Steinsson (2008). I find that older households spend significantly more on services. The services expenditure share of households over 80 years old is 20 percentage points higher than those in their early 30s. At the same time, services adjust their prices on average every 13 months, whereas goods every 3 months. The average frequency at which the price of the consumption bundle is adjusted is heterogeneous across age groups ranging from 8.2 months for young households to almost 10 months for older households. This relationship is stable over the sample period and when controlling for other households' characteristics.

Through the lens of a standard 3-equation New Keynesian model, I evaluate how changes in price stickiness affect the responsiveness of output and inflation to monetary shocks. A decrease in the frequency of price adjustment results in a more muted response of inflation since fewer firms adjust their price, but a more substantial response of output, since firms would need to adjust their production more vigorously. However, output and inflation are not equally sensitive to changes in the price stickiness parameter. The response of output is significantly influenced by the frequency of price adjustment, whereas inflation is only marginally affected. This is due to the fact that with higher price stickiness fewer firms can adjust their price every period. Inflation responds less to shocks and also becomes less sensitive to changes in the other macroeconomic variables. Since prices cannot be adjusted, firms respond by adjusting their production more. Moreover, firms anticipate that on average they might not be able to adjust their price for a longer time period. The expectations channel results in a further increase in output responsiveness. Due to the lower sensitivity of inflation to changes in the economy, the increase in output responsiveness has only a marginal impact on the responsiveness of inflation.

The theoretical framework delivers two key predictions on how monetary policy transmission is influenced by demographic trends. An increase in the share of older individuals increases the demand for services resulting in a lower frequency of price adjustment at the aggregate level. Therefore, the first prediction is a stronger response of output following a monetary shock because fewer firms can adjust their price. The second prediction is that the response of inflation in older economies is only slightly more muted because the sensitivity of inflation to changes in the economy is lower.

I test these macroeconomic predictions by exploiting the cross-sectional variation in demographic structures and economic activity among U.S. states. I document that the share of services is positively related to population aging. I then compute the responses of state-level real GDP from the Bureau of Economic Analysis (BEA) as well as inflation rates from Hazell et al. (2022) to a monetary shock adopting a panel local projection approach à la Jordà (2005). Exogenous variations in interest rate are captured using the Romer and Romer (2004) monetary shocks series. By interacting the responses with state-level demographic structure, I confirm that the economic activity of states with a relatively higher old-age dependency ratio responds more to monetary shocks. In contrast, the response of inflation is not significantly influenced by the different age characteristics.

This empirical evidence motivates the last part of the paper, where I develop a two-sector overlapping generations New Keynesian model to investigate how monetary policy shock propagation is influenced by population aging. The model incorporates a rich demographic structure with age-specific mortality rates, labor productivity, and consumption preferences over the services and goods sectors. The sectors differ in their degree of price stickiness, and only the output from the goods sector can be stored and invested. I calibrate the model to match the realized and projected population distribution and the different sectoral preferences across age groups observed in the data.

The theoretical model is then used to answer the following questions: What is the relationship between monetary policy effectiveness and demographic trends? Are age groups heterogeneously affected by the different monetary policy pass-through induced by population aging? And to what extent does the new channel proposed in this paper contribute to changes in this relationship?

In line with the empirical evidence, the model implies that the change in the U.S. population distribution and mortality rates between 1980 and 2010 increased the contemporaneous response of output to monetary shocks but only marginally affected the response of inflation. Demographic trends alone increased the output response by 6.5% in 2010 relative to 1980 and in 2050 the response is expected to be 10% higher relative to 1980. The increase in output responsiveness is mainly driven by an increase in the sensitivity of the consumption of younger households to changes in interest rate. Moreover, I find that population aging accounts for around one-third of the total change in monetary policy effectiveness induced by the higher share of expenditures dedicated to services and that consumption heterogeneity across age groups significantly contributed to that.

Understanding how and through which channels the shifts in demographic structure influence the transmission of monetary policy shocks is crucial for policymakers and central bankers to conduct optimal monetary policy. While in the recent literature, much attention has been dedicated to studying the effects of aging on government debt and fiscal policy, the focus on the implications for monetary policy has been limited. Most of these studies concentrate on the long-term consequences on the level of the interest rate and inflation. Indeed, given the slow-moving pace of demographic trends, the impact of population aging on the transmission of monetary policy shocks has been considered negligible. However, the results of this paper show that population aging can significantly influence the effectiveness of short-term monetary policy.

Related literature. This paper contributes to two strands of the literature. First, the results complement the large body of empirical and theoretical evidence on the relationship between monetary policy and demographic trends. As previously mentioned, most of the literature has focused on the effects on the long-term steady-state level of the interest rates and inflation[1] rather than on the short-term implications. Few exceptions include Fujiwara and Teranishi (2008), Kantur (2013), and Yoshino and Miyamoto (2017), which use a two-agents model with workers and retirees to study the effectiveness of monetary policies from a theoretical perspective. Bielecki et al. (2021) formulate a life-cycle model calibrated on the Euro Area to show that demographic trends have contributed to the decline in the natural interest rate and have exacerbated the risk of hitting the lower bound and that the pressure is expected to continue. Braun and Ikeda (2021) develop an overlapping generations model to evaluate how household responses to monetary policy shocks vary over the lifecycle. Finally, Brzoza-Brzezina and Kolasa (2021) study the importance of asset distribution across generations for the redistributive effects of monetary policy.

From an empirical point of view, Kopecky (2022) document that population age structure plays an essential role in the relationship between excess money growth and inflation. Using a cointegrated VAR approach for the U.S. and Euro Area, Bobeica et al. (2017) uncover a positive long-run relationship between inflation and the growth rate of the working-age population. Similarly, de Albuquerque et al. (2020), in a comprehensive analysis across 24 countries, find that the 35-64 years old group exerts disinflationary pressure while older population groups appear to contribute strongly to inflationary dynamics.

The empirical evidence I provide concerning the negative correlation between age and the frequency of price adjustments of the consumption bundle build on Cravino et al. (2022). Using both cross-country analyis and household-level data for the U.S., the authors establish that part of the observed increase in the share of services in expenditures is explained by the fact that older individuals devote a larger share of their expenditures to services. My distinct focus, in comparison to Cravino et al. (2022), is on delineating how the shifting relative importance of the services sector, induced by demographic trends, influences the effectiveness of monetary policy.

The prevailing body of literature investigating the relationship between the monetary policy pass-through and demographic structures argue that the younger populations respond more to monetary shocks, thereby implying that population aging might diminish the efficacy of monetary policy. Wong (2021), for instance, finds that younger households demonstrate greater consumption adjustments in response to interest rate fluctuations, attributed to their higher frequency of refinancing or entering new loans compared to older households. By exploiting the cross-sectional variation across U.S. states, as I do in the empirical section, Leahy and Thapar (2022) unveil that the responses of private employment and personal income are more pronounced the greater the share of the population between

[1]See, among others, Carvalho et al. (2016), Aksoy et al. (2019), Eggertsson et al. (2019), Papetti (2019), Lis et al. (2020), Papetti (2021), Bielecki et al. (2020), Lisack et al. (2021) and Auclert et al. (2021).

40 and 65 years of age. Contrary to these prevailing arguments, I provide new evidence suggesting that a rise in the share of old people actually augments the pass-through of monetary policy and I propose a novel mechanism to account for this phenomenon, centered on consumption heterogeneity across age groups regarding services and goods. The conclusion of my results agrees in spirit with Berg et al. (2021) that demonstrate that the consumption of older households is more responsive to monetary policy shocks because of life-cycle wealth effects. I view their work as complementary to mine. I document empirically that the heterogeneity channel I propose is quantitatively meaningful and accounts for around 30-40% of the overall difference in economic activity responsiveness between young and old U.S. states. It is worth noting that the remaining channels through which population distribution affects the transmission of monetary policy, including the wealth effects from Berg et al. (2021), are still found to amplify output responsiveness to monetary shocks.

The second strand is the literature on the time-varying effects of monetary policy shocks on real activity and inflation. Several factors have been proposed to explain these changes, including reforms in the institutional structure of the credit markets (Boivin et al., 2010), the distribution of savings from refinancing mortgages (Wong, 2021), stronger anchoring of expectations as well as demographic trends (Imam, 2014, Kronick and Ambler, 2019). In this paper, I contribute to this literature by establishing that population aging exerts downward pressure on the aggregate frequency of price adjustment, thereby increasing output responsiveness and decreasing inflation responsiveness to shocks over time. This result is also confirmed in a cross-country comparison by Galesi and Rachedi (2018) who illustrate that the response of inflation to monetary shocks in countries with a larger share of services intermediaries is more muted but the response of output is stronger.

Road map. The remaining paper is organized as follows. Section 2 uses household-level expenditure data to document the negative relationship between age and the frequency of price adjustment. In section 3, I derive which are the theoretical predictions of a change in price stickiness using a standard 3-equation New Keynesian model. Section 4 studies the heterogeneous effects of monetary policy shocks across U.S. states according to their economic and demographic structures. In section 5, I develop the two-sector OLG NK model to assess how the transmission of monetary policy shocks in the U.S. has been influenced by demographic trends and to what extent consumption heterogeneity explains this. Finally, section 6 concludes.

2 Micro-level evidence

Using household-level data for the U.S., I document significant heterogeneity in price stickiness across the consumption bundles of different age groups. In particular, older people purchase more services rather than goods and the firms in the services sector tend to adjust less often their prices. Therefore, an increase in the share of old people puts downward pressure on the aggregate frequency of price adjustment.

2.1 Heterogeneity in the frequency of price adjustment

2.1.1 Data

I show how the frequency of price adjustment varies with household age using micro-data for the U.S. To do so, I combine data on expenditure shares from the Consumer Expenditure Survey (CEX) run by the Bureau of Labor Statistics (BLS)[2] for the 1982-2018 period with the item-level frequency of price adjustment data from Nakamura and Steinsson (2008), which is computed as the fraction of the number of times an item changes its price over the number of times the item is observed[3]. The expenditure data from the CEX are available at Universal Classification Code (UCC) level for about 600 categories whereas the frequency of price adjustment from Nakamura and Steinsson (2008) at the Entry Level Items (ELI) level for 272 categories. Therefore, as in Clayton et al. (2018) and Cravino et al. (2020), I implement a "many-to-one" merge from UCCs to ELIs by summing up the expenditures of all UCCs linked to the same ELI. Because a few ELIs do not find a linked UCC, e.g., rent, the final dataset covers 263 ELIs out of 272[4].

I then aggregate households into age groups based on the reference person's age, that is the age of the household head[5]. The average frequency of price changes for age group a, $\bar{\theta}_t^a = \sum_j \omega_{t,j}^a \theta_j$, is computed as the weighted average of the product-specific frequencies of price changes θ_j from Nakamura and Steinsson (2008) using as weights the age group-specific expenditure shares $\omega_{t,j}^a$ from the CEX[6]. As an alternative measure of price stickiness, I compute the mean implied duration. I define for each ELI category the mean implied duration as $d = \frac{-1}{ln(1-f)}$, where f is the frequency of price adjustment, which measures after how many months, on average, a firm in sector j adjusts its price. I then compute the mean implied duration for each age group a similarly to the frequency of price changes.

Before presenting the price stickiness heterogeneity across age groups, it is useful to see how it evolved over time and how it relates to demographic trends. The core idea of this paper is well summarized in Figure 2. On the left panel, I compare the time series from 1980 to 2018 for the U.S. old-age dependency ratio (left axis) with the scatterplot of the share of consumption devoted to services as well as the relative polynomial fit (right axis). The distinction between goods and services, which I will discuss more in detail later, is extremely important for my analysis since the share of services consumed increases over the life cycle (with the share for older households being around 20 percentage points more than for younger households) and because the two categories have remarkably different frequencies of price adjustments (goods adjust on average every 3 months

[2] The CEX survey respondents are asked about their expenditures for the full consumption basket. The CEX is made up of two separate surveys: the Interview and the Diary. The first one covers the full range of expenditures on a quarterly basis, while the second provides more detailed information at a weekly frequency for certain product categories like food and clothing. A set of demographic characteristics are reported in both surveys. In the two modules there are questions regarding around 600 Universal Classification Code (UCC) categories.

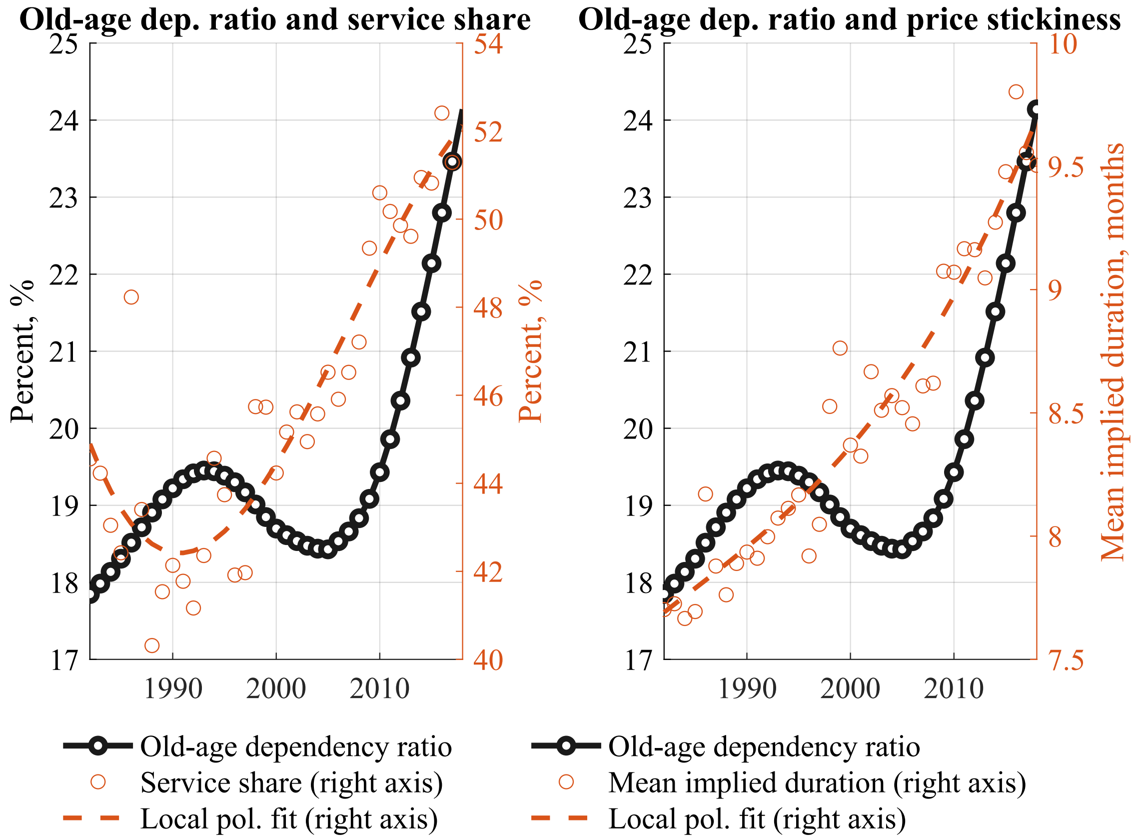
[3] Figure **??** reports heterogeneity in price rigidities across 19 categories and between goods and services.

[4] See section A of the Online Appendix for more details about the data.

[5] The results are similar if it is used the average age across all household members.

[6] The implicit assumption I make is that the frequency of price adjustment at sectoral level θ_j is constant over time. This assumption is partly tested by Nakamura and Steinsson (2008) who compare the frequency of price adjustment over two different periods, 1988-1997 and 1998-2005, and they show that the parameters are rather stable over time.

Figure 2: Old-age dependency ratio, service share, and price stickiness



Notes: The left panel of the plot shows the evolution of the U.S. old-age dependency ratio over time (left axis) alongside the time series of the share of consumption devoted to services (right axis). The right panel compares the time series of the U.S. old-age dependency ratio with the mean implied duration of prices (right axis). The source of the data is the World Bank Population Estimates And Projections as well as the CEX data.

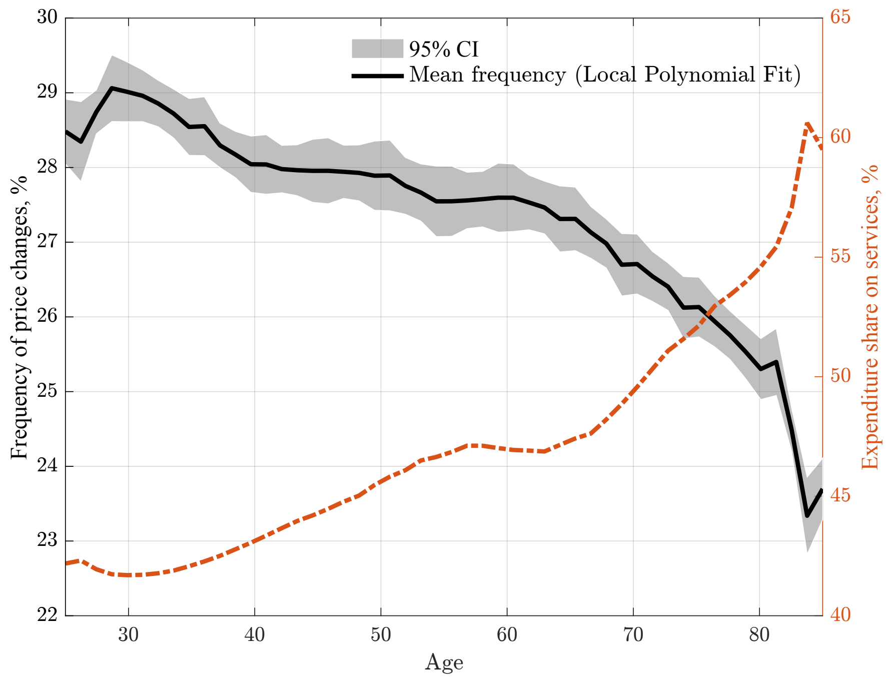
whereas services every 13 months). On the right panel, I compare the same time series of the U.S. old-age dependency ratio (left axis) with the scatterplot of the mean implied duration as well as the relative polynomial fit (right axis).

The evolution of the demographic structure can be considered to some extent exogenous but, despite being rather slow-moving, it is likely to have non-negligible effects on the economy. In particular, as shown in Cravino et al. (2022), population aging explains around a fifth of the increase in the share of services consumed over the last 40 years which overall rose from 44% to 52%. Moreover, given that firms in the services sector adjust their prices much less frequently than firms in the goods sector, the rise in the share of services resulted in a decrease in the aggregate frequency of price adjustment with the mean implied duration increasing from around 8 months to 9.5 months. Therefore, since demographic trends contributed to the change in the share of services, they are also partially responsible for the observed decrease in the frequency of price adjustment. As every standard New Keynesian model predicts, the lower the frequency of price adjustment, the stronger the response of output and the more muted the response of inflation to monetary policy shocks.

2.1.2 Price stickiness across age groups

In this section, I document significant heterogeneity in price stickiness across age groups due to the different expenditure categories they consume. Figure 3 plots the weighted average frequency of price adjustment for each age group, $\bar{\theta}^a$ (left axis). There is a clear and significant negative correlation between age and the consumption bundle's price adjustment frequency[7]. The average frequency of price adjustment for households above the age of 80 years is more than 20% lower than that of households between the ages of 15 and 25 years[8]. Figure 17 in Section E of the Online Appendix also reports the mean implied duration for each age group. The mean implied duration significantly increases over the life cycle from around 8.2 months to almost 10 months.

Figure 3: Frequency of price adjustment and services consumption across age groups



Notes: The figure plots the weighted average frequency of price adjustment (left axis) alongside the share of consumption devoted to services (right axis) across age groups. The shaded area is the 95% confidence band. The frequency of price adjustment is computed as the fraction of the number of times an item changes its price over the number of times the item is observed and expressed in percent per month. The expenditure shares are computed using data from the CEX for the period 1982-2018 whereas the sectoral price stickiness parameters are retrieved from Nakamura and Steinsson (2008).

[7]In section B of the Online Appendix I perform some robustness checks regarding the negative relationship between price stickiness and age. First, I control that the negative relationship between age and frequency of price adjustment is stable over time. Second, I evaluate whether demographic characteristics other than age, e.g., education status and income level, might explain the findings of this section. Third, I check that no outlier in the expenditure categories is responsible for the pattern observed. The results confirm the strong negative relationship between the frequency of price adjustment of the consumption bundle and age.

[8]As shown in Figure 17 in Section E of the Online Appendix, excluding temporary sales in the computation of the frequency of price adjustments shift the entire relationship downward but does not affect the relative relationship across age groups.

The main driver behind this negative relationship is the higher share of services consumed by older households. As it can be noticed in Figure 3, the share of consumption devoted to services (right axis) increases from around 40% for younger households up to 60% for older ones[9]. Nakamura and Steinsson (2008) document that services tend to have a much higher level of price stickiness with an average price duration of 13 months compared to a 3 months duration for goods[10]. Given the heterogeneity in consumption bundles across age groups and the different frequency of price adjustments across sectors, the expenditures of older households are characterized by a much stronger price stickiness relative to young households[11].

To shed further light on which categories mainly drive the relationship between age and price stickiness, I focus now on more granular expenditure categories. Table 1 in Section E of the Online Appendix shows the expenditure shares across some age groups for twenty of the main consumption categories. In line with previous findings, the largest disparity can be observed in health expenditures where the average consumption share of households above the age of 80 years is almost 16 percentage points larger than that of households below the age of 25 years. Moreover, younger households tend to spend relatively more on categories like Education, Entertainment, and Private Transportation. In contrast, Energy and Household Furnishings and Operations constitute a larger component of the older household consumption bundle.

The left panel of Figure 4 plots the frequency of price change on the y-axis against the difference in the expenditure shares between the age groups $(75; 80]$ and $(25; 30]$ on the x-axis. A positive value means that the older group has higher expenditure shares in that category. Most of the categories gather around zero suggesting that the two age groups have similar expenditure shares. However, the categories more intensively brought by older households tend to be characterized by a lower frequency of price adjustment while the opposite holds for the categories mainly purchased by younger households. The correlation between the x-axis and y-axis variables is -0.153.

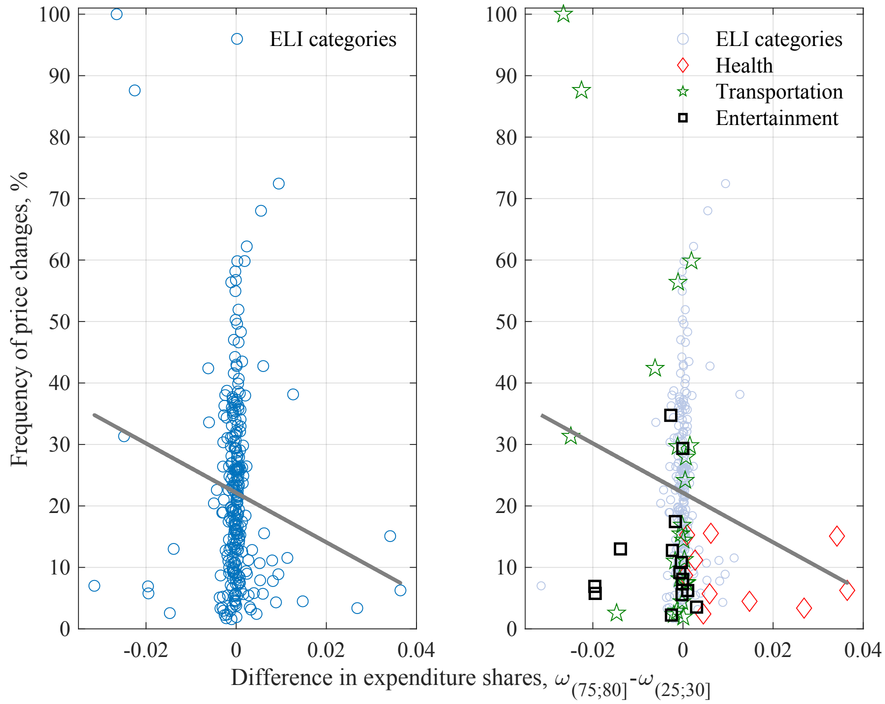
On the right panel of Figure 4, I highlight some of the categories for which expenditure heterogeneity is more evident. As previously mentioned, medical expenses are a major component of the elderly consumption bundle and at the same time, they are characterized by an extremely low frequency of price adjustment. The opposite is true for Transportation: younger households spend more on these categories and the firms in this sector are able to adjust their prices more frequently.

[9] I classify as Goods the following expenditure categories: Food at home, Vehicle purchasing, Gas, Entertainment equipment, Appliances, furniture and fixtures, Alcoholic beverages, Clothing and other apparel, Tobacco, Personal care goods. I classify them as Services: Health, Utilities, Car maintenance, Repairs and insurance, Food away from home, Domestic services and childcare, Education, Entertainment services, Public transport, and Personal care services.

[10] Several potential explanations have been suggested in the literature to explain the difference in price stickiness between the two sectors. For example, the production of services is much more labor-intensive than the production of goods. The high wage stickiness might then translate into a lower frequency of price adjustment for services. Alternatively, services face lower price competition since innovation is less common in the services sector than in the goods sector. Micro funding the different frequencies of price adjustment across sectors is beyond the scope of this paper and, therefore, in the theoretical model price stickiness is set exogenously.

[11] Cravino et al. (2022) test more systematically the relationship between age and the share of consumption devoted to services. The authors control for income decile dummies and region-time fixed effects and they still document large differences in service expenditures across households of different age groups.

Figure 4: Expenditure differences across age group



Notes: The left panel plots the frequency of price adjustment against the difference in sectoral expenditure shares for the age groups (75; 80] and (25; 30]. The right panel shows the same plot highlighting some important categories: Entertainment, Health, and Transportation. The fitted linear regression line of the data is included in both panels.

3 The 3-equation New Keynesian model

To evaluate how the increase in price stickiness induced by population aging might affect the propagation of monetary shocks, I start with a standard 3-equation New Keynesian model[12].

The three equations of the model are the IS curve (1), the Phillips curve (2), and the interest rate rule (3). These equations relate the output gap $\hat{x}_t$ (defined as the deviation of output from its flexible price counterpart), the inflation rate $\hat{\pi}_t$ and the real interest rate $\hat{r}_t$:

$$\hat{x}_t = -\frac{1}{\sigma}\left(\hat{r}_t - E_t\hat{\pi}_{t+1}\right) + E_t\hat{x}_{t+1}, \tag{1}$$

$$\hat{\pi}_t = \beta E_t\hat{\pi}_{t+1} + \kappa(\sigma+\eta)\hat{x}_t, \tag{2}$$

$$\hat{r}_t = \phi_\pi\hat{\pi}_t + \phi_x\hat{x}_t + \nu_t, \tag{3}$$

where $\kappa \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}$ is the slope of the Phillips curve. All variables are expressed in log deviation from a zero inflation steady state. σ is the intertemporal elasticity of substitution, β is the discount factor, η is the Frisch elasticity of labor supply and θ is the fraction of firms that cannot reset their prices each period. The interest rate rule coefficients, ϕ_π and ϕ_x, capture the response of the central

[12]The derivation of the model is rather standard in the literature so I refer the interested reader to Galí (2015).

bank to changes in inflation and output gap respectively. We assume that the monetary policy shock ν_t follows an AR(1) process with persistence ρ, i.e., $\nu_t = \rho\nu_{t-1} + \varepsilon_t^\nu$.

It is possible to express the output gap and the inflation as a function of only the monetary policy shock and the model parameters using the method of undetermined coefficients[13]. It can be shown that:

$$\hat{x}_t = -\left(1 - \beta\rho\right)\Lambda_\nu \nu_t, \tag{4}$$

$$\hat{\pi}_t = -\kappa\Lambda_\nu \nu_t, \tag{5}$$

where $\Lambda_\nu \equiv \frac{1}{(1-\beta\rho)[\sigma(1-\rho)+\phi_x]+\kappa(\phi_\pi-\rho)}$. If the conditions for a unique stationary equilibrium are satisfied, Λ_ν is greater than zero so both the coefficients $(1-\beta\rho)\Lambda_\nu$ and $\kappa\Lambda_\nu$ are positive. Therefore, an expansionary monetary policy shock, i.e., a decrease in ν_t, leads to a persistent increase in the output gap and inflation.

However, the two coefficients differ in magnitude as well as in terms of their sensitivity to changes in the frequency of price adjustment. To see this, I set the model parameters to their standard value in the literature[14], and I compute the contemporaneous response of the output gap and inflation to a 100 basis point expansionary shock, i.e., $\nu_t = -1$, as a function of the price stickiness parameter θ. From 1980 to 2020 the mean implied duration has increased from 7.5 months to almost 10 months as one can see from Figure 2, which would suggest that the price stickiness parameter has changed from 0.6 to 0.7 so I consider this interval.

The relationships between the contemporaneous responses and price rigidity are reported in Figure 5. First of all, the relationship is upward-sloping for the output gap but downward-sloping for inflation confirming that an increase in price stickiness results in a more muted response of inflation to shocks but stronger for output. Second, the response of inflation is remarkably less sensitive to changes in price rigidities. Increasing the price stickiness parameter from 0.6 to 0.7 increases the time zero response of output by 56% (from 0.75% to 1.18%) whereas it decreases the response of inflation by only 25% (from 1% to 0.75%).

The different sensitivities of inflation and output to changes in price stickiness are due to the fact that a lower frequency of price adjustment implies that fewer firms can adjust their price every period. Therefore, following a monetary shock the response of inflation is more muted and inflation also becomes less sensitive to changes in the other macroeconomic variables, i.e., $\kappa(\sigma+\eta)$ from the Phillips curve (2) is decreasing when θ increases. The firms that cannot adjust their price respond by adjusting their production more. On top of that, firms anticipate that on average they might not be able to adjust their price for a longer time period. The expectations channel increases the responsiveness of output even more. Due to the lower sensitivity of inflation to changes in the economy, the increase in output responsiveness has only a marginal impact on the responsiveness of inflation.

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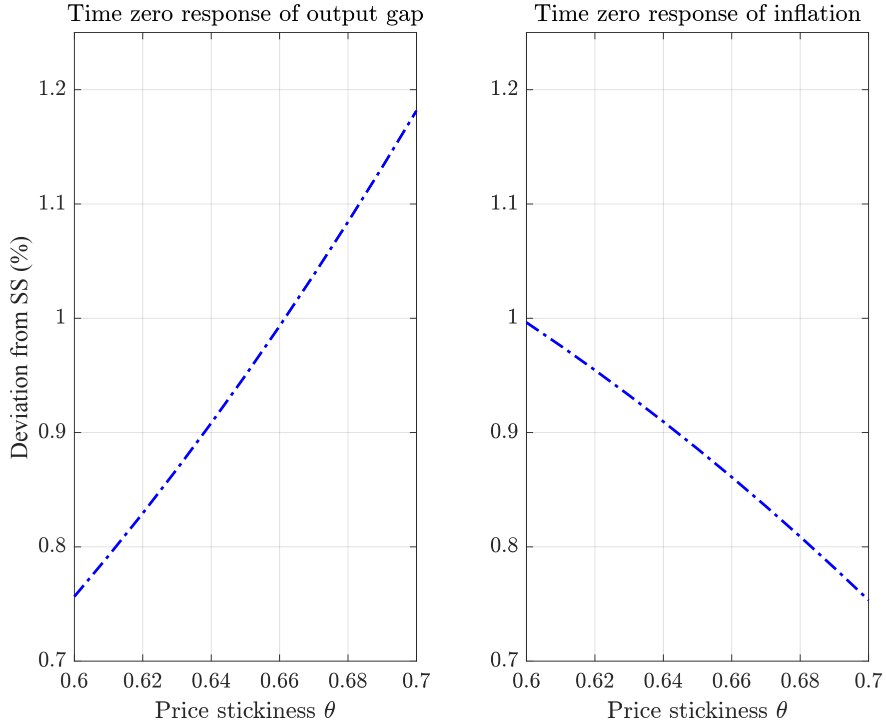
[13] See Chapter 3 of Galí (2015).

[14] $\sigma = 1$ such that the utility function is in log-form, $\beta = 0.995$, $\eta = 1$, $\phi_\pi = 1.5$, $\phi_x = 0.2$ and $\rho = 0.8$.

Figure 5: Contemporaneous response of output gap and inflation as a function of price stickiness



Notes: The figure plots the contemporaneous response of output gap (left panel) and inflation (right panel) to a 100 basis point decrease in interest rate as a function of the price stickiness parameter θ.

The results from the standard 3-equation NK model suggest that the impact of demographic trends on the transmission of monetary shocks is asymmetric between output and inflation. The decrease in the frequency of price adjustment due to the heterogeneity in consumption bundle across age groups is expected to significantly increase the responsiveness of output and to have a more negligible effect on inflation. In the next section, I empirically test these hypotheses by exploiting the cross-sectional variation in demographic structures and economic activity across U.S. states.

4 Macro-level implications

In section 2 I provide evidence of a positive relationship over time between the mean implied duration, the services share, and the old-age dependency ratio which might influence the way monetary policy shocks propagate in the economy. At the aggregate level, a decrease in the frequency of price adjustment leads to a more muted response of inflation (since only a smaller fraction of firms resets their price every period) and to a stronger response of output (since firms that are unable to reset their prices need to respond by adjusting their production). As I document in section 3, these variations are not expected to be symmetrical for output and inflation. In particular, the response of output should be much more sensitive to changes in price stickiness than that of inflation.

To test the macro-level implications of the micro-level results I find, ideally, I would like to compare how economic activity reacts to shocks in periods of a high and low old-age dependency ratio. However, as shown in Figure 1, the demographic structure in the U.S. evolved slowly in the past decades so this state-dependent approach is not feasible since there is basically no variation over time. Therefore, I compensate for the lack of time variation by exploiting the cross-sectional variation in the old-age dependency ratio across U.S. states. First, I document that within-state population aging is related to a shift in economic activity toward the service sectors. Second, I provide new empirical evidence that the economic activity of older states is more responsive to monetary policy shocks in line with the predictions from the household-level data.

4.1 Data

I collect state- and country-level macroeconomic variables from different sources. The main variable of interest at the state level is the real aggregate and sectoral GDP and sectoral employment from the Bureau of Economic Analysis (BEA) as well as the annual inflation rate from Hazell et al. (2022). Whereas inflation rate are available at a quarterly frequency, the GDP is available only at an annual frequency. The country-level variables that are used as controls are collected from FRED and include the industrial production (IP), the consumer price index (CPI), the federal funds rate (FFR), the unemployment rate, and the commodity price index computed by Ramey (2016). I also include information on state population size and demographics from the U.S. Census Bureau.

4.2 Population aging and the service sector

I start by studying how changes in demographic structure are related to the structural transformation that shifts the economic activity from manufacturing to services. Figure 6 shows the relationship between the old-age dependency ratio and the share of GDP from services at the U.S. state level from 1965 until 2020. There is a striking positive correlation between the two variables both at the state level as well as aggregate level, i.e., the higher the state-level old-age dependency ratio the higher the share of GDP from the service sector.

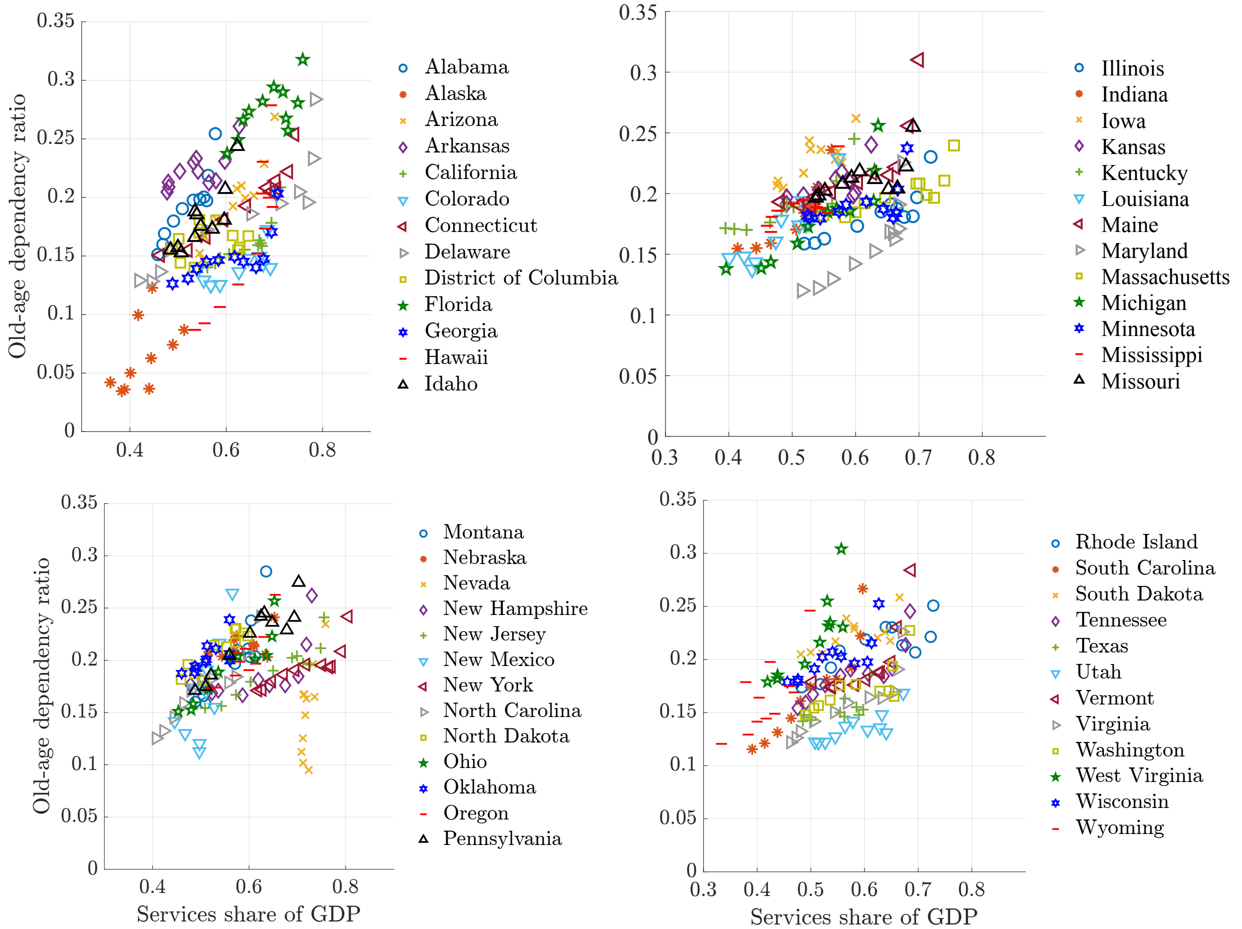
Several confounding factors could explain the positive relationship documented in Figure 6. For example, as the population of a state gets older the state also becomes richer leading to a rise in the relative size of the service sector. To more formally evaluate how populating aging contributes to the increase in the service sector, I follow the same empirical specification from Cravino et al. (2022):

$$\omega_{i,t} = \alpha_i + \beta Age_{i,t} + \gamma GDP\_pc_{i,t} + \varepsilon_{i,t}, \tag{6}$$

where $\omega_{i,t}$ is the share of GDP from the service sector for state i at time t, α_i is a state fixed effect, $Age_{i,t}$ is the state-level old-age dependency ratio, and $GDP\_pc_{i,t}$ is the state level log of the GDP per capita. Standard errors are clustered at the state level.

The results from equation (6) are reported in Table 1. The positive coefficient β in Column (1) indicates that indeed aging is associated with a reallocation of economic activity towards the

Figure 6: State-level old-age dependency ratio and services share of GDP



Notes: Each panel reports the scatter plot of the relationship between the old-age dependency ratio and the share of GDP from services at the U.S. state level. For ease of exposition, the states are split into four groups in alphabetical order. Each dot represents the average over a 5-year period starting from 1965 until 2020. *Source*: Bureau of Economic Analysis and U.S. Census Bureau.

service sector, even after controlling for income. The finding is in line with Cravino et al. (2022) who document the same relationship for a broad set of developed countries.

The result also holds controlling for the square of the log of GDP per capita, adding a battery of extra controls[15], and using as dependent variable the share of employment in the service sector as in Columns (2) to (4) respectively. Finally, to tackle any concern about the endogeneity of the demographic structure, I follow Shimer (2001) and Rachedi and Basso (2021) and instrument the old-age dependency ratio with lagged birth rates. As baseline instrument I use the 20-year lagged

[15]I include the state-level share of male workers, white workers, college-educated workers, small firms, young firms, aggregate inflation rate as well as inflation rates in the tradable and non-tradable sector, log of housing price, establishment deaths and births.

Table 1: Population aging and the service sector

	(1) Services share GDP	(2) Services share GDP	(3) Services share GDP	(4) Services share empl.	(5) Services share GDP
Old-age dep. ratio	0.436***	0.394***	0.610***	0.141***	1.366***
	(0.0985)	(0.0981)	(0.123)	(0.0462)	(0.130)
Log(GDPpc)	0.0587***	0.0248*	0.148	0.167*	-0.0193***
	(0.00475)	(0.0129)	(0.200)	(0.0862)	(0.00687)
Log(GDPpc)*Log(GDPpc)		0.00604**	-0.0377	-0.0205*	0.0117***
		(0.00260)	(0.0286)	(0.0119)	(0.00107)
Observations	2595	2595	702	1149	2172
R^2	0.901	0.903	0.959	0.910	0.724
Extra controls	No	No	Yes	No	No
$C-DF$					465.700

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

birth rates[16]. The results from the IV specification are reported in Column (5)[17] and the coefficient of the variable of interest is still positive and statistically significant. Overall, these findings confirm that population aging is an important driver behind the observed increase in the service sector as shown in Figure 6.

4.3 Regional responses to monetary policy shocks

Having shown that demographic trends lead to an increase in the relative size of services, I now investigate how states with different demographic structures are heterogeneously affected by monetary policy shocks. The predictions from the theoretical model in section 3 are that, due to the higher level of price stickiness in the service sector and the increase in the share of services consumed over the life cycle, the economic activity in older U.S. states should be more sensitive to changes in interest rate. At the same time, no significant differences should be found for the responses of inflation.

I compute the average state-level response to a monetary policy shock by estimating a panel local projection à la Jordà (2005):

$$y_{i,t+h} = \alpha_{i,h} + \beta_h MP_t + \theta_{i,h} X_{i,t-1} + \gamma_h X_{t-1} + \epsilon_{i,t+h}, \tag{7}$$

for different horizons $h = 1, ..., 16$. As dependent variable $y_{i,t}$, I use the state-level log of real GDP and the annual inflation rate. The narrative based Romer and Romer (2004) shocks is adopted as monetary shocks MP_t and state fixed effects $\alpha_{i,h}$ are included. The state controls $X_{i,t-1}$ are the lagged dependent variable and the log of the population size whereas as aggregate controls X_{t-1} I follow Ramey (2016) by including IP, CPI, FFR, unemployment rate, and commodity price index. To deal with the potential endogeneity, all control variables, except for the monetary policy shocks, are lagged by one period. Standard errors are clustered at the state and time level. The main

[16] Quantitatively similar results are obtained with the 25-year lagged birth rates or the 20-30 year lagged birth rates as in Rachedi and Basso (2021).

[17] Cragg-Donald F-tests for weak instruments are reported.

coefficient of interest is β_h which captures the impact of a one percentage point monetary policy shock on the dependent variable over the horizon h.

To evaluate how the different age characteristics across U.S. states influence monetary policy effectiveness, I follow an approach similar to the one proposed by Cloyne et al. (2022) and Jamilov et al. (2023). I define a dummy variable $D_{i,t}^{O}$ equal one when the old-age dependency ratio in state i at time t is in the top quintile of the cross-sectional distribution and zero otherwise. I then interact the dummy with the monetary shock MP_t:

$$y_{i,t+h} = \alpha_{i,h} + \delta_{t,h} + \gamma_h D_{i,t}^{O} + \beta_h^{O} D_{i,t}^{O} MP_t + \theta_{i,h} X_{i,t-1} + \epsilon_{i,t+h}, \tag{8}$$

where $\delta_{t,h}$ is the time fixed effects that absorb the monetary shocks and the aggregate variables. The coefficients β_h^{O} capture how states are heterogeneously affected by monetary policy shocks according to their demographic structure. The interaction coefficient can be interpreted as the differential response to a contractionary monetary shock of older states (for which the old-age dependency ratio belongs to the top 20%) relative to the baseline group (states whose ratio belongs to the bottom 80%).

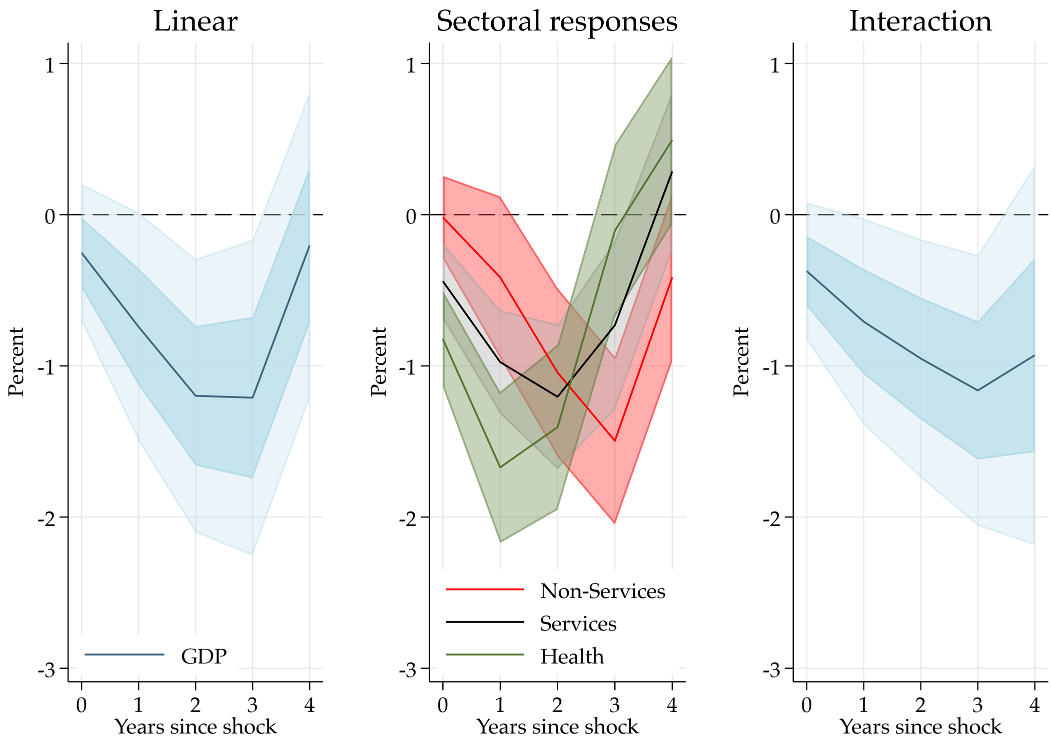
I start by focusing on the impact of monetary policy shocks on the log of real GDP. The left panel of Figure 7 plots the estimated β_h coefficient at different horizons h from equation (7). The dark and light-shaded areas are respectively the 68% and 95% standard deviation confidence intervals. Following a contractionary monetary shock, that is an exogenous increase in interest rate, the real GDP by 1.2% after 3 years. The magnitude and the shape of the response are in line with those found in the literature.

The middle panel of Figure 7 plots the responses to a monetary policy shock for different components of the GDP: Services, the non-services components of GDP, and health expenditures. In line with the price stickiness channel, the contemporaneous response of services is stronger relative to the non-services components of GDP. One year after the shock, services decrease by 1% compared to 0.4% for the non-services component. On top of that, health expenditures, the sector with the lowest frequency of price adjustments as documented in the previous section, decrease the most following a contractionary shock.

The right panel of Figure 7 plots the estimated β_h^{O} coefficients from equation (8) using real GDP as dependent variable. The negative coefficients suggest that the economic activity of older states is more responsive to monetary shocks. The effect is statistically significant and economically meaningful. After three years these states experience a decrease in real GDP up to around 1% larger relative to the baseline group which is particularly sizable once compared to the aggregate average decrease of about 1.2%.

Figure 8 reports the same responses using the annual inflation rate as the dependent variable. Following a contractionary shock, the annual inflation rate decreases by approximately 0.4 percentage points after 4 years. In line with the theoretical predictions of section 3, I find no significant differences in the inflation responses across states along the old-age dependency ratio distribution. As I will show in section 5, the more complex model I develop is able to replicate this result.

Figure 7: Impact of monetary policy on the real GDP and its components in young and old states

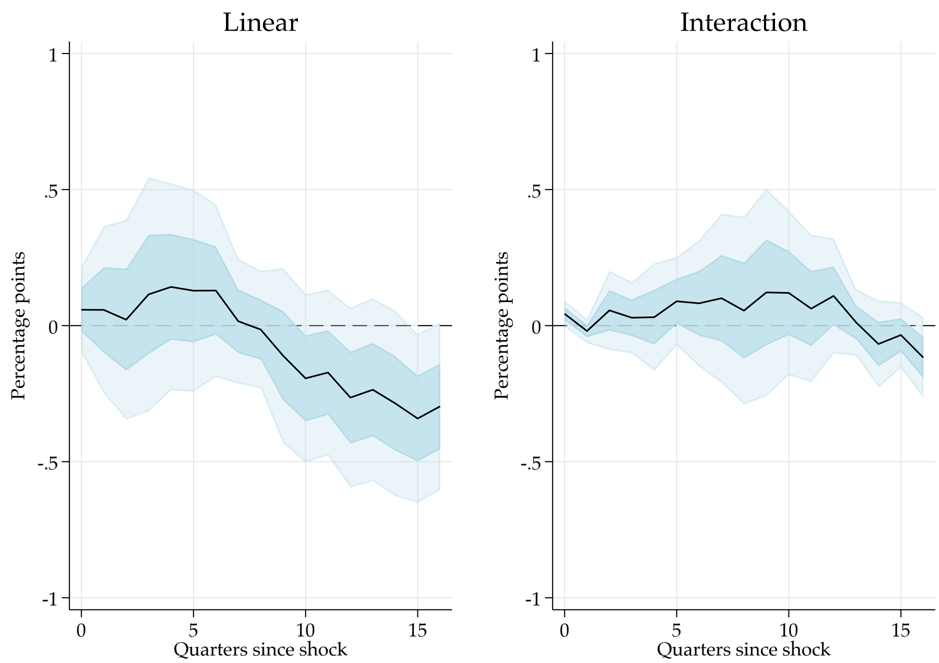


Notes: The left panel of the figure plots the response of the state-level log of real GDP to a percentage point contractionary monetary policy shock, as well as the 68% (dark shaded area) and 95% (light shaded area) confidence intervals. The horizontal axis is in years. The middle panel reports the responses for different components of the regional GDP: Services, the non-services components of GDP, and health expenditures as well as the 68% confidence intervals. The right panel reports the interaction coefficients between the monetary policy shock and the dummies identifying the top 20% of the old-age dependency ratio distribution.

These empirical findings confirm that the demographic profile plays an important role in the pass-through of monetary policy. Change in the population distribution is partially responsible for the shift toward the service sector. At the same time, the older the demographic structure of the economy, the lower the frequency of price adjustment, and the stronger the response of output to shock.

The service channel proposed in this paper is unlikely to be the only mechanism through which population aging affects the transmission of monetary policy. Changes in the population profile affects also the asset distribution, labor market participation, etc. To get a sense of the importance of the service channel relative to the other channels, I compare the real GDP response from equation (8) with an alternative specification in which I control for the interaction of the monetary shock with the services component of the GDP. In this way, the contribution to the increase in output responsiveness coming from the sectoral heterogeneity is shut down.

Figure 8: Impact of monetary policy on the regional annual inflation rate

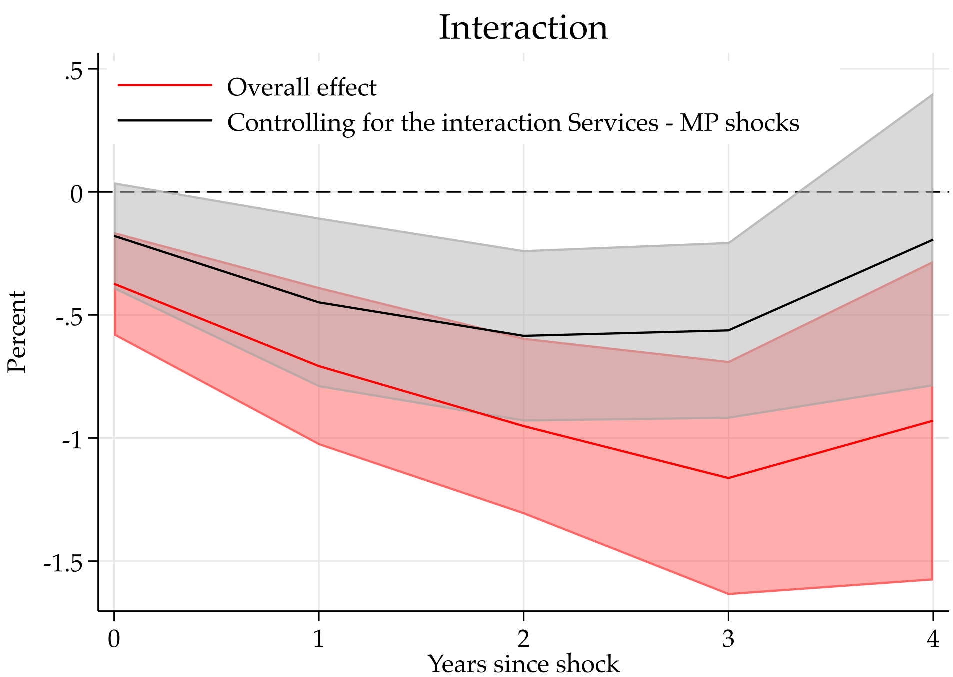


Notes: The left panel of the figure plots the response of the state-level annual inflation rate to a percentage point contractionary monetary policy shock, as well as the 68% (dark shaded area) and 95% (light shaded area) confidence intervals. The horizontal axis is in quarters. The right panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the services/manufacturing production ratio distribution.

The interaction coefficients between the monetary policy shocks and the state-level dummy for the demographic structure are reported in Figure 9. Controlling for the higher sensitivity of the services sector to monetary shocks reduces the difference in responsiveness between old and young states. The difference between the two responses suggests that the service channel accounts for approximately 30-40% of the total effects in the first two years after the shock. It is important to notice that the interaction coefficients are still negative and significant even after controlling for sectoral heterogeneity meaning that also the other mechanisms through which demographic trends influence the transmission of monetary policy overall leads to an increase in responsiveness. Armed with this empirical understanding, in the next section I develop a two-sector OLG-NK model to evaluate the impact of demographic trends on the transmission of monetary policy shocks and quantify the size of the new channel.

In section C of the Online Appendix I try a number of alternative specifications to strengthen the validity of the results which I here briefly summarize. First, I repeat the same empirical analysis excluding the five smallest states by population, i.e., Alaska, North Dakota, Vermont, Washington D.C., and Wyoming, as well as Florida. Second, I investigate whether our results are sensitive to altering the beginning and the end of the sample as well as the number of lags. Third, I repeat

Figure 9: Impact of monetary policy on the real GDP in young and old states, with and without controlling for services' responsiveness



Notes: The figure plots the interaction coefficients between the monetary policy shock and the dummies identifying the top 20% of the old-age dependency ratio distribution, as well as the 68% confidence intervals. The red line captures the overall effects of the monetary shock whereas the black line is obtained by controlling for the different responsiveness of services to monetary shocks. The horizontal axis is in years.

the same empirical analysis using different thresholds to distinguish between old and young states. Fourth, I include extra state-level control in the regressions like measures of the housing market, firms' and workers' characteristics, and GDP per capita. Fifth, whether spillover effects from other states might bias the results. Sixth, as alternative measures of monetary shocks, I also employ the high-frequency identification from Nakamura and Steinsson (2018) as well as the shocks from Miranda-Agrippino and Ricco (2021) cleaned from the informational rigidities of the monetary announcements. Seventh, for the dependent variable, I use the services component of the local GDP as a proxy for the non-tradable sector. The bottom line is that the basic pattern, in which the older the demographic profile of a state the stronger the effects of monetary policy, survives all of these modifications.

5 A quantitative life-cycle model

This section presents a two-sector overlapping generations (OLG) model for a closed economy with New Keynesian frictions in price settings that will be used to evaluate the impact of population aging in the U.S. on monetary shock propagation. The model presented here is an extension of the

OLG models derived in Heer et al. (2017), Bielecki et al. (2020), and Bielecki et al. (2021) with one crucial modification: households of different ages have heterogeneous preferences over two sectors, services and goods, which differ in terms of the frequency of price adjustment.

5.1 Demographics

Households are born at age $j = 1$ (equivalent to real life age of 15), live for a maximum of $J = 85$ years (real-life age of 99), and survive each period with an age-specific probability s_j. The parameter $(1 - s_j)$ is then the age-specific mortality rate. The households work until they are $jw = 50$ years old (real-life age of 64) and then retire. I denote with N_j the size of cohort j relative to the total population and so we have that $\sum_{j=1}^{J} N_j = 1$. As in Jaimovich et al. (2013), Heer et al. (2017) and Cooley and Henriksen (2018) the size of each age group is constant over time in order to match the empirical age-specific population shares with the model implied ones[18].

5.2 Households

The representative household of age j at time t maximizes its discounted lifetime utility (13) by choosing aggregate consumption $c_{t,j}$, the amount of hours to supply $l_{t,j}$ and the amount of assets to hold the sequent period $a_{t+1,j+1}$ subject to a budget constraint (10). The household receives a lump-sum transfer beq_t as well as an income $y_{t,j}$ composed of the net of tax labor-income $(1 - \tau_t)W_t l_{t,j} h_j$ if younger than jw years old, pension transfer from the government pen_t if older than jw years old. The transfers come from the unintentional bequests left by the households who die every period which is redistributed equally across all living agents. I express a variable in real terms by deflating it by the aggregate price index and define the relative price of the two sectors as $Z_t = \frac{P_t^G}{P_t^S}$.

The value function of the household of age j at time t can then be summarized as:

$$V_{t,j} = \max_{c_{t,j}, l_{t,j}, a_{t+1,j+1}} u\left(c_{t,j}, l_{t,j}\right) + \beta s_j \mathbb{E}_t V_{t+1,j+1}, \tag{9}$$

subject to the following constraints:

$$P_{t,j} c_{t,j} + P_t a_{t+1,j+1} = R_t^a P_{t-1} a_{t,j} + y_{t,j}, \tag{10}$$

$$y_{t,j} = (1 - \tau_t) W_t l_{t,j} h_j \mathbf{I}_{j \leq jw} + P_t pen_t \mathbf{I}_{j > jw} + P_t beq_t, \tag{11}$$

$$a_{t,0} = 0, \qquad a_{t+J+1,J+1} = 0, \tag{12}$$

where R_t^a is the gross nominal rate on the real stock of assets that are managed by investment funds, W_t is the nominal wage per effective hour, h_j is the age-specific labor productivity rate, $\mathbf{I}$ is an indicator function to distinguish workers from retirees. Households are born and die without assets.

[18] Households of age j die every period at a rate $(1 - s_j)$ so the reader might think of an age-specific migration rate that keeps the size of each cohort constant.

Finally, the utility function takes the form:

$$u\left(c_{t,j}, l_{t,j}\right) = \Big(\frac{c_{t,j}^{1-\sigma}}{1-\sigma} - \nu \frac{l_{t,j}^{1+\eta}}{1+\eta}\Big). \tag{13}$$

The bundle of services and goods consumed by the household is given by:

$$c_{t,j} = \Big[\alpha_j^{\frac{1}{\eta}} (c_{t,j}^{S})^{\frac{\eta-1}{\eta}} + (1-\alpha_j)^{\frac{1}{\eta}} (c_{t,j}^{G})^{\frac{\eta-1}{\eta}}\Big]^{\frac{\eta}{\eta-1}}, \tag{14}$$

where the parameters $0 < \alpha_j < 1 \; \forall j$ capture the age-specific preferences over the services sector and will be used to match the expenditure shares observed in the data. η is the elasticity of substitution between services and goods. The price index associated with this bundle is:

$$P_{t,j} = \Big[\alpha_j (P_t^S)^{1-\eta} + (1-\alpha_j)(P_t^G)^{1-\eta}\Big]^{\frac{1}{1-\eta}}. \tag{15}$$

5.3 Firms

On the firms' side, there are two sectors: one that produces services and one goods. The main differences between the two sectors stem from the fact that only the output of the goods sector can be used for capital investment and they differ in their frequency of price adjustment. In line with the empirical evidence, a lower share of firms in the services sector is able to adjust prices each period. As in standard New Keynesian models, the production side in each sector is split into a competitive final goods firm and a continuum of intermediate goods firms.

Final firms. For each sector $s \in \{S, G\}$, the final good is produced under perfect competition using a continuum of intermediate goods indexed by i with a constant-returns-to-scale technology. The final firms are price-takers and they solve the profit-maximization problem:

$$\max_{Y_{i,t}^s} P_t^s Y_t^s - \int_0^1 P_{i,t}^s Y_{i,t}^s \, dj, \tag{16}$$

subject to the CES production function where the parameter ϵ denotes the elasticity of substitution across different varieties of intermediate goods:

$$Y_t^s = \Big(\int_0^1 (Y_{i,t}^s)^{\frac{\epsilon-1}{\epsilon}} \, di\Big)^{\frac{\epsilon}{\epsilon-1}}. \tag{17}$$

Intermediate firms. The optimization problem of the monopolistically competitive intermediate good producer i is divided into two stages. In the first stage, for a given production function $Y_{i,t}^s$, the intermediate firm chooses the amount of inputs $L_{i,t}^s$ and $K_{i,t}^s$, taking nominal prices as given, such that costs are minimized:

$$\min_{L_{i,t}^s, K_{i,t}^s} W_t L_{i,t}^s + R_t^k K_{i,t}^s \qquad s.t. \;\; Y_{i,t}^s = (K_{i,t}^s)^{\psi} (L_{i,t}^s)^{1-\psi},$$

where ψ is the capital share in the production function and R^k_t is the nominal rental rate on capital.

In the second stage, $Y^s_{i,t}$ and $P^s_{i,t}$ are determined such that the discounted real profits are maximized subject to the demand function of the final output producer. However, firms are not free to adjust their prices as they want since they face a Calvo staggered price setting mechanism: in each period, a fraction θ^S of services intermediate goods producers and a fraction θ^G of manufacturing intermediate goods producers cannot reset their prices and maintain those of the previous period. The Calvo friction parameters are constant over time and differ across sectors to match the empirical estimates on the lower frequency of price adjustment in the services sector relative to the goods sector, that is $\theta^S > \theta^G$.

The fact that a firm in sector s might not be able to adjust its price in period t with probability θ^s makes the pricing problem dynamic equal to solving:

$$\max_{P^s_{i,t}} \mathbb{E}_0 \sum_{t=0}^{\infty} \Big(\prod_{r=0}^{t} R_r^{-1} \Big) (\theta^s)^r \Big[(P^s_{i,t} - MC^s_{t+r}) \Big(\frac{P^s_{i,t}}{P^s_{t+r}} \Big)^{-\epsilon} Y^s_{t+r} \Big], \tag{18}$$

where MC^s_t is the nominal marginal cost in sector s. Since intermediate goods producers are risk-neutral they use the nominal risk-free rate to discount expected future profit flows.

5.4 Investment funds

As in Bielecki et al. (2021), the households' savings are managed by perfectly competitive and risk-neutral investment funds which transfer the earned gross return back to households every period. The portfolio managed by the investment funds consists of physical capital K_t, bonds B_t, and claims on intermediate goods-producing firms (shares) $D_{i,t}$. A representative investment fund maximizes the expected present value of future gross returns:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Big(\prod_{r=0}^{t} R_r^{-1} \Big) \Big[[R^k_{t+1} + (1-\delta) Q_{t+1}] K_{t+1} + R_t P_t B_{t+1} + \int_0^1 [P_{t+1} F_{i,t+1} + P^d_{i,t+1}] D_{i,t+1} \, di \Big], \tag{19}$$

where δ is the depreciation rate of capital, R_t denotes the gross nominal risk-free rate, Q_{t+1} is the nominal price of a unit of capital, and $D_{i,t}$ refers to the number of shares issued by intermediate goods producing firm i which are traded at the end of period t at price $P^d_{i,t}$ and yield real dividends $F_{i,t}$. The nominal balance sheet of investment funds at the end of period t can be written as:

$$P_t A_{t+1} = Q_t (1-\delta) K_t + P_t I_t + P_t B_{t+1} + \int_0^1 P^d_{i,t} D_{i,t+1} \, di. \tag{20}$$

I_t denotes investment in physical capital which accumulates according to:

$$K_{t+1} = (1-\delta) K_t + \Big[1 - S_k \Big(\frac{I_t}{I_{t-1}} \Big) \Big] I_t, \tag{21}$$

where $S_k()$ captures investment adjustment costs which have the following functional form:

$$S_k\Big(\frac{I_t}{I_{t-1}}\Big) = \frac{S_1}{2}\Big(1 - \frac{I_t}{I_{t-1}}\Big)^2. \tag{22}$$

Finally, since I assume that all revenues are transferred back to households, the ex-post rate of return on assets R_t^a is implicitly given by:

$$R_t^a P_{t-1} A_t = [R_t^k + (1-\delta)Q_t]K_t + R_{t-1}P_{t-1}B_t + \int_0^1 [P_t F_{i,t} + P_{i,t}^d] D_{i,t}\, di. \tag{23}$$

5.5 Government

The government funds a pay-as-you-go social security system. The amount of pension benefits pen_t received by households with age above jw is given by the replacement rate $\bar{d}$ and the average net labor income $(1-\tau_t)W_t\bar{h}$. The tax rate on labor income τ_t is set such that the budget is balanced in each period:

$$P_t pen_t = \bar{d}(1-\tau_t)W_t\bar{h}, \tag{24}$$

$$\tau_t W_t \sum_{j=1}^{jw} N_j l_{t,j} h_j = P_t pen_t \sum_{j=jw+1}^{J} N_j, \tag{25}$$

where $\bar{h} = \frac{\sum_{j=1}^{jw} h_j}{jw}$ is the average efficiency-hours worked in the working life-periods.

5.6 Monetary authority

The central bank follows the following simple Taylor-type rule:

$$\frac{R_t}{R} = \Big(\frac{\pi_t}{\pi}\Big)^{\phi_\pi}\Big(\frac{Y_t}{Y}\Big)^{\phi_y} e^{\nu_t}, \tag{26}$$

where R_t is the gross nominal interest rate, $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross rate of aggregate inflation, Y_t is the aggregate output and R, π, and Y are the steady state values of the respective variable. ϕ_π and ϕ_y measure the elasticity at which the monetary authority adjusts the interest rate to changes in the current inflation rate and output and ν_t is a monetary shock following an $AR(1)$ process with persistence ρ.

Aggregate output is defined as $P_t Y_t = P_t^S Y_t^S + P_t^G Y_t^G$, and aggregate price level as $P_t = \Big[\omega_t^{\frac{1}{\eta}}(P_t^S)^{1-\eta} + (1-\omega_t)^{\frac{1}{\eta}}(P_t^G)^{1-\eta}\Big]^{\frac{1}{1-\eta}}$ where $\omega_t = \sum_j \alpha_j \chi_{t,j} \frac{P_{t,j}^{\eta-1}}{\sum_j \chi_{t,j} P_{t,j}^{\eta-1}}$ and $\chi_{t,j}$ is the share of household j expenditure in aggregate expenditures at time t. See section D of the Online Appendix for the full list of model equations.

5.7 Market clearing

The market for final output in both sectors needs to clear. Only the output of the goods sector can be stored into the next period and used for capital investment while the output of the services sector needs to be consumed every period. Hence:

$$Y_t^S = C_t^S, \tag{27}$$

$$Y_t^G = C_t^G + K_{t+1} - (1-\delta)K_t. \tag{28}$$

Moreover, both the labor and the capital market also need to clear:

$$L_t = L_t^S + L_t^G = \sum_{j=1}^{J} N_j l_{t,j} h_j, \tag{29}$$

$$K_t = K_t^S + K_t^G = \sum_{j=1}^{J} N_j a_{t+1,j+1}. \tag{30}$$

Since bonds are traded only between (identical) investment funds they are in zero net supply, $B_t = 0$. Finally, the lump-sum transfer beq_t from the unintentional bequests is equal to:

$$beq_t = \sum_{j=1}^{J} (N_{j-1} - N_j) \frac{R_t^a}{\pi_t} a_{t,j}. \tag{31}$$

5.8 Quantitative analysis

I am interested in studying how demographic trends affect monetary policy effectiveness. Therefore, I use the model to study the transmission of monetary policy shocks around three steady states that differ only in terms of population distribution N_j, mortality rate $(1 - s_j)$, and service preferences α_j. All other parameters are fixed. I choose 1980 as the first steady state and baseline since that is when CEX data, necessary to compute the sectoral preferences across age groups, becomes available. The second steady state is 2010 and the final steady state is set at 2050 using the United Nations (2017) World Population Prospects projection for the U.S.

5.8.1 Calibration

The model parameters are set in two ways: externally set with the values in the literature and internally set to target data moments.

The externally set parameters are reported in Table 2. As previously mentioned, households live for a maximum of 85 ($J = 85$) years and then die with certainty. They work until they are $jw = 50$ years old (64 years old in real life) and then they retire. The elasticity of intertemporal substitution σ, the disutility of labor supply ϕ, and the inverse of the Frisch elasticity ν are set to their standard values of 1, 4, and 2 respectively. The elasticity of substitution between the two sectors η, which captures how easy it is for the household to switch goods and services, is from Galesi and Rachedi (2018) and set to 0.4. The investment adjustment cost curvature S_1 equals 4.39 as in Bielecki et al. (2021). The pension replacement rate $\bar{d}$ is taken from Bárány et al. (2022) and the Taylor rule coefficients are set to the standard values in the literature. Finally, the Calvo parameters for the

Table 2: Externally set parameters

Parameter	Value	Description
J	85	Terminal life-age (99). Death with certainty at age 100
jw	50	Terminal working-age (64)
σ	1	Elasticity of intertemporal substitution
ϕ	4	Disutility of labor supply
ν	2	Inverse of the Frisch elasticity of labor supply
η	0.4	Elasticity of substitution between services and goods from Galesi and Rachedi (2018)
ψ	0.33	Cobb-Douglas capital elasticity of output
S_1	4.39	Investment adjustment cost curvature from Bielecki et al. (2021)
$\bar{d}$	0.33	Pension replacement rate. Source: Bárány et al. (2022)
ϕ_π	1.5	Inflation coefficient in the Taylor rule
ϕ_y	0.2	Output coefficient in the Taylor rule
ρ	0.8	Monetary shock persistence
σ_{ϵ^r}	1	Std. Dev. of Monetary shock

Notes: The table reports the externally set parameters of the model.

services sector θ^S and the goods sector θ^G are set to 0.77 and 0.25 respectively in order to match the mean implied duration in months estimated by Nakamura and Steinsson (2008).

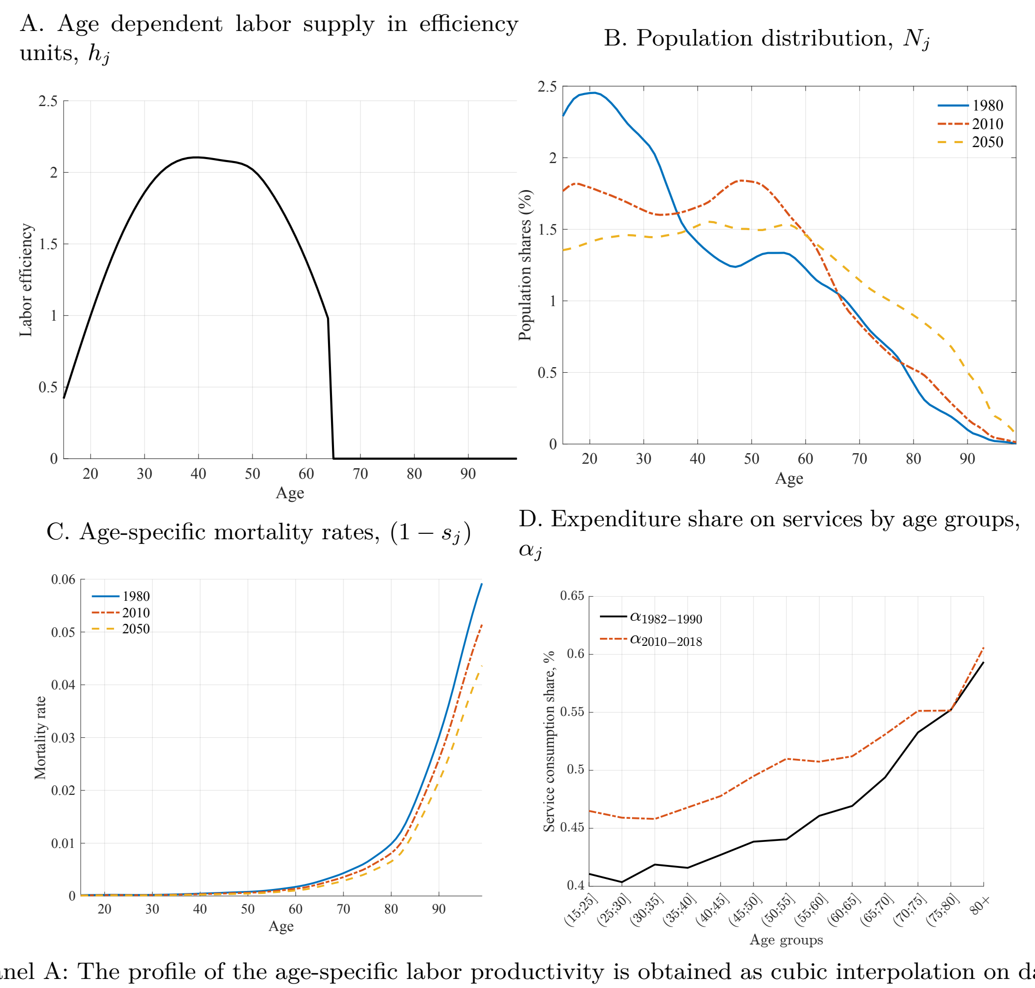
The internally calibrated parameters are reported in Table 3. The discount factor β and the depreciation rate δ are set to 0.999 and 0.02 respectively in order to match the annual interest rate and the capital-output ratio estimated in the early 80s. The elasticity of demand for each intermediate good ϵ is set to 6 such that the steady-state markup is equal to 20%. The age-group-specific labor productivity parameters h_j, shown in Panel A of Figure 10, are obtained as cubic interpolation on data points provided by Domeij and Floden (2006) in order to match the hump-shaped distribution of labor income over the life cycle. The data points are the product of participation rates computed by Fullerton (1999) and productivity by Hansen (1993).

Table 3: Calibrated parameters

Parameter	Value	Description	Target
β	0.999	Discount factor	Annual interest rate between 4 and 5 %
δ	0.02	Depreciation rate	Capital-output ratio between 2 and 2.7
N_j	Panel B of Figure 10	Population shares. *Source*: United Nations (2017) World Population Prospects	Realised and forecasted population shares
$(1 - s_j)$	Panel C of Figure 10	Age-specific survival probability. *Source*: Social Security Administration	Realised and forecasted mortality rates
α_j	Panel D of Figure 10	Share of consumption devoted to services	Age-group service preferences from CEX
h_j	Panel A of Figure 10	Age-group specific labor productivity from Domeij and Floden (2006) and Hansen (1993)	Wage profile
ϵ	6	Elasticity of demand for each intermediate good	Steady state markup of 20%
θ^S	0.77	Calvo Frequency Services. *Source*: Nakamura and Steinsson (2008)	Price adjustment every 13 months
θ^G	0.25	Calvo Frequency Goods. *Source*: Nakamura and Steinsson (2008)	Price adjustment every 3 months

Notes: The table reports the internally calibrated parameters of the model.

Figure 10: Age specific parameters



Notes: Panel A: The profile of the age-specific labor productivity is obtained as cubic interpolation on data points provided by Domeij and Floden (2006). The data points are the product of participation rates computed by Fullerton (1999) and productivity by Hansen (1993). Panel B: The plot shows the population share distribution across age groups for 1980, 2010, and the forecasted values for 2050. *Source*: UN (2017) World Population Prospects. Panel C: The plot displays the age-group quarterly mortality rates in 1980, 2010, and the forecasted values for 2050. *Source*: Table 7 from the Cohort Life Tables for the Social Security Area. Panel D: The plot displays the average age group level expenditure shares on services across age groups over two different periods. *Source*: CEX.

The most important parameters for the analysis are the shares of each age group N_j, the age-specific mortality rates $(1 - s_j)$, and the shares of consumption devoted to services α_j. The U.S. population distributions for the years 1980, 2010, and 2050, reported in Panel B of Figure 10, are retrieved from the United Nations (2017) World Population Prospects. As one can notice, demographic trends are a complex phenomenon that cannot be entirely captured by simply considering the effects on workers and retirees. On the one hand, the share of people below 35 years old is decreasing over time whereas the share of people above 65 years old is increasing. On the other hand, the share of highly productive workers (households between 35 and 65 years old) has actually increased relative to 1980. These shifts in labor force participation might have conflicting predictions regarding the effectiveness of monetary policy if not properly included in the model.

Much more straightforward is the analysis of the changes in the U.S. mortality rates $(1 - s_j)$ reported in Panel C of Figure 10. s_j are the conditional survival probabilities at quarterly frequency, i.e., the propability that a households of age j is alive the next period. For all the age groups considered, the survival probabilities have increased from 1980 to 2010 and it is expected to increase even further in 2050.

Panel D of Figure 10 shows the share of consumption α_j that each age group devotes to services. The services shares are computed from the CEX data which is available since the early 80s. Since there are no predictions regarding the state of these shares in 2050 when I evaluate how changes in preferences influence the pass-through of monetary policy I focus only on the 1980 and 2010 steady states. The share of services increases over the life cycle in line with previous findings. Since the early 80s, each age group has increased its consumption of services mainly because of income and price effects as shown in Cravino et al. (2022).

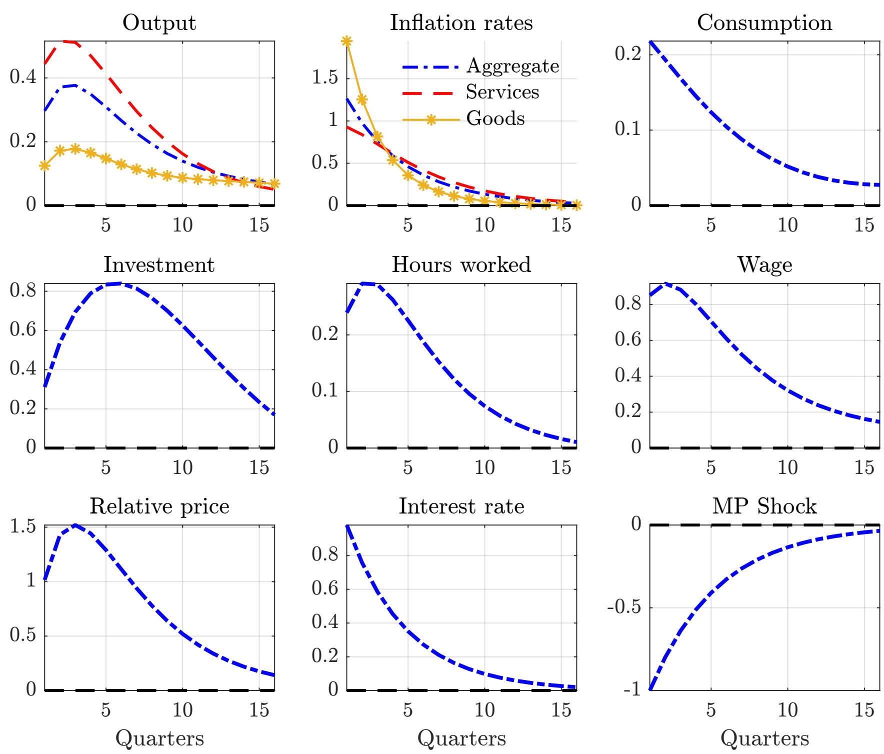
I assess the quality of the calibration of the lifecycle parameters by comparing some untargeted moments with the data. In particular, Figure 18 in Section E of the Online Appendix plots the age profile of assets implied by the model (normalized to asset holdings at age 65) with the age profile observed over different years in the Survey of Consumer Finances (normalized for the group 65-54). The model performs quite well in replicating the hump-shaped lifecycle asset profile which peaks around 60 years old. In line with the data, individuals borrow when young and dissave after they retire.

The theoretical model developed is used to answer several questions concerning the relationship between demographic trends and monetary policy effectiveness. First, I evaluate whether population aging has influenced the responsiveness of output and inflation to monetary shocks. Second, I exploit the rich demographic structure of the model to study the consumption of which age groups is the most sensitive to changes in the interest rate. Third, I quantify the importance of the novel channel I propose, i.e., consumption heterogeneity. Fourth, I show that demographic trends play a significant role in explaining the variation of the pass-through of monetary policy even when compared to other channels like the increase in the share of services consumed due to price and income effects.

5.8.2 Monetary policy over the lifecycle

Figure 11 reports the IRFs to an expansionary monetary shock of the main variables in the model computed using the demographic structure in 1980. The shapes and the magnitudes are in line with the literature. Output, inflation, consumption, and investment increase following a 100 basis points expansionary monetary policy shock, i.e., an exogenous decrease in the interest rate. The central bank then responds by increasing the real interest rate to slow down economic growth until the economy returns to the initial steady state.

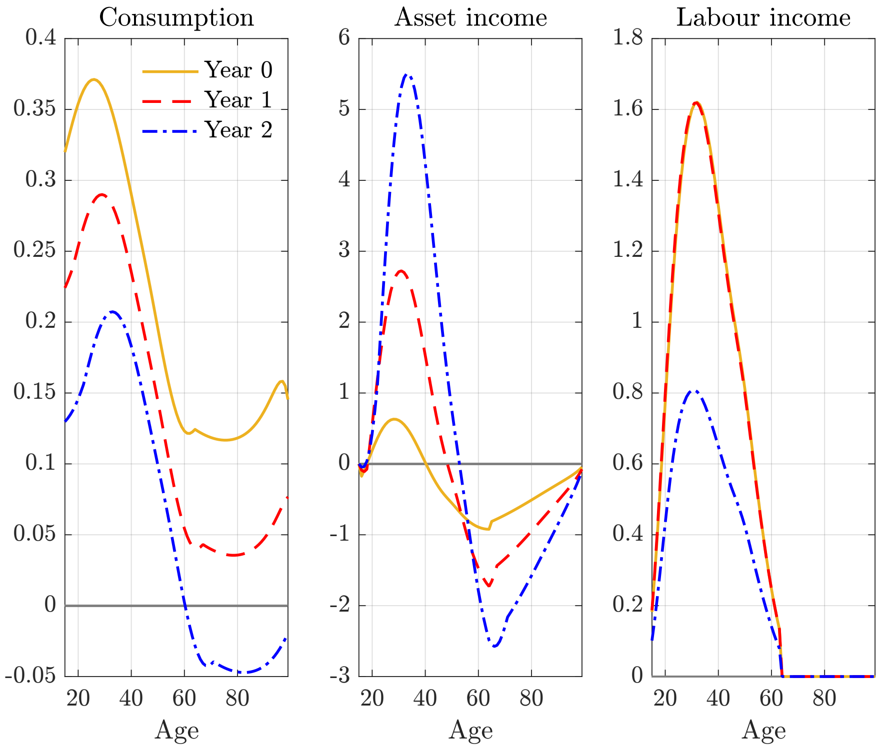
Figure 11: Model impulse response functions



Notes: The plot reports the IRFs of several variables of interest computed using 1980 as steady states.

Of particular interest are the responses in the two top left panels. Given the different price stickiness parameters between the two sectors, the price response in the services sector is more muted relative to the response in the goods sector. Since firms in the services sector cannot adjust their prices as frequently, they respond to the shock by adjusting their production more vigorously leading to a stronger and less persistent response of the output in the services sector relative to the response in the goods sector. This is in line with the empirical evidence provided in Section 4. As previously underlined, the sensitivity of output and inflation to different price stickiness is not symmetric. Output in the services sector is significantly more responsive to shocks whereas the response of inflation in the same sector is only marginally more muted.

Figure 12: Model impulse response functions by age



Notes: The plot reports the IRFs by age of several variables of interest computed using 1980 as steady states. The responses are expressed as deviations from steady-state as a percentage of steady-state consumption.

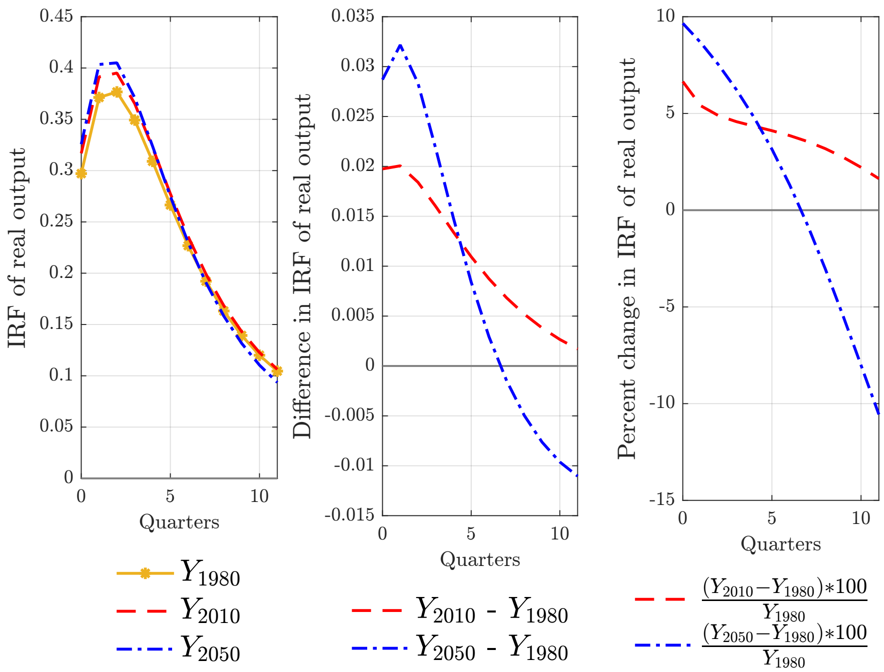
I report in Figure 12 the deviations of consumption, asset, and labour income in the year that monetary policy is expanded and the subsequent 2 years. The deviations are expressed as a percentage of steady-state total consumption of a household of the given age. Both the sign and the magnitude of the responses depend on the age of the household. The relationship between age and consumption responsiveness is highly not linear. In particular, the consumption responsiveness increases until households are 30 years old and then drastically decreases. After they turn 60, the relationship becomes rather stable with a slight increase towards the end. The higher sensitivity of the consumption of younger individuals to monetary shocks is in line with the empirical evidence provided by Wong (2021) for the U.S.

The negative relationship between age and consumption responsiveness is due to the hump-shaped distribution of assets and labor productivity reported in Figure 18 of Section E of the Online Appendix and Panel A of Figure 10 respectively. Young households have just entered the labor market and they have fewer assets so whenever there is a shock to the economy they are not able to smooth consumption over time as much as older households. Following a decrease in interest rate, labour income increases for all the working households but not homogeneously. At the same time, asset income increases for young households as they start saving more, whereas decreases for older ones as they dissave.

5.8.3 Demographic trends and the effectiveness of monetary policy

I now focus on the influence that demographic trends have had on monetary shock propagation in the U.S. over the last decades and the influence that they will have in the next 30 years. I compute the response of output to an expansionary monetary shock using the population distribution N_j and the mortality rates $(1 - s_j)$ in 1980, 2010, and 2050. All the other parameters, including the services shares α_j, are kept fixed and set to their 1980 values.

Figure 13: Model IRFs of output for different demographic structures

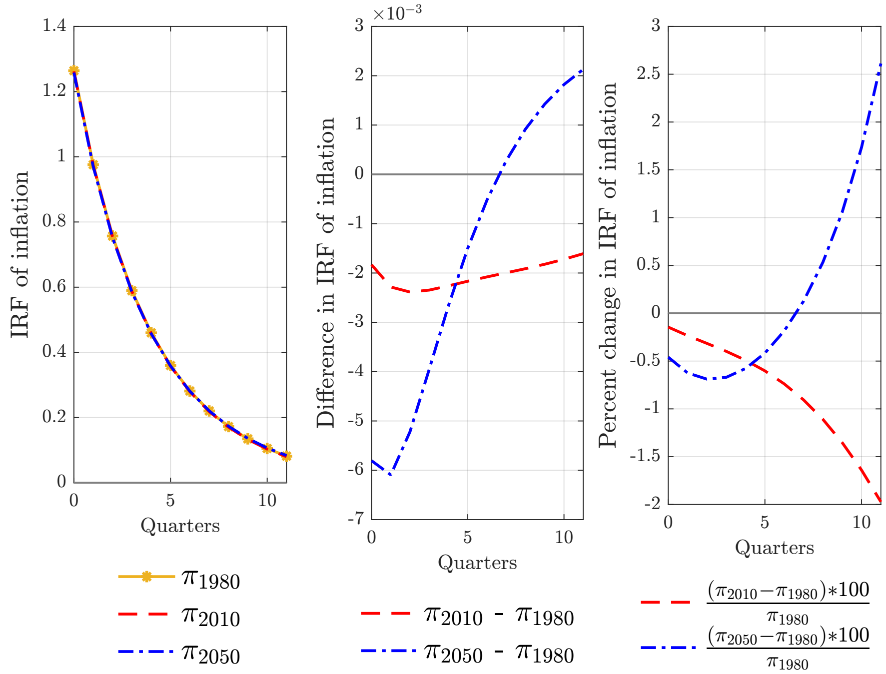


Notes: The left panel of the plot reports the IRFs of output across the three different steady states changing only the population distribution and mortality rate and keeping service preferences at the 1980 values. The middle panel shows the first differences between these IRFs, i.e., the difference between the IRF of output in 2050 and 2020 with the respect to the baseline IRF in 1980, whereas the right panel reports the percentage change in IRFs across the different steady states.

The responses are plotted in the left panel of Figure 13. Moving from 1980 to 2010 and then to 2050 results in a stronger response of output to the shock. On top of that, the responses have become less persistent over time. In the middle panel, I report the differences in output responses with respect to the baseline of 1980. By increasing the share of old people who have a higher preference for the services sector, the demographic structures of 2010 and 2050 increase the response of output by 2 and 2.9 percentage points respectively relative to that of 1980. The right panel shows the same results in percent deviation: simply changing the population distribution and the mortality rate over time makes the response of output 6.5% stronger in 2010 relative to 1980 and 10% stronger in 2050.

Figure 14 reports the same analysis for the responses of the aggregate inflation rate. In line with the empirical evidence found in Section 4, demographic trends have a negligible impact on the IRFs

Figure 14: Model IRFs of inflation for different demographic structures



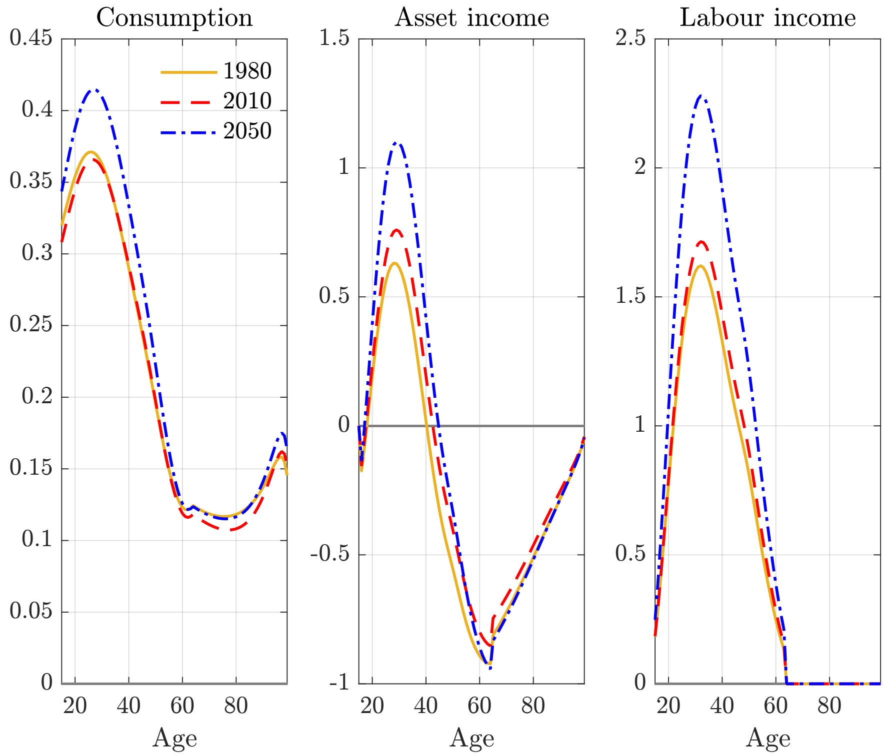
Notes: The left panel of the plot reports the IRFs of inflation across the three different steady states changing only the population distribution and mortality rate and keeping service preferences at the 1980 values. The middle panel shows the first differences between these IRFs, i.e., the difference between the IRF of inflation in 2050 and 2020 with the respect to the baseline IRF in 1980, whereas the right panel reports the percentage change in IRFs across the different steady states.

of inflation: the demographic structures of 2010 and 2050 relative to that in 1980 result in more muted responses of inflation (so the differences $\pi_{2010} - \pi_{1980}$ and $\pi_{2050} - \pi_{1980}$ are negative) but the overall decrease is less than 1% for both steady states.

On the one hand, the empirical findings and the theoretical model suggest that demographic trends lead to an increase in output responsiveness as shown in Figure 7 and Figure 13. On the other hand, the age-specific consumption responses in Figure 12 reveal that older households are much less sensitive to changes in interest rate. These two results seem to contradict each other: How can demographic trends, by increasing the share of the less responsive agents in the economy, i.e., old people, lead at the same time to an overall stronger response of output to monetary shocks? To answer this question, I examine which age groups are more exposed to the structural transformation induced by population aging.

The left panel of Figure 15 presents the model-implied percent change of consumption for each age group following an expansionary monetary shock using the demographic structure of 1980, 2010, and 2050. The change in population distribution from 1980 to 2010 has a negligible and rather homogeneous effect on consumption responsiveness across age groups. However, in 2050 demographic trends will have an extremely heterogeneous impact across age groups and the consumption of younger households will be the one most affected by demographic trends. For the age group between

Figure 15: Heterogeneous responses to expansionary monetary policy shocks, by age



Notes: The plot reports the model-implied percent change of consumption, asset and labour income across age groups following an expansionary shock using the demographic structure of 1980, 2010, and 2050. The responses are expressed as deviations from steady-state as a percentage of steady-state consumption.

25 and 35 years old, consumption will respond approximately 15% more in 2050 than in 1980. The consumption responses of older people are basically unaffected.

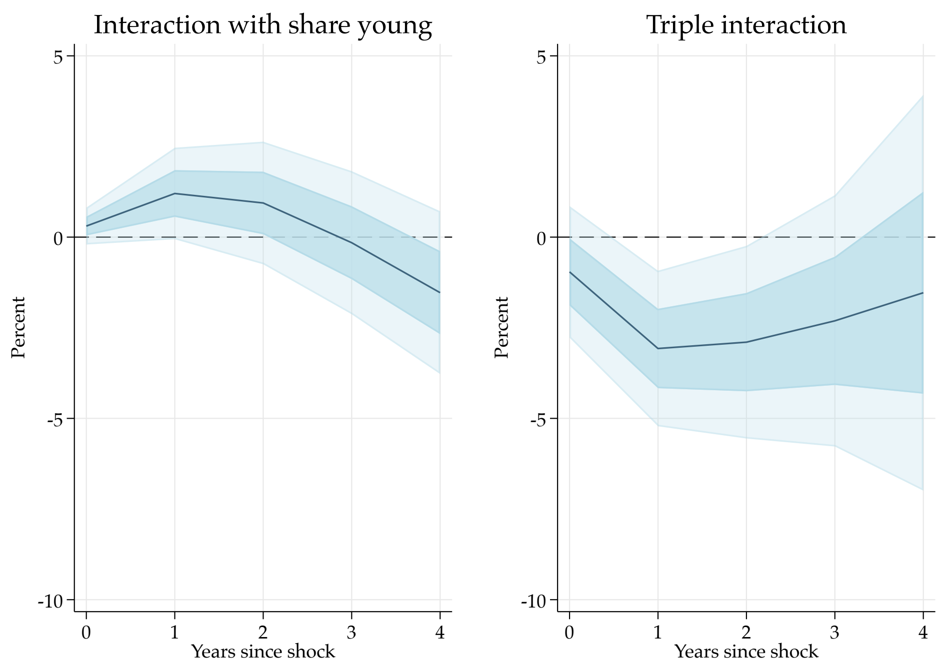
Hence, the inverse relationship between consumption responsiveness and age, along with the increased output response to monetary shocks resulting from population aging, do not represent conflicting phenomena. The decline in consumption responsiveness throughout the life cycle may have mistakenly suggested that demographic trends would render output less sensitive to monetary policy shocks. In fact, holding other factors constant, the rise in the proportion of the less responsive demographic group, namely, older individuals, due to population aging, would naturally dampen aggregate consumption sensitivity, resulting in a more muted output response to shocks. However, as depicted in the middle and right panels of Figure 15, shifts in the population distribution lead to a stronger reaction in both asset and labor income for younger households. Therefore, the heightened responsiveness of young households' consumption induced by population aging counteracts the changes in demographic composition, ultimately augmenting output responsiveness.

This mechanism can be empirically tested using the same state-level data of Section 4. The model's predictions are twofold: (i) The economic activity of older states is more responsive to monetary shocks. Moreover, (ii) the higher pass-through observed in older states is driven by the fact that younger households are more responsive within these states compared to younger states.

Prediction (i) has already been confirmed by the findings presented in Figure 7 which shows how GDP in states with higher old-age dependency ratio is significantly more responsive to monetary shocks. To evaluate prediction (ii), I define a new dummy variable $D^Y_{i,t}$ equal one when the share of 15-25 years old in state i at time t is in the top quintile of the cross-sectional distribution and zero otherwise. I modify the baseline specification by including the triple interaction between the young share dummy $D^Y_{i,t}$, the old-age dependency ratio dummy $D^O_{i,t}$ and the monetary policy shocks MP_t. The triple interaction captures the complementary effects of being in a state with a high old-age dependency ratio and a high share of young individuals. The regression becomes:

$$\begin{aligned} y_{i,t+h} = \alpha_{i,h} + \delta_{t,h} + \gamma^O_h D^O_{i,t} + \gamma^Y_h D^Y_{i,t} + \gamma^{OY}_h D^O_{i,t} D^Y_{i,t} + \beta^O_h D^O_{i,t} MP_t + \beta^Y_h D^Y_{i,t} MP_t + \\ + \beta^{OY}_h D^O_{i,t} D^Y_{i,t} MP_t + \theta_{i,h} X_{i,t-1} + \epsilon_{i,t+h}. \end{aligned} \tag{32}$$

Figure 16: Impact of monetary policy on the real GDP in young and old states, triple interaction



Notes: The left panel of the figure plots the interaction coefficients between the monetary policy shock and the dummies identifying the top 20% of the share of 15-25 years old, as well as the 68% (dark shaded area) and 95% (light shaded area) confidence intervals. The horizontal axis is in years. The right panel reports the triple interaction coefficients between the monetary policy shock, the dummies identifying the top 20% of the share of 15-25 years old and the dummies identifying the top 20% of the old-age dependency ratio distribution.

The results from equation (32) are reported in Figure 16. On the left panel, I display the interaction coefficients between the monetary policy shocks and the dummy identifying the state whose share of 15-25 years old is in the top quintile. As expected given the previous results, the economic activity of younger states is less responsive to monetary shocks. The triple interaction coefficients are presented on the right panel. The coefficients are negative and statistically significant. This means that the GDP responses in states with $D^O_{i,t} = 1$ and $D^Y_{i,t} = 1$ is stronger than for states with $D^O_{i,t} = 1$ but $D^Y_{i,t} = 0$. Thus, conditionally on having a high old-age dependency ratio, states with a larger share of young individuals are much more sensitive to monetary shocks as predicted by the theoretical model.

5.8.4 The importance of consumption heterogeneity

The variation in monetary policy effectiveness caused by changes in the demographic structure so far documented is the result of the interaction of several channels. The shift in population distributions across the three steady states results in different labor market participation, asset distribution, etc. To quantify the importance of the new proposed channel, i.e., consumption heterogeneity across age groups, I compare the changes in output and inflation responsiveness shown in Figure 13 and Figure 14 with a counterfactual scenario. In the baseline specification, I compute the responses to a monetary policy shock using the three different steady-state values for the demographic structure and keeping everything else fixed including the service preferences. In the counterfactual scenario, I still change the demographic parameters from 1980 to 2050 but I assume that the share of consumption devoted to services α_j is constant across age groups and equal to the weighted mean value of 1980.

Figure 17 reports the percent changes of output under the baseline and the counterfactual scenario for 2010 relative to 1980 (left panel) and for 2050 relative to 1980 (right panel). Neglecting consumption preferences heterogeneity across age groups leads to a sizable underestimation of the effect of demographic trends on monetary policy: the percent change of the response of output on impact drops from 6.6% to 5% in 2010 and from 9.7% to 5.3% in 2050. The contribution of the service channel to the overall effects is comparable to the empirical evidence provided in Figure 9. In the data as well this channel explained up to 40% of the total increase in responsiveness.

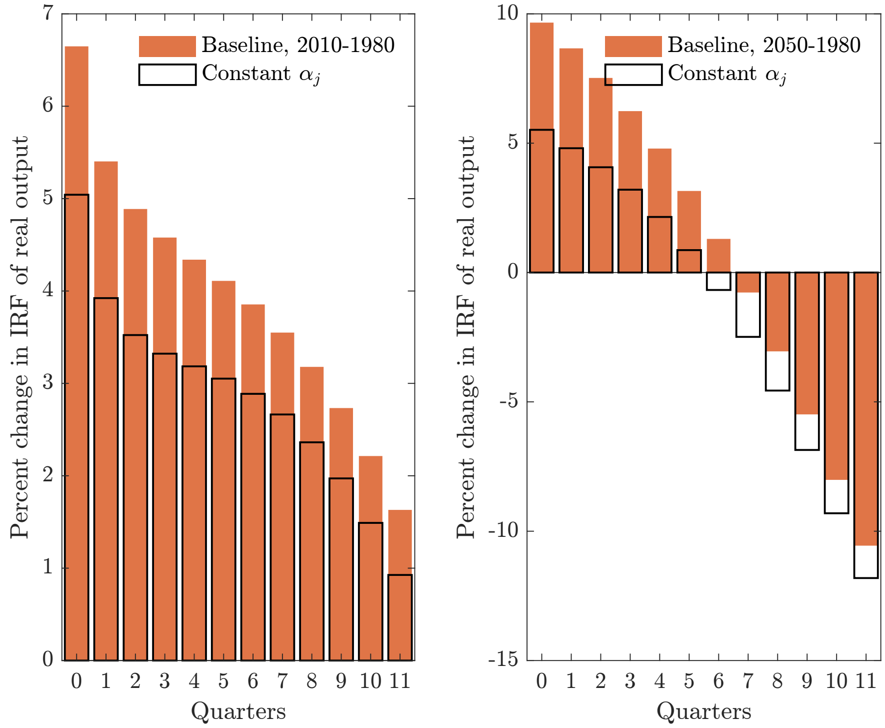
It is important to notice that demographic trends still lead to an increase in the effectiveness of monetary policy. This is mainly due to the other demographic channels included in the model. This is in line with the empirical evidence of Section 4 which confirms that even neglecting sectoral heterogeneity the other mechanisms through which population distribution affects the pass-through of monetary policy are such that output reacts more strongly in older states.

The same exercise is repeated for inflation and reported in Figure 18. A symmetrical effect is found here: neglecting preference heterogeneity results in an overestimation of the impact of population aging on the response of inflation. The effect is such that the percent change is smaller from 1980 to 2010 than in the baseline and becomes even positive for 2050.

5.8.5 Demographic trends vs. price and income effects

As demonstrated in Cravino et al. (2022), population aging accounts for around a fifth of the total rise in the share of services whereas the real income growth and changes in relative prices

Figure 17: Model IRFs of output between the baseline and the contrafactual scenario

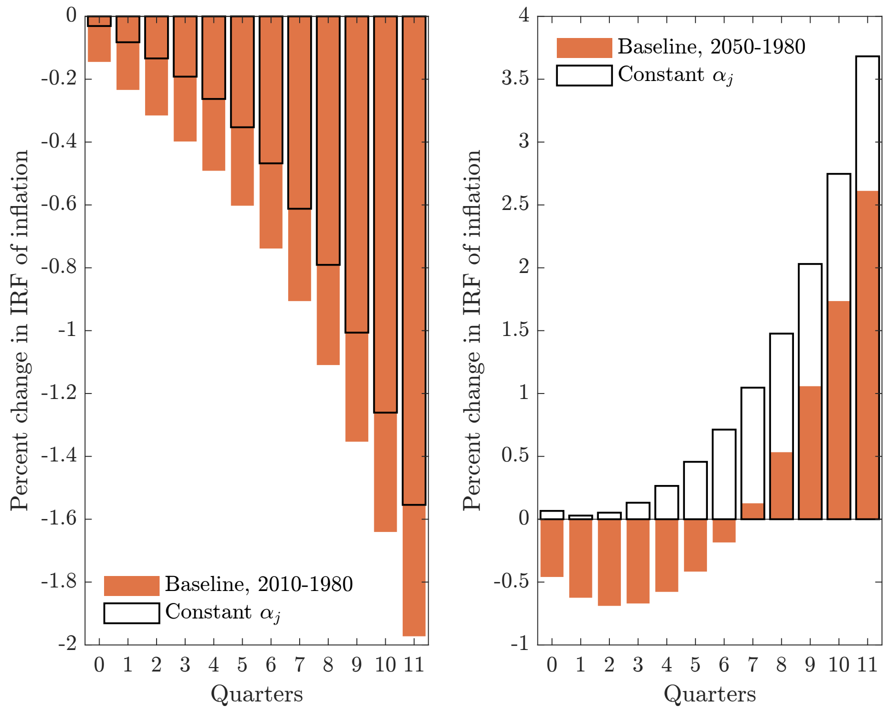


Notes: The plot compares the percent changes of output for 2010 relative to 1980 (left panel) and for 2050 relative to 1980 (right panel) for the baseline and a contrafactual scenario in which all age groups have the same sectoral preferences.

explain another three fifth. To quantify the importance of demographic trends for monetary policy propagation relative to other channels that lead to an increase in services, I compare the variation in output and inflation responsiveness under three different scenarios. In the first scenario, I isolate the demographic component by computing the percent change in the IRFs of output and inflation from 1980 to 2010 by adjusting the population distribution and mortality rates but keeping the service preferences constant as in Figures 13 and 14. The results are reported in the blue bars of Figure 19. The responses of output are shown on the left panel and the responses of inflation are on the right panel. In the second scenario, I isolate the importance of all the other channels, e.g., price and income effects, excluding population aging by varying the service preferences from 1980 to 2010 but keeping the demographic structure of 1980 (red bars). In the third scenario, I adjust both the demographic structures and service preferences to the two steady states (black line).

The response of output in 2010 is 20% stronger than in 1980 when both the demographic structure and the service preferences are changed and a significant share of this increase is explained by population aging alone. The ratio between the blue bars and the black line in the left panel is approximately 30% suggesting that, even though other structural changes like income and price effects are important drivers of the change in services share, demographic trends account for a sizable extent of the overall effect.

Figure 18: Model IRFs of inflation between the baseline and the contrafactual scenario



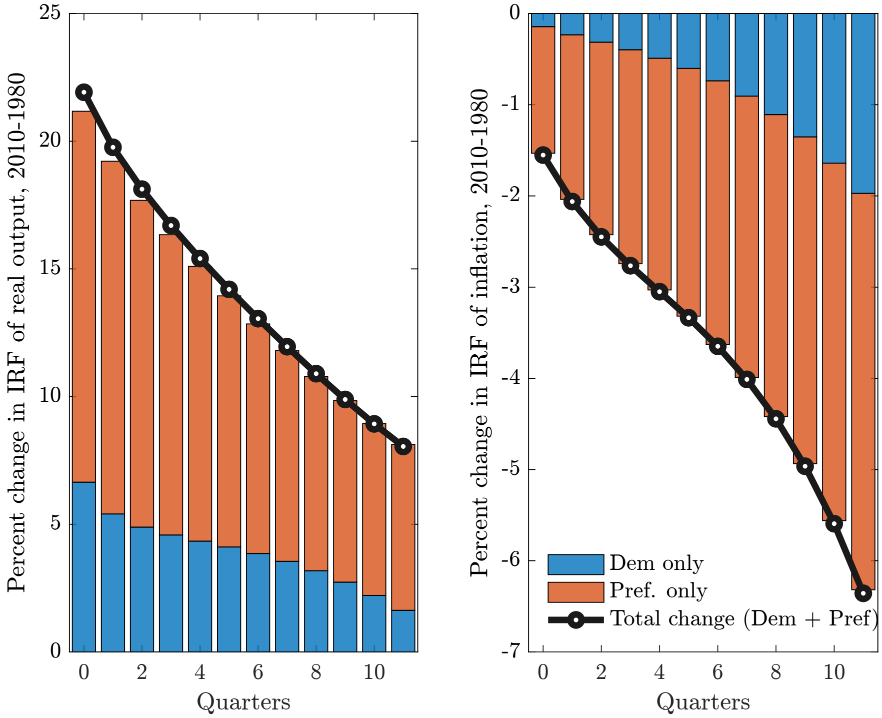
Notes: The plot compares the percent changes of inflation for 2010 relative to 1980 (left panel) and for 2050 relative to 1980 (right panel) for the baseline and a contrafactual scenario in which all age groups have the same sectoral preferences.

The right panel of Figure 19 delivers a similar story for inflation. The percent change in IRFs is between 1.5% and 6.5% more muted in 2010 relative to 1980 and the share explained by demographic trends is between 10% and 25%

The contribution of demographic trends to the changes in output and inflation responsiveness can be further decomposed into its sub-components: mortality rates and population distribution. In Figure 20 of Section E of the Online Appendix, I compare the variation in output and inflation responsiveness under three different scenarios: changing mortality rates from 1980 to 2010 and keeping the population distribution of 1980 (blue bars), keeping mortality rates at their 1980 values and changing population distribution from 1980 to 2010 (red bars), and adjusting both demographic parameters from 1980 to 2010 (black line). Population distribution is clearly the most important driver behind the increase in monetary policy pass-through.

The results so far presented suggest that the demographic trends experienced by the U.S. in the last decades and that are expected to happen in the next 30 years will significantly influence the way monetary policy shocks propagate. Different age groups are not homogeneously affected by the increase in the pass-through of monetary policy and younger households are the most exposed. Finally, I demonstrate that population aging accounts for a sizable share of the overall change in

Figure 19: Model IRFs under different scenarios



Notes: The left panel of the plot shows the percent change in impulse responses for output from 1980 to 2010 under three different scenarios: using the population distribution and mortality rates of 1980 and 2010 but services preferences kept fixed at the 1980 values (blue bars, same plot as before), using the service's preferences of 1980 and 2010 but the demographic structure of 1980 (red bars) and finally using both the demographic structures and services preferences of the two steady states (black line). The right panel shows the same percent change but for inflation.

monetary policy effectiveness and that the novel channel proposed in this paper, i.e., consumption heterogeneity across age groups, significantly contributes to the increase in output responsiveness.

5.8.6 Sensitivity analyis

I evaluate the robustness of the theoretical results in a number of variations of the benchmark model. For each alternative specification, I compute the percent change in the IRFs of output and inflation under the different population distribution and mortality rates for 1980 and 2010. Table 4 reports the results.

First of all, I relax the assumption that the production function of the services and the goods sectors have the same labor share. As in Galesi and Rachedi (2018), the labor share of services is set equal to 0.5283 whereas the labor share of goods is set equal to 0.2927. Second, I allow the two sectors to differ in their elasticity of substitution across varieties within sectors. In particular, the elasticities are calibrated to match the estimates of Rebekka and Vermeulen (2012) on the markups of services and manufacturing in the United States. I target a markup equal to 38% in the services sector and to 28% in the goods sector. Third, following Jones (2021) and Papetti (2019), instead of imposing a constant disutility of labor ϕ across age groups, I assume it to be equal to the cumulative

Table 4: Response of Output and Inflation - Robustness Checks

	Output response (%)			Inflation response (%)		
	Time 0	After 1 year	After 2 years	Time 0	After 1 year	After 2 years
Baseline	6.64	4.33	3.17	-0.14	-0.49	-1.11
Different ψ	6.12	4.05	2.90	-0.08	-0.31	-0.78
Different ϵ	5.41	3.74	2.78	-0.17	-0.41	-0.79
Different ϕ	7.49	4.63	2.94	-0.13	-0.45	-1.03
Constant τ	6.23	4.07	2.98	-0.11	-0.38	-0.88
$\theta^G = \theta^S$	2.79	3.91	2.78	0.02	-0.26	-1.30

Notes: The table reports the percent change in IRFs of output and inflation between 1980 to 2010 under alternative assumptions of the model.

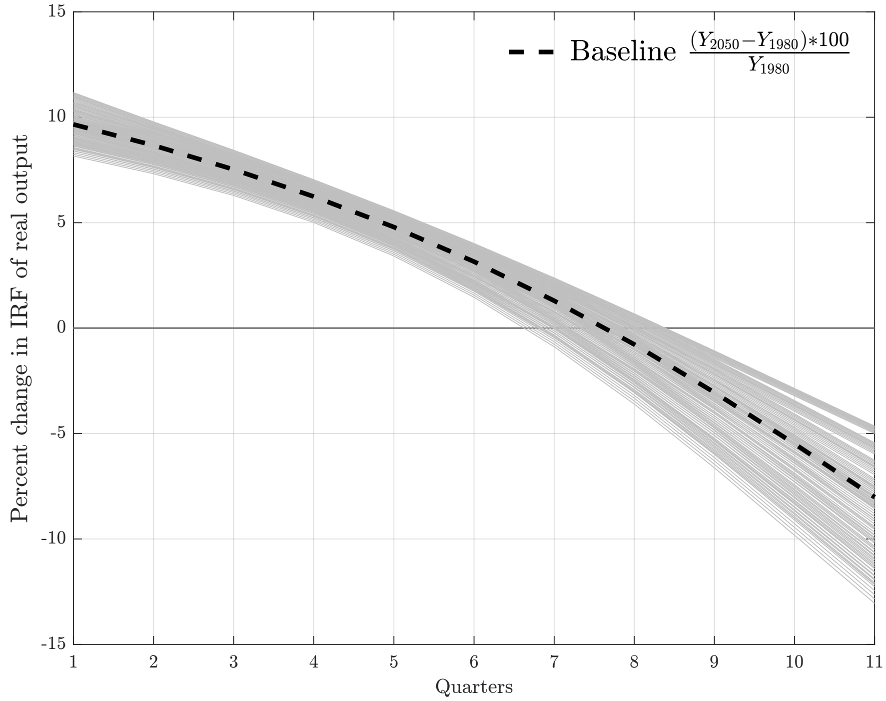
density function of a normal distribution. Figure 19 in Section E of the Online Appendix shows the shape and details of the functional form and parameter values. Fourth, for the PAYGO pension system instead of the constant replacement rate $\bar{d}$ used in the baseline, I fix the contribution rate at the steady state level $\tau = 0.0653$ while the replacement rate $\bar{d}$ is adjusted such that the government budget is balanced in each period.

All these cases deliver quantitatively similar results to the baseline specification (which is reported in the first row of Table 4). This holds on impact as well as after one and two years after the monetary shocks. The robustness exercise confirms that the main conclusions of the previous section are insensitive to several of the assumptions made: demographic trends from 1980 to 2010 significantly increased the responsiveness of output to shocks whereas they had a minor effect on the responsiveness of inflation.

The implicit assumption I have made throughout the paper is that sectoral price stickiness will not change in the future. However, several ongoing trends, e.g., automation and online shopping, are likely to affect the frequency at which prices are adjusted. Therefore, in Figure 20 I test how sensitive are the results to difference price stickiness parameters. The black dashed line reports the percentage change in output due to demographic trends from 1980 to 2050. This is the baseline response obtained by setting $\theta^S = 0.77$ and $\theta^G = 0.25$ as for the main analysis. I compare this response with the responses from 100 different combinations of θ^S and θ^G increasing and decreasing their values by up to 20% (gray lines). The range of percentage changes of the contemporaneous responses to an expansionary monetary shock is between around 8 and 11%. Therefore, the specific values chosen for the price stickiness parameters do not affect the main conclusion that demographic trends will increase the responsiveness of output to monetary shocks.

Finally, one might be concerned that the different responses of output and inflation between the two sectors stem from their structural differences, e.g., the fact that only the output from

Figure 20: Model IRFs of output for different demographic structures, alternative price stickiness parameters



Notes: The figure reports the percentage change in IRFs changing the population distribution and mortality rate from 1980 to 2050. The black dashed line is the baseline response obtained with $\theta^S = 0.75$ and $\theta^G = 0.25$. The gray lines are the responses from 100 different combinations of θ^S and θ^G increasing and decreasing their values by up to 20%.

the goods sector can be stored and invested, rather than from the different frequencies of price adjustments. To isolate the role played by price stickiness, the last row of Table 4 reports the percent change in the IRFs assuming that the share of firms unable to adjust their prices is the same between the two sectors, i.e., $\theta^G = \theta^S = 0.77$. The contemporaneous effect of demographic trends on the responsiveness of output is significantly reduced from 6.6% to 2.8%. This suggests that the structural differences between the two sectors only marginally contribute to the total change in monetary policy effectiveness caused by population aging.

6 Conclusion

For almost every country in the world, the share of old people is projected to significantly increase and the share of the working population to decrease over the next decades. However, given the extremely slow-moving pace of this transition, limited attention has been given to the way these demographic trends might influence the effectiveness of monetary policy.

I propose and quantify a new channel through which the transmission of monetary policy shocks is affected by the demographic structure of the economy. Using household-level data for the U.S., I show that older people tend to purchase more from product categories that on average adjust their prices less often. Therefore, changes in the population distribution shift the aggregate demand towards categories with higher price stickiness, resulting in a stronger response of output to shocks.

To confirm the macro implications of these micro-level findings, I empirically evaluate whether the responsiveness of U.S. states' economic activity to monetary shocks is heterogeneous in their demographic structure. I find that population aging leads to an increase in the relative share of services and that the real GDP of older states responds significantly more to shocks. No significant differences are found for inflation.

Finally, to assess the overall effects of population aging on the pass-through of monetary policy, I develop a two-sector OLG NK model. I find that demographic trends have a sizable impact on the response of output, that the consumption of younger households is the most exposed to these trends, and that the novel channel I proposed significantly contributes to this.

In conclusion, my research provides substantial evidence that demographic trends, despite their long-term nature, should not be overlooked by policymakers and central bankers even when it comes to short-term policy decisions like the level of the interest rate. The rise in output responsiveness documented implies that contractionary increases in interest rate to tackle the surge in inflation, like the ones we are experiencing in the post-Covid period, will result in a deeper recession compared to the same shocks a few decades ago just because of the different demographic structure. On top of that, younger households are the ones who will observe the strongest decrease in consumption so better coordination between the fiscal and monetary side is necessary to avoid the cost of the recession mainly borne by them.

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