Demographic Trends and the Transmission of Monetary Policy

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Abstract

This paper studies the impact of demographic trends on the effectiveness of monetary policy. I propose and quantify a novel channel to explain how population aging might affect the transmission of monetary policy: older individuals devote a larger share of their consumption bundle to product categories with higher levels of price rigidity - categories that adjust their prices less often - so the aggregate frequency of price adjustment decreases as the population ages. Using micro-level consumer expenditure data, I document a negative relationship between age and price adjustment frequency, primarily driven by the higher share of services in older households' consumption. At the macro level, increased price rigidity implies a stronger output response to monetary shocks. To test this, I exploit cross-sectional variation among U.S. states, confirming a positive relationship between population aging, the share of services, and sensitivity to monetary shocks. I further rationalize these findings with a two-sector overlapping generations New Keynesian model. Using U.S. population projections, I estimate that demographic shifts from 1980 to 2010 increased output responsiveness to monetary shocks by 6%, with an anticipated increase of 10% by 2050. The effects of monetary policy are extremely heterogeneous across age groups, with younger households experiencing the largest consumption impact. Finally, I show that the consumption heterogeneity channel introduced in this paper plays a significant role in amplifying the responsiveness of output to monetary policy shocks in aging populations.

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

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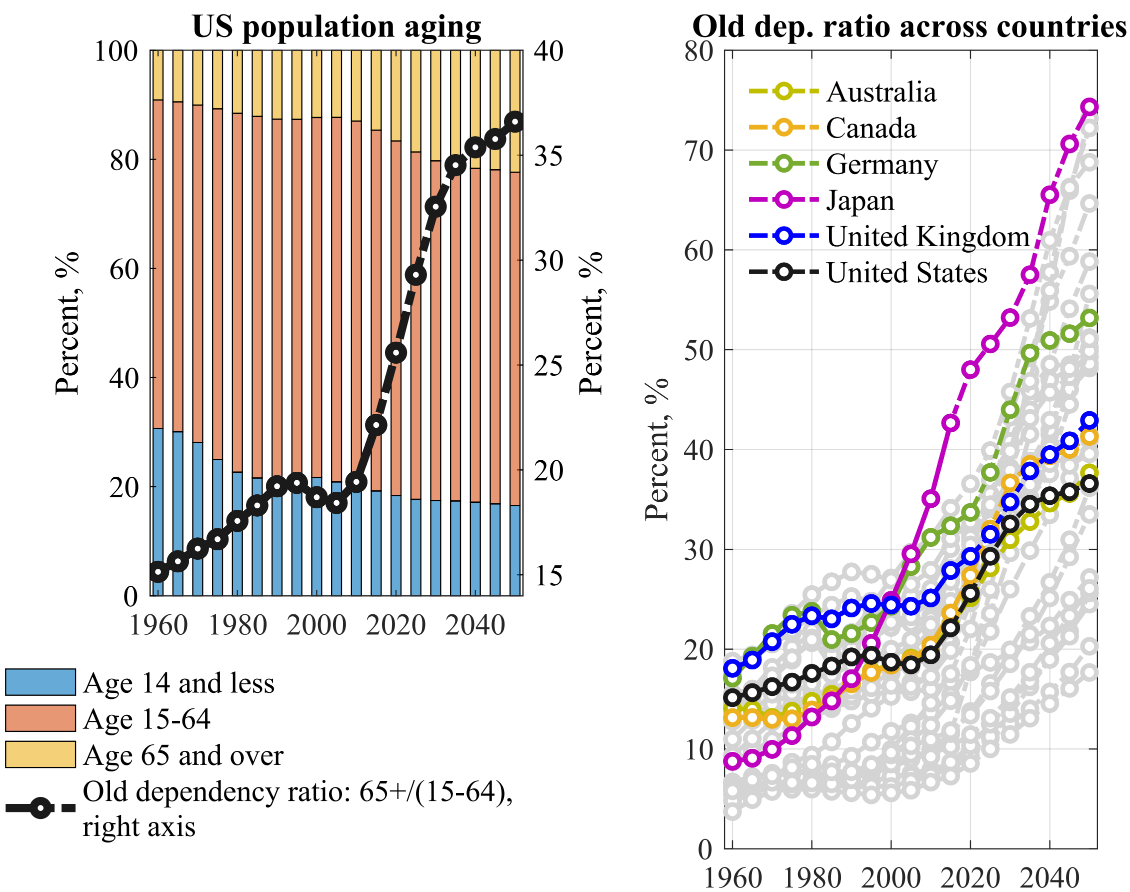
1 Introduction

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 dashed part of the lines identify the population projections. 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 population 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. Cloyne et al. (2020) document that in the United Kingdom and United States outright home-owners, who tend to be older households, are significantly less responsive to an interest rate change. Similarly, Aditya (2017) shows that the consumer spending of younger households, who tend to have higher mortgage balances relative to their incomes, is more sensitive to house price fluctuations caused by looser borrowing constraints. Matthias and Schneider (2006) study the distributional

[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).

effects of inflation through changes in the value of nominal assets. Young households are particularly impacted due to their typically higher levels of nominal debt relative to old households. Wong (2021) 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 pronunced the greater the share of the population between 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. The age-specific expenditure weights across major consumption categories are reported in Table 5 of the Appendix. 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.

[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.

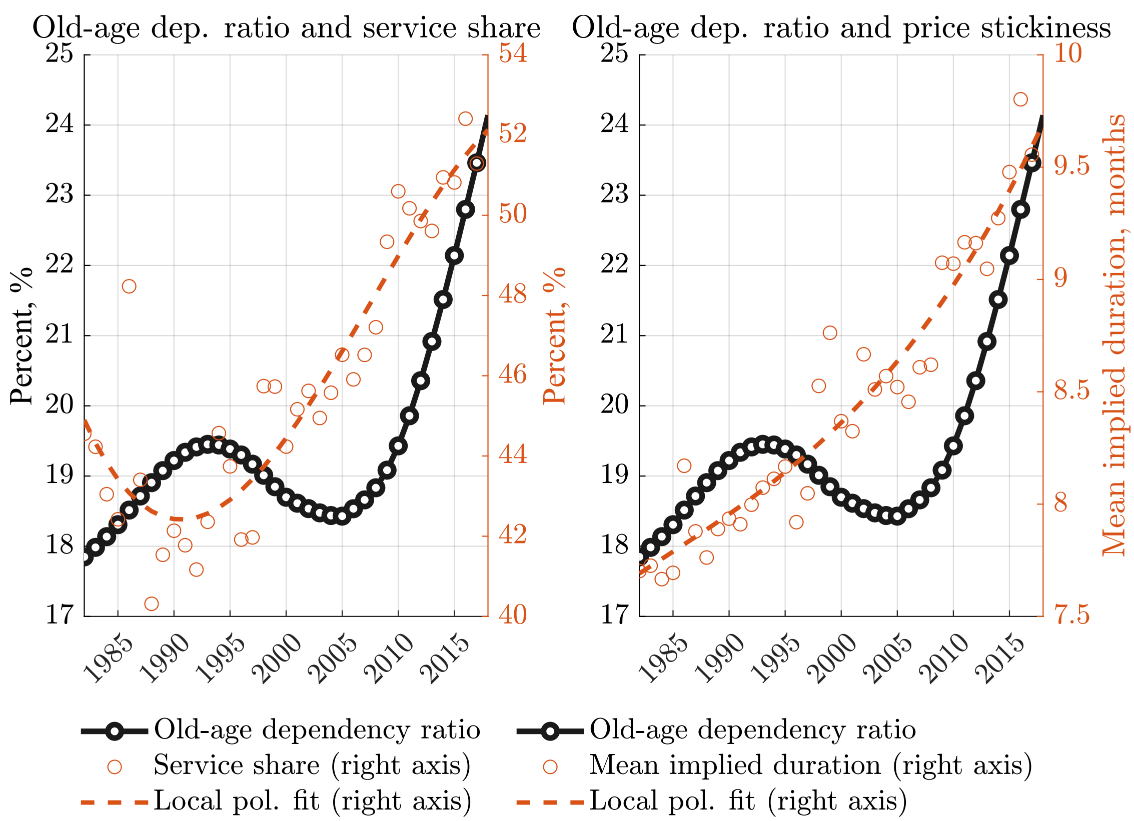
[3]Figure 36 of the Appendix reports heterogeneity in price rigidities across 19 categories and between goods and services.

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

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

Throughout this paper, I assume that the frequency of price adjustment at the sectoral level, denoted as θ_j, remains constant over time. This assumption is supported by empirical evidence from studies by Nakamura and Steinsson (2008), Klenow and Kryvtsov (2008), and Gautier et al. (2024). Nakamura and Steinsson (2008) compare price adjustment frequencies across two periods, 1988-1997 and 1998-2005, and find that these parameters are relatively stable over time. Similarly, Klenow and Kryvtsov (2008), using microdata for the U.S. Consumer Price Index from the BLS, document minimal variation in the frequency of price adjustments between 1988 and 2004. More recently, Gautier et al. (2024) calculate a time-varying measure of price change frequency for the euro area and several individual countries from 2005 to 2019, further confirming that the frequency of price adjustment remains relatively stable despite significant macroeconomic changes. In Section 5.8.6, I also test the robustness of the theoretical results by varying the parameters related to price stickiness, showing that the main conclusions are not sensitive to the specific values chosen for these parameters.

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 for the period 1982-2018.

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 1982 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 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 between 1982 and 2016 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.

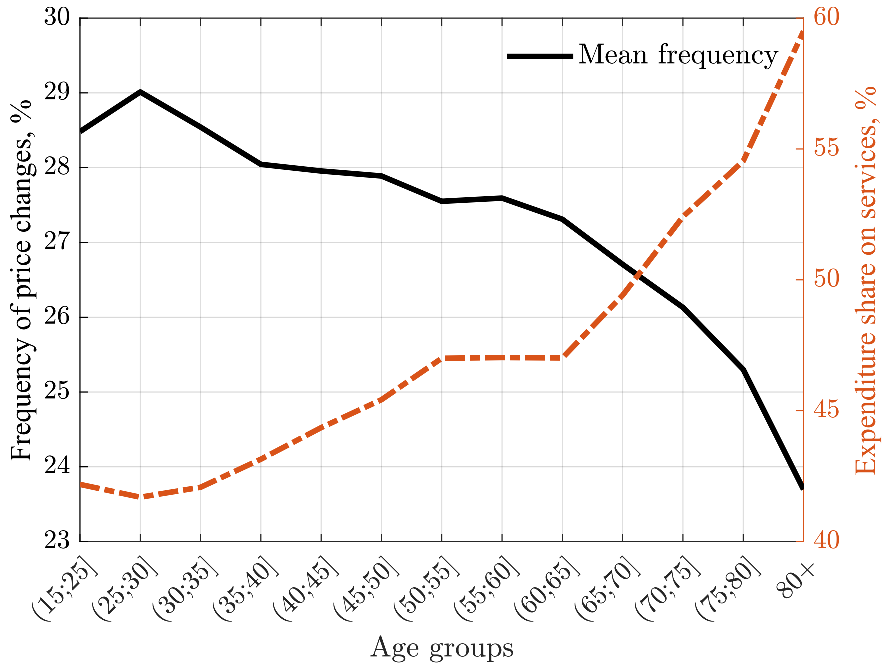
2.1.2 Price stickiness across age groups

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 average frequency of price adjustment across time 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. 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[6]. Figure 36 in Section E of the 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.

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

[6] As shown in Figure 36 in Section E of the 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.

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



Notes: The figure plots the average frequency of price adjustment (left axis) alongside the share of consumption devoted to services (right axis) over the lifecycle. 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).

(right axis) increases from around 40% for younger households up to 60% for older ones[7]. 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[8]. 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.

In Section B of the Appendix, I report the same negative relationship between price stickiness and age across different time periods. While there is some marginal variation over time—partly due to changes in included consumption categories and partly due to actual shifts in expenditure weights—the overall relationship remains relatively stable. This suggests that the finding is not

[7] 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.

[8] 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.

driven by cohort effects and that the link between age and service consumption remains consistent over time.

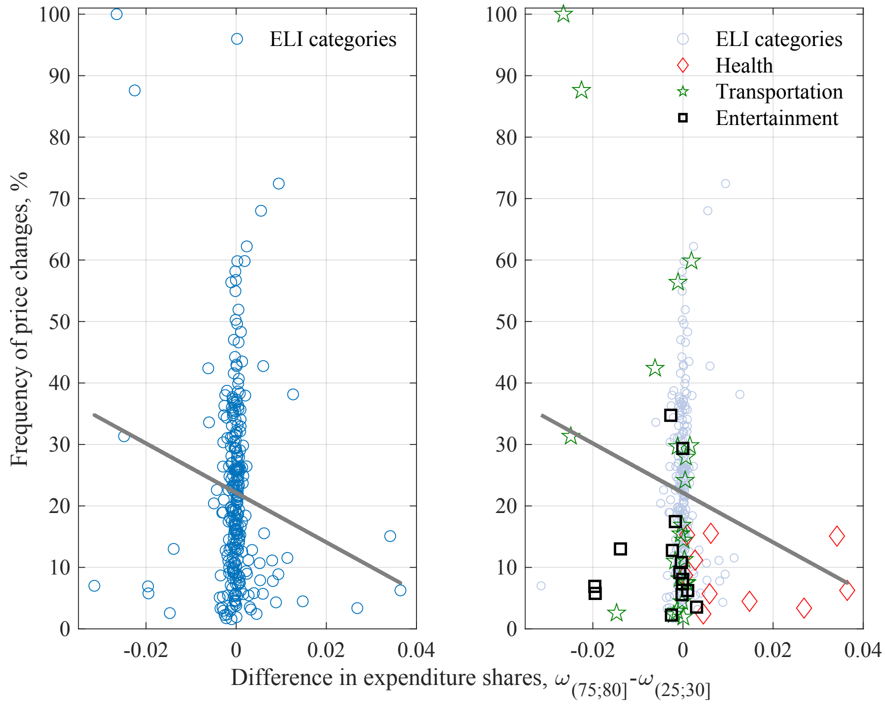
The observed negative relationship between price stickiness and age may be influenced by other demographic factors beyond age alone. For instance, the accumulation of wealth over the lifecycle could contribute to a greater preference for services, which typically exhibit higher price stickiness. To better isolate the effect of age, I conduct robustness checks in Section B of the Appendix. In these checks, I use education level and consumption as proxies for wealth. Even after conditioning on these factors, the strong negative relationship between the frequency of price adjustments within the consumption bundle and age remains robust. Moreover, the relationship between age and the proportion of consumption allocated to services is further examined in a more systematic way by Cravino et al. (2022). The authors control for income deciles and region-time fixed effects, yet still find significant differences in service expenditures among households of varying age groups. Therefore, the evidence suggests that price stickiness increases with age, even when controlling for a comprehensive set of household characteristics.

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 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 bought 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. A more detailed breakdown of age-specific expenditure weights across major consumption categories can be found in Table 5 of the Appendix.

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.

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

How the increase in price stickiness induced by population aging might affect the propagation of monetary shocks? I begin with a standard three-equation New Keynesian model, which allows me to analytically derive theoretical predictions regarding how variations in the frequency of price adjustments affect the responsiveness of output and inflation to such shocks. These predictions suggest that as price stickiness increases output should become more responsive to monetary policy interventions whereas the effects on inflation responsiveness is expected to be negligible. In Section 4, I empirically test these predictions using data from the U.S., and the results confirm the theoretical expectations. Finally, in Section 5, I extend the analysis by incorporating these dynamics into a more complex OLG NK model. The results from this model further corroborate the initial predictions, demonstrating that the relationship between price stickiness and the propagation of monetary shocks remains consistent even within a more sophisticated and realistic framework.

The simple model consists of three equations: the IS curve (1), the Phillips curve (2), and the interest rate rule (3)[9]. These equations relate the output gap $\hat{x}_t$ (defined as the deviation of output

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

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 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[10]. 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 $\left(1-\beta\rho\right)\Lambda_\nu$ 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.

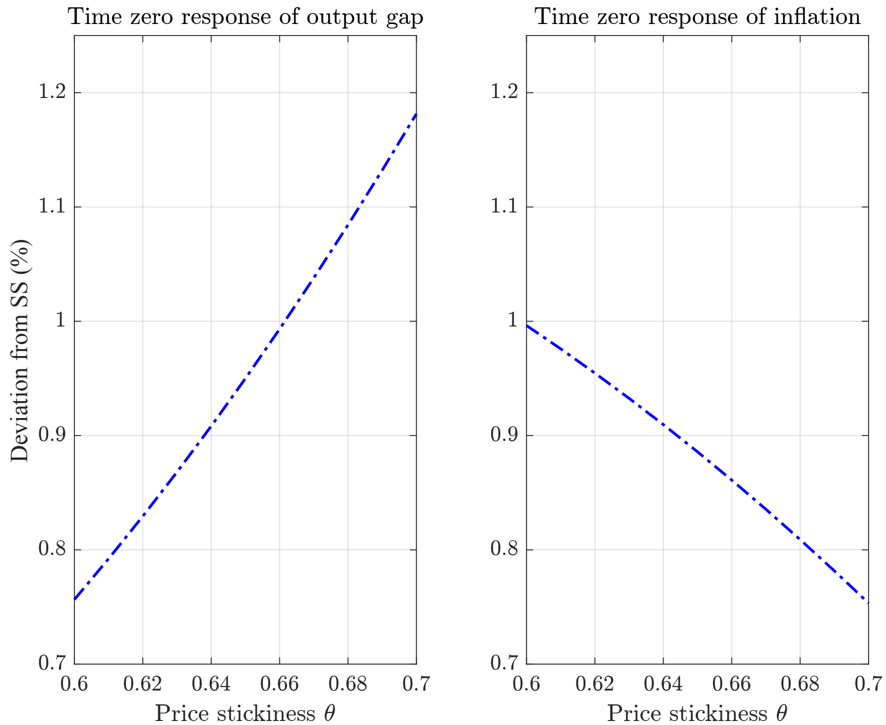
However, the two coefficients differ in magnitude as well as in terms of their sensitivity to changes in the frequency of price adjustment. To see this, I set the model parameters to their standard values in the literature[11], and I compute the contemporaneous response of the output gap and inflation to a 100 basis point expansionary shock, i.e., $\nu_t = -1$, as a function of the price stickiness parameter θ. From 1982 to 2018 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%).

[10] See Chapter 3 of Galí (2015).

[11] $\sigma = 1$ 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 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.

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. In particular, the model predict that a decrease in the frequency of price adjustment due to the heterogeneity in consumption bundle across age groups is expected (i) to significantly increase the responsiveness of output and (ii) to have a more negligible effect on inflation. In the next section, I empirically test these predictions by exploiting the cross-sectional variation in demographic structures and economic activity across U.S. states.

4 Macro-level implications

To test the macro-level implications of the micro-level results I have documented, 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 and the simple theoretical model.

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 37 of the Appendix 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 37. 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 population 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.

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

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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 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[12], 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 birth rates[13]. The results from the IV specification are reported in Column (5)[14] 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 37.

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

[12] 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.

[13] 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).

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

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[15] 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[16]. The main 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 $D^O_{i,t}$ 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:

$$y_{i,t+h} = \alpha_{i,h} + \delta_{t,h} + \gamma_h D^O_{i,t} + \beta^O_h D^O_{i,t} MP_t + \theta_{i,h} X_{i,t-1} + \epsilon_{i,t+h}, \tag{8}$$

where $\delta_{t,h}$ is the time fixed effects that absorb the monetary shocks and the aggregate variables. The coefficients β^O_h 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%).

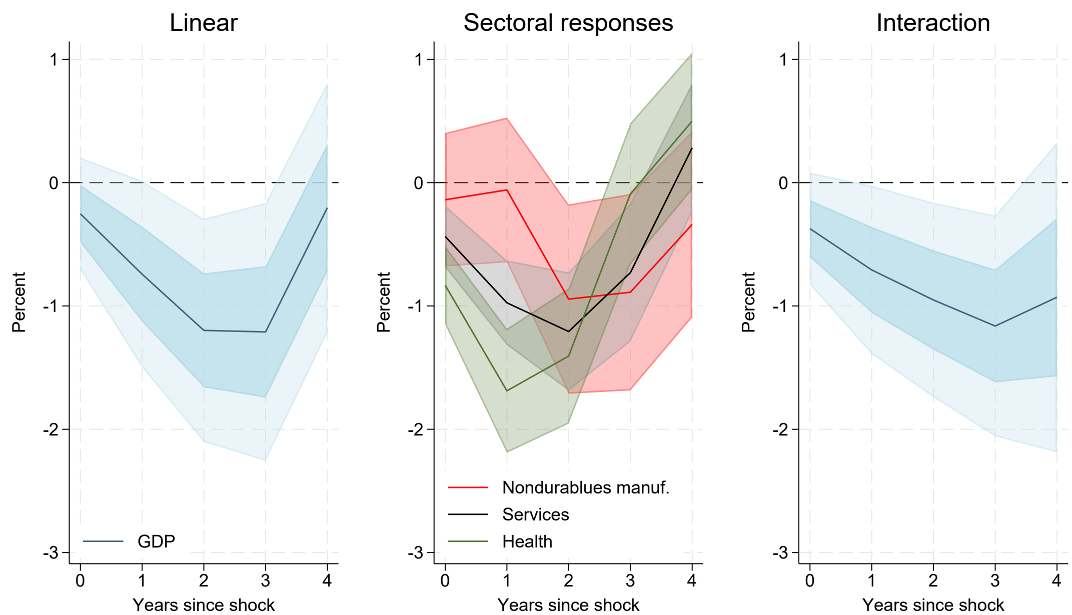
I start by focusing on the impact of monetary policy shocks on the log of real GDP. The left panel of Figure 6 plots the estimated β_h coefficient at different horizons h from equation (7). The dark and light-shaded areas are respectively the 68% and 95% standard deviation confidence intervals. Following a contractionary monetary shock, that is an exogenous increase in interest rate, the real GDP decreases 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 6 plots the responses to a monetary policy shock for different components of the GDP: Services, the non-durables manufacturing components of GDP, and health

[15] In Section C of the Appendix I show that the results are robust to using the services component of the local GDP as dependent variable as a proxy for the non-tradable sector to control for interstate trade.

[16] Similar results are obtained using Driscoll and Kraay (1998) standard errors.

Figure 6: 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-durables manufacturing 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.

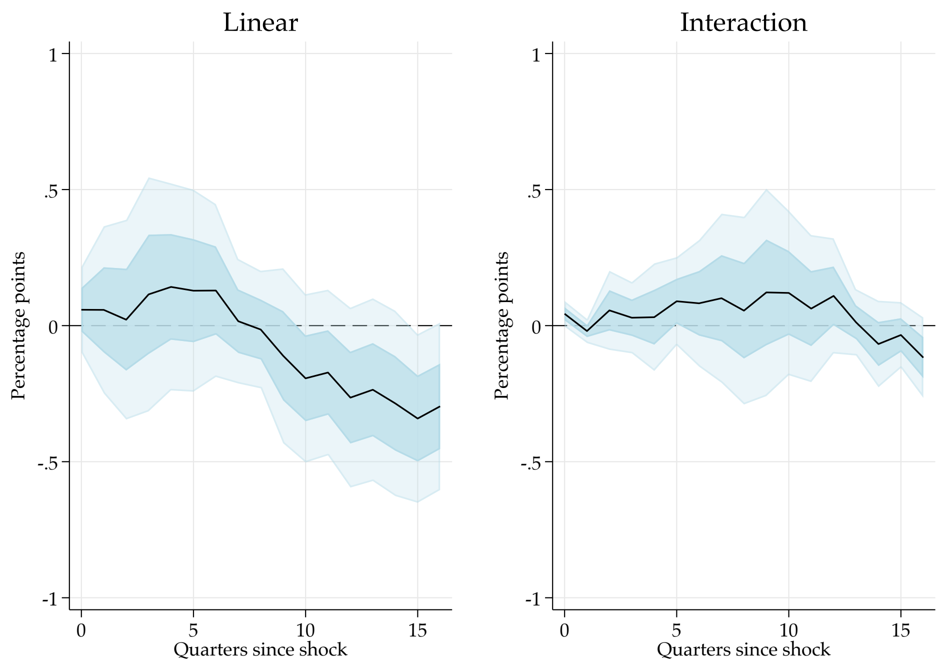
expenditures. In line with the price stickiness channel, the contemporaneous response of services is stronger relative to the non-durables manufacturing components of GDP.[17] Moreover, health expenditures, the sector with the lowest frequency of price adjustments as documented in the previous section, decrease the most following a contractionary shock.

The right panel of Figure 6 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 7 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

[17] Figure 41 of the Appendix tests and confirms that the difference is statistically significant by computing the responses of the difference between services and health expenditures with the non-durables manufacturing.

Figure 7: 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 dummies identifying the top 20% of the old-age dependency ratio distribution.

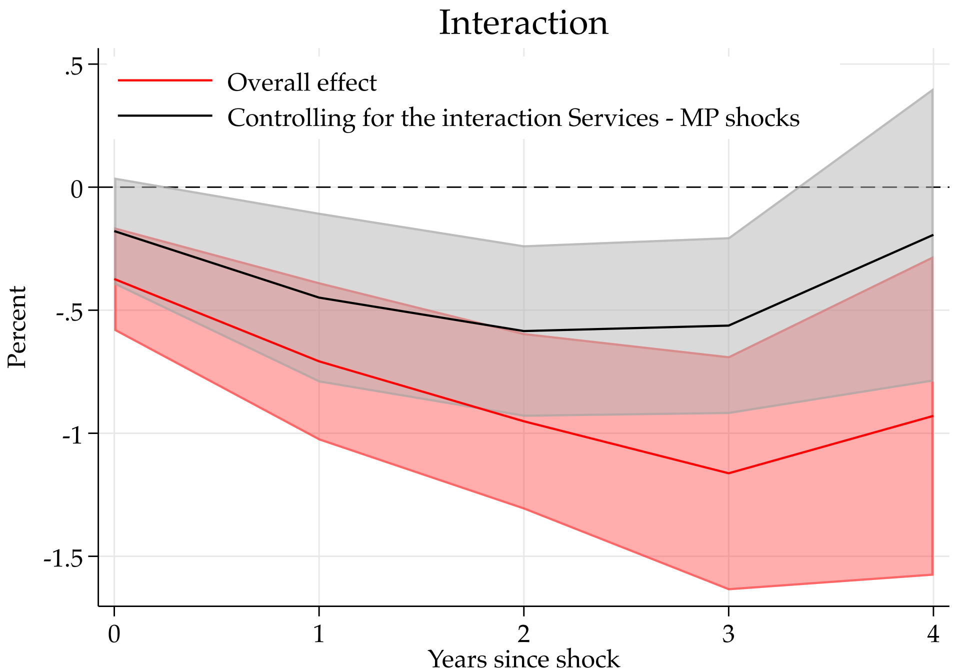
differences in the inflation responses across states along the old-age dependency ratio distribution. As I will show in Section 5, the more complex model I develop is able to replicate this result.

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.

The interaction coefficients between the monetary policy shocks and the state-level dummy for the demographic structure are reported in Figure 8. Controlling for the higher sensitivity of the

Figure 8: 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.

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 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 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 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. 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 $Z_t = \frac{P_t^G}{P_t^S}$.

[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.

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:

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

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

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

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. 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_t^k is the nominal rental rate on capital.

In the second stage, $Y_{i,t}^s$ and $P_{i,t}^s$ 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.[19] 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:

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

where MC_t^s 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.

[19] The different responses in the two sectors can be obtained similarly by introducing nominal frictions as in Rotemberg (1982). In this alternative class of models, all firms adjust their prices each period, but they face quadratic costs of adjusting prices. Calibrating different price adjustment costs for goods and services would achieve the desired result.

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:

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

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 $P_{i,t}^d$ and yield real dividends $F_{i,t}$. The nominal balance sheet of investment funds at the end of period t can be written as:

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

I_t denotes investment in physical capital which accumulates according to:

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

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

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

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:

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

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:

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

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

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:

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

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 $P_t = \left[\omega_t^{\frac{1}{\eta}} (P_t^S)^{1-\eta} + (1-\omega_t)^{\frac{1}{\eta}} (P_t^G)^{1-\eta}\right]^{\frac{1}{1-\eta}}$ 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 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 evaluating 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 rates $(1 - s_j)$, 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.

The Calvo parameters for the services sector ($\theta^S = 0.77$) and the goods sector ($\theta^G = 0.25$) are calibrated to match the average price duration estimates from Nakamura and Steinsson (2008). This calibration implicitly assumes that sectoral price stickiness remains constant over time. This assumption is supported by empirical evidence from Nakamura and Steinsson (2008), Klenow and Kryvtsov (2008), and Gautier et al. (2024), who find that the frequency of price adjustment has remained relatively stable despite substantial macroeconomic changes. In Section 5.8.6, I assess the robustness of the results to alternative values of price stickiness and show that the main conclusion—that demographic trends increase the responsiveness of output to monetary shocks—remains unchanged.

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 9, 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 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.

Table 3: Calibrated parameters

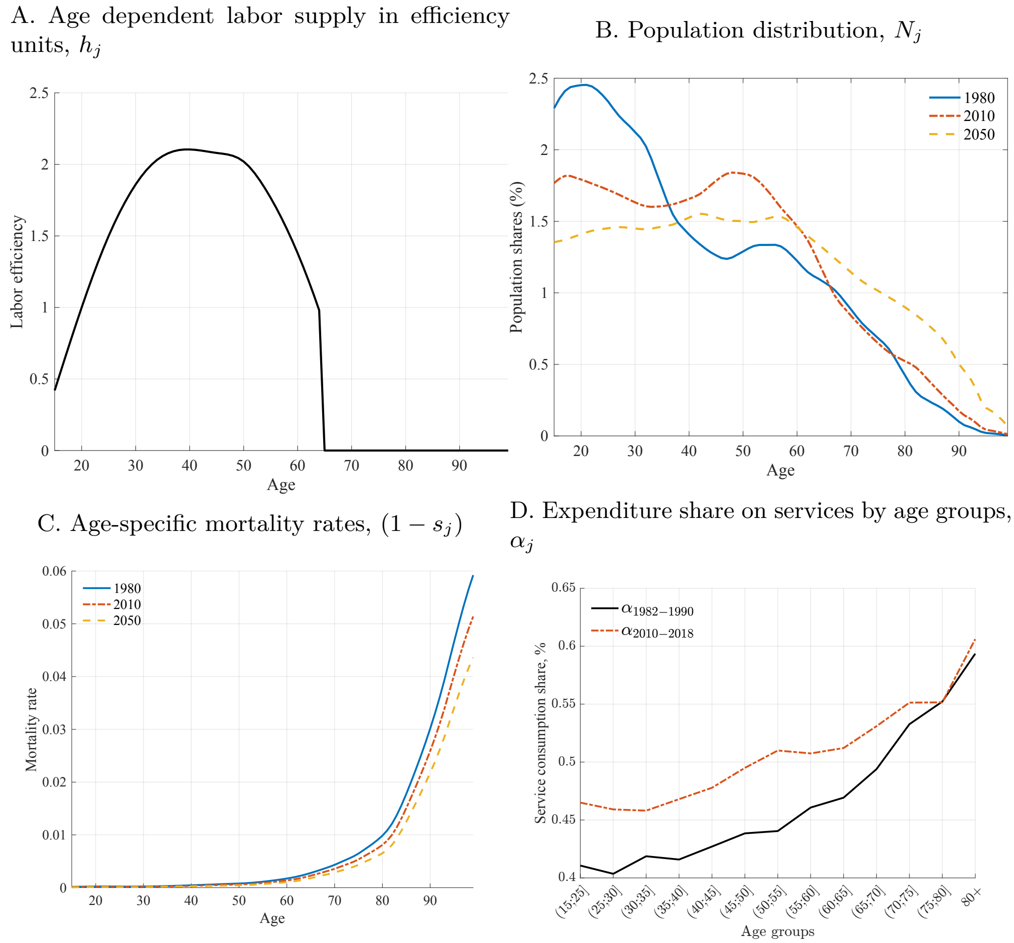
Parameter	Value	Description	Target
β	0.999	Discount factor	Annual interest rate between 4 and 5 %
δ	0.02	Depreciation rate	Capital-output ratio between 2 and 2.7
N_j	Panel B of Figure 9	Population shares. *Source*: United Nations (2017) World Population Prospects	Realised and forecasted population shares
$(1 - s_j)$	Panel C of Figure 9	Age-specific survival probability. *Source*: Social Security Administration	Realised and forecasted mortality rates
α_j	Panel D of Figure 9	Share of consumption devoted to services	Age-group service preferences from CEX
h_j	Panel A of Figure 9	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.

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 9, 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 9. 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.

Figure 9: 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.

Panel D of Figure 9 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 39 in Section E of the 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.

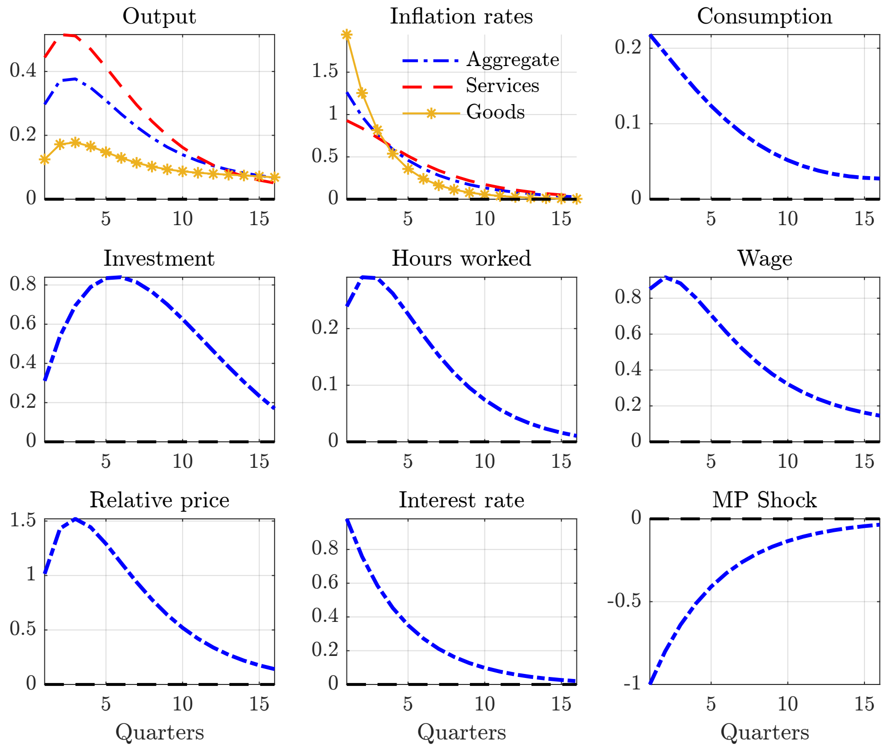
5.8.2 Monetary policy over the lifecycle

Figure 10 reports the IRFs to an expansionary monetary shock of the main variables in the model computed using the demographic structure in 1980. The responses are measured as percentage deviations from their respective steady-state values. 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 nominal interest rate to slow down economic growth until the economy returns to the initial steady state.

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.

I report in Figure 11 the contemporaneous deviations of consumption, asset, and labour income as well as the subsequent 1 and 2 years after that monetary policy is expanded, i.e., after 4 and 8 quarters. 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 (left panel) 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.

Figure 10: Model impulse response functions



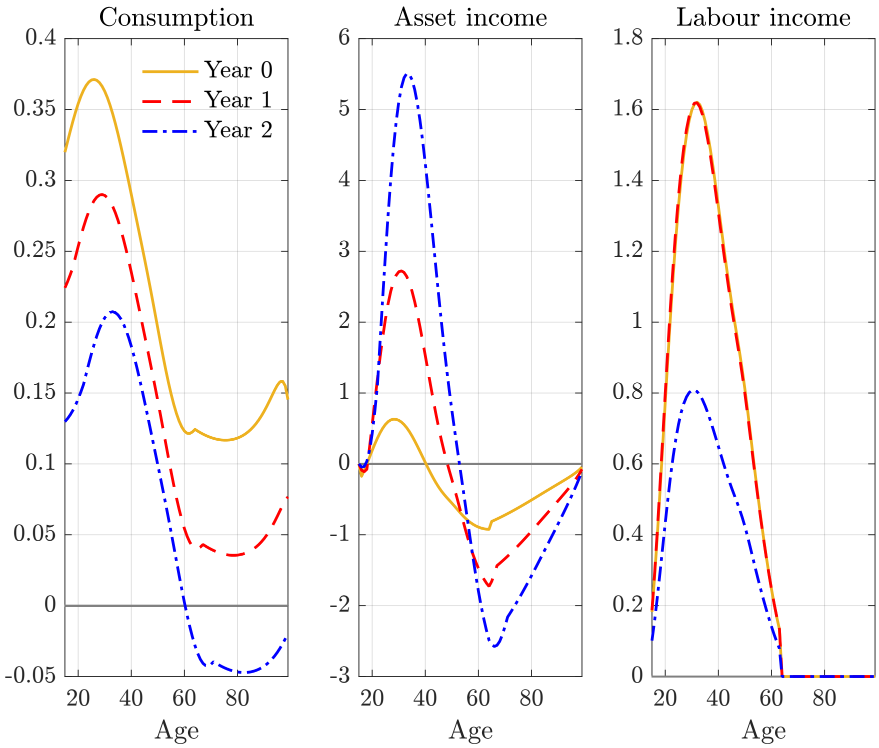
Notes: The plot reports the IRFs of several variables of interest computed using 1980 as steady states following a 100 basis points expansionary monetary policy shock. The responses are measured as percentage deviations from their respective steady-state values.

The negative relationship between age and consumption responsiveness is due to the hump-shaped distribution of assets and labor productivity reported in Figure 39 of Section E of the Appendix and Panel A of Figure 9 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 (right panel). At the same time, asset income increases for young households as they start saving more, whereas decreases for older ones as they dissave (middle panel).

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 11: Model impulse response functions by age



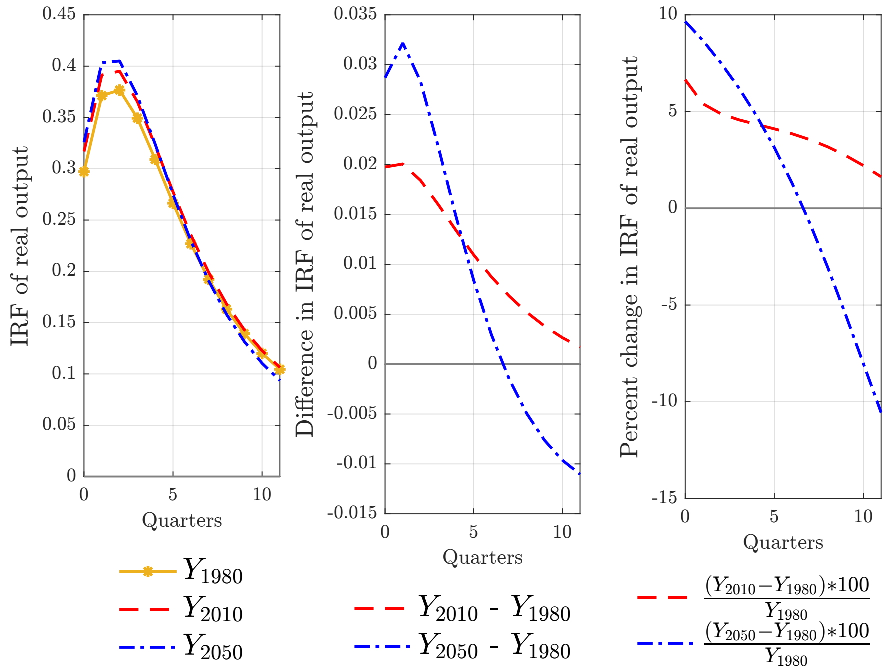
Notes: The plot reports the IRFs by age of several variables of interest computed using 1980 as steady states. The IRFs shown are the contemporaneous responses as well as the responses 1 and 2 years after the shock, i.e., after 4 and 8 quarters. The responses are expressed as deviations from steady-state as a percentage of steady-state consumption.

It is important to underline that this exercise does not isolate the contribution of the consumption channel in affecting the transmission of monetary policy shocks. All the different channels through which demographic trends influence monetary policy are included in the model, i.e., wealth distribution, labour market participation, etc. So the documented effects refer to the overall impact of population aging. In Section 5.8.4 I disentangle the role played by consumption heterogeneity relative to the overall effects.

The responses are plotted in the left panel of Figure 12. 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 13 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 12: Model IRFs of output for different demographic structures



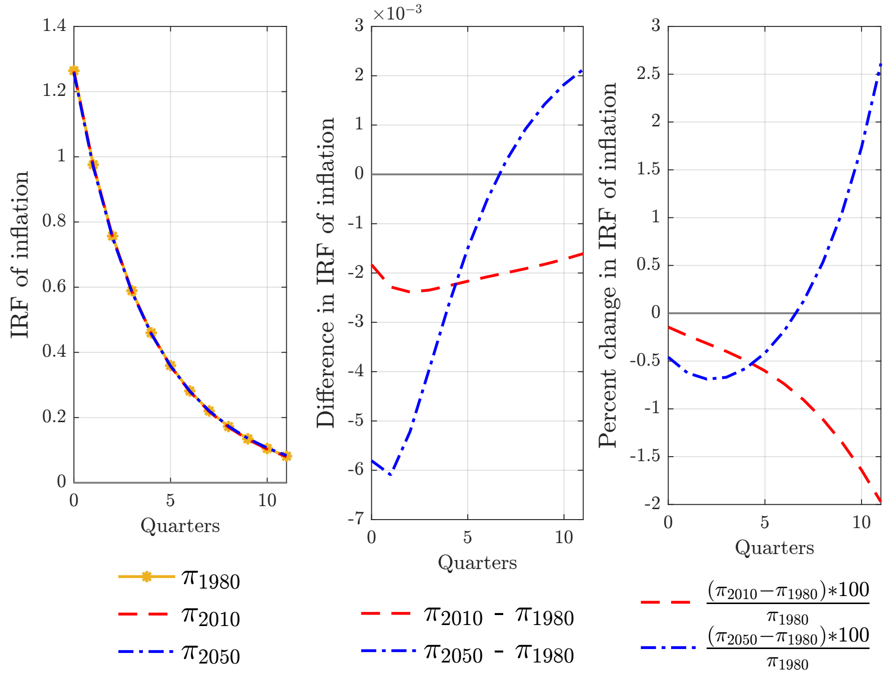
Notes: The left panel of the plot reports the IRFs of output across the three different steady states changing only the population distribution and mortality rate and keeping service preferences at the 1980 values. The middle panel shows the first differences between these IRFs, i.e., the difference between the IRF of output in 2050 and 2010 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, both the empirical findings and the theoretical model indicate that demographic trends increase the responsiveness of output to monetary policy, as illustrated in Figures 6 and 12. On the other hand, Figure 11 shows that older households are significantly less responsive to interest rate changes—a result consistent with empirical evidence from Wong (2021). At first glance, these two findings appear contradictory: how can an economy with a rising share of older, less responsive individuals become more sensitive overall to monetary shocks? To address this apparent paradox, I analyze how different age groups are affected by the structural transformation driven by population aging.

The left panel of Figure 14 reports the model-implied percent change in consumption by age group following an expansionary monetary shock, under the demographic structures of 1980, 2010, and 2050. The demographic shift from 1980 to 2010 has little impact and remains relatively uniform across age groups. By contrast, the projected 2050 demographics show a highly uneven pattern: younger households, particularly those aged 25 to 35, exhibit a much stronger response—about

Figure 13: 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 2010 with the respect to the baseline IRF in 1980, whereas the right panel reports the percentage change in IRFs across the different steady states.

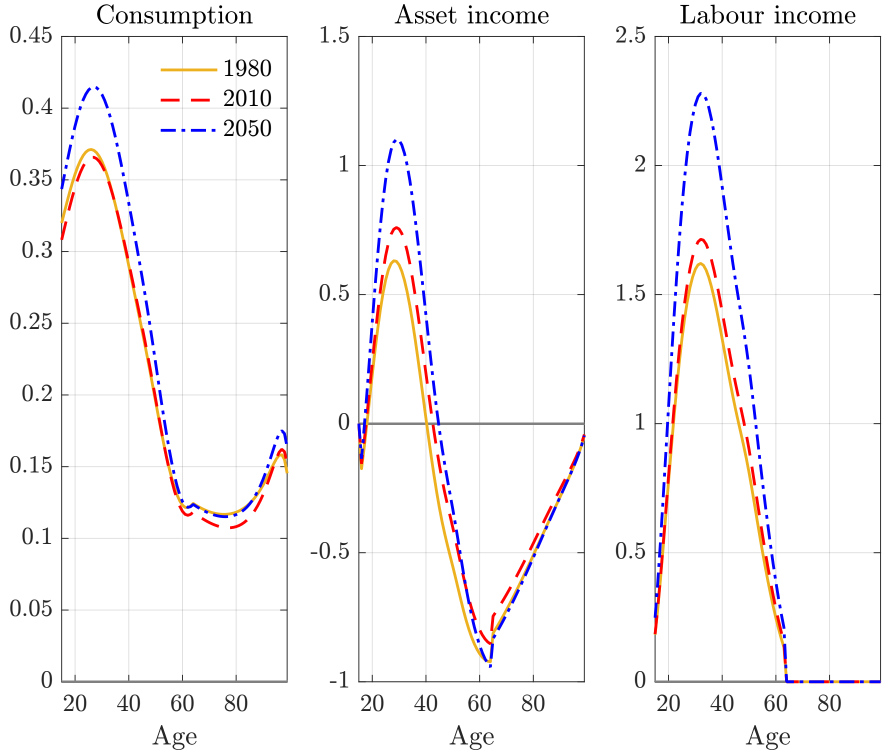
15% higher than in 1980—while the consumption response of older households remains largely unchanged.

These findings reconcile the earlier tension. The fact that older individuals are less responsive to interest rate changes does not imply that population aging reduces overall output sensitivity to monetary policy. While a greater share of less responsive (older) agents would, in isolation, reduce aggregate consumption sensitivity, this effect is offset by a second channel. As shown in the middle and right panels of Figure 14, demographic change also amplifies the transmission of monetary shocks to younger households through larger changes in their asset and labor income. This increased exposure raises the consumption responsiveness of young households, ultimately outweighing the compositional drag from aging and leading to a stronger aggregate output response.

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 6 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

Figure 14: Heterogeneous responses to expansionary monetary policy shocks, by age



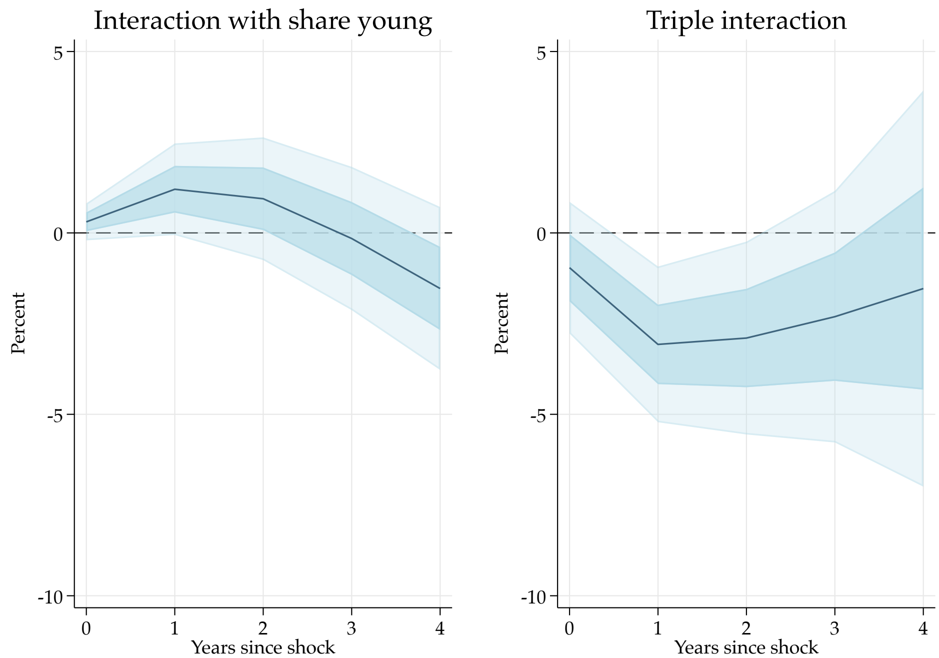
Notes: The plot reports the model-implied percent change of consumption, asset and labour income across age groups following an expansionary shock using the demographic structure of 1980, 2010, and 2050. The responses are expressed as deviations from steady-state as a percentage of steady-state consumption.

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:

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

The results from equation (32) are reported in Figure 15. On the left panel, I display the interaction coefficients between the monetary policy shocks and the dummy identifying the states 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 response 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

Figure 15: Impact of monetary policy on the real GDP in young and old states, triple interaction



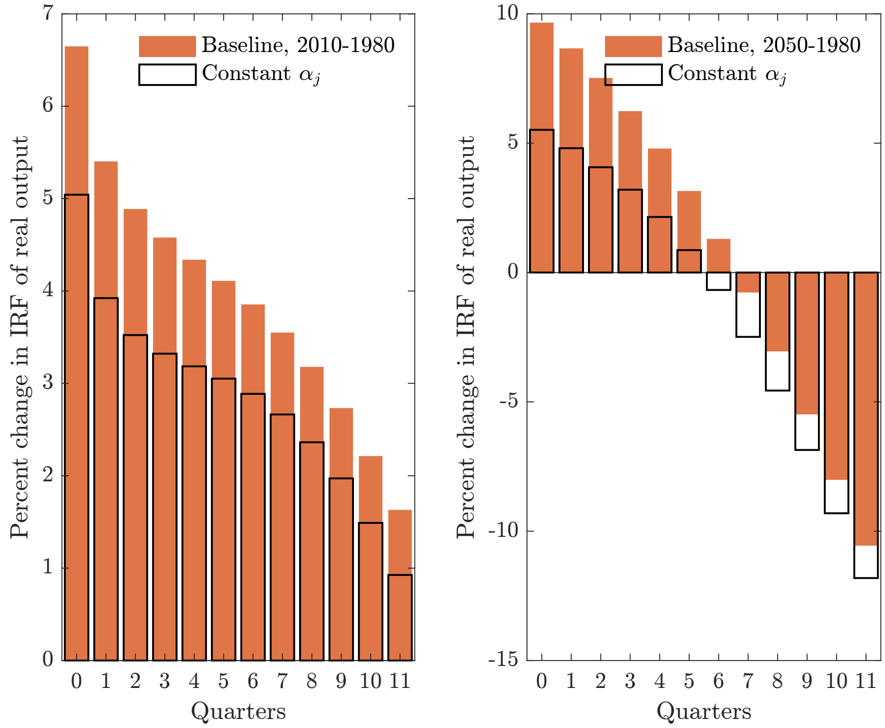
Notes: The left panel of the figure plots the interaction coefficients between the monetary policy shock and the dummies identifying the top 20% of the share of 15-25 years old, as well as the 68% (dark shaded area) and 95% (light shaded area) confidence intervals. The horizontal axis is in years. The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

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 12 and Figure 13 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 16: Model IRFs of output between the baseline and the contrafactual scenario



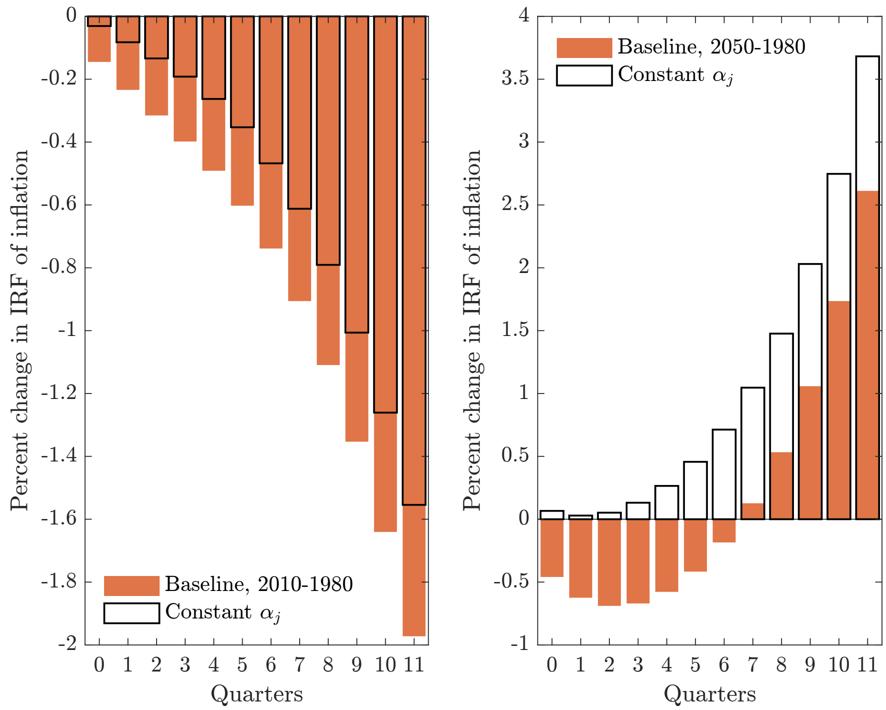
Notes: The plot compares the percent changes of output for 2010 relative to 1980 (left panel) and for 2050 relative to 1980 (right panel) for the baseline and a contrafactual scenario in which all age groups have the same sectoral preferences.

Figure 16 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 8. 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 17. 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.

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



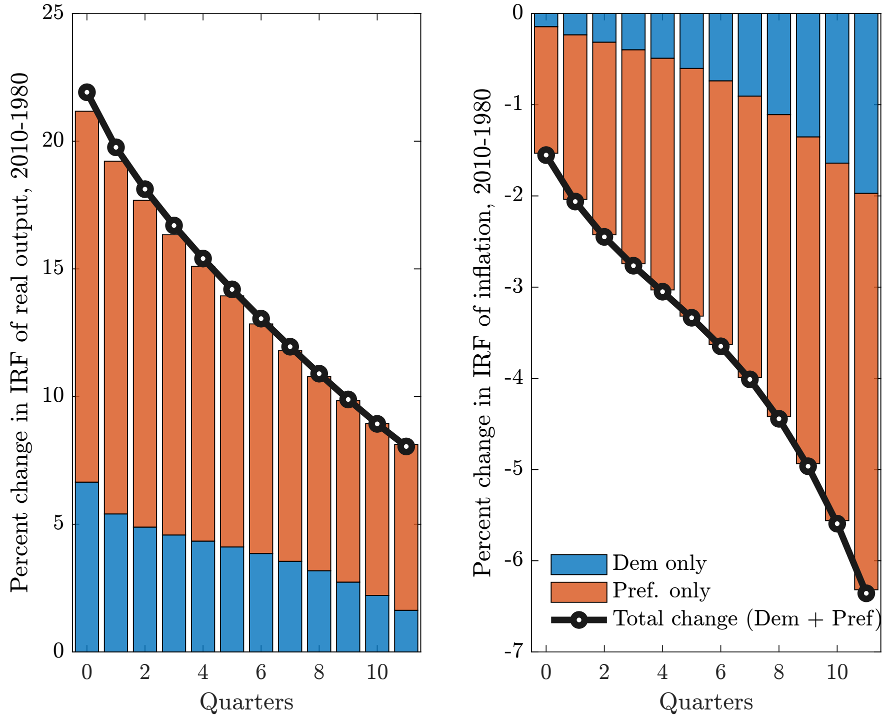
Notes: The plot compares the percent changes of inflation for 2010 relative to 1980 (left panel) and for 2050 relative to 1980 (right panel) for the baseline and a contrafactual scenario in which all age groups have the same sectoral preferences.

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 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 12 and 13. The results are reported in the blue bars of Figure 18. 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

Figure 18: 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.

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.

The right panel of Figure 18 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%[20].

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

[20]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 40 of Section E of the 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.

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 density function of a normal distribution. Figure 39 in Section E of the 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.

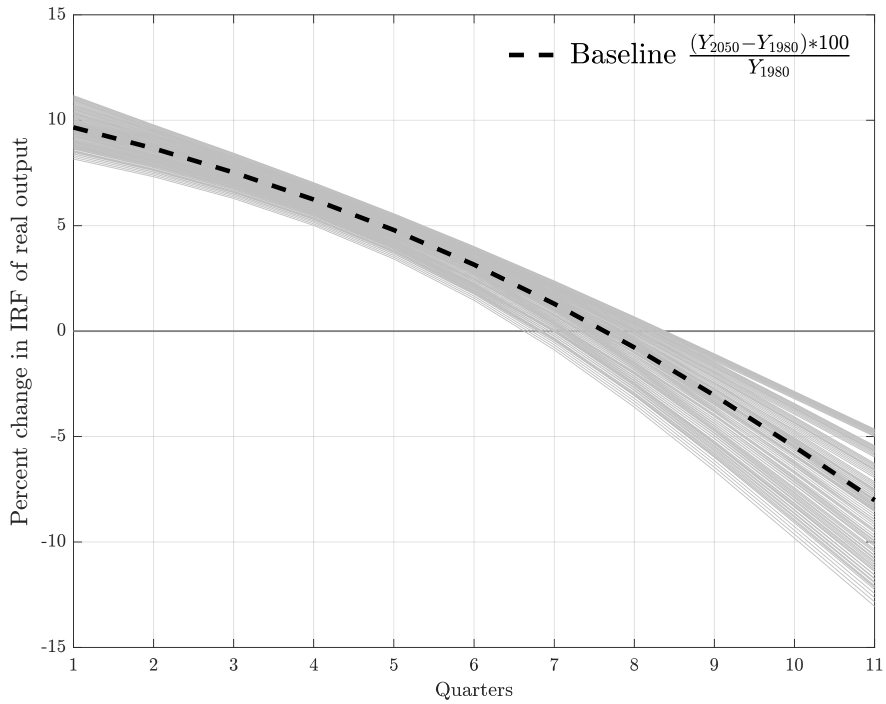
Table 4: Response of Output and Inflation - Robustness Checks

	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.

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

Figure 19: 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 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. The empirical evidence provided by Nakamura and Steinsson (2008), Klenow and Kryvtsov (2008), and Gautier et al. (2024) suggest that the frequency of price adjustment has remained relatively stable over time despite significant macroeconomic changes.

To further reassure the reader, in Figure 19 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 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 one experienced 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 that the cost of a recession is mainly borne by them.

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A Data sources

A.1 CEX

The expenditure data necessary to compute age-group level weights are obtained from the Consumer Expenditure Survey (CEX). The survey is run by the Bureau of Labor Statistics and covers expenditures, income, and demographic characteristics of households in the United States since the beginning of the 80s and it is the main source of data for the construction of the U.S. Consumer Price Index.

The CEX contains two modules: the Interview and the Diary. The first covers the entire household consumption bundle and the respondents are interviewed for a maximum of four consecutive quarters regarding the purchases over the previous three months. The second focuses more on daily expenditures such as groceries and personal products for two consecutive survey reference weeks.

Household expenditures are collected at Universal Classification Code (UCC) level for about 600 categories. Moreover, demographic characteristics such as age, education, gender, race, etc. are included as well. Since the Diary and Interview surveys contact different households each year, to obtain the full consumption profiles the households are aggregated into age groups based on the age of the respondent.

The UCC level is the most disaggregated expenditure level available in the survey. These categories can be aggregated into less granular categories as, in increasing order, the Entry Level Items (ELI), the Item Strata, and the Expenditure Class. As an example, the UCC categories *White bread (020110)* and *Bread other than white (020210)* can be aggregated into the ELI *Bread (FB011)* and then into the Item Strata *Bread (FB01)* which is one of the components of the Expenditure Class *Bakery products (FB)*. The concordance across levels is provided by the BLS in the document "CPI requirements for CE" Appendix B.

Since the data on the frequency of adjustment provided by Nakamura and Steinsson (2008) are provided at the ELI level, the expenditure data at the UCC level from CEX are aggregated at the ELI level as well. Out of the 272 categories in Nakamura and Steinsson (2008), I have a match for 263 ELIs which can be further aggregated into 180 Item Strata or 67 Expenditure Classes.

To compute the expenditure shares for each product category at the age-group level, I proceed in the following way. First, I compile the consumption data from the two surveys of the CEX. From the Interview survey, I obtain information about each household interviewed month and year, monthly expenditures at the UCC level for the previous three months as well as its demographic characteristics. Similarly, from the Diary survey, I gather data on household weekly expenditure (at the UCC level as well) and its demographic characteristics. The Interview data file is then appended to the Diary to get the whole sample of UCCs.

Then, in line with the BLS procedure and following the instructions in the document "CPI Requirements of CE", several adjustments are performed on the expenditure data.

Homeowner insurance/maintenance/major appliance. The housing expenses on insurance, maintenance, and major appliances need to be corrected to take into account that these expenditures include an investment component for homeowners. Therefore, in line with BLS, the homeowner's total expenditure on the corresponding UCC categories is multiplied by a factor of 0.43 to isolate the consumption portion. The factor is based on the likelihood that renters will purchase these types of appliances and perform these types of home maintenance and improvement.

Medical care. The BLS redistributes the weights from private health insurance and the Medicare premium to the other medical care services using the National Health Expenditure (NHE) tables produced by the Center for Medicare and Medicaid Services (CMS). Since this information is not publicly available, I follow Cravino et al. (2020) by taking the redistributing factors from the NHE *Table 20 Private Health Insurance Benefits and Net Cost; Levels, Annual Percent Change and Percent Distribution, Selected Calendar Years 1960-2015*.[21] The factors from this table allow us to redistribute the expenditures from private health insurance and Medicare premiums to health care service categories, such as nursing homes and adult day services.

Used cars and trucks. Expenditures on used cars and trucks should only reflect dealer value added. However, the data on trade-in values of cars and trucks are not provided by the CEX. Therefore, as in Cravino et al. (2020) which found that the ratio of trade-in values and other sales of vehicles to spending on used cars and trucks is around 1/2, I reduce the spending on used cars and trucks to half to isolate only the dealer value added.

Gasoline. In the CEX data total gasoline expenditures are available only for one UCC category (470111). However, Nakamura and Steinsson (2008) computes the frequency of price adjustment for three different ELIs: *Regular Unleaded Gasoline (TB011)*, *Midgrade Unleased Gasoline (TB012)* and *Premium Unleased Gasoline (TB013)*. Since the price stickiness parameters are similar among the three categories (88.6, 87.6, and 86.9 respectively), the expenditure weight of total gasoline is matched with the average frequency of price adjustment for the three ELIs.

Finally, I aggregate households into age groups and calculate the relative expenditure shares. The Interview and the Diary survey different households but both modules provide data on the age of the respondent so the grouping is rather straightforward. I then compute the average expenditure for each UCC category at age group in the calendar year. The fact that a respondent interviewed in February will report personal consumption not only for January but also for November and December of the previous year needs to be taken into account. Similar to what the Bureau of Labor Statistics (BLS) does for the computation of the official Consumer Price Index (CPI), I create a variable called MO_SCOPE to control for the number of months a household reports expenditures during a calendar year. Therefore, this variable takes value 1 if the household is interviewed in February and value 3 if it is interviewed from April onwards. In the Diary survey, there is no distinction between the survey period and the expenditure reference period. Hence, the variable MO_SCOPE is always equal to 3 for the households in the Diary survey since all their purchases refer to the same calendar year in which they are interviewed. The weekly expenditures are multiplied by 13 to convert them into quarterly expenditures.

[21] See the link `https://www.cms.gov/research-statistics-data-and-systems/statistics-trends-and-reports/nationalhealthexpenddata/nhe-fact-sheet.html`

Following the BLS procedure, I can then use the formula below to compute the average expenditure for each UCC category k at each age group level a. First, for household i at age group a, I aggregate over all the expenditures on good k during the calendar year. Second, the household total expenditures are weighted by the sampling weights, fwt, provided by BLS to make the survey sample representative of the U.S. population. Third, the weighted household expenditures are summed up at the age group level. Fourth, to obtain the monthly average income spent on good k by decile d, we divide the annual weighted household expenditures for category k by the sum of the weighted number of months household at age group a reported expenditures during the calendar year. Then, to annualize the average UCC category expenditure at the age group level it is sufficient to multiply the monthly average expenditure by twelve:

$$X_k^a = \frac{\sum_i fwt_i^a \sum_t c_{i,k,t}^a}{\sum_i fwt_i^a \ MO\_SCOPE_i^a} \times 12 \tag{33}$$

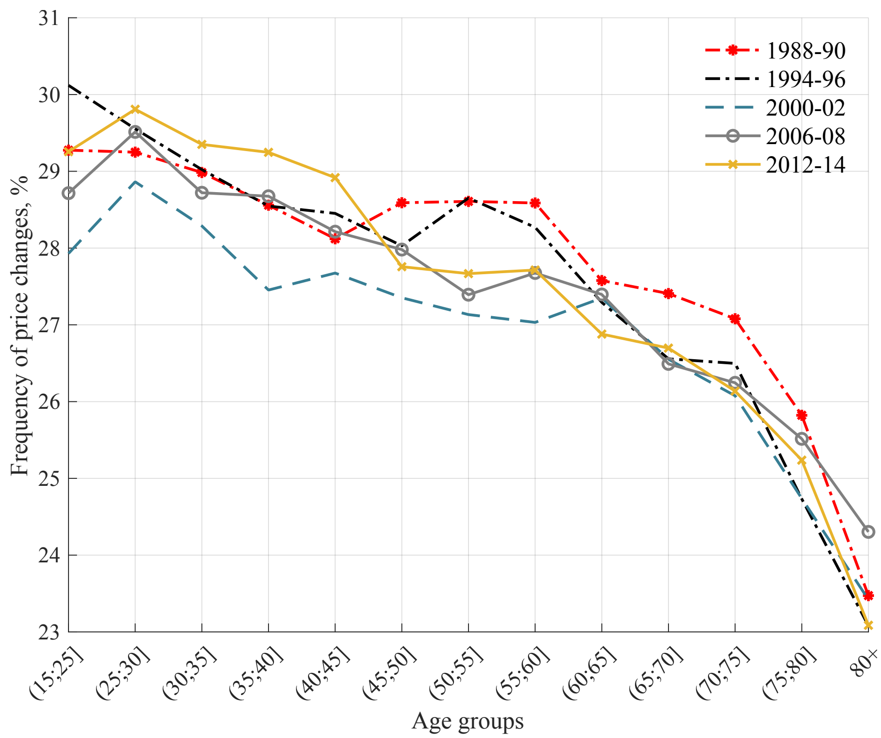
where fwt_i^a is the frequency weight for household i at age group a, $c_{i,k,t}^a$ refers to the annual consumption on UCC category k by household i at age group a and $MO\_SCOPE_i^a$ identifies the number of months per year household i reported its expenditures.

In the final step, I compute the age group level average expenditure for each UCC category. I then aggregate the UCC categories according to the constructed concordance between UCC categories and ELIs to get the age group level average expenditure X_j^a for each of the 259 ELIs and the corresponding expenditure share $\omega_j^a = \frac{X_j^a}{\sum_k X_j^a}$.

B Robustness for the microlevel analyis

I first control that the negative relationship between age and frequency of price adjustment is stable over time. Figure 20 shows the same pattern for different periods. There is some marginal variation across time periods, partly due to the fact that some consumption categories are dropped and some are added, and partly due to actual changes in expenditure weights. However, the main conclusion still holds: the frequency of price adjustment decreases with age.

Figure 20: Frequency of price adjustment across age groups and time



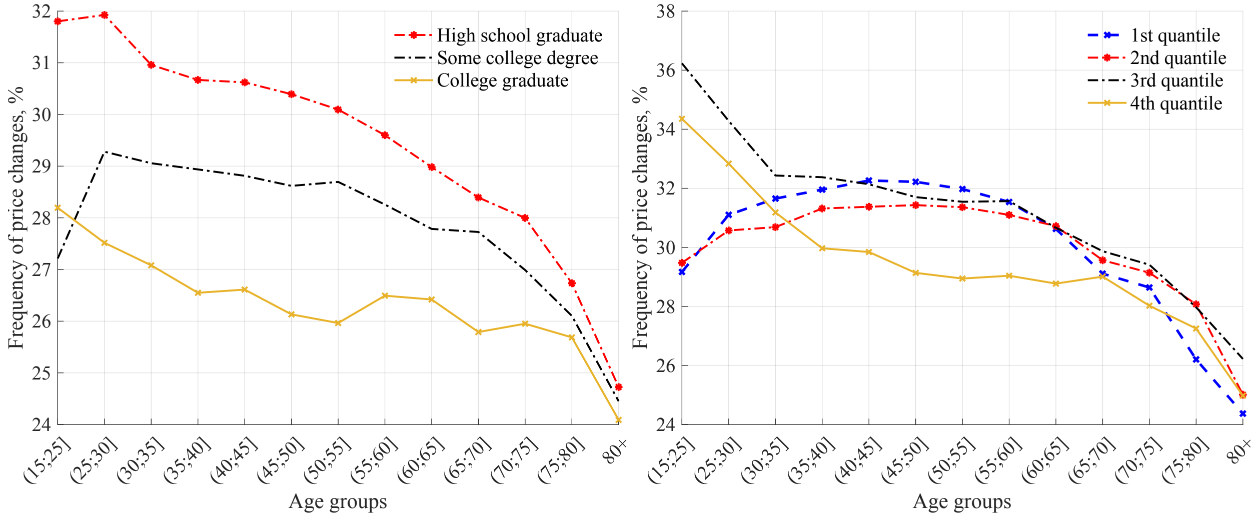
Notes: The figure plots the weighted average frequency of price adjustment at the age group level across five different time periods. The frequency of price adjustment is computed as the fraction of the number of times an item changes its price over the number of times the item is observed and expressed in percent per month. The source of the data is the CEX.

A potential source of concern regarding the main findings is that these patterns might be explained by demographic characteristics other than age. Indeed, Clayton et al. (2018) show that prices are more rigid in sectors selling to college-educated households whereas Cravino et al. (2020) demonstrates that price stickiness displays an inverse U-shaped distribution across income groups.

To control that these demographic characteristics do not drive the results, I compute the frequency of price adjustment across age groups conditioning on the education level of the respondents as well as on the consumption quantile to which they belong[22].

[22] Cravino et al. (2020) use the imputed income level which is available only from 2004 onward. For this reason, I use consumption level as a proxy for income. Moreover, since the households interviewed in the Interview survey are not the same ones interviewed in the Diary survey, for this robustness check I focus only on the Interview survey.

Figure 21: Frequency of price adjustment across age groups, education levels, and consumption quantiles

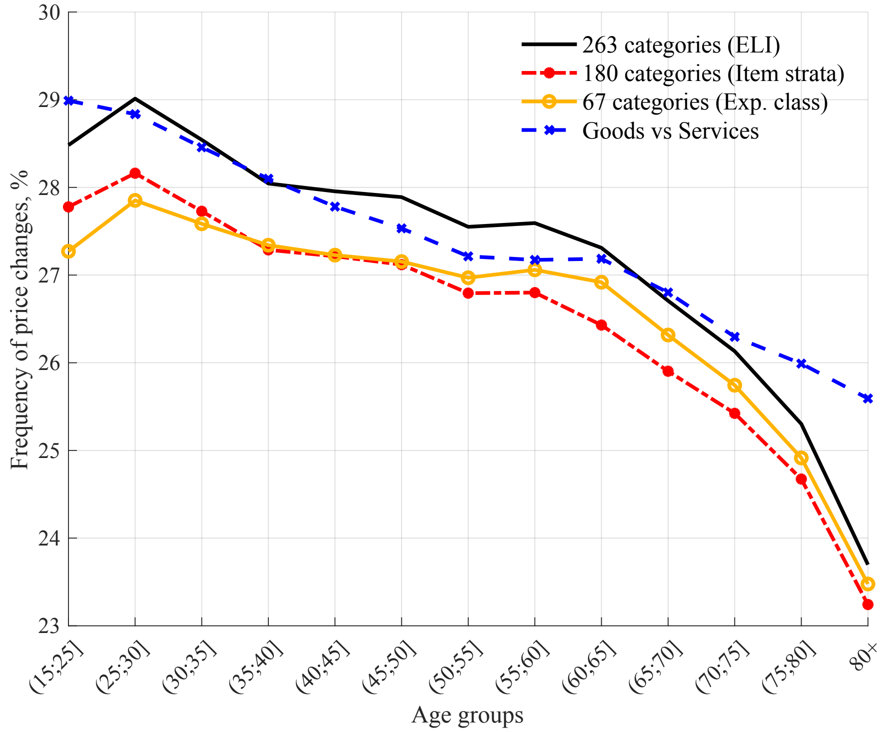


Notes: The left panel plots the weighted average frequency of price adjustment at the age groups level for three different education levels. The right panel reports the weighted average frequency of price adjustment at the age group level for different consumption quantiles. The frequency of price adjustment 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 left panel of Figure 21 confirms that the consumption bundles of college-educated households have a lower frequency of price adjustment as in Clayton et al. (2018). In line with the findings of Cravino et al. (2020), the right panel of Figure 21 shows that the average frequency of price adjustment tends to decrease along the consumption distribution. However, conditioning on education level as well as on consumption does not weaken the negative relationship between the frequency of price adjustment and age.

Finally, I check that no outlier in the expenditure categories is responsible for the pattern observed. Figure 22 shows that aggregating the 263 items into less and less granular groups does not remarkably affect the observed negative relationship between age and frequency of price adjustment. In particular, the classification of each expenditure category into goods or services almost entirely captures the relationship of interest

Figure 22: Frequency of price adjustment across age groups, alternative aggregation



Notes: The figure plots the average frequency of price adjustment across age groups when the expenditure categories are aggregated at ELI, Item Stata, and Expenditure Class level as well as Goods and Services. 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.

C Robustness for the regional responses

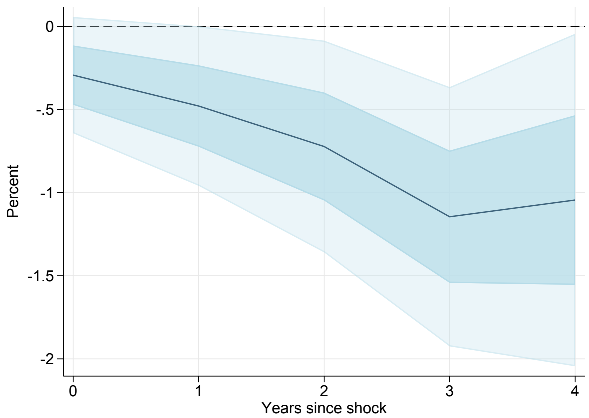
In this section, I consider a number of robustness checks to the baseline specification. First, I repeat the same empirical analysis excluding the five smallest states by population, i.e., Alaska, North Dakota, Vermont, Washington D.C., and Wyoming as well as Florida. As can be seen in Figure 23, this has basically no effect on the interaction coefficients both for real GDP (top row) and inflation (bottom row).

Second, I investigate whether our results are sensitive to altering the beginning and the end of the sample. Coibion (2012) shows how few episodes in the early 80s can be the main drivers of the impulse responses computed using local projection with Romer and Romer (2004) shocks. Therefore, I perform the same analysis starting our sample in 1985 as well as truncating all data in 2006 to exclude the financial crisis period. The results are reported in Figure 24. In this case, the results are also robust.

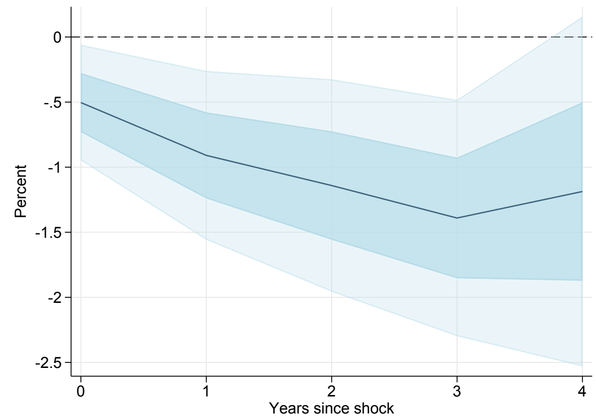
Third, I evaluate whether including different lags of the dependent variable y and the shock might alter the results. I then compute the responses of real GDP and inflation controlling for one lag of y and one lag of the shock, four lags of y and one lag of the shock, one lag of y and four lags

Figure 23: Impact of monetary policy on regional variables, dropping states

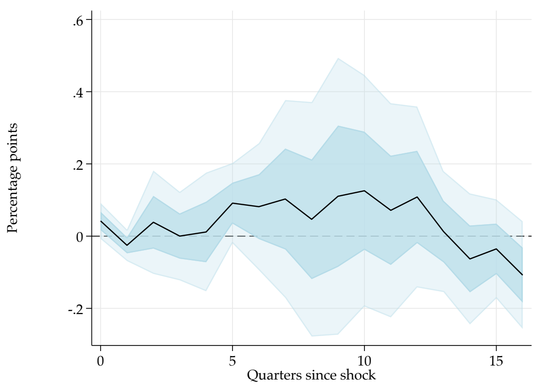
A. Real GDP excluding Alaska, North Dakota, Wyoming, Vermont, District of Columbia



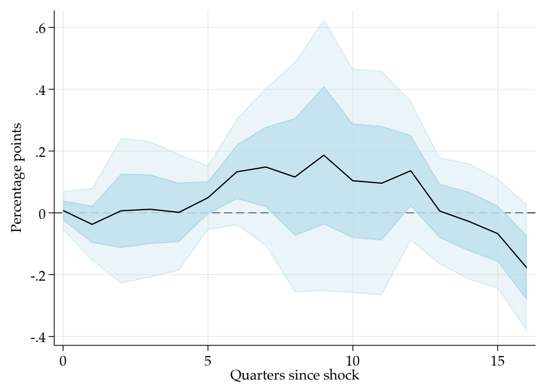
B. Real GDP excluding Florida



C. Inflation rate excluding Alaska, North Dakota, Wyoming, Vermont, District of Columbia



D. Inflation rate excluding Florida

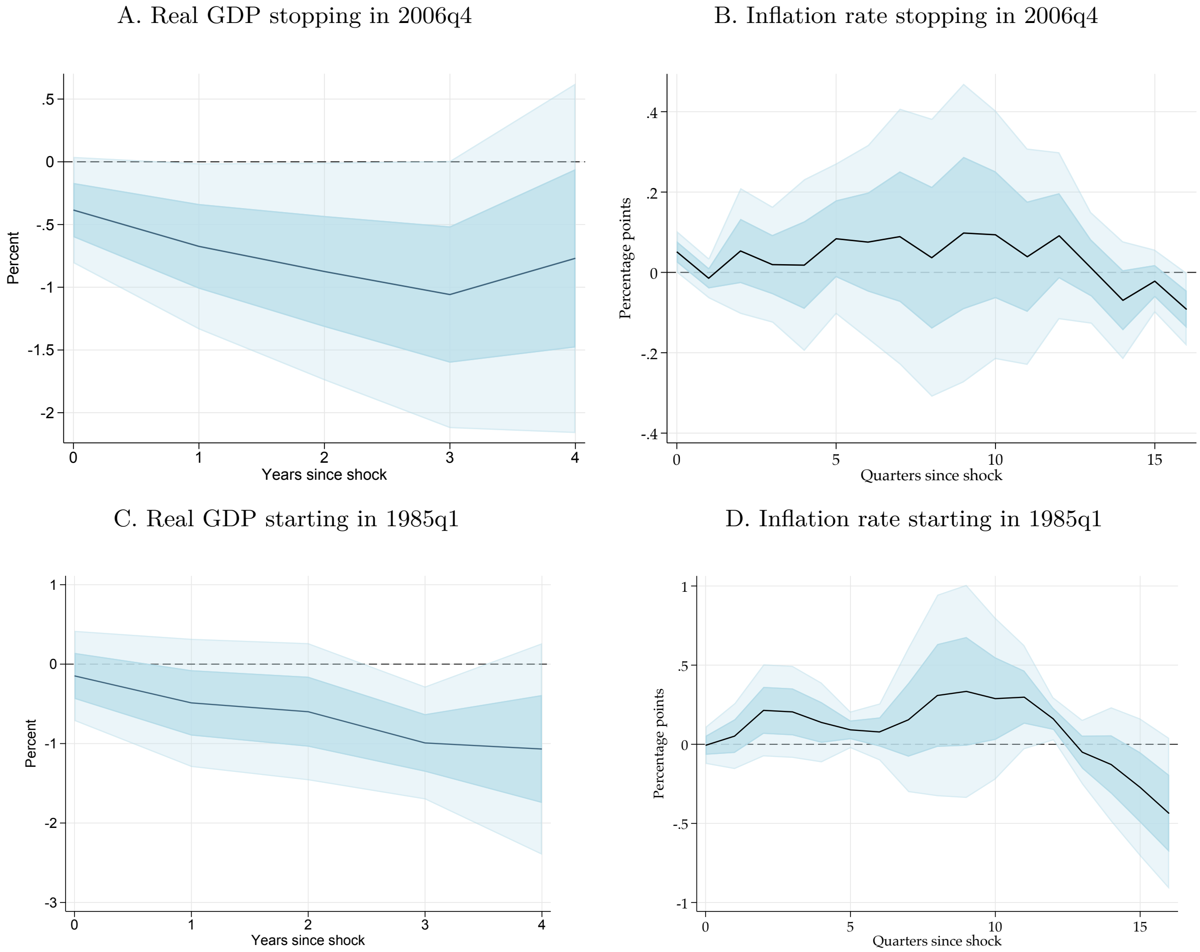


Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

of the shock, four lags of y and four lags of the shock. Figure 25 and Figure 26 show the responses. The results are basically unaffected by the alternative lag specifications.

Fourth, I consider different thresholds of the old-age dependency ratio distribution which I interact with the monetary shock. I consider a state old if its ratio belongs to the top quartile, one-third, and half of the distribution. I also interact the monetary policy shocks directly with the level of the old-age dependency ratio. The impulse response functions are reported in Figure 27. These alternative thresholds reinforce the conclusion that the effectiveness of monetary policy is influenced by the demographic profile in the economy.

Figure 24: Impact of monetary policy on regional variables, different subperiods

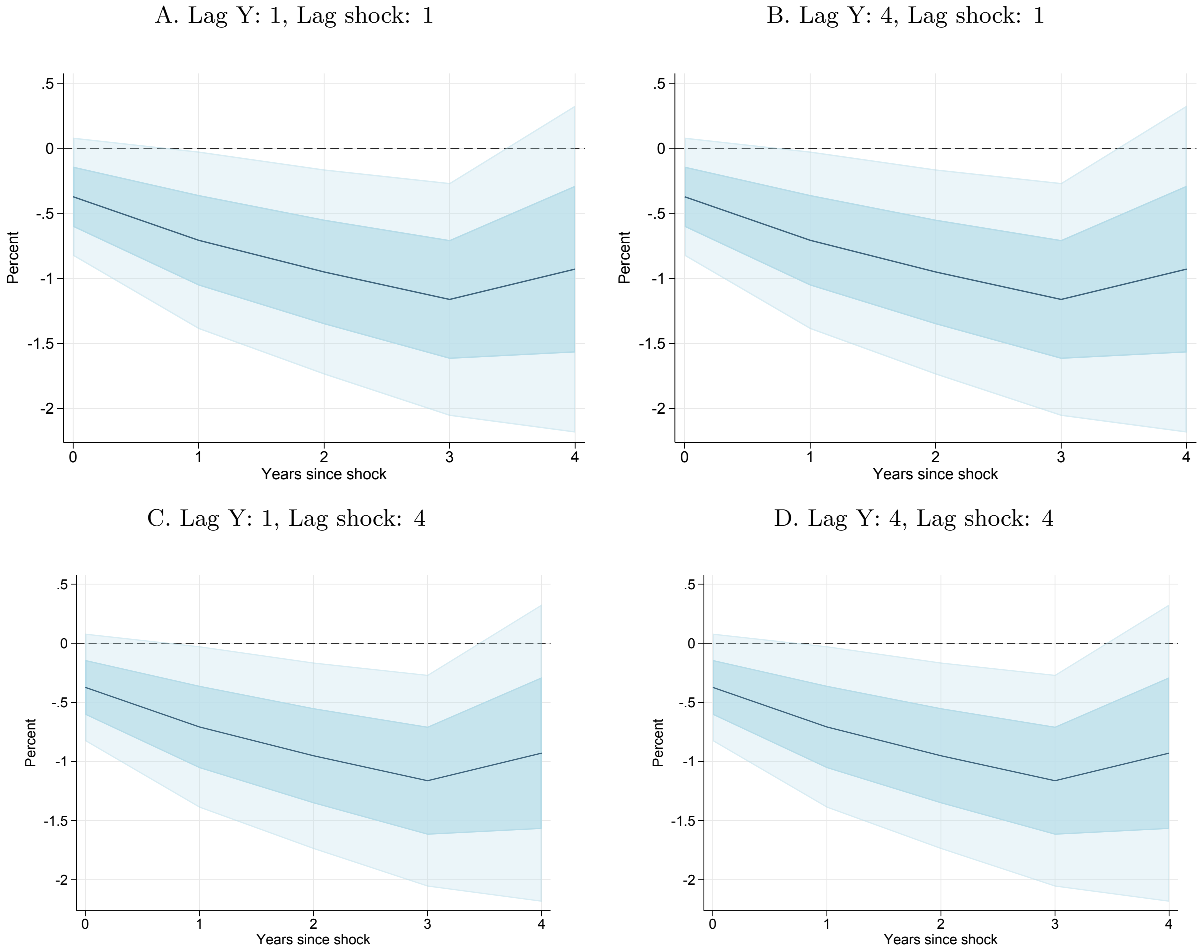


Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

Fifth, another source of concern might be that state characteristics other than the population distribution may confound the results. To control for these state characteristics, I extend the baseline specification by interacting different control variables with the monetary policy shock[23]. For example, Wong (2021) document that the consumption of young homeowners reacts more strongly to monetary policy shocks. Therefore, I consider different measures of the housing market like house prices and the fraction of mortgages that are adjustable-rate mortgages (ARMs) both retrieved from the FHFA. I also control for the share of white workers, college-educated workers, small firms (below 249 employees), and young firms (younger than 5 years old) using data from the LEHD. As suggested by Leahy and Thapar (2022), to take into account that the entrepreneurial

[23]The results are not affected if the controls are not interacted with the shocks.

Figure 25: Impact of monetary policy on the regional real GDP, different lags



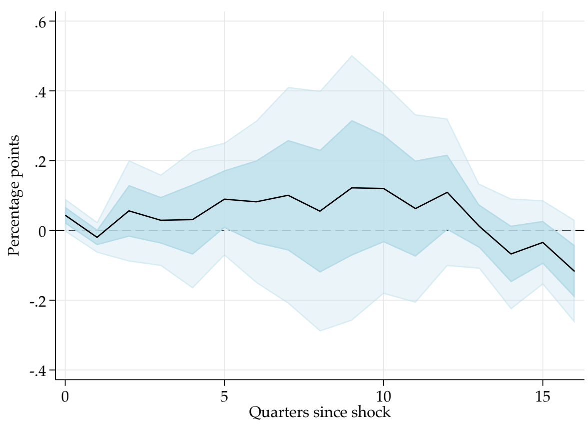
Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable the state-level real GDP. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively. The horizontal axis is in years.

activities of the middle-aged might lead to different responsiveness across states, I include the log of establishment deaths and births from the BLS. Finally, Cravino et al. (2020) argues that higher-income households tend to purchase goods with stickier prices. Since households' age and income tend to be positively correlated, the results could reflect this mechanism. To control for this, I add the interaction between state GDP per capita and the monetary shocks as an additional regressor. I report all these extra robustness checks in Figures 28 to and Figure 32.

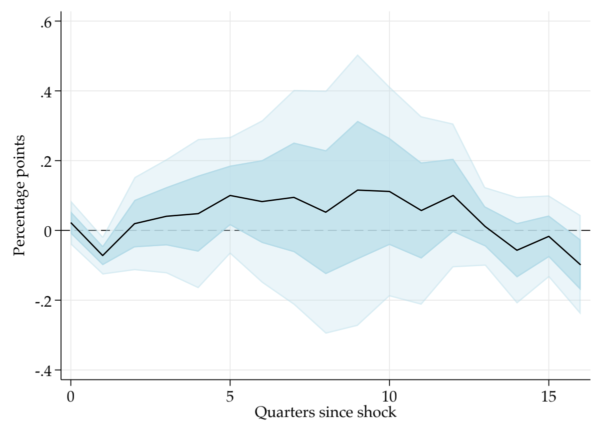
Sixth, one obvious question is whether the results are driven by the choice of monetary policy shocks. Therefore, as additional estimation techniques, I present the results using the high-frequency identification from Nakamura and Steinsson (2018) as well as the shocks from Miranda-Agrippino and Ricco (2021) cleaned from the informational rigidities of the monetary announcements. The

Figure 26: Impact of monetary policy on the regional inflation rate, different lags

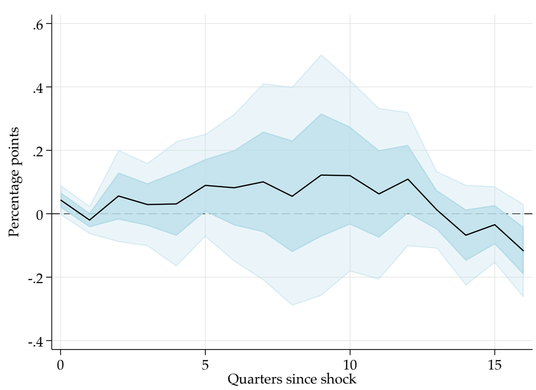
A. Lag Y: 1, Lag shock: 1



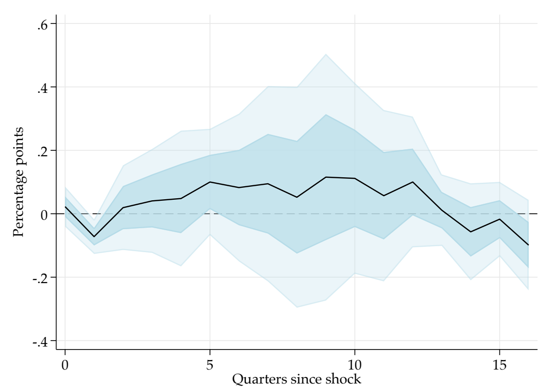
B. Lag Y: 4, Lag shock: 1



C. Lag Y: 1, Lag shock: 4



D. Lag Y: 4, Lag shock: 4



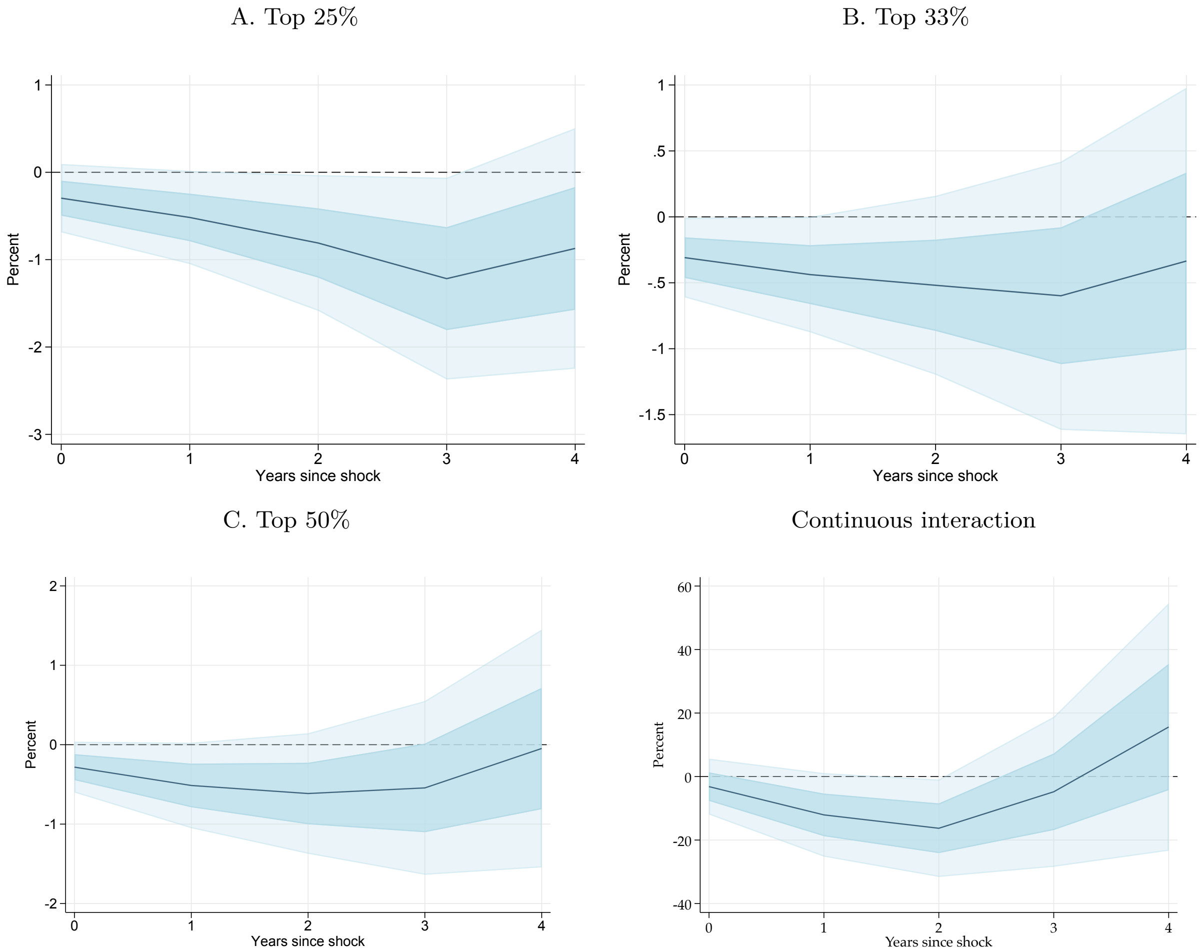
Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable the state-level inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

key idea of the approach in Nakamura and Steinsson (2018) is to use changes the change in the 3-month ahead Fed Funds futures within a 30-minute window surrounding scheduled Federal Reserve announcements. Since the time window is relatively small, one can consider these changes to be entirely due to the announcement itself and orthogonal to the information set of the financial market.

The results are presented in Figure 33 using as dependent variables the real GDP and annual inflation rate. All the regressions include the same controls as in the baseline specification. The responses of the interaction coefficients are comparable in shape and magnitude to the baseline specification being significantly stronger for older states.

Seventh, spillover effects from other states might bias the results. It could be the case that the stronger response of GDP observed in older states is actually due to an increase in the demand for tradable goods from the surrounding states rather than from the different frequencies of price

Figure 27: Impact of monetary policy on the regional real GDP, different thresholds

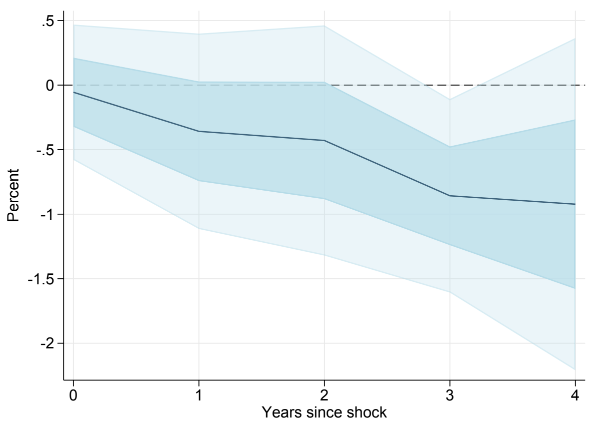


Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable the state-level real GDP. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively. The horizontal axis is in years.

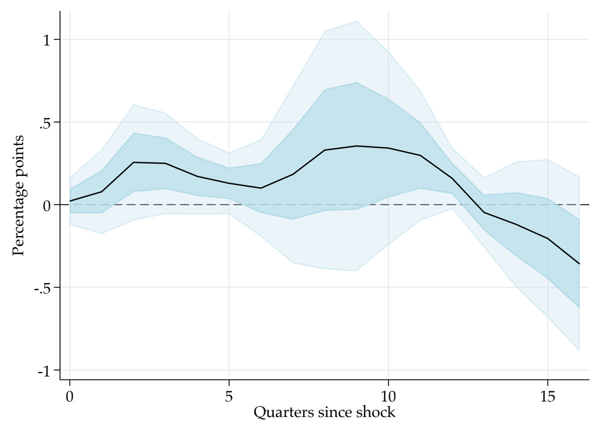
adjustment across age groups. I test this hypothesis by using the services component of GDP as the dependent variable and as a proxy for the consumption of non-tradable goods: since services are usually not traded across states, differences in responses to shocks are mainly caused by local characteristics. The results are reported in Figure 34. The response of services in states with a higher old-age dependency ratio is significantly stronger suggesting that the main results are not driven by spillover effects.

Figure 28: Impact of monetary policy on regional variables, extra controls

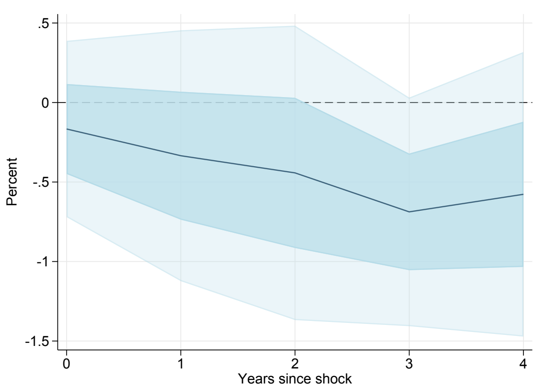
A. Real GDP controlling for house prices



B. Inflation rate controlling for house prices



C. Real GDP controlling for fraction of ARMs

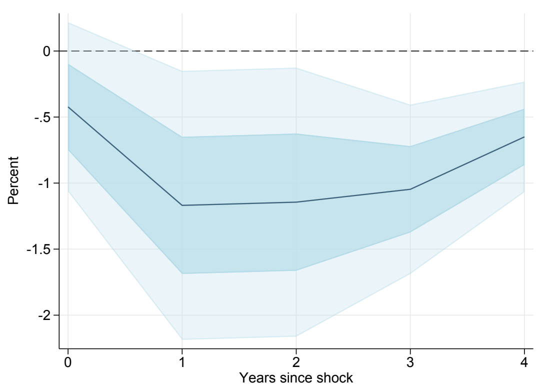


D. Inflation rate controlling for fraction of ARMs

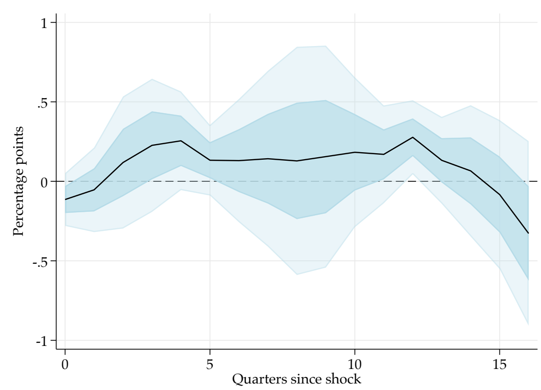
Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

Figure 29: Impact of monetary policy on regional variables, extra controls

A. Real GDP controlling for workers' race

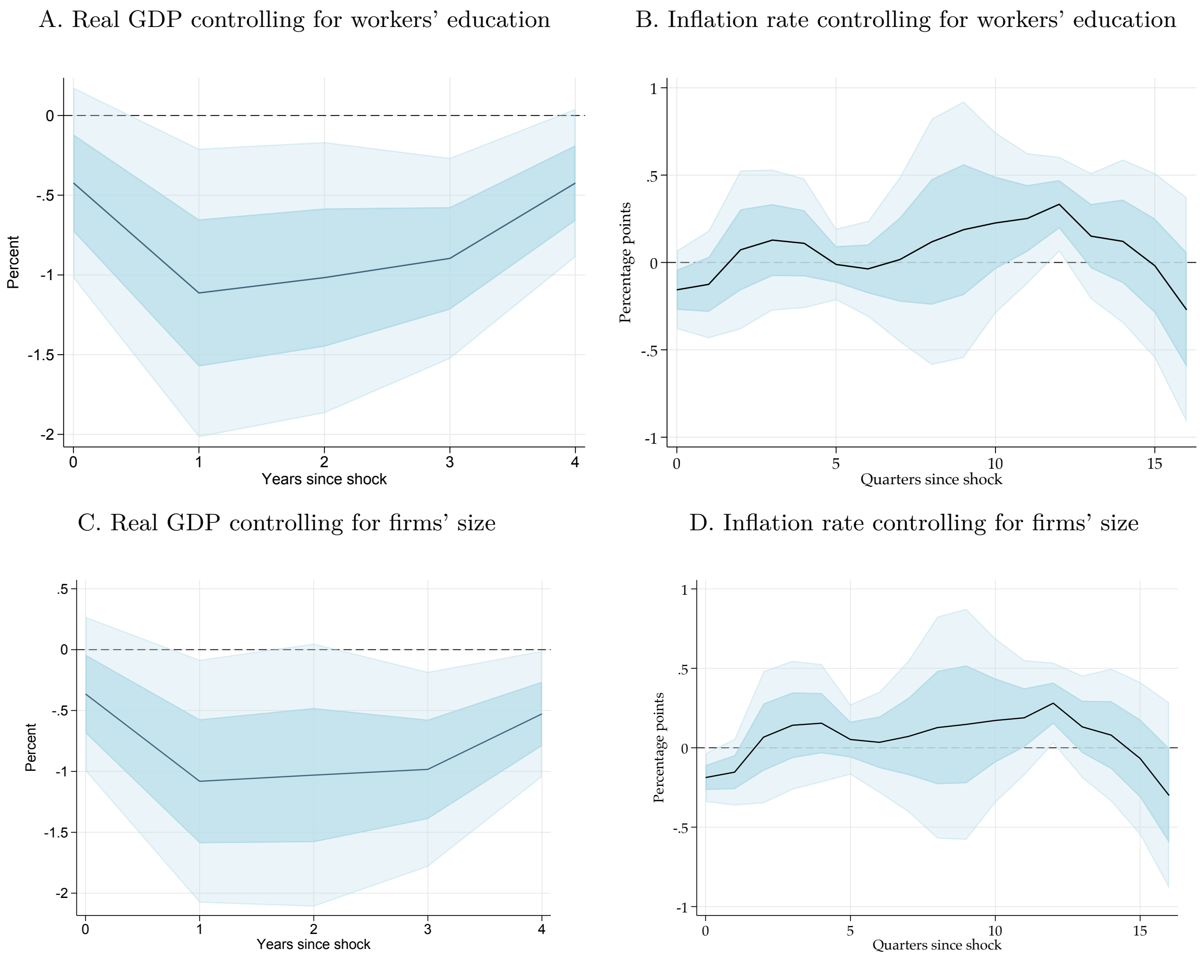


B. Inflation rate controlling for workers' race



Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

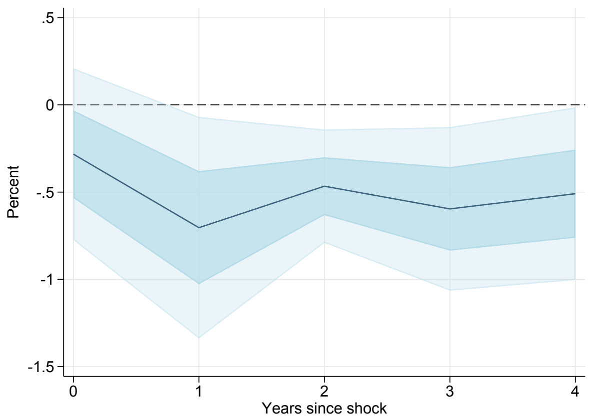
Figure 30: Impact of monetary policy on regional variables, extra controls



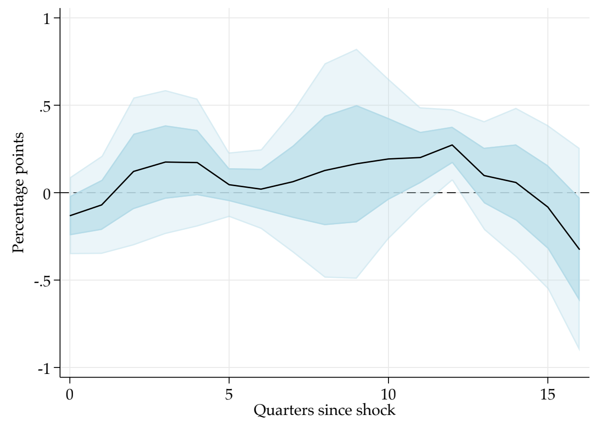
Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

Figure 31: Impact of monetary policy on regional variables, extra controls

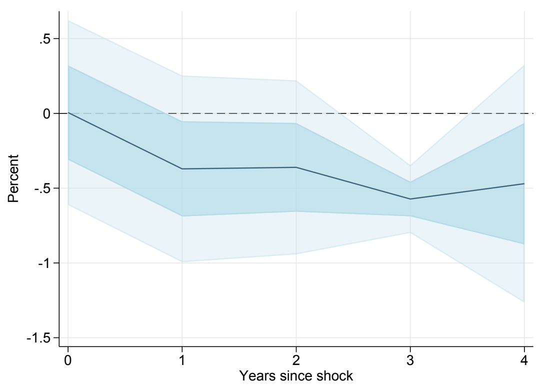
A. Real GDP controlling for firms' age



B. Inflation rate controlling for firms' age



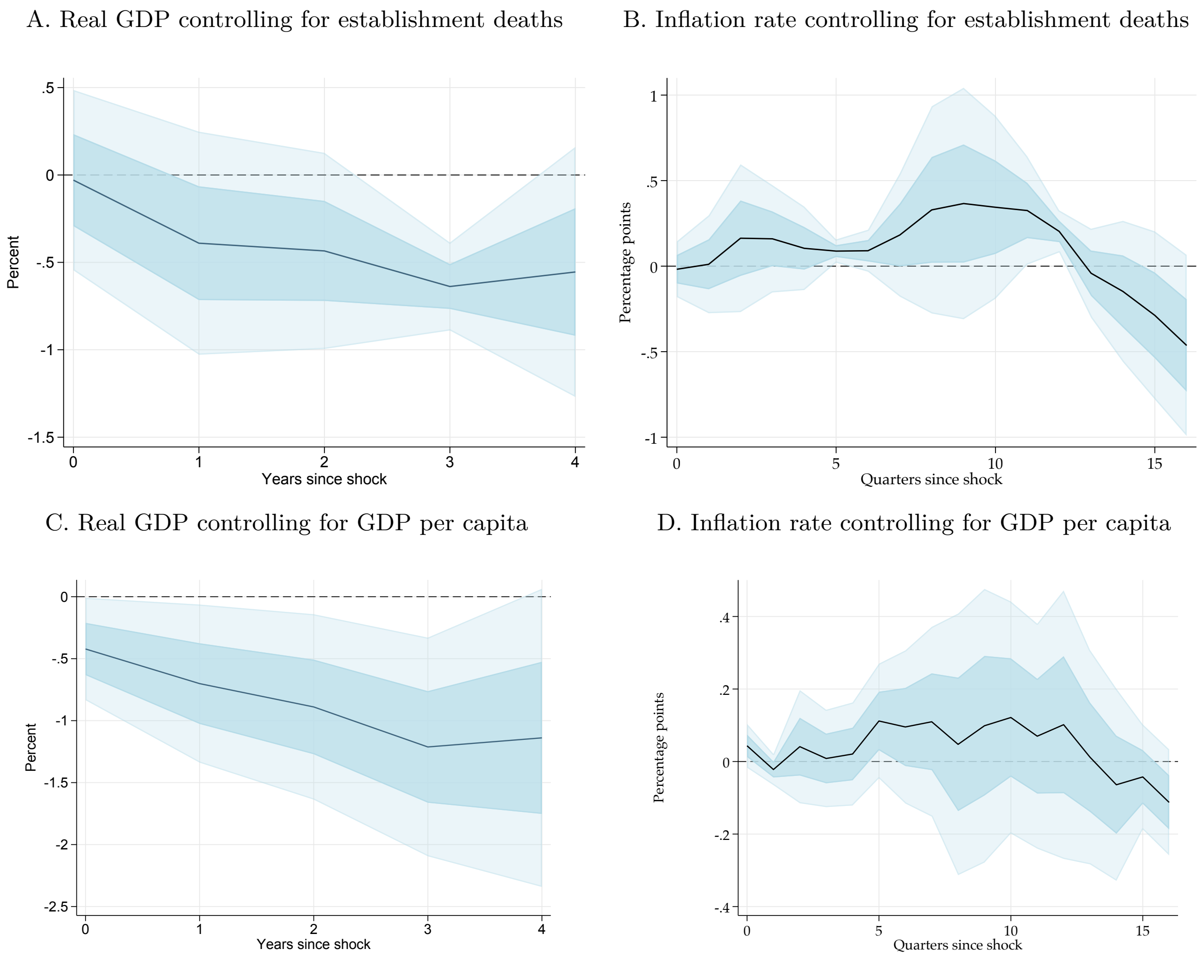
C. Real GDP controlling for establishment births



D. Inflation rate controlling for establishment births

Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate.

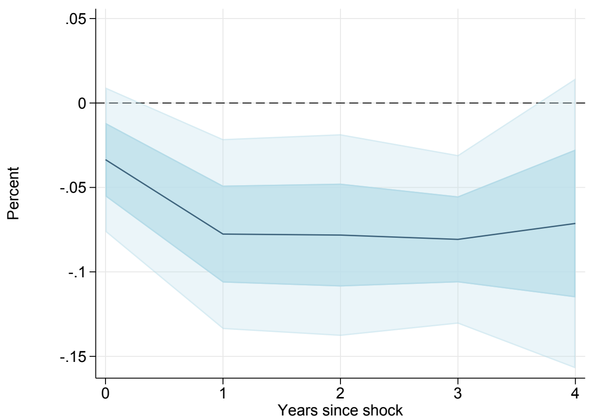
Figure 32: Impact of monetary policy on regional variables, extra controls



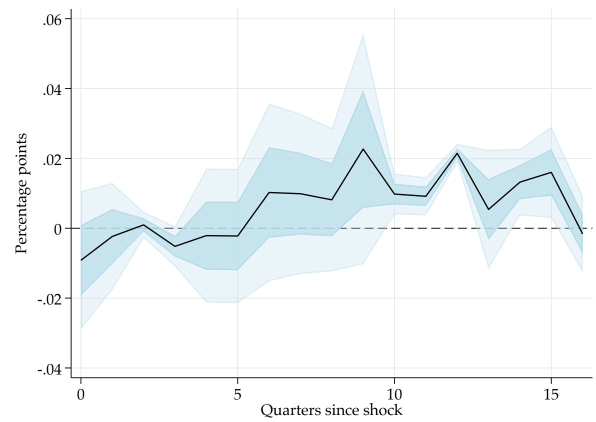
Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

Figure 33: Impact of monetary policy on regional variables, different monetary shocks

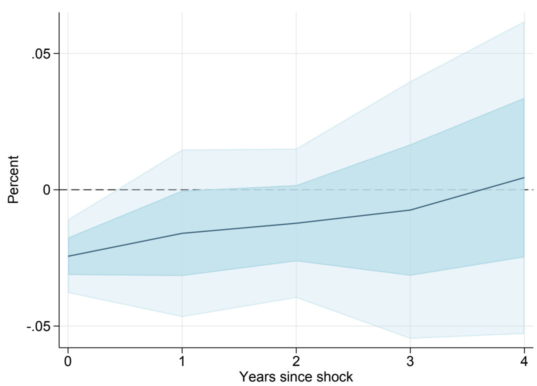
A. Real GDP with shocks from Nakamura and Steinsson (2018)



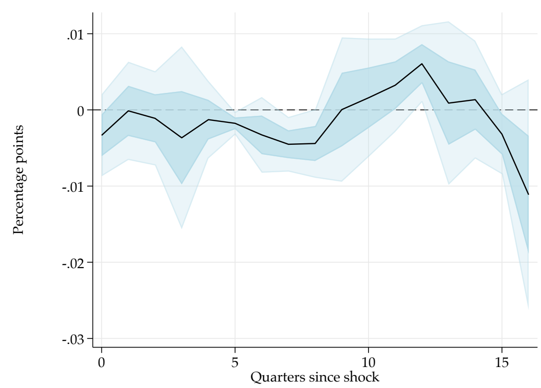
B. Inflation rate with shocks from Nakamura and Steinsson (2018)



C. Real GDP with shocks from Miranda-Agrippino and Ricco (2021)

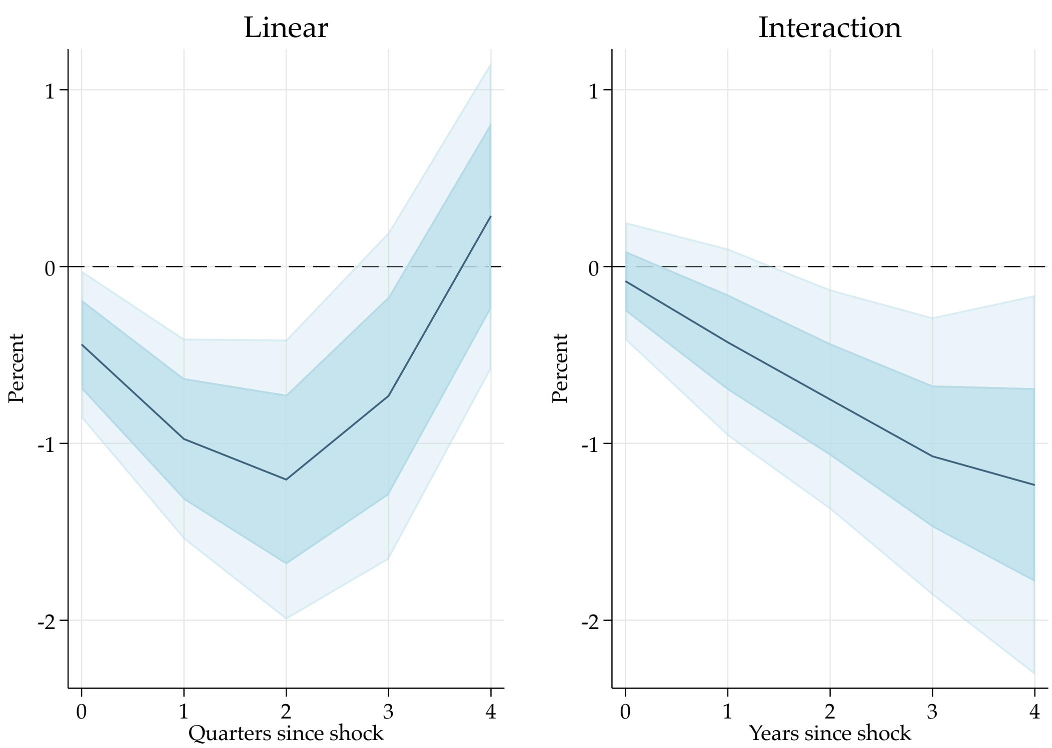


D. Inflation rate with shocks from Miranda-Agrippino and Ricco (2021)



Notes: Each panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution using as dependent variable either the state-level real GDP or the inflation rate. The dark shaded area and the light shaded area represent the 68% and the 95% confidence intervals respectively.

Figure 34: Impact of monetary policy on the production of the regional services



Notes: The left panel of the figure plots the response of the state-level log of the real services production 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 right panel reports the interaction coefficients between the monetary policy shock and the dummy identifying the top 20% of the old-age dependency ratio distribution.

D List of model equations

This appendix presents the full set of equations of the model. Each period t there is a distribution of households of different ages j with $j \in \{1, ..., J\}$. On the supply side, there are two sectors s, services and goods, so that $s \in \{S, G\}$. Variables are expressed in real terms as $x_t = \frac{X_t}{P_t}$, the sectoral MC_t^s are deflated by the relative P_t^s.

To derive a measure ω of aggregate expenditure weights for the service sector I proceed as follow. The demand functions for services and goods relative to the households maximization problem are given by:

$$c_{t,j}^S = \alpha_j \Big(\frac{P_t^S}{P_{t,j}}\Big)^{-\eta} c_{t,j}, \qquad c_{t,j}^G = (1-\alpha_j)\Big(\frac{P_t^G}{P_{t,j}}\Big)^{-\eta} c_{t,j}, \tag{34}$$

where $c_{t,j}$ is the aggregate consumption of household j and $P_{t,j}$ is the price index associated with its bundle.

Adding across households, one can obtain the following expression of the sectoral aggregate demand:

$$C_t^S = \omega_t \Big(\frac{P_t^S}{P_t}\Big)^{-\eta} C_t, \qquad C_t^G = (1-\omega_t)\Big(\frac{P_t^G}{P_t}\Big)^{-\eta} C_t, \tag{35}$$

where, following Cravino et al. (2020), the expenditure share is defined as $\omega_t \equiv \sum_j \alpha_j \chi_{t,j} \frac{P_{t,j}^{\eta-1}}{\sum_j \chi_{t,j} P_{t,j}^{\eta-1}}$ and $\chi_{t,j}$ is the share of household j in aggregate expenditures at time t. One can then define the aggregate price index as $P_t \equiv \Big[\omega_t^{\frac{1}{\eta}}(P_t^S)^{1-\eta} + (1-\omega_t)^{\frac{1}{\eta}}(P_t^G)^{1-\eta}\Big]^{\frac{1}{1-\eta}}$. To simplify the log-linearization process, ω_t is assumed to be constant and equal to its steady state value.

Households:

$$P_{t,j}^* c_{t,j} + a_{t+1,j+1} = \frac{R_t^a}{\pi_t} a_{t,j} + (1-\tau_t) w_t l_{t,j} h_j \mathbf{I}_{j \le jw} + pen_t \mathbf{I}_{j > jw} + beq_t \tag{36}$$

$$a_{t,0} = 0 \qquad a_{t+J+1,J+1} = 0 \tag{37}$$

$$\nu l_{t,j}^\eta = \frac{(1-\tau_t) w_t h_j \mathbf{I}_{j \le jw}}{Z_t^{\omega - \alpha_j}} c_{t,j}^{-\sigma} \tag{38}$$

$$\frac{c_{t,j}^{-\sigma}}{P_{t,j}^*} = \beta s_j \frac{c_{t+1,j+1}^{-\sigma}}{P_{t+1,j+1}^*} \frac{R_{t+1}^a}{\pi_{t+1}} \tag{39}$$

Firms:

$$P_t^{S,*} mc_{i,t}^S = \Big(\frac{w_t}{(1-\psi)}\Big)^{1-\psi} \Big(\frac{r_t^k}{\psi}\Big)^{\psi} \tag{40}$$

$$P_t^{G,*} mc_{i,t}^G = \Big(\frac{w_t}{(1-\psi)}\Big)^{1-\psi} \Big(\frac{r_t^k}{\psi}\Big)^{\psi} \tag{41}$$

$$K_{i,t}^s = \frac{\psi w_t}{(1-\psi) r_t^k} L_{i,t}^s \tag{42}$$

$$f_t = Y - w_t L_t - r_t^k K_t \tag{43}$$

$$v_t^s = (1-\theta^s)\left(\pi_t^{s,\#}\right)^{-\epsilon}(\pi_t^s)^{\epsilon} + \theta^s(\pi_t^s)^{\epsilon} v_{t-1}^s \tag{44}$$

$$(\pi_t^s)^{1-\epsilon} = (1-\theta^s)\left(\pi_t^{s,\#}\right)^{1-\epsilon} + \theta^s \tag{45}$$

$$x_{1,t}^s = \frac{1}{R_t} Y_t^s P_t^{s,*} mc_{i,t}^s + \theta^s \beta \mathbb{E}_t (\pi_{t+1}^s)^{\epsilon} x_{1,t+1}^s \tag{46}$$

$$x_{2,t}^s = \frac{1}{R_t} Y_t^s P_t^{s,*} + \theta^s \beta \mathbb{E}_t (\pi_{t+1}^s)^{\epsilon-1} x_{2,t+1}^s \tag{47}$$

$$\pi_t^{s,\#} = \frac{\epsilon}{\epsilon-1}\pi_t^s \frac{x_{1,t}^s}{x_{2,t}^s} \tag{48}$$

Representative investment fund:

$$K_{t+1} = (1-\delta)K_t + \Big[1 - \frac{S}{2}\Big(\frac{I_t}{I_{t-1}} - 1\Big)^2\Big] I_t \tag{49}$$

$$A_{t+1} = q_t(1-\delta)K_t + I_t + p_t^d \tag{50}$$

$$\frac{R_t^a}{\pi_t} A_t = \Big[r_t^k + q_t(1-\delta)\Big]K_t + f_t + p_t^d \tag{51}$$

$$R_t q_t = \mathbb{E}_t\Big[\Big(r_{t+1}^k + q_{t+1}(1-\delta)\Big)\pi_{t+1}\Big] \tag{52}$$

$$R_t p_t^d = \mathbb{E}_t\Big[\Big(p_{t+1}^d + f_{t+1}\Big)\pi_{t+1}\Big] \tag{53}$$

$$1 = q_t\Big[1 - \frac{S}{2}\Big(\frac{I_t}{I_{t-1}} - 1\Big)^2 - S\Big(\frac{I_t}{I_{t-1}} - 1\Big)\frac{I_t}{I_{t-1}}\Big] + \mathbb{E}_t\Big[\frac{\pi_{t+1}}{R_t} q_{t+1} S\Big(\frac{I_{t+1}}{I_t} - 1\Big)\Big(\frac{I_{t+1}}{I_t}\Big)^2\Big] \tag{54}$$

Government:

$$pen_t = \bar{d}(1-\tau_t) w_t \sum_{j=0}^{jw} N_j h_j \tag{55}$$

$$\tau_t w_t \sum_{j=0}^{jw} N_j h_j = pen_t \sum_{j=jw+1}^{J} N_j \tag{56}$$

Monetary authority:

$$\frac{R_t}{R} = \Big(\frac{\pi_t}{\pi}\Big)^{\phi_\pi}\Big(\frac{Y_t}{Y}\Big)^{\phi_y} e^{\nu_t^r} \tag{57}$$

$$\nu_t^r = \rho^{\nu}\nu_{t-1}^r + \epsilon_t^{\nu} \tag{58}$$

Market clearing:

$$L_t = L_t^S + L_t^G = \sum_{j=1}^{jw} N_j h_j n_{t,j}, \quad A_t = \sum_{j=1}^{J} N_{j-1} a_{t,j}, \quad K_t = K_t^S + K_t^G \tag{59}$$

$$beq_t = \sum_{j=1}^{J}(N_{j-1} - N_j) a_{t,j} \frac{R_t^a}{\pi_t} \tag{60}$$

$$Y_t^S = (K_t^S)^\alpha (L_t^S)^{1-\alpha} / v_t^S = C_t^S \tag{61}$$

$$Y_t^G = (K_t^G)^\alpha (L_t^G)^{1-\alpha} / v_t^G = C_t^G + I_t \tag{62}$$

$$C_t = P_t^{S,*} C_t^S + P_t^{G,*} C_t^G \tag{63}$$

$$Y_t = P_t^{S,*} Y_t^S + P_t^{G,*} Y_t^G \tag{64}$$

$$C_t^S = \sum_{j=1}^{J} \alpha_j \Big(P_{t,j}^{S,*}\Big)^\eta N_j c_{t,j}, \qquad C_t^G = \sum_{j=1}^{J} \Big(1-\alpha_j\Big) \Big(P_{t,j}^{G,*}\Big)^\eta N_j c_{t,j} \tag{65}$$

Price dynamics

$$\frac{\pi_t^G}{\pi_t^S} = \frac{Z_t}{Z_{t-1}} \tag{66}$$

$$\pi_t = \pi_t^S \frac{\omega + (1-\omega) Z_t^{1-\eta}}{\omega + (1-\omega) Z_{t-1}^{1-\eta}} \tag{67}$$

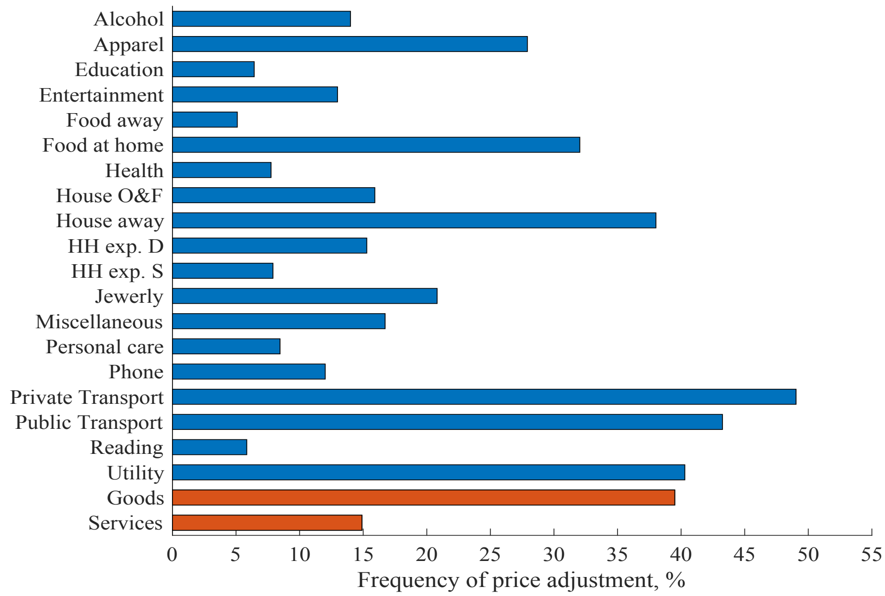
$$P_t^{S,*} = \frac{P_t^S}{P_t} = \Big[\omega + (1-\omega) Z_t^{1-\eta}\Big]^{\frac{1}{\eta-1}}, \quad P_t^{G,*} = \frac{P_t^G}{P_t} = \Big[\omega Z_t^{\eta-1} + (1-\omega)\Big]^{\frac{1}{\eta-1}} \tag{68}$$

$$P_{t,j}^{*} = \frac{P_{t,j}}{P_t} = \Big[\frac{\alpha_j + (1-\alpha_j) Z_t^{1-\eta}}{\omega + (1-\omega) Z_t^{1-\eta}}\Big]^{\frac{1}{1-\eta}} \tag{69}$$

$$P_{t,j}^{S,*} = \frac{P_{t,j}}{P_t^S} = \Big[\alpha_j + (1-\alpha_j) Z_t^{1-\eta}\Big]^{\frac{1}{1-\eta}}, \quad P_{t,j}^{G,*} = \frac{P_{t,j}}{P_t^G} = \Big[\alpha_j Z_t^{\eta-1} + (1-\alpha_j)\Big]^{\frac{1}{1-\eta}} \tag{70}$$

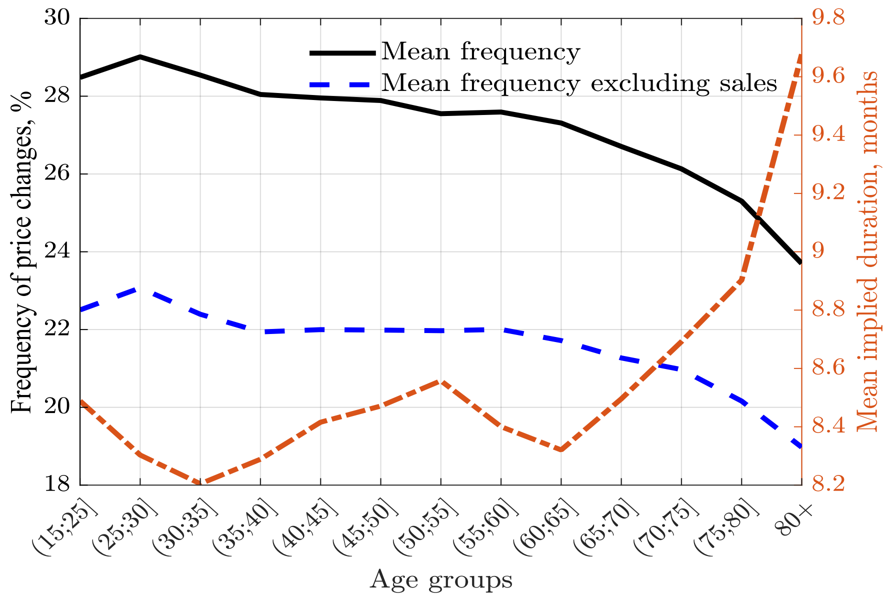
E Additional figures and tables

Figure 35: Average price rigidities across expenditure categories



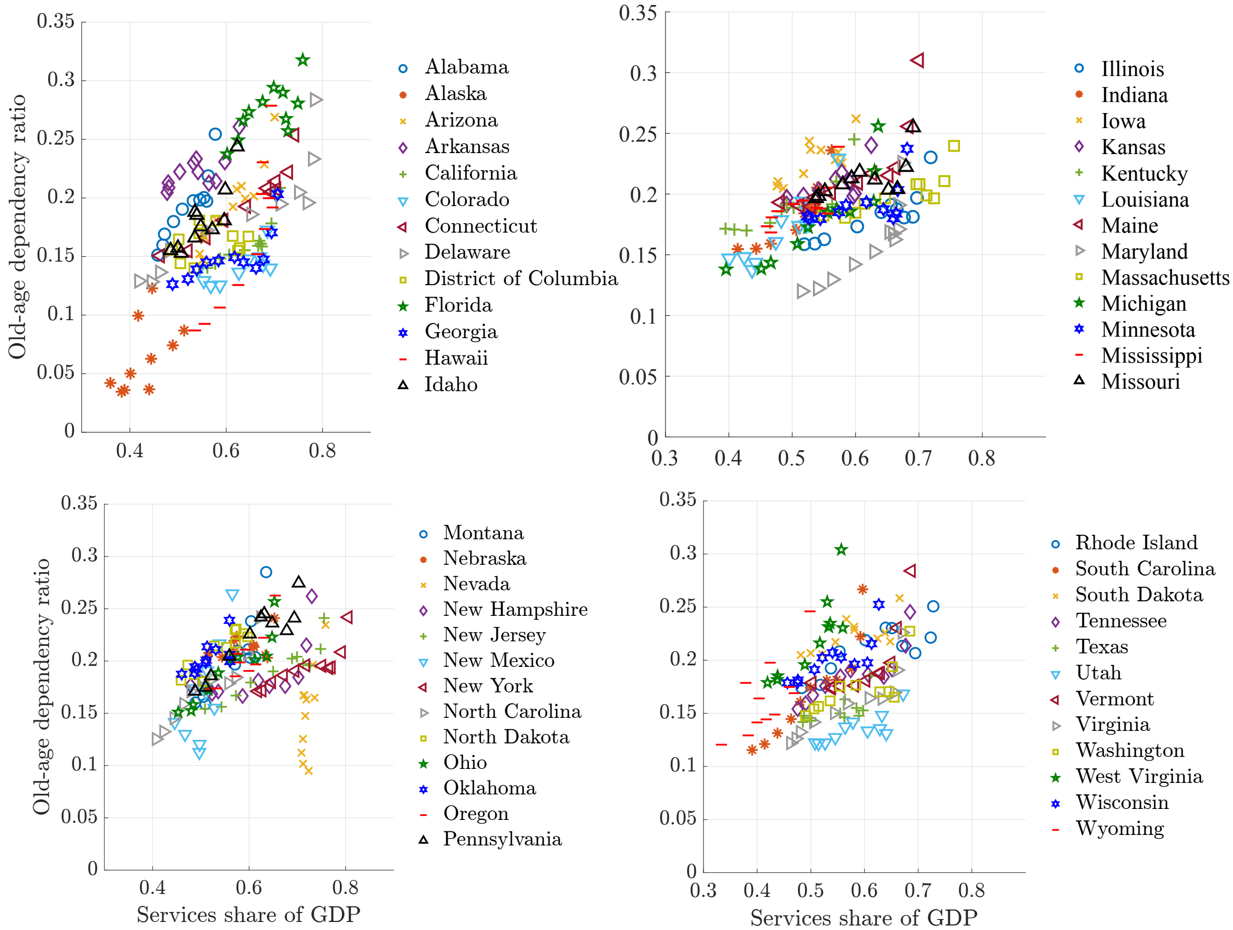
Notes: The bar plot shows the weighted average frequency of price adjustment across different expenditure categories as well as for the aggregation of the categories into Goods and Services.

Figure 36: Frequency of price adjustment and mean implied duration across age groups



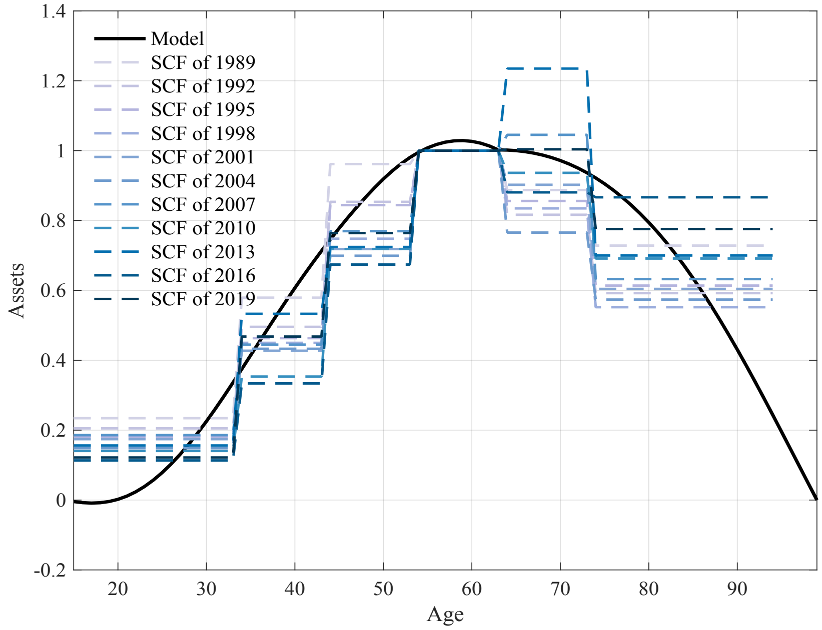
Notes: The figure plots the weighted average frequency of price adjustment with and without temporary sales (left axis) alongside the mean implied duration (right axis) across age groups. The expenditure shares are computed using data from the CEX whereas the sectoral price stickiness parameters are retrieved from Nakamura and Steinsson (2008).

Figure 37: State-level old-age dependency ratio and services share of GDP



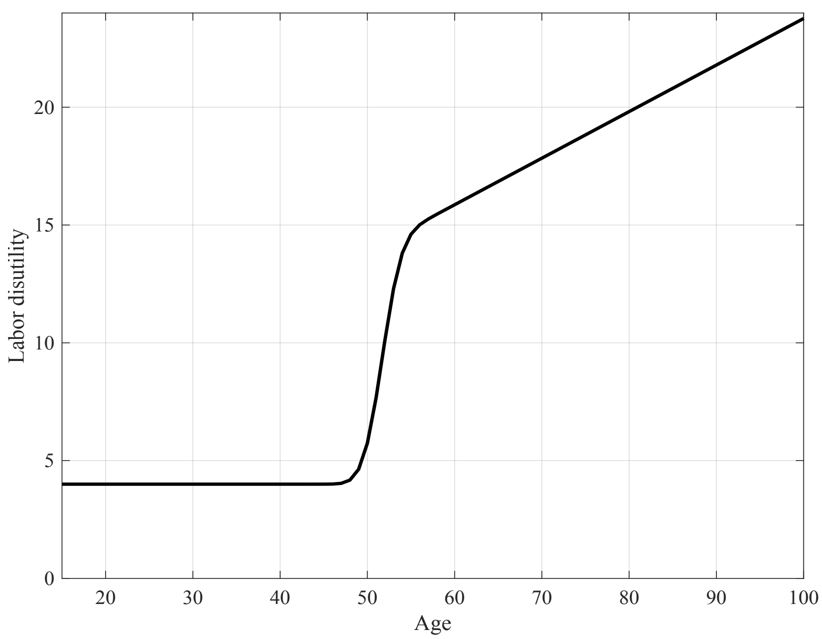
Notes: Each panel reports the scatter plot of the relationship between the old-age dependency ratio and the share of GDP from services at the U.S. state level. For ease of exposition, the states are split into four groups in alphabetical order. Each dot represents the average over a 5-year period starting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

Figure 38: Model vs Data



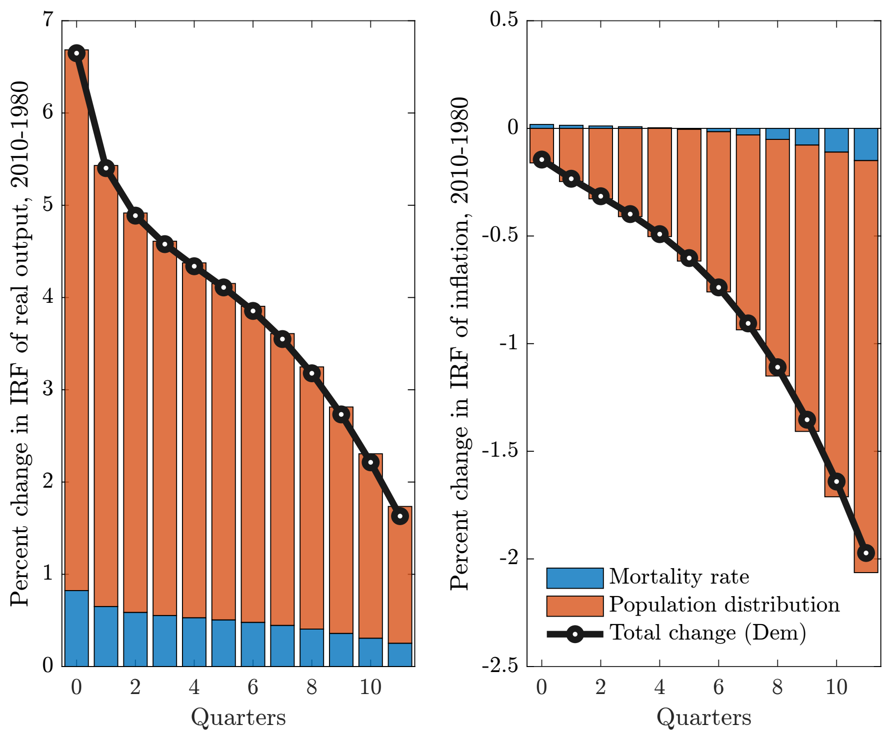
Notes: The plot compares the steady state assets profile from the model (Age 65 = 1) with the asset profile taken from the Survey of Consumer Finances for different years (Age group 55-64 = 1). *Source*: Survey of Consumer Finances.

Figure 39: Age dependent disutility of labor supply, ν_j



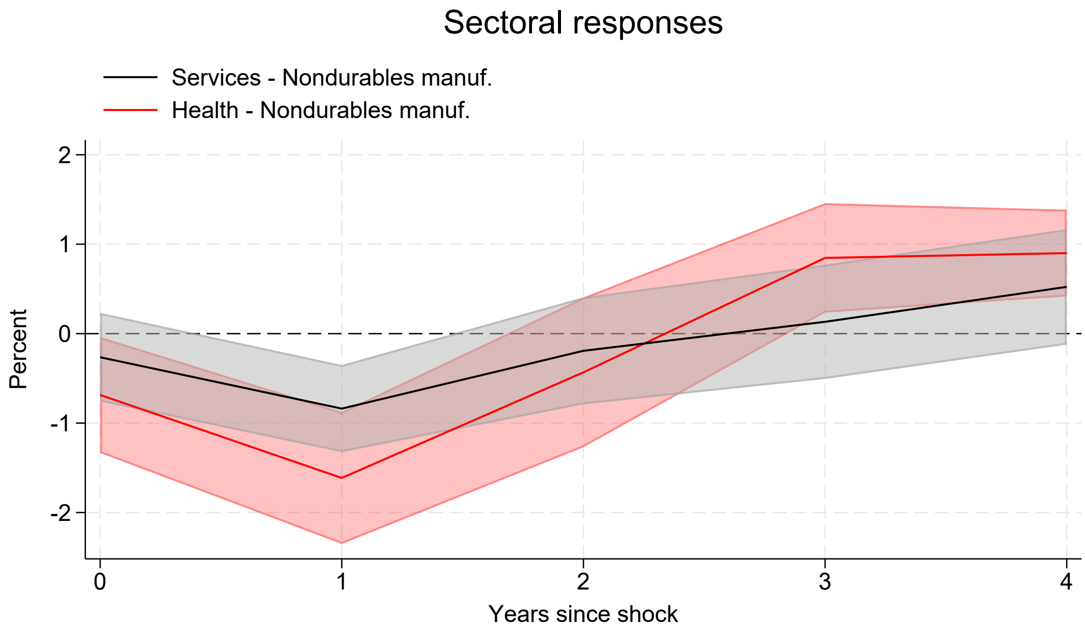
Notes: Following Jones (2021), the time-invariant disutility of labor supply is given by the following expression: $\nu_j = b_0 + (b_1 \frac{j}{J+1}) \int_{-\infty}^{J} \frac{1}{(J+1)b_3\sqrt{2\pi}} exp\left\{\frac{1}{2}\left(\frac{j-(J+1)b_2}{(J+1)b_3}\right)^2 dj\right\}$ where the parameter values chosen are: $b_0 = 4$, $b_1 = 17$, $b_2 = 0.65$, $b_3 = 0.02$ as in Papetti (2019). $J + 1 = 86$ is the number of periods the individual can be alive since the household enters the world at age 15 and remains alive up to the maximum age of 100. Finally, the integral expression is the normal cumulative distribution function over age j with mean $b_2(J + 1)$ and standard deviation $b_3(J + 1)$.

Figure 40: 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 of 1980 and 2010 but mortality rates kept fixed at the 1980 values (blue bars), using the mortality rates of 1980 and 2010 but the population distribution of 1980 (red bars) and finally using both the population distribution and mortality rates of the two steady states (black line). The services preferences are kept fixed at the 1980 values. The right panel shows the same percent change but for inflation.

Figure 41: Impact of monetary policy on the components of real GDP



Notes: The figure plots the response of the differences between the state-level services and health expenditures with the non-durables manufacturing components of 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.

Table 5: The table reports the expenditure shares across the major consumption categories for different age groups

	Age groups						
	25-	(30,35]	(40,45]	(50,55]	(60,65]	(70,75]	80+
Alcohol	2.1	1.4	1.2	1.2	1.2	1.1	0.6
Apparel	5.1	4.8	4.7	4.2	3.8	3.1	2.3
Education	6.7	1.5	2.4	3.9	1.0	0.6	0.4
Energy	3.8	5.0	5.4	5.5	6.0	6.7	7.9
Entertainment	5.9	7.0	7.5	6.9	6.8	6.0	4.4
Food Away	6.1	5.6	5.8	5.8	5.6	5.1	4.1
Food at Home	11.4	12.5	13.0	12.1	12.3	12.9	13.5
Medical	3.4	5.4	6.4	7.6	10.7	15.1	19.0
Household F&O	6.4	9.9	9.1	9.0	9.8	10.1	11.1
Other Lodging	1.2	1.0	1.4	2.0	1.8	2.0	0.9
Owned Dwellings	1.8	6.5	7.5	7.7	8.1	7.6	5.9
Other Expenses	0.9	1.1	1.3	1.4	1.6	1.8	2.4
Personal Care	1.9	1.9	2.0	1.9	1.9	2.0	2.1
Private Transportation	20.5	21.8	21.7	21.6	20.8	17.5	11.3
Public Transportation	1.2	1.3	1.4	1.5	1.8	1.7	1.1
Reading	0.3	0.4	0.4	0.5	0.6	0.7	0.7
Rented Dwellings	19.4	10.8	6.4	4.4	3.7	3.9	10.2
Tobacco	1.3	1.0	1.1	1.2	1.1	0.8	0.4
Water	0.6	1.1	1.2	1.2	1.3	1.5	1.7