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Demographic Aging and the New Keynesian Phillips Curve

Gene Ambrocio*

Abstract

I document a statistical link between old-age dependency ratios and average markups. I propose that a mechanism whereby households develop deep habits in consumption as they age could explain this feature of the data. I show that when this mechanism is embedded in an overlapping generations New Keynesian model, the slope of the New Keynesian Phillips Curve flattens as the population ages. Further, the contractionary effects of monetary policy surprises on output are amplified. These results suggest that the challenges faced by monetary policy may become more pronounced as populations age.

JEL Codes: D11, E21, E32, E52, J11

Keywords: population aging, Phillips curve, deep habits, market power, markups

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Demographic aging is one of the most predictable changes that many economies currently face. Several countries, notably Japan and many countries in Europe, already have more than a fifth of the population aged 65 and over and this is only expected to grow larger. Consequently, many studies have looked into the economic implications of aging. However, these have primarily focused on the implications on savings and wealth, rates of return on assets, and labor markets.[1] In contrast, relatively less attention has been placed on how aging affects consumption behavior in dimensions other than with regard to life-cycle consumption-savings patterns. In this paper, I study the implications of aging on aggregate sensitivities to price changes and draw out implications for firm market power and the conduct of monetary policy.

First, I document a new stylized fact, that average markups are positively correlated with the old-age dependency ratio especially for developed countries. I show that this correlation is not driven by common trends, broad structural changes (e.g., the shift towards services), or other potentially confounding factors. Focusing on results using a sample of OECD countries, the average increase in the share of the old from 1980 to 2016 could account for about 10% of the increase in average markups in OECD countries over the same period.

There are several possible mechanisms that could explain this relationship. A relatively direct explanation would be that households gradually become price insensitive as they age. Indeed, several studies have attributed part of the observed increase in markups to declining price sensitivities of households (Brand, 2021; Doepper et al., 2022; Atalay et al., 2023). It is quite reasonable to think that peo-

[1] See e.g., Krueger and Ludwig (2007); Ferrero (2010); Carvalho et al. (2016); Aksoy et al. (2019); Rachel and Summers (2019); Gagnon et al. (2021); Auclert et al. (2021); Acemoglu and Restrepo (2022); Jones (2023) and Maestas et al. (2023).

ple slowly develop tastes and preferences for a specific brand or product as they get older. As households age, they accumulate brand loyalty and are less likely to try out other (and new) brands (Bornstein, 2021). Across households, these preferences would vary and give rise to a phenomenon referred to as *niche consumption* described in Neiman and Vavra (2023) whereby individual households would consume a few brands or varieties but households in the aggregate consume a diverse variety of products. In turn, such an accumulation of *brand capital* within individual households would allow firms to charge more for the products that they sell. Therefore, as households age, firms are able to charge higher markups.

This hypothesis is not altogether new. Parks and Barten (1973) speculated as much several decades ago after examining differences in price elasticities of households across several OECD member countries. They found that countries with older households tended to be more price inelastic on average. There is also more recent evidence corroborating this hypothesis. *Niche consumption* is more prevalent among older households relative to the young.[2] Bornstein (2021) find that older US households tend to be more persistent in consuming the same brands and are less likely to try out newer brands. In this paper, I also show that older households tend to care more about non-price characteristics when making food purchases using European household survey data.

Motivated by these features in the data, I develop a model of age-dependent consumption preferences to draw out the implications of aging on market power and the conduct of monetary policy. The starting point of the model is deep habits in consumption (Ravn et al., 2006). Deep habits at the differentiated goods level critically affects the ability of monopolistic competitive firms to extract markups

[2]See Figure 3 in Neiman and Vavra (2023).

from sales. Further, when deep habits are formed over households' lifetimes, the age distribution becomes an important determinant to aggregate deep habits and thus the shape of demand curves that firms face. I embed deep habits formation in a basic New Keynesian framework augmented with Blanchard-Yaari overlapping generations.[3] With this mechanism, an aging population results in higher average markups charged by firms.

The mechanism I propose differs from the model of *niche consumption* in Neiman and Vavra (2023). Markups are unchanged in Neiman and Vavra (2023) as competitive forces from an increase in the number of aggregate varieties consumed cancel out the additional market power that firms get as households concentrate more on consuming their preferred varieties. On the other hand, monopolistic competitive firms in my model take full advantage of declining price sensitivities as households age leading to an increase in markups.[4] My mechanism is closer to *consumer inertia* described in Bornstein (2021). While Bornstein (2021) focuses on the implications of aging-induced increase in consumer inertia on the formation of new firms and business dynamism, I focus on the implications of aging-induced increase in habits on the pricing decision of firms and monetary policy.

The model predicts that aging-induced increases in average deep habits results in higher market power by firms. In turn, and with Rotemberg price adjustment costs, we also get a flattening of the New Keynesian Phillips Curve. This is because, as earlier pointed out in Lubik and Teo (2014), deep habits brings expectations regarding changes in future demand into the current pricing problem of firms. This makes

[3] See e.g., Ravn et al. (2010); Lubik and Teo (2014); Zubairy (2014); Leith et al. (2015) for other examples of New Keynesian models with deep habits.

[4] In contrast, Feenstra et al. (2022) are able to link consumer preference heterogeneity with market power in that they assume non-negligible fractions of consumer groups have similar preferences that differ across groups.

firms more reluctant to change prices (and thus their market share) in response to shocks today. Moreover, monetary tightening becomes more contractionary and more persistent. When the model is calibrated to match demographic and markup developments in Japan over the last few decades, I find that the changes due to demographic aging can acount for almost four percent of the increase in markups.

More importantly, in conjunction with other developments that raise firm market power, demographic aging has a significant impact on the worsening of the inflation-output trade-off faced by monetary policy accounting for nearly a third of the increase in the output cost of disinflation.[5] Evidence from state-dependent local projections on the response of output to a monetary policy surprise using the *Trilemma* identification approach of Jorda et al. (2020) confirm the model's prediction that population aging worsens the output cost of monetary tightening.

It should be noted that I do not claim that demographic aging is the most important driver of observed changes to markups charged by firms or the slope of the New Keynesian Phillips Curve. The results from the calibrated model themselves highlight that other factors are more important in these respects. Further, De Loecker and Eeckhout (2020) (and De Loecker et al., 2020) show that the increase in average markups across countries over the last few decades has largely been driven by the right tail of the markup distribution and that reallocation of market share from low- to high-markup firms plays an important role.[6] In follow-up work, De Loecker et al. (2021) identify productivity and market structure as key factors in the increase of markups while Liu et al. (2022) propose a low-interest rate environment as conducive to increasing market concentration and market power.

[5]The output cost due to disinflation used in this paper is calculated with respect to a temporary reduction in inflation, e.g., when the monetary authority has deemed it to be currently too high, and not a permanent reduction in the inflation rate (target).

[6]See also the rise of *superstar* firms who charge higher markups in Autor et al. (2020).

With regard to the role of demographic changes, Cravino et al. (2022) link aging with reallocation of production by arguing that older households consume more service-related products which tend to have higher markups. In turn, Mangiante (2023) shows that these sectors also tend to have higher degrees of price rigidity such that the sectoral shift towards services also worsens the output-inflation trade-off faced by monetary policy. However, the stylized evidence I document indicate that sectoral reallocation does not present a complete picture of the link between aging and markups. Specifically, the correlation between aging and markups that I find in the data controls for structural changes (e.g., the share of services, size of government, financial development, labor market conditions, and trade). Further, Doepper et al. (2022) among others point out that markups have also increased within product categories. As such, the mechanism that I highlight provides a complementary explanation linking firm market power and demographic aging.

The results I provide complement the broader literature linking demographics, inflation, and monetary policy. Recent studies focus on the implications of aging on inflation and monetary policy arising largely from aging-induced changes to the natural rate of interest.[7] Juselius and Takats (2021) provide evidence linking demographic changes to low frequency variation in inflation. Katagiri et al. (2020) show that under the fiscal theory of the price level and when fiscal policies are determined via maximizing the welfare of current voters, an increase in life expectancy is deflationary while a fall in the birthrate is inflationary. Regarding the implications of aging on the effectiveness of monetary policy, Leahy and Thapar (2022) argue that the age distribution materially affects entrepreneurial activity while Bornstein (2021) relates aging to the formation of new (and smaller) firms and hence the com-

[7] See e.g., Fujiwara and Teranishi (2008); Bullard et al. (2012); Goodhart and Pradhan (2020).

position of firms who would respond differently to monetary policy.[8] I propose an aging-consumption mechanism as an additional channel.

My results linking demographic aging with the flattening of the New Keynesian Phillips Curve adds to the literature examining whether the Phillips Curve has indeed flattened. This is a topic that has garnered much debate since the Great Recession and the apparent transition of the US economy towards secular stagnation. Many have argued that the Phillips Curve has been flat for some time already (Blanchard, 2016; McLeay and Tenreyro, 2019; Del Negro et al., 2020; Stock and Watson, 2020; Barnichon and Mesters, 2021). This is corroborated with evidence from Hazell et al. (2022) who also find that the slope of the US Phillips curve was small even as far back as the 1980s.

The anchoring of inflation expectations is one of the more common reasons brought up to explain a flat(ter) Phillips Curve. Other explanations propose non-linearities and state dependencies in nominal rigidities as an explanation for why the slope declines as trend inflation falls (Forbes et al., 2021; Costain et al., 2022) or shifts in production networks (Hoeynck, 2020; Rubbo, 2023). Closest to the channel I propose is the one suggested in Fujiwara and Matsuyama (2022) whereby a shift towards less market competition can account for both the observed increase in markups and decline in estimated slopes of the Phillips Curve. The results I provide suggest that demographic aging may also contribute to jointly explaining the trend increase in markups and the trend decline in the slope of the Phillips Curve.

The next section provides some evidence on the statistical link between the age structure and markups. Section 2 introduces an Overlapping Generations New Keynesian model with Deep Habits to rationalize the observed relationship between

[8] See also Liang et al. (2018) and Aksoy et al. (2019).

demographic factors, average markups and the price elasticity of households. Section 3 draws out the implications of demographic aging on firm market power and the conduct of monetary policy. Section 4 tests the model predictions regarding the output-inflation trade-off of monetary policy and population aging. Finally, Section 5 concludes with some remarks.

1. Demographics and markups

I collect data on annual macroeconomic and socio-demographic indicators covering 40 countries over the period 1980 to 2016 from the World Bank World Development Indicators. These are matched to estimates of average markups from De Loecker and Eeckhout (2020). The sample consists of a mix of both OECD member and non-member countries. Descriptive statistics, the list of countries covered, and the sample coverage per country are reported in Appendix tables A.1 and A.2. On average, life expectancy, the share of old-age dependents, and markups have grown over time while the share of the young and population growth have both declined (see Figure A.1 in the Appendix). These are also generally more readily apparent for developed or OECD member countries in the sample.

1.1. Empirical evidence on the relation between the age distribution and markups

A univariate regression of markups on several demographic factors show a positive correlation between average markups and the age-dependency ratio, life expectancy, population growth, the fertility rate, and the share of female to total population.[9] These are, of course, simple correlations and very likely to be spurious. We have not accounted for potential common trends or cross-country factors that may generate these correlations. The demographics variables themselves are highly correlated with each other. To take into account these considerations, I regress markups on combinations of demographic factors as well as year and country fixed effects (standard errors clustered by country). In addition, several control variables are included in these regressions to capture differences in economic structure, financial development, and labor market characteristics. In particular, the list of control variables include real GDP, the ratios of the current account and total trade to GDP, government spending as a fraction of GDP, savings to GDP, and the share of services to GDP as factors relating to economic structure. Further, variables such as the labor force participation rate, the unemployment rate, and population density are used to control for labor market characteristics while the ratio of stock market capitalization to GDP and domestic credit to GDP are used to account for financial development. Table 1 reports results from these regressions.

[9] See Table A.3 in the Appendix. I also find that net migration is not statistically correlated with average markups.

Table 1: Multivariate regression of markups on demographics

Dep. var.: Markups	(1)	(2)	(3)	(4)	(5)	(6)
Age dependency ratio (total)	0.009**	0.009**	0.006*	0.004*		
	(0.00)	(0.00)	(0.00)	(0.00)		
Share young to total pop.					0.014*	0.008*
					(0.01)	(0.00)
Share old to total pop.					0.017*	0.015*
					(0.01)	(0.01)
Share female to total pop.	0.024	-0.144*	-0.089*	-0.057	-0.095*	-0.071*
	(0.03)	(0.08)	(0.05)	(0.04)	(0.05)	(0.04)
D.Life exp. at birth (years)	0.062	0.042	0.013	0.012	0.015	0.015
	(0.04)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)
Population growth(annual %)	0.051*	-0.016	-0.012	-0.004	-0.012	0.000
	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
L.Markups			0.428**	0.489***	0.425**	0.492***
			(0.19)	(0.12)	(0.19)	(0.12)
Additional controls	NO	YES	YES	YES	YES	YES
Fixed effects	Y,C	Y,C	Y,C		Y,C	
Observations	1356	628	628	628	628	628
Adj. R-sq.	0.584	0.758	0.805		0.805	
AR(1) p-value				0.000		0.000
AR(2) p-value				0.914		0.884

,, and *** indicate statistical significance at the 10, 5, and 1% levels. Cluster-robust standard errors (by country) and robust standard errors for the dynamic panel regressions are reported in parentheses. The table reports multivariate regressions of average markups on combinations of demographic factors and several control variables. Data is annual and covers the period 1980-2016 for 40 countries. For the Arellano-Bover-Blundell-Bond dynamic panel regressions, p-values from tests of residual serial correlation up to 2 lags are also reported. Control variables used, but not reported, are real GDP, the ratio of current account to GDP, the ratio of total trade to GDP, the ratio of government expenditures to GDP, the savings to GDP rate, the share of Services sector value-added to GDP, the labor force participation rate, the unemployment rate, population density, the ratio of stock market capitalization to GDP, and the ratio of domestic credit to GDP. Panel fixed effects regressions include year and country fixed effects.*

Column 1 of Table 1 reports results from a regression with only the demographics variables and country and year fixed effects while column 2 reports results once the additional control variables are included in the specification. I find that the age-dependency ratio and possibly the share of female to total population remain significantly correlated with average markups. I include lagged markups in the regression specifications reported in columns 3 and 4 using panel fixed effects and a dynamic panel regression respectively. In these regressions, the age-dependency ratio remains a statistically significant predictor of average markups. Finally, columns 5 and 6 report panel fixed effects and dynamic panel regression results when the age dependency ratio is split into the share of the young and old dependents. Here I find that both the share of the young and old dependents matter for the correlation between age-dependency and average markups. Using the coefficient estimates in columns 5 and 6, a 5.2% increase in the share of the old age dependents (the average increase in the sample from 1980 to 2016) would raise markups by 0.08 to 0.09 which is between 16% to 18% of the average increase in markups in the sample over 1980 to 2016.

I repeat the regression exercise using sub-samples of the data. In particular, I split the sample across three periods and into OECD-member and non-member countries. Regression results are reported in Table 2. Columns 1 to 3 report results when the sample is split into three time periods, 1980-1992, 1993-2004, and 2004-2016 respectively. Columns 4 and 5 report results when I restrict the sample to OECD member and non-member countries respectively. I find that the coefficient on the share of young dependents is no longer statistically significant in any of the sub-samples. On the other hand, the coefficient on the share of old dependents remain statistically significant and positive for the latter two-thirds of the sample (covering 1992-2016) and for the OECD member country sub-sample. Using the coefficient estimates from column 4, an increase of the share of old age dependents by 6.2% (the change in average shares for OECD countries from 1980 to 2016), would increase markups by 0.07 or about 10% of the increase in average markups in OECD countries from 1980 to 2016.

Table 2: Regression results: Subsamples

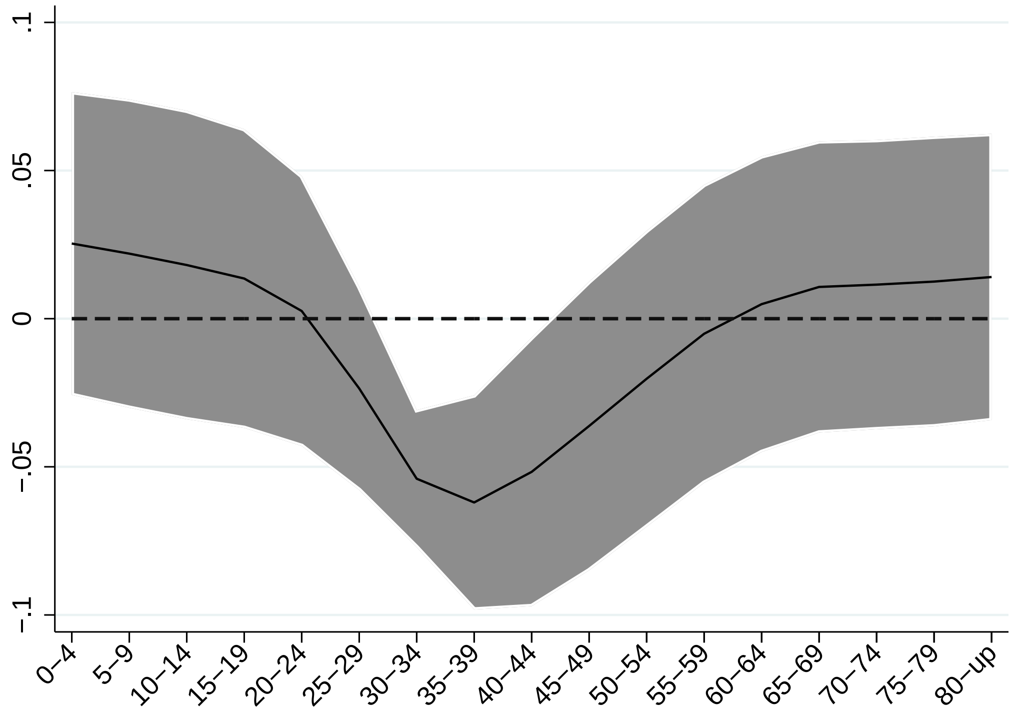
Dep. var.: Markups	(1)	(2)	(3)	(4)	(5)
Sample	80-92	92-04	05-16	OECD	non-OECD
Share young to total pop.	-0.006	0.048	0.015	0.002	0.003
	(0.02)	(0.03)	(0.01)	(0.00)	(0.01)
Share old to total pop.	0.013	0.061*	0.029**	0.011*	-0.008
	(0.05)	(0.04)	(0.01)	(0.01)	(0.02)
Share female to total pop.	-0.021	0.170	-0.108**	-0.069*	0.075
	(0.19)	(0.25)	(0.05)	(0.04)	(0.05)
D.Life exp. at birth (years)	-0.107*	0.097	-0.015	-0.028	0.099
	(0.06)	(0.07)	(0.03)	(0.02)	(0.07)
Population growth(annual %)	0.062	-0.013	0.022	0.030**	-0.011
	(0.04)	(0.04)	(0.02)	(0.01)	(0.02)
L.Markups	0.238	0.180	0.581***	0.814***	0.397***
	(0.17)	(0.17)	(0.06)	(0.05)	(0.10)
Additional controls	YES	YES	YES	YES	YES
Observations	158	374	452	591	393
AR(1) p-value	0.027	0.046	0.002	0.003	0.074
AR(2) p-value	0.316	0.131	0.797	0.358	0.129

,, and *** indicate statistical significance at the 10, 5, and 1% levels. Robust standard errors are reported in parentheses. The table reports Arellano-Bover-Blundell-Bond dynamic panel regressions of average markups on combinations of demographic factors and several control variables. The p-values from tests of residual serial correlation up to 2 lags are also reported. Control variables used, but not reported, are real GDP, the ratio of current account to GDP, the ratio of total trade to GDP, the ratio of government expenditures to GDP, the savings to GDP rate, the share of Services sector value-added to GDP, the labor force participation rate, and population density.*

At this point, the results indicate that the old age dependency ratio is the most consistent demographic predictor of average markups. I then verify whether this threshold (65 and over) is indeed the right one by running regression specifications which take into account the full age distribution of the population. I take the share of the population in five year age increments (e.g. 0-4, 5-9, 10-14, etc.) up to

80 years of age and older as the key explanatory variable. As these shares are highly persistent and correlated with each other, I use factor analysis to shrink the number of explanatory variables. Juselius and Takats (2021) make use of a similar approach to study the link between demographic changes and inflation.[10] I extract four factors from the 17 age groups and run regressions using the same controls as before. Regression results are reported in Table A.4 in the Appendix. I use the coefficient estimates on the four factors along with the factor loadings of the 17 age categories to map out the marginal contribution of each age category on markups in relative terms. The resulting contributions are plotted in Figure 1.

Figure 1: Marginal effects of age group shares on markups



The figures plot the implied marginal effects of each age sub-group from a factor transform corresponding to regression specification (1) in Table A.4. The shaded area represents the 68% interval while the solid black line indicates the point estimates.

The implied effects reported in Figure 1 confirm the earlier findings that both

[10]In the Appendix, I also report regression results using the polynomial shrinkage approach adopted by Juselius and Takats (2021). See Table A.4.

the share of young and old age dependents tend to increase average markups when using the full sample. More accurately, I find evidence suggesting that the implied effect of the share of working age population on average markups is negative. The implied thresholds from this analysis are slightly different from the conventional *15 and under* and *65 and over* limits used when calculating the share of old and young dependents. In particular, the results indicate that the share of those aged in between their mid twenties and early fifties are associated with lowering average markups. Further, the results indicate a trend increase in the contribution to markups starting from the mid thirties rather than an abrupt change once a household reaches old age.

1.2. Potential channels linking demographic aging and market power

What might explain these findings? We can consider the two main economic activities of households, labor provision and consumption. With regard to the latter, one can further distinguish between changes in the composition of the consumption basket as a household ages and a general change in consumption behavior over lifetimes.

Regarding the provision of labor services, potential change in the propensity to supply labor or one's market power when negotiating wages in the labor market may change as households age. Aging may also change the structure of the economy through related supply-side mechanisms. Boucekkine et al. (2002) provide a theory of endogenous human capital accumulation to show that changes in both fertility and longevity could have medium and long-term consequences for growth. Feyrer (2007) provide evidence linking the age structure with aggregate productivity. Acemoglu and Restrepo (2022) link aging with increased automation in production. Another important aspect is with regard to aging and innovation or entrepreneurship. Liang et al. (2018); Aksoy et al. (2019); Bornstein (2021), and

Leahy and Thapar (2022) show that the age distribution matters for innovation and entrepreneurial activity.

At the same time, aggregate consumption behavior may also change over households' lifetimes.[11] For instance, Della Vigna and Pollet (2007) show that demographic changes generate predictable shifts in demand for specific sectors and consequently their profitability and stock returns. Regarding life cycle consumption baskets, Cravino et al. (2022) and Mangiante (2023) show, using household data from the United States, that services consumption increases as a households age while Banks et al. (2019) highlight medical-related expenditures as an important aspect to differences in old-age consumption between US and UK households.

1.3. The age structure and price sensitivites

Another dimension to the aging and consumption relationship may be that households' sensitivities to relative prices may decline as they get older. Doepper et al. (2022) use detailed micro data on prices and quantities in the US to show that the 30% increase in markups from 2006-2019 is likely partly due to a decrease in consumer price sensitivity over time.[12] Changes in consumption baskets over time is ruled out as the documented relationship focuses on changes within product categories over time. In turn, Brand (2021) find that price elasticities have dropped by about 25% over 2006-2017. A related finding by Neiman and Vavra (2023) is that the average household's spending is increasingly concentrated in a few products while households as a group are consuming a larger variety of products over time. They refer to this as *niche consumption*. While Neiman and Vavra (2023) focus

[11] I am omitting a discussion on the large literature regarding life-cycle consumption as these largely pertain to consumption vis-a-vis savings decisions over the life cycle.

[12] See also Atalay et al. (2023).

mostly on trends over time, their results also indicate that older households exhibit stronger niche consumption behavior. Further reinforcing these results are those documented by Bornstein (2021) regarding consumer inertia. He finds that older households are more likely to continue consuming brands that they have consumed in the past and are less likely to try out new or other brands.

These recent findings echo results from much earlier studies. For instance, Pollak and Wales (1981) have shown decades ago using British household data that the age distribution matters for demand elasticities. Further, Parks and Barten (1973) use data from 1950 to 1967 and 14 OECD countries to show that increasing the proportion of dependents reduces price elasticities. This has led Parks and Barten (1973) to speculate that:

> Old people's spending patterns may be dominated by strong habit patterns that make them less sensitive to price changes. Teenagers may be affected by peer pressures that explain their insensitivity to prices when compared with working-age adults; however they seem to show higher sensitivity when compared with old people. (Parks and Barten, 1973, p. 849)

This paper focuses on this hypothesis and explores its implications on firm price setting and the conduct of monetary policy. The emphasis placed on this channel is not because there is evidence to suggest that it is more important than the other, complementary, channels. Rather, the focus on changing price sensitivities over lifetimes is motivated by the relatively less attention placed to it in the recent literature. It is also, a very intuitive and simple channel. Bronnenberg et al. (2012) provide evidence that households' consumption is partly driven by *brand capital* which firms exploit by charging higher prices, i.e. markups. As Parks and Barten

(1973) alluded to many years ago, brand capital - preferences for specific varieties - may be something that households accumulate over time as they age.

I find additional evidence consistent with this hypothesis using European household survey data taken from the Eurobarometer Survey 77.2 conducted on March 2012. The survey, with over 26 thousand respondents from 27 European countries, covered issues concerning food purchases among others. Specifically, respondents were asked how important several features such as the price, the quality, the geographic origin, and the brand of the product, are when making food purchases. Responses to the importance of these features for food purchases are coded into 4 categories with 1 corresponding to *very important* and 4 to *not at all important*. The key explanatory variables are age groups in bins of 10 year increments (with 15-24 years of age as the omitted age category) and if the household has children. To control for other factors which may influence the relative importance of price and non-price features in food purchases, I include education, occupation, home ownership, reported difficulties in paying bills, marital status, gender, type of community, self-reported social status, internet use and ability, online purchases activity, and food logo awareness as control variables. Regression results are reported in Table 3.

Table 3: Importance of price and non-price features in food purchases

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. var.:	PRICE		QUALITY		GEOGRAPHIC ORIGIN		BRAND	
25 - 34 years	0.018	0.020	-0.035*	-0.034*	-0.145***	-0.148***	-0.055*	-0.063**
35 - 44 years	0.023	0.024	-0.038	-0.038*	-0.238***	-0.245***	-0.058	-0.071**
45 - 54 years	0.016	0.016	-0.051**	-0.050**	-0.285***	-0.298***	-0.068	-0.082**
55 - 64 years	0.070**	0.071**	-0.081***	-0.081***	-0.342***	-0.349***	-0.062	-0.077*
65 years and older	0.135***	0.127***	-0.083***	-0.080***	-0.370***	-0.376***	-0.072	-0.093*
With children	-0.030**	-0.030**	0.022	0.023*	0.057***	0.056***	0.028*	0.026
Additional controls	YES	YES	YES	YES	YES	YES	YES	YES
Fixed effects	CNTRY	NUTS2	CNTRY	NUTS2	CNTRY	NUTS2	CNTRY	NUTS2
Adj. R-squared	0.175	0.188	0.053	0.067	0.120	0.137	0.117	0.138
Observations	15977	15977	16092	16092	15946	15946	15759	15759

,, and *** indicate statistical significance at the 10, 5, and 1% levels from cluster-robust standard errors (by country or NUTS-2 regional classifications). The table reports multivariate regressions of the importance of several price and non-price features for food purchases on age and other factors. Note that the dependent variable is on a 4-point scale and coded such that 1 is very important and 4 is not at all important. Data is taken from the Eurobarometer Survey 77.2 conducted on March 2012 with respondents from 27 European countries. Additional control variables are education, occupation, home ownership, reported difficulties in paying bills, marital status, gender, type of community, self-reported social status, internet use and ability, online purchases, and food logo awareness. All specifications include either country or NUTS-2 fixed effects.*

The results indicate that the importance of prices for food purchases is decreasing with age, particularly as one reaches the mid 50s in age (columns 1 and 2 of Table 3). Consistent with these results, other non-price features become more important for food purchases as one becomes older (columns 3 to 8). Furthermore, the results also indicate that those with children tend to care more about prices.

In the next section I formalize this hypothesis that the age distribution matters for the aggregate sentitivity of households to prices and hence average markups. The next section describes a simple model which expands on the basic New Keynesian model with Deep Habits by incorporating a mechanism through which households develop deep habits as they age.

2. Age-dependent habits, and markups

This section presents an Overlapping Generations New Keynesian model with Deep Habits which links the age distribution to firm pricing behavior. The model draws on a key insight of deep habits that consumption habit persistence at the goods level effectively makes demand for differentiated goods less elastic (Ravn et al., 2006). It also brings expectations of changes in future demand into the current pricing problem of firms (Lubik and Teo, 2014). When augmented with a mechanism wherein habits develop as households age, the age distribution of the population begins to matter for the shape of demand curves faced by firms. In turn, it helps determine the markups that monopolistic competitive firms charge on the goods that they sell.

The objective of the model is to parsimoniously introduce age-specific deep-habits into a simple benchmark model with the minimum of ingredients to flesh out the implications on the New Keynesian Phillips Curve. The starting point is a simple version of the New Keynesian model with deep habits. I assume Blanchard-Yaari overlapping generations in order to generate an admittedly simplistic age distribution. To this setup, I add a key mechanism which is described in detail in the next section whereby households develop stronger deep habits as they age.

2.1. A model of deep habit development over lifetimes

Consider a household born at time $t-J$ and denoted with j who maximizes utility from consuming a basket of goods of unit length and indexed by i representing the *sectors* of the economy.[13] The economy in which this household resides in

[13] There is a continuum of households $j \in J$ of a given age J.

produces a variety of products for each sector also of unit length and indexed by k. The whole product space is characterized by a unit square Ω with $i \in [0,1]$ sectors and $k \in [0,1]$ varieties per sector. Let $\Sigma_j \subset \Omega$ represent the set of products for which household j has an inherent or latent preference for - meaning that consuming this subset of products is preferred by household j relative to products not in this subset. Let $\Omega_i \subset \Omega$ denote the subset of all products in sector i and $\Sigma_{j,i} \subset \Omega_i, \Sigma_j$ be the subset of preferred goods for a given sector i by household j. For simplicity, assume that $\Sigma_{j,i}$ contains the same number of elements for each sector i such that the set of preferred varieties in each sector is of equal length denoted by $0 \leq s \leq 1$. Consuming a variety from this preferred set has the unique property that the marginal utility is higher. Specifically let the marginal utility of consuming preferred and non-preferred varieties be given by,

$$\frac{\partial U_{j,t}}{\partial c_{i,k,t}} = \begin{cases} \bar{x}\left[c_{i,k,t} - \bar{c}\right]^{-1/\eta} & \text{if} \quad k \in \Sigma_j \\ \bar{x}\left[c_{i,k,t}\right]^{-1/\eta} & \text{if} \quad k \notin \Sigma_j \end{cases} \tag{1}$$

where $\bar{x} > 0$ and $\bar{c} > 0$ are some reference levels that will be more explicitly defined in subsequent sections.

Not all of the products are available to household j for consumption in every period. Instead, when household j enters the market for goods in period t she randomly encounters a store offering a particular variety $k_{j,i,t}$ for each sector. The household can then consume either the variety offered or any variety previously encountered for each sector. That is, the household can choose to consume any variety in the set $\Omega_{j,t} = \Omega_{j,t-1} \cup \{k_{j,i,t}\}_{i=0}^{1}$.[14] If any of the preferred varieties is in this set, then the household consumes (randomly one of) that variety and if not, then

[14]For completeness, $\Omega_{j,t} = \emptyset \quad \forall t < t - J$.

the household (indifferently) consumes any one of the varieties in the set.

The likelihood that household j encounters, and thus consumes, its preferred variety follows a geometric distribution over the number of times the household enters the market for goods or, equivalently, the household's age J. For any given period, the likelihood that the store *matched* to household j offers a variety in her preferred set is given by s, the success parameter of a Bernoulli distribution. Consequently, the probability that a household encounters and consumes her preferred variety at age J in time t for sector i ($\mathbf{1}_{i,j,t}$) is given by the cumulative distribution function of the geometric distribution, $1-(1-s)^J$.

$$Pr(\{k_{j,i,t'}\}_{t'=t-J}^{t} \cap \Sigma_{j,i} \neq \emptyset) \equiv \mathbb{E}[\mathbf{1}_{i,j,t}] = 1-(1-s)^J \tag{2}$$

For simplicity, let $\Sigma_{j,i}$ also be randomly drawn across households and sectors such that the expected likelihood of consuming a preferred variety by one household at a given age is equal to the mass of households of that age consuming their preferred variety for each and all sectors.

The setup described above could be described as a random search (and matching) model with an ex-ante defined preferred set of varieties. It can nevertheless also be interpreted as a model where one develops preferences for or learns about their preferred consumption basket over their lifetime with repeated consumption experience. In this regard one can think of s as the probability that a household wakes up one day and develops habits for consuming a good. This would be analogous to the concepts of the accumulation of *brand capital* (Bronnenberg et al., 2012), *consumer inertia* (Bornstein, 2021), or *niche consumption* (Neiman and Vavra, 2023). The intuition is simple. Everyone starts out as an uninformed beginner or novice with regard to consuming various goods. Initially, the most salient differentiator across brands and varieties would be the price. As one repeatedly consumes and gains familiarity with a particular product category, one begins to value and distinguish between the non-price features of a product. Therefore, as one ages, one is also less likely to let the price be the sole differentiating factor when making purchases. Consequently, one becomes more likely to be willing to pay more for these additional features.

In what follows, I embed this mechanism in an otherwise standard New Keynesian Deep Habits model that has been augmented to incorporate Blanchard-Yaari overlapping generations.

2.2. Households

Time is discrete and denote with N_t the mass of households in the economy for period t where $N_0 = 1$. At the beginning of every period a fraction g^b of the mass of households in the previous period are born. At the end of each period a fraction g^d of all household exit the economy such that the mass of households grow at the rate $g^b - g^d$ every period.

$$N_t = (1 + g^b - g^d)^t N_0 \tag{3}$$

Henceforth, all quantities will be expressed in per capita terms. Define $g \equiv g^b/(1 + g^b - g^d)$, a summary statistic for the age distribution. Then the time-invariant age distribution $f(J)$ of households who have lived for J periods is given by,

$$f(J) = g(1-g)^{J-1} \tag{4}$$

where $J \in [1, \infty]$. Households derive utility from consumption, provide labor services, and save in a one-period risk-free asset. They maximize the discounted sum of utility from consuming a basket of goods comprised of one variety, indexed by

$k \in [0,1]$, for each sector $i \in [0,1]$ and the provision of labor services yielding the following program for a household j born J periods from today,

$$max \qquad \mathbb{E}_t \sum_{t'=0}^{\infty} (\prod_{t''=0}^{t'} \tilde{\beta}_{t''}) U(\{c_{i,j,t+t'}\}, h_{j,t+t'}) \tag{5}$$

subject to:

$$U = \frac{x_{j,t}^{1-\sigma}}{1-\sigma} - \frac{h_{j,t}^{1+\kappa}}{1+\kappa} \tag{6}$$

$$x_{j,t} = \left[\int_0^1 (c_{i,j,t} - \theta_{i,j,t} c_{i,t-1})^{\frac{\eta-1}{\eta}} di\right]^{\frac{\eta}{\eta-1}} \tag{7}$$

$$\int_0^1 P_{i,t} c_{i,j,t} di + B_{j,t} = R_{t-1} B_{j,t-1} + W_t h_{j,t} + \Phi_t \quad \forall t \tag{8}$$

where $\Phi_t = \int \Phi_{i,t} di$ are firm profits treated as exogenous by households, σ is the coefficient of relative risk aversion, κ is the inverse Frisch elasticity of labor supply, η is the elasticity of demand for differentiated goods, $c_{i,t} = \sum_{J=1}^{\infty} \int_{j \in J} c_{i,j,t} dj f(J)$ is aggregate consumption in sector i, and where I have dropped the subscript k to simplify terms.[15] Finally, $\tilde{\beta}_t = (1-g^d)\beta \psi_t \psi_{t-1}^{-1}$ is the exit probability-adjusted discount factor. The variable ψ_t captures what I would refer to as demand shocks and follows an auto-regressive process,

$$log\left(\frac{\psi_t}{\psi_{t-1}}\right) = (1-\rho_b)\bar{\psi} + \rho_b log\left(\frac{\psi_{t-1}}{\psi_{t-2}}\right) + \sigma_b \varepsilon_{b,t} \tag{9}$$

where $\varepsilon_{b,t} \sim i.i.d.N(0,1)$ are the demand shocks and $\bar{\psi}$ is assumed to be zero with $\psi_t = 1 \forall t < 1$ so that the steady state discount factor is given by $(1-g^d)\beta$. Further, $\theta_{i,j,t}$ is the deep habits parameter which is capturing the eventuality that household j encounters and consumes a preferred variety in sector i in period t. In particular, I assume that it is either zero when the household has not encountered her preferred

[15]Each household only consumes one variety per sector and the problem that firms producing different varieties in a given sector (or households consumption of a given variety in a sector) are symmetric.

variety yet or some constant when she has.

$$\theta_{i,j,t} = \mathbf{1}_{i,j,t}\theta \tag{10}$$

where $\mathbb{E}[\mathbf{1}_{i,j,t}] = 1-(1-s)^J$ is the probability derived in the previous section and where s is the parameter governing the unconditional likelihood of having encountered a preferred variety.[16]

The households' problem yield the following optimality conditions,

$$c_{i,j,t} = x_{j,t}\left[\frac{P_{i,t}}{P_t}\right]^{-\eta} + \theta_{i,j,t}c_{i,t-1} \tag{11}$$

$$h^{\kappa}_{j,t} = x^{-\sigma}_{j,t}W_t/P_t \tag{12}$$

where

$$P_t = \left[\int_0^1 P^{1-\eta}_{i,t}di\right]^{\frac{1}{1-\eta}} \tag{13}$$

Here, the aggregate price level is given by equation 13 and aggregate consumption for sector i (which is the same across all the varieties in that sector) is the sum of consumption across all households by age group ($c_{i,t} = \sum_{J=1}^{\infty} c_{i,J,t}f(J)$).[17]

I abstract from potential heterogeneity due to differences in budget constraints and the accumulation of savings by assuming that savings decisions are relegated to a representative household who provides within and across cohort consumption insurance. Further, there is zero net supply of the risk-free asset such that in equilibrium $B_{j,t} = B_t = 0$ for all households and periods.[18] A symmetric equilibrium

[16] Note that the reference $\theta_{i,j,t}c_{i,t-1}$ for household j's consumption of $c_{i,j,t}$ is an aggregate consumption variable. This could be interpreted as adding a herding or *keeping up with the Joneses* aspect to the mechanism.

[17] In turn, consumption of all households of age J is just the sum of individual consumption, $c_{i,J,t} = \int_{j\in J} c_{i,j,t}$.

[18] One interpretation of this assumption is the presence of a well-functioning social security system.

for households within the same age group yield the Euler equation,

$$x_{J,t}^{-\sigma} = \tilde{\beta}_t R_t \mathbb{E}_t [x_{J,t+1}^{-\sigma} P_t / P_{t+1}] \tag{14}$$

and aggregating across households in a symmetric equilibrium yields the aggregate Euler and demand equations,

$$\begin{aligned} x_t^{-\sigma} &= \tilde{\beta}_t R_t \mathbb{E}_t [x_{t+1}^{-\sigma} P_t / P_{t+1}] && (15) \\ c_{i,t} &= x_t \left[\frac{P_{i,t}}{P_t} \right]^{-\eta} + \tilde{\theta} c_{i,t-1} && (16) \end{aligned}$$

where $x_t \equiv \sum_{J=1}^{\infty} x_{J,t} f(J)$ while $c_{i,t} \equiv \sum_{J=1}^{\infty} c_{i,J,t} f(J)$ and,

$$\begin{aligned} \tilde{\theta} &\equiv \sum_{J=1}^{\infty} \theta_{i,J,t} f(J) \\ &= \theta s [1 - (1-s)(1-g)]^{-1} && (17) \end{aligned}$$

Note here that the age distribution is crucial to average deep habits $\tilde{\theta}$. A young and dynamic population with high entry and exit of households (large g) exhibits lower habit persistence than an aging population with low entry and exit (small g). For instance, at the extreme where agents live for one period ($g = 1$), aggregate deep habits is proportional to the relative size of preferred sets, $\tilde{\theta} = \theta s$. On the other hand, when agents are infinitely-lived with no entry and exit ($g = 0$) then deep habits are maximized and $\tilde{\theta} = \theta$. The parameter s governs the speed at which households develop deep habits. When s is zero then there are no deep habits ($\tilde{\theta} = 0$) and when all varieties are preferred ($s = 1$) then deep habits are maximized ($\tilde{\theta} = \theta$).

2.3. Firms

Production in this economy is comprised of two layers, consumption goods and intermediate goods (or inputs). The sole purpose of the second layer is to introduce another parameter which determines markups and is associated with the supply-side of the economy (the production elasticity of substitution between intermediate inputs). Changing this parameter will allow the model, in a reduced-form way, to capture alternative explanations of the rise in markups and flattening of the slope of the Phillips curve due to supply-side changes in areas such as production networks and the degree of market competition (Hoeynck, 2020; Fujiwara and Matsuyama, 2022; Rubbo, 2023). I describe each of the layers of production in the following sections.

2.3.1. Consumption goods production

Consumption goods are produced using a basket of intermediate inputs. Infinitely-lived firms produce varieties of differentiated consumption goods in monopolistic competitive markets and maximize the expected sum of profits discounted by households' stochastic discount factor q_t by choosing intermediate inputs demand and consumption goods prices. A firm producing good i solves the following problem (variety k is omitted for simplicity),

$$\begin{aligned}
max \qquad & \mathbb{E}_t \sum_{s=0}^{\infty} q_{t+s} \Phi_{i,t+s} && (18)\\
\text{subject to:} & \\
\Phi_{i,t} &= P_{i,t} c_{i,t} - \int_{m=0}^{1} P_{m,t} Y_{m,t} dm && (19)\\
c_{i,t} &= x_t \left[\frac{P_{i,t}}{P_t}\right]^{-\eta} - \tilde{\theta} c_{i,t-1} && (20)\\
c_{i,t} &\leq y_{i,t} = \left[\int_{m=0}^{1} Y_{m,t}^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}} && (21)
\end{aligned}$$

where $c_t \equiv \int c_{i,t} di$ is aggregate consumption, $Y_{m,t}$ are intermediate inputs with price $P_{m,t}$, and γ is the production elasticity of substitution between intermediate inputs.

The solution to the firms' problem yield the following optimality conditions,

$$\begin{aligned}
P_{m,t}/P_t &= \lambda_{i,t}[Y_{i,t}/Y_{m,t}]^{1/\gamma} && (22)\\
P_t \lambda_{d,t} + P_t \lambda_{i,t} &= P_{i,t} + \tilde{\theta} \mathbb{E}_t \frac{q_{t+1}}{q_t} P_{t+1} \lambda_{d,t+1} && (23)\\
P_{i,t} c_{i,t} &= \eta \lambda_{d,t} P_t (c_{i,t} - \tilde{\theta} c_{i,t-1}) && (24)
\end{aligned}$$

where $\lambda_{i,t}$ is the multiplier on production (marginal cost, equation 21) and $\lambda_{d,t}$ is the multiplier on demand (equation 20). Equation 22 can be rearranged to the demand for input $Y_{m,t}$ by aggregating across sectors.

$$Y_{m,t} = \int_{i=0}^{1} Y_{i,t} \lambda_{i,t}^{\gamma} \left[\frac{P_{m,t}}{P_t}\right]^{-\gamma} di \qquad (25)$$

2.3.2. Intermediate goods production

The intermediate inputs to consumption goods are produced using labor by infinitely-lived monopolistic competitive firms who maximizes the expected sum of profits discounted by households' stochastic discount factors by choosing labor demand and intermediate input prices subject to Rotemberg price adjustment costs. A firm producing intermediate input m solves the following problem,

$$
\begin{aligned}
max \qquad & \mathbb{E}_t \sum_{s=0}^{\infty} q_{t+s}\Phi_{m,t+s} && (26)\\
\text{subject to:} & \\
\Phi_{m,t} \;=\; & P_{m,t}Y_{m,t} - W_t h_{m,t} - \frac{\delta}{2}P_{M,t}c_t\left(\frac{P_{m,t}}{P_{m,t-1}} - \pi^*\right)^2 && (27)\\
Y_{m,t} \;=\; & \int_{i=0}^{1} Y_{i,t}\lambda_{i,t}^{\gamma}\left[\frac{P_{m,t}}{P_t}\right]^{-\gamma} di && (28)\\
Y_{m,t} \;\leq\; & A_t h_{m,t} && (29)
\end{aligned}
$$

where π^* is an inflation target set by the monetary authority, δ is the cost of price adjustment parameter, and $P_{M,t} = \left[\int_{m=0}^{1} P_{m,t}^{1-\gamma}\right]^{\frac{1}{1-\gamma}}$ is the average price level for intermediate inputs. The productivity of labor inputs A_t is the same across firms and follows an auto-regressive process,

$$
log(A_t) = (1-\rho_a)\bar{A} + \rho_a log(A_{t-1}) + \sigma_a \varepsilon_{a,t} \tag{30}
$$

where $exp(\bar{A})$ is steady-state productivity, ρ_a is the persistence parameter, and $\varepsilon_{a,t}$ are productivity shocks with $\varepsilon_{a,t} \sim i.i.d.N(0,1)$.

The solution to the firms' problem yield the following optimality conditions,

$$
\begin{aligned}
W_t/P_t &= \lambda_{h,t}A_t && (31)\\
P_{m,t} &= P_t\lambda_{m,t} + P_t\lambda_{h,t} && (32)\\
Y_{m,t} &= \gamma\lambda_{m,t}\int \lambda_{i,t}^{\gamma}Y_{i,t}di\left[\frac{P_{m,t}}{P_t}\right]^{-\gamma-1} + \delta c_t \frac{P_{M,t}}{P_{m,t-1}}\left(\frac{P_{m,t}}{P_{m,t-1}} - \pi^*\right) \\
&\quad -\delta\mathbb{E}_t\frac{q_{t+1}}{q_t}c_{t+1}\frac{P_{M,t+1}}{P_{m,t}}\frac{P_{m,t+1}}{P_{m,t}}\left(\frac{P_{m,t+1}}{P_{m,t}} - \pi^*\right) && (33)
\end{aligned}
$$

where $\lambda_{h,t}$ is the multiplier on production (marginal cost, equation 29) and $\lambda_{m,t}$ is the multiplier on demand (equation 28).

2.4. Monetary policy and aggregation

I close the model with a description of monetary policy which follows a Taylor-type rule,

$$\frac{R_t}{R^*} = \left[\frac{R_{t-1}}{R^*}\right]^{\rho_r} \left[\frac{\pi_t}{\pi^*}\right]^{\alpha_\pi(1-\rho_r)} \left[\frac{y_t}{y^*}\right]^{\alpha_y(1-\rho_r)} exp(\varepsilon_{r,t}) \tag{34}$$

where $\pi_t = P_t/P_{t-1}$ is the gross inflation rate, R^* and y^* are the steady-state nominal rate and output respectively, and $\varepsilon_{r,t}$ are monetary policy surprises. The full set of aggregate equilibrium conditions implied by the model assumptions are reported in the appendix. In the next section, I draw out the model's implications regarding factors driving steady state markups, the New Keynesian Phillips Cure, and the output-inflation trade-off faced by monetary policy.

3. Model implications

As a first step, I derive an expression for steady state markups in the model which is defined as the ratio of consumption good prices to productivity-adjusted nominal wages. The (deterministic) steady state markup μ is given by,

$$\begin{aligned} \mu &\equiv \lambda_h^{-1} = [\frac{\gamma-1}{\gamma}\lambda_i]^{-1} \\ \mu &= \left[\frac{\gamma}{(\gamma-1)}\right]\left[\frac{\eta}{(\eta-1)}\right]\left[\frac{1-\tilde{\theta}}{1-\tilde{\theta}\left(\frac{\eta-\tilde{\beta}}{\eta-1}\right)}\right] \end{aligned} \tag{35}$$

which is increasing in the degree of deep habits. Further, aging or less demographically dynamic economies (low g) feature higher average deep habits (see equation

17) and thus higher markups. The model predicts that aging societies are characterized by larger average markups.

It should be noted that the extent to which deep habits affects markups also depend on the consumption elasticity of substitution η and the discount factor $\tilde{\beta}$.[19] Specifically, the effect of deep habits on markups decrease as $\eta - \tilde{\beta}$ approaches $\eta - 1$ (e.g., as η becomes larger or $\tilde{\beta}$ approaches 1).

Further, markups are decreasing in the production elasticity of substitution γ. If supply-side factors generate a decrease in the elasticity of substitution across intermediate inputs, then the level of markups in the model will increase. Changes in this parameter is meant to capture supply-side forces that would generate the increase in markups as proposed in the literature (e.g., production networks and barriers to entry as in Hoeynck, 2020; Fujiwara and Matsuyama, 2022; Rubbo, 2023).

Incidentally, the model also predicts that the labor share - defined as the share of labor to total income - declines when societies age. In the model the labor share of income is inversely proportional to the markup. Thus, as societies age and average deep habits increase, average markups also increase which lower the share of income attributed to labor.

3.1. The New Keynesian Phillips Curve

To get an analytical expression for the New Keynesian Phillips Curve (NKPC) implied by the model, I take first order log approximations of the equilibrium equations to simplify the expressions. Define variables in *hats* as in log-deviations from

[19] The discount factor enters the markup equation as it is the discount factor used by firms when maximizing profits. If firms and households have different discount factors, then the firm discount factor would be the relevant parameter for markups.

a zero inflation steady state, e.g., $\hat{y}_t \equiv log(y_t) - log(y^*)$. Further, by taking log approximations, assuming that products of log-deviations are approximately zero, and simplifying leads to the following three equations characterizing monetary policy, the New Keynesian IS curve, and the NKPC as well as two equations defining the evolution of marginal costs for consumption goods and intermediate inputs production. To further simplify the expressions below, I also drop the preference and productivity shocks.

$$\hat{r}_t = \rho_r \hat{r}_{t-1} + (1-\rho_r)[\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t] + \varepsilon_{r,t} \quad (36)$$

$$\hat{y}_t = \frac{1}{1+\tilde{\theta}} \mathbb{E}_t \hat{y}_{t+1} + \frac{\tilde{\theta}}{1+\tilde{\theta}} \hat{y}_{t-1} - \frac{1-\tilde{\theta}}{1+\tilde{\theta}} \frac{1}{\sigma} [\hat{r}_t - \mathbb{E}_t \hat{\pi}_{t+1}] \quad (37)$$

$$\hat{\pi}_t = \tilde{\beta} \mathbb{E}_t \hat{\pi}_{t+1} + \frac{\gamma - 1}{\delta} \left[\hat{\lambda}_{h,t} - \hat{\lambda}_{i,t} \right] + \tilde{\beta} \mathbb{E}_t \hat{\lambda}_{i,t+1} - (1+\tilde{\beta}) \hat{\lambda}_{i,t} + \hat{\lambda}_{i,t-1} \quad (38)$$

$$\hat{\lambda}_{i,t} = \Theta_1 \hat{y}_t - \Theta_2 \mathbb{E}_t \hat{y}_{t+1} - \Theta_3 \hat{y}_{t-1} \quad (39)$$

$$\hat{\lambda}_{h,t} = (\kappa + \frac{\sigma}{1-\tilde{\theta}}) \hat{y}_t - \Theta_4 \hat{y}_{t-1} \quad (40)$$

The reduced-form parameters Θ_1 to Θ_4 are functions of parameters $\{\tilde{\beta}, \tilde{\theta}, \eta, \sigma\}$ and are all equal to zero when $\tilde{\theta}$ is zero. In particular, these reduced-form parameters are strictly positive and increasing in deep habits whenever $\tilde{\theta} > 0$. This also means that without deep habits then $\hat{\lambda}_{i,t} = 0$ and the model simplifies to a standard New Keynesian model.

Before examining the NKPC, we first comment on the IS curve under deep habits. First, as one would expect, deep habits adds smoothing to output and the IS curve is no longer purely forward looking but is now a weighted average of past and expected future output. Second, deep habits attenuates the response of output (or demand) to interest rate and demand shocks. This already implies that larger interest rate movements are needed in order to stimulate or depress demand under deep habits. While significant in itself, a monetary authority would be more interested in the trade-off between output and inflation in response to interest rate changes. For this we have to refer to the NKPC.

As can be seen in equation 38 representing the NKPC of the model, there are two marginal costs to take into account and one of them ($\hat{\lambda}_{i,t}$) is purely related to deep habits. This term adds leads and lags of output into the NKPC. We can substitute the equations for the marginal costs into the NKPC to derive the NKPC in terms of inflation and output.

$$\begin{aligned}\hat{\pi}_t &= \tilde{\beta}\mathbb{E}_t\hat{\pi}_{t+1} + \left[\frac{\gamma-1}{\delta}(\kappa + \frac{\sigma}{1-\tilde{\theta}}) - \tilde{\beta}(\Theta_1+\Theta_3) - (1+\frac{\gamma-1}{\delta})\Theta_1\right]\hat{y}_t \\ &\quad -\Theta_2\tilde{\beta}^2\mathbb{E}_t\hat{y}_{t+2} + (\Theta_1 + (1+\tilde{\beta}+\frac{\gamma-1}{\delta})\Theta_2)\tilde{\beta}\mathbb{E}_t\hat{y}_{t+1} - \Theta_2\tilde{\beta}\mathbb{E}_{t-1}\hat{y}_t \\ &\quad +(\Theta_1 + (1+\tilde{\beta}+\frac{\gamma-1}{\delta})\Theta_3 - \frac{\gamma-1}{\delta}\Theta_4)\hat{y}_{t-1} - \Theta_3\hat{y}_{t-2}\end{aligned} \tag{41}$$

where the last two rows of equation 41 disappear and the coefficient on current output reduces to the standard slope of the NKPC without deep habits. With deep habits, the coefficient on current output tends to decrease as deep habits increase. Further, leads and lags of output are now present in the NKPC such that the *slope* of the NKPC defined as the coefficient on current output is no longer a sufficient statistic describing the relationship between inflation and output in the NKPC.

In order to fully appreciate the implications of demographic aging and deep habits on the conduct of monetary policy, in the next section I calibrate the model to match demographic and markup changes for Japan and use the calibrated model to draw out the responses of both inflation and output to monetary policy surprises.

3.2. Model-implied contribution of demographic aging to markups

I calibrate the model to match demographics and average markups in Japan for two periods, the early 1980s (1980-1985) and early 2010s (2011-2016). For each period, annual data is averaged in terms of life expectancy, population growth, as well as average markups from De Loecker and Eeckhout (2020). For the demographic features, I calibrate the parameters gb and gd to best match average population growth and life expectancy. I then set the maximum value of deep habits θ so that the average deep habits across both periods is approximately 0.85 and set the parameter s such that average deep habits flatten out at about 55 years of age. Finally, I match average markups by varying the elasticity of substitution parameters η and γ. Specifically, I set the two elasticity parameters approximately equal and match markups in the first period. I then calibrate a different γ for the second period in order to match markups in the 2010s. Table 4 reports a comparison of the model and data in terms of the observables. The last two rows also report average deep habits implied by the parameters as well as the value of the elasticity of substitution required to match average markups.

Table 4: Model-implied vs. actual demographic features and markups

	1980-1985		2011-2016	
	Data	Model	Data	Model
Population growth	0.688	0.688	-0.141	-0.141
Life expectancy.	76.901	76.897	83.398	83.400
Markups	1.036	1.036	1.280	1.280
Average Deep habits		0.753		0.947
Consumption elasticity		56.913		56.913
Production elasticity		59.848		4.969

The table reports model-implied demographics and markups against the data for Japan and the periods 1980-1985 and 2011-2016. The last three rows also report the implied average deep habits given the demographics calibration and the value of the elasticity of substitution parameters required to match average markups.

As there are a sufficient number of free parameters, the calibration is generally able to generate a decline in birth rates, an increase in life expectancy, and an increase in markups. The rest of the parameters are calibrated as standard in the literature. Table A.7 in the Appendix reports the calibrated values of the other parameters.

Given the model calibrations, we can also decompose the change in markups from the 1980s to the 2010s into what is due to demographic changes and other factors captured by the change in the production elasticity of substitution γ. Table 5 reports the breakdown when I calibrate the model to the 1980s, to the 2010s but without changing the demographic structure, and finally to the 2010s including the demographic changes. The first column reports the steady state markup while the second column reports the share of the change in markups relative to the 1980s.

Table 5: Decomposition of the change in markups

	Level	Share
1980-1985 Baseline	1.036	
2011-2016 with no demog. change	1.275	96.2
2011-2016 All changes	1.280	100.0

The table reports model-implied markups when the model is calibrated to match Japan for the periods 1980-1985 and 2011-2016. The first row reports the 1980-1985 baseline. The second row reports markups when the production elasticity of substitution γ is allowed to increase to 2011-2016 levels but demographics parameters (and thus deep habits) are kept to 1980-1985 levels. Finally, the third row reports the 2011-2016 markups when both demographics and production elasticities are calibrated to 2011-2016.

The results indicate that demographic changes only have a marginal impact on markups at 3.8% of the total change. In the data, demographic changes were able to account for about 10% of the increase in markups for OECD countries. The model is not able to match this as the effect of deep habits on markups also depend on the consumption elasticity of substitution η and the discount factor $\tilde{\beta}$ (see equation 35).

In order for demographic changes to have a larger share of the increase in markups then either the consumption elasticity of substitution has to be lower (which will prevent the model from matching markups in the 1980s) or the discount factor (of firms) would need to be lower than the calibrated value of 0.99. If, for instance, firms were to be more myopic, then changes in average deep habits would have stronger effects on average markups. The reason behind this feature is that firms know that when they raise prices today, their market share declines both today and in the future because of deep habits. Therefore a discount factor close to one for firms constrains their incentives to capitalize on inelastic demand today. Conversely, if firms have a short-term view of profits, then they would be more inclined to raise prices to take advantage of inelastic demand today.

3.3. Demographic aging and the effects of monetary policy surprises

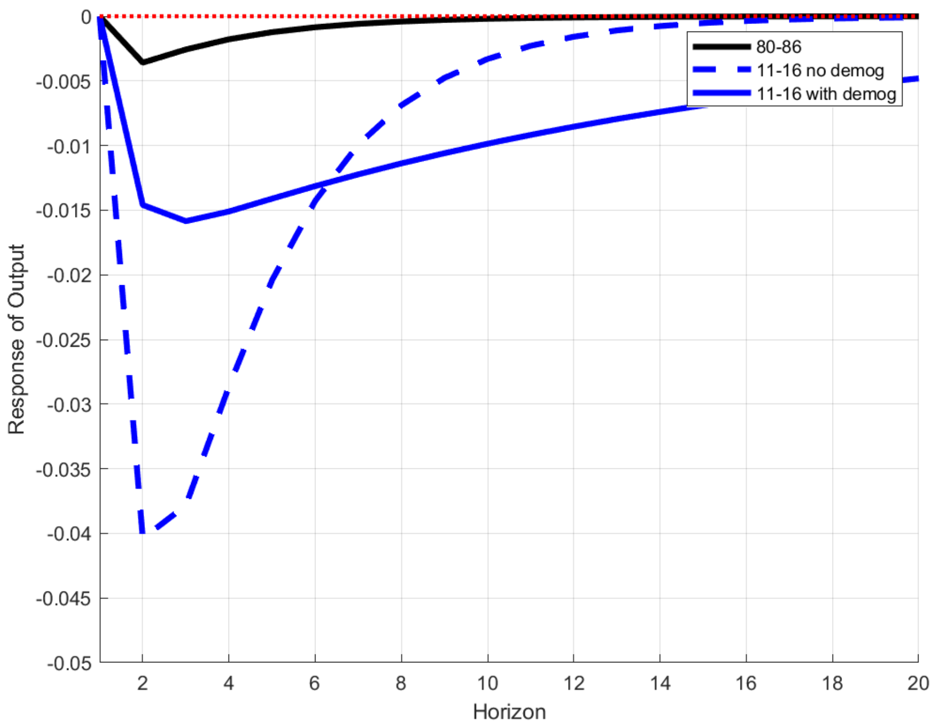
I now move on to the model's implications regarding demographic aging and the conduct of monetary policy. As noted in previous sections, the *slope* of the NKPC is no longer a sufficient statistic to characterize the trade-offs between inflation and output faced by monetary policy. Consequently, I use the model to generate responses of inflation and output to a monetary policy surprise and compare the response of output in the model when calibrated to the 1980s and the 2010s.

The size of the shock is calibrated to generate a cumulative decline in the inflation rate of one percent over a fixed horizon of 2, 5, or 20 years. Table 6 reports the cumulative response of output and inflation to a monetary policy surprise shock across calibrations. Figure 2 plot the impulse responses.

The figure indicates a dramatically stronger response of output to a monetary policy surprise in the 2010s relative to the 1980s. That is, a monetary policy shock which lowers inflation by the same amount will significantly and more persistently reduce output in the 2010s relative to the 1980s. The assumption of Rotemberg price rigidities is key to this finding. Under this assumption, the model generates a link between (the increase in) steady state markups and the output cost of disinflation. Nevertheless, if one were to assume that the frequency of price adjustment is endogenous to the fickleness of consumer demand (i.e., if the frequency of price changes falls as consumers become more habitual in their consumption), then a similar result may be obtained in a Calvo setting.

Demographic changes play an important role in increasing the output cost of disinflation. When the model is calibrated to keep demographic parameters to the

Figure 2: Response of output and inflation to a monetary surprise: Japan



The figure plots the model-implied responses of output to a monetary policy surprise shock when the model is calibrated to Japan in the 1980s and the 2010s. The size of the shock is calibrated to generate the same cumulative response of inflation across scenarios. The solid black line reports the response of output for the 1980-1985 baseline. The dashed blue line reorts the response of output when the production elasticity of substitution is calibrated to 2011-2016 but demographic parameters remain at 1980-1985 levels. Finally, the solid blue line reports the impulse response when both demographics and elasticity parameters are calibrated to 2011-2016.

level in the 1980s but for markups to increase due to supply-side factors, we see that output falls by more in the short run but goes back to the steady state relatively quickly in about 5 years. However, with demographic changes, while the initial fall in output is attenuated, it is also more persistent and the cumulative fall in output over a 20 year horizon is about 50% larger than in the calibration without demographic changes. That is, about one third of the longer-run increase in the output cost of disinflation from the 1980s to the 2010s is due to demographic aging.

Table 6: Response of output to monetary policy surprises

Horizon	2 year	5 year	20 year
1980-1985 Baseline	-0.011	-0.012	-0.012
2011-2016 with no demog. change	-0.163	-0.174	-0.174
2011-2016 All changes	-0.108	-0.189	-0.247

The table reports the model-implied cumulative response of output over a 2, 5, and 20 year horizon to a monetary policy surprise shock when the model is calibrated to match Japan for the periods 1980-1985 and 2011-2016. The size of the shock is calibrated to generate a cumulative response of inflation of one percent at the specified horizon. The first row reports cumulative responses using the 1980-1985 calibration. The second row reports results when the production elasticity of substitition is calibrated to 2011-2016 while demographic parameters are kept to 1980s levels. The third row allows for both demographics and elasticity parameters to change to 2011-2016 levels.

The simulations indicate that demographic aging accounts for a disproportionately larger share of the increase in the output cost of disinflation relative to its share in the increase in markups. This seems to be largely due to the increase in persistence when average deep habits are higher due to aging. This is confirmed in simulation results from an alternative model specification where aging directly affects the consumers' elasticity of substitution and there are no deep habits. In this version of the model without deep habits (and therefore no aging-induced increase in persistence), the contribution of aging to the increase in the output cost of disinflation is proportional to the contribution of aging to the increase in steady state markups.[20]

4. Testing the model implications

The simulated response of output to monetary surprises across the changing demographic features of Japan reported in the previous section presents a testable implication of the model. More generally, the model suggests that the output response to monetary tightening (which results in a standardized fall in inflation) should be increasing in the proportion of the elderly in the population. To test this implication, I run state-dependent local projections of the impact of monetary surprises on output and inflation where the relevant state is the old-age dependency ratio. To identify monetary surprises, I follow Jorda et al. (2020) and exploit the *trilemma* of international finance to obtain an instrument for monetary policy surprises in countries which peg their currencies.

I collect annual data from the macrofinance database of Jorda et al. (2017) for macroeconomic variables and the Trilemma instrument and the United Nations Population Division for a long history of the old-age dependency ratio. The sample period is restricted to the years 1950 to 2016 and covers 16 developed countries which have pegged their currency at some point during the sample period.[21] The average old-age dependency ratio for countries in the sample went from 16.3 to 30.7 over this period. I then estimate the following equation via instrumental variables local projections,

$$y_{t+h,c} = \alpha_{c,h} + \Delta\hat{r}_{t,c}\beta_{1,h} + x_{t,c}\gamma_{1,h} + od_{t,c} \times \left[\Delta\hat{r}_{t,c}\beta_{2,h} + x_{t,c}\gamma_{2,h}\right] + \varepsilon_{t+h,c} \qquad (42)$$

[20] See Table A.8 in the appendix.

[21] See Jorda et al. (2020) for further details on the construction of the Trilemma instrument. Summary statistics and the list of countries covered are reported in Table A.5 in the appendix.

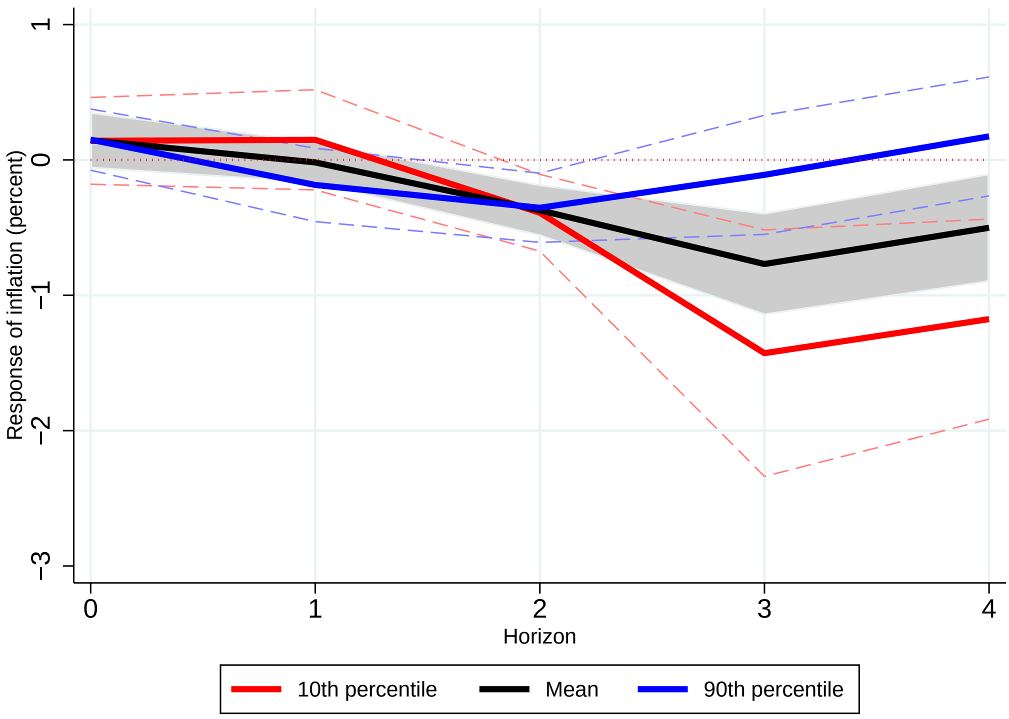
where $y_{t+h,c}$ is either real GDP or CPI inflation in country c at year $t+h$, $\Delta\hat{r}_{t,c}$ is the change in the short-term interest rate instrumented with the *trilemma* approach of Jorda et al. (2020), $od_{t,c}$ is the old-age dependency ratio, and $x_{t,c}$ are a set of control variables. The set of control variables follows closely the specification in Jorda et al. (2020) and includes contemporaneous values of first differences in log real GDP per capita and CPI inflation (except when they are the dependent variable), log real consumption per capita, log real investment per capita, short and long term interest rates, log real house prices, log real stock returns, the credit to GDP ratio, and up to two lags of the same set of variables.[22] I estimate local projections for horizons of zero to four. Taking into account leads and lags, the resulting sample (kept the same across horizon specifications) contains 538 observations.

As can be seen in equation 42, all variables are interacted with the old-age dependency ratio which is the relevant state variable in the state-dependent local projection exercise. To facilitate the estimation, the old-age dependency ratio has been standardized within the sample. All specifications include country fixed effects and standard errors are clustered by country as in Jorda et al. (2020). Figure 3 plots the state-dependent impulse responses ($\hat{\beta}_{1,h} + \hat{\beta}_{2,h} \times od$) of CPI inflation to a monetary surprise for three states of the old age dependency ratio. The black line reports the impulse response at the average old-age dependency ratio in the sample (21%), the red line is the corresponding impulse response for the 10th percentile (14% or -1.28 standard deviations) of the old-age dependency ratio, and the blue line is for when the old-age dependency ratio is equivalent to the 90th percentile (27%). The shaded area represent the 90% confidence interval around the impulse response at the average old-age dependency ratio while the dashed red and blue lines correspond to

[22] Following Jorda et al. (2020), the control variables are also interacted with a dummy for the years 1973 to 1980 to address the *price puzzle*.

the 90% confidence intervals around the impulse responses for the 10th and 90th percentile of the old-age dependency ratio respectively.

Figure 3: Response of inflation to a monetary surprise: Trilemma IV

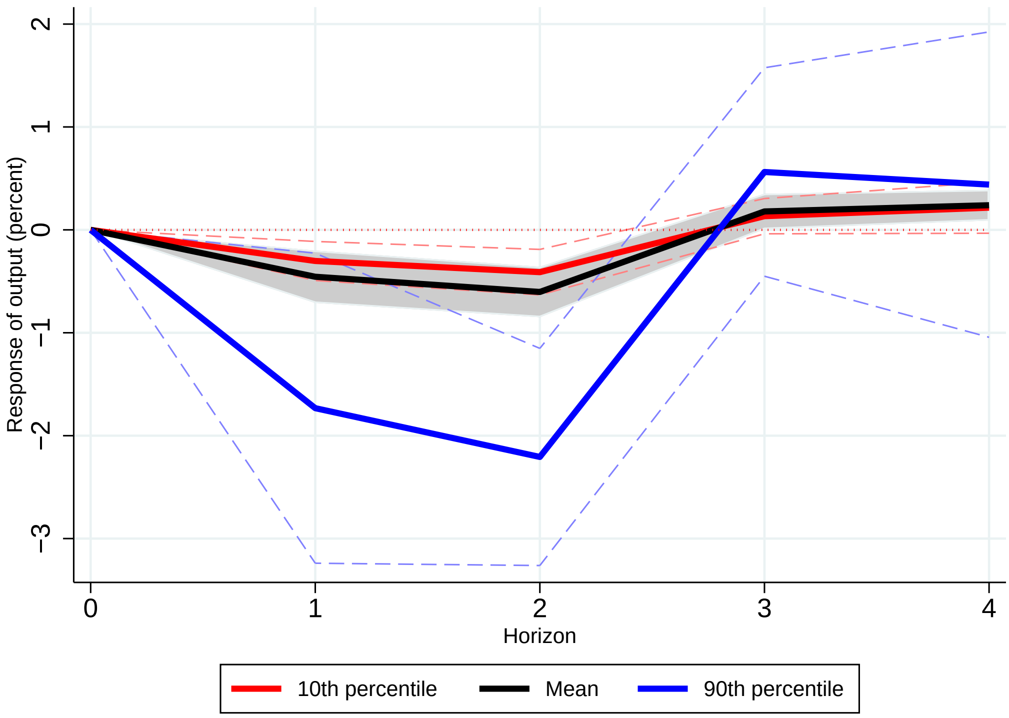


The figure plots the estimated response of CPI inflation to a monetary policy surprise using the Trilemma instrumental variable identification when the old-age dependency ratio is equivalent to 14 (red), 21 (black), and 27% (blue) which are the 10th, mean, and 90th percentiles in the sample. The size of the shock is a 1 percentage point increase in the short term interest rate. The gray shaded area and dashed red and blue lines represent the corresponding 90% confidence intervals.

Consistent with the notion that the slope of the NKPC flattens as the old-age dependency ratio increases, Figure 3 shows that the response if inflation to a monetary surprise is more muted when the old-age dependency ratio is higher. In the next exercise, I recover the response of output to a monetary surprise. To facilitate comparison across different states, I normalize the size of the monetary policy shock to generate a one percent cumulative decline in inflation after four years. Figure 4 plots the impulse responses across three values of old-age dependency ratios following the scheme used in the previous figure.

As predicted by the model, Figure 4 shows that the output cost of a monetary

Figure 4: Response of output to a monetary surprise: Trilemma IV



The figure plots the estimated response of real GDP to a monetary policy surprise using the Trilemma instrumental variable identification when the old-age dependency ratio is equivalent to the 10th (14%, red), mean (21%, black), and 90th percentile (27%, blue) respectively. For each impulse response, the size of the shock has been calibrated to generate a cumulative fall of inflation of one percent by horizon four. The gray shaded area and dashed red and blue lines represent the corresponding 90% confidence intervals.

tightening is much larger when the old-age dependency ratio is higher. This is driven by the weaker impact of monetary tightening on inflation when the old-age dependency ratio is higher. Since monetary policy surprises are less effective in lowering inflation when the old-age dependency ratio is higher, a larger monetary policy intervention would be necessary to bring down inflation by one percent over a four year horizon. Table 7 summarizes this finding. The first 5 rows of the table report the cumulative output loss from horizons zero to four. The last row reports the size of the monetary policy surprise that is needed to generate a cumulative fall in inflation of one percent in four years and is the shock size which generates the output loss in the previous rows. Each column reports results for a different level of the old-age dependency ratio.

Table 7: Cumulated response of output to monetary policy surprises: Trilemma IV

Old-age dep. ratio	10th percentile	Sample Mean	90th percentile
$h = 0$	-0.000	-0.000	-0.000
$h = 1$	-0.302	-0.456	-1.733
$h = 2$	-0.713	-1.059	-3.939
$h = 3$	-0.580	-0.880	-3.377
$h = 4$	-0.365	-0.640	-2.937
Shock size	0.370	0.660	3.080

The table reports the cumulated response of output to a monetary tightening using the Trilemma instrumental variable identification. Each column reports results for different states of the old-age dependency ratio. The 10th percentile corresponds to a ratio of 14%, the sample mean is 21%, and the 90th percentile is 27%. The first five rows report the cumulated response of log real GDP per capita at horizons zero to four. The last row reports the size of the monetary policy surprise which generates the impulse responses and is consistent with a cumulated fall in inflation of one percent by four years.

As indicated in the last row of Table 7, the size of the monetary policy surprise needed to bring down inflation by one percent in four years is about 8 times larger when the old-age dependency ratio is at the 90th percentile (or equivalent to 27%) relative to when it is at the 10th percentile (14%). The cumulative output loss after four years (penultimate row) is also eight times larger. In fact, there is virtually no difference in the impulse response of output to a monetary surprise across old-age dependency ratios if the size of the shock is kept constant.

5. Conclusion

In this paper, I show that demographic factors, particularly the share of the old to total population, may be related to the determination of markups charged by firms or equivalently their market power. I focus on a specific potential channel, that households accumulate habits as they age, and develop a New Keynesian Deep Habits model around this hypothesis. I then use the model to show that demographic aging can increase firm market power (markups) and also lead to a flattening of the New Keynesian Phillips Curve. More broadly, I show that demographic aging can significantly worsen the output-inflation trade-off faced by monetary policy. These results suggest that the challenges faced by monetary policy may become more pronounced as populations age.

The calibrated model is not able to completely match the implied contribution of demographic aging on firm market power in the data for OECD countries. This suggests that there are potentially other channels linking the age distribution to market power. The model presented in this paper is quite simplified and does not feature other potential channels (e.g., on the composition of consumption baskets and labor markets, innovation and entrepreneurial activity, etc.). Exploring interactions between aging-induced declines in price sensitivities and these complementary channels is left for future work.

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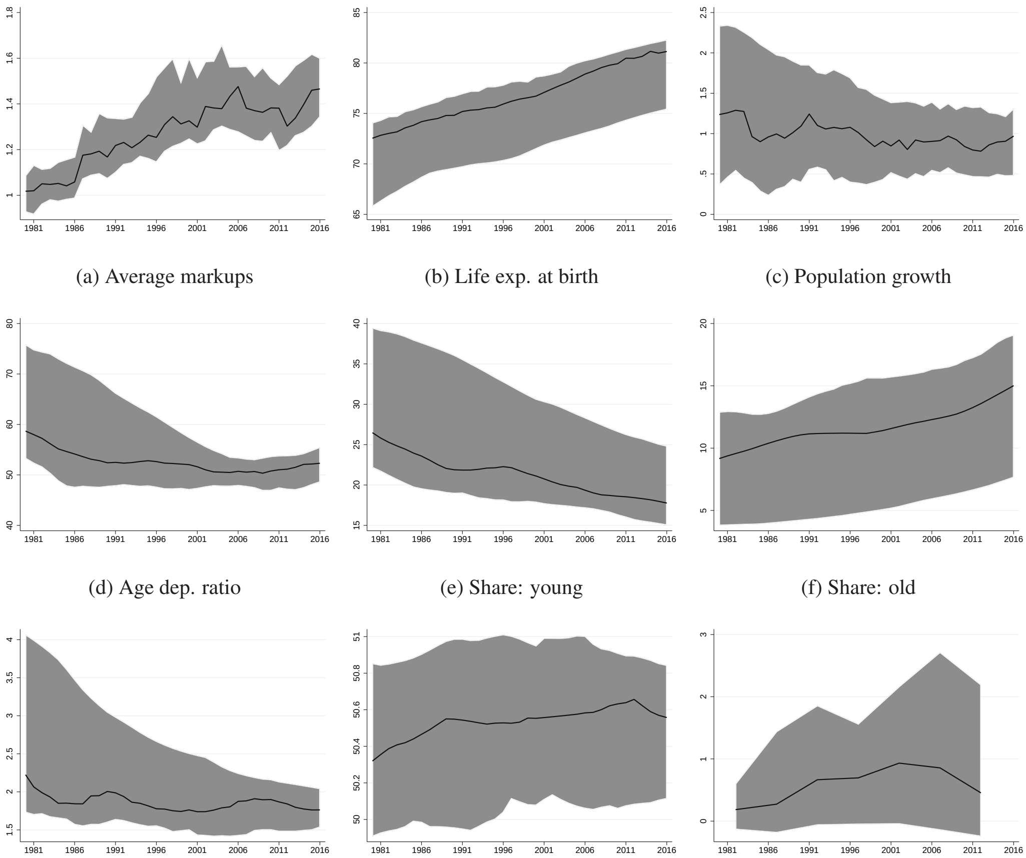
Appendix

Appendix A.1. Appendix Figures

Figure A.1: Demographics and markups over time



(a) Average markups (b) Life exp. at birth (c) Population growth

(d) Age dep. ratio (e) Share: young (f) Share: old

(g) Fertility rate (h) Share: Female (i) Net migration

The figures plot the evolution of several demographics variables and average markups of 40 countries over time. The shaded area represents the interquartile range while the black lines reports the median values.

Appendix A.2. Appendix Tables

Table A.1: Country panel data descriptive statistics

	Mean	St. dev.	Obs.	Description
Markups	1.34	0.31	1382	Average markups
Age dependency ratio (total)	54.57	10.81	1480	Share of young (0-14) and old (65+) to working age pop.
Share young to total pop.	24.37	8.22	1480	Share of young (0-14) to total pop.
Share old to total pop.	10.64	5.27	1480	Share of old (65+) to total pop.
Life exp. at birth (years)	74.22	6.24	1480	Life expectancy at birth, total (years)
Population growth(annual %)	1.08	0.82	1479	Population growth in annual %
Fertility rate	2.18	0.94	1480	Fertility rate (births per woman)
Share female to total pop.	50.42	0.90	1480	Share of felae to total pop.
Net migration (% of pop.)	0.97	1.88	280	Net migration to total pop.
Real GDP growth (annual %)	3.30	3.59	1478	Real GDP growth in annual %
Real GDP per capita	24609.52	19630.46	1478	GDP per capita in constant 2010 USD
CPI inflation	24.30	250.70	1404	Consumer price index (2010=100) inflation in annual %
Unemployment rate	6.96	4.77	1122	Unemployment rate as % of labor force
Currrent Account to GDP	0.24	5.40	1339	Current account balance as % of GDP
Trade (% of GDP)	74.70	67.61	1478	Total trade as % of GDP
External balance (% of GDP)	1.56	6.14	1478	External balance on Goods and Sercices as % of GDP
Gov. Cons. Exp. (% of GDP)	15.96	5.03	1471	General government final consumption exp. as % of GDP
Gross savings (% of GDP)	24.79	8.03	1337	Gross savings as % of GDP
Labor force part. rate	60.65	7.50	1308	Labor force participation rate as % to population aged15+
Services value-added (% of GDP)	57.13	9.70	1225	Services sector value added as % of GDP
Manufacturing value-added (% of GDP)	17.57	5.68	1244	Manufacturing value added as % of GDP
Market cap of listed firms (% of GDP)	77.87	113.39	1147	Market cap. of listed dom. firms as % of GDP
Private domestic credit (% of GDP)	80.31	51.05	1221	Domestic credit to private sector as % of GDP
Population density	414.85	1295.86	1460	People per square kilometer of land area
Share rural to total pop.	29.44	18.69	1480	Rural population to total pop.

Data is annual covering 40 countries from 1980-2016. Average annual markups are obtained from De Loecker and Eeckhout (2020). The rest of the variables are sourced from the World Bank World Development Indicators database.

Table A.2: Country panel data samples by country

	Markups		Age dep. ratio			Markups		Age dep. ratio	
Country	First	Last	First	Last	Country	First	Last	First	Last
ARG	1986	2016	1980	2016	IRL	1980	2016	1980	2016
AUS	1980	2016	1980	2016	ITA	1980	2016	1980	2016
AUT	1980	2016	1980	2016	JPN	1980	2016	1980	2016
BEL	1980	2016	1980	2016	KOR	1980	2016	1980	2016
BRA	1980	2009	1980	2016	MEX	1980	2016	1980	2016
CAN	1980	2016	1980	2016	MYS	1980	2016	1980	2016
CHE	1980	2016	1980	2016	NLD	1980	2016	1980	2016
CHL	1985	2016	1980	2016	NOR	1980	2016	1980	2016
CHN	1982	2016	1980	2016	NZL	1980	2016	1980	2016
COL	1987	2016	1980	2016	PAK	1988	2016	1980	2016
DEU	1980	2016	1980	2016	PER	1987	2016	1980	2016
DNK	1980	2016	1980	2016	PHL	1988	2016	1980	2016
ESP	1980	2016	1980	2016	PRT	1985	2016	1980	2016
FIN	1980	2016	1980	2016	SGP	1980	2016	1980	2016
FRA	1980	2016	1980	2016	SWE	1980	2016	1980	2016
GBR	1980	2016	1980	2016	THA	1987	2016	1980	2016
GRC	1980	2016	1980	2016	TUR	1987	2016	1980	2016
HKG	1982	2016	1980	2016	USA	1980	2016	1980	2016
IDN	1989	2016	1980	2016	VEN	1987	2016	1980	2016
IND	1989	2016	1980	2016	ZAF	1982	2016	1980	2016

The table reports the year of the first and last observations for average markups and age dependency ratios for each country in the sample. Country codes are ISO-3166 alpha-3 three letter country codes.

Table A.3: Univariate regressions of markups on demographic factors

Dep. var.: Markups	(1)	(2)	(3)	(4)	(5)	(6)
Age dependency ratio (total)	0.002**					
	(0.00)					
Life exp. at birth (years)		0.006***				
		(0.00)				
Population growth(annual %)			0.033***			
			(0.01)			
Fertility rate				0.022**		
				(0.01)		
Share female to total pop.					0.016**	
					(0.01)	
Net migration (% of pop.)						-0.011
						(0.01)
Constant	1.239***	0.886***	1.310***	1.298***	0.538	1.340***
	(0.04)	(0.10)	(0.01)	(0.02)	(0.41)	(0.02)
Observations	1382	1382	1381	1382	1382	263
Adj. R-sq.	0.003	0.012	0.006	0.003	0.001	0.001

,, and *** indicate statistical significance at the 10, 5, and 1% levels. Robust standard errors reported in parentheses. The table reports univariate regressions of average markups on several demographic characteristics. Data is annual and covers the period 1980-2016 for 40 countries.*

Table A.4: Factor and polynomial shrinkage regression results

Dep. var.: Markups	(1)	(2)	(3)	(4)
Age dist. factor 1	-0.011	0.009		
	(0.05)	(0.05)		
Age dist. factor 2	-0.070**	-0.054**		
	(0.03)	(0.02)		
Age dist. factor 3	0.037***	0.033***		
	(0.01)	(0.01)		
Age dist. factor 4	-0.019*	-0.009		
	(0.01)	(0.01)		
Age dist. poly 1			0.039*	0.055***
			(0.02)	(0.02)
Age dist. poly 2			-0.011**	-0.013***
			(0.01)	(0.00)
Age dist. poly 3			0.001**	0.001***
			(0.00)	(0.00)
Age dist. poly 4			-0.000**	-0.000***
			(0.00)	(0.00)
Share female to total pop.	-0.090**	-0.071**	-0.062	-0.061*
	(0.04)	(0.03)	(0.04)	(0.04)
D.Life exp. at birth (years)	0.029	0.035	0.029	0.041
	(0.03)	(0.03)	(0.03)	(0.03)
Population growth(annual %)	-0.012	-0.012	-0.007	-0.008
	(0.01)	(0.01)	(0.01)	(0.01)
L.Markups	0.387*	0.469***	0.388*	0.462***
	(0.20)	(0.11)	(0.20)	(0.11)
Additional controls	YES	YES	YES	YES
Fixed effects	Y,C	Y	Y,C	Y
Observations	628	628	628	628
Adj. R-sq.	0.810		0.810	
AR(1) p-value		0.000		0.000
AR(2) p-value		0.741		0.679

,, and *** indicate statistical significance at the 10, 5, and 1% levels. Cluster-robust standard errors (by country) for the panel fixed effects regression and robust standard errors for the dynamic panel regressions are reported in parentheses. The table reports multivariate regressions of average markups on factor and polynomial shrinkages of the age distribution along with other demographic factors and several control variables. Data is annual and covers the period 1980-2016 for 40 countries. For the Arellano-Bover-Blundell-Bond dynamic panel regressions, p-values from tests of residual serial correlation up to 2 lags are also reported. Control variables used, but not reported, are real GDP, the ratio of current account to GDP, the ratio of total trade to GDP, the ratio of government expenditures to GDP, the savings to GDP rate, the share of Services sector value-added to GDP, the labor force participation rate, the unemployment rate, population density, the ratio of stock market capitalization to GDP, the ratio of domestic credit to GDP, and a linear time trend. Panel fixed effects regressions include year and country fixed effects.*

Table A.5: State-dependent local projections data summary statistics

	Mean	St. dev.	Obs.
Old-age dependency ratio	20.74	5.15	544
Log CPI	411.97	89.60	544
Log real GDP per capita	418.79	38.34	544
Short term interest rate	6.08	4.27	544
Long term interest rate	7.23	3.67	544
Log real consumption per capita	418.71	37.51	544
Log real investment per capita	-426.30	432.79	544
Credit to GDP ratio	0.75	0.35	544
Log real house price	-13.50	48.07	544
Log real stock price	-7.09	328.42	544

Data is annual covering 16 countries from 1950-2016. Macroeconomic variables are obtained from Jorda et al. (2017) while the old-age dependency ratios are obtained from the United Nations Population Division.

Table A.6: State-dependent local projections data country coverage

Country	Obs.	Country	Obs.
Australia	29	Italy	37
Belgium	63	Japan	18
Canada	39	Netherlands	25
Denmark	64	Portugal	26
Finland	59	Spain	43
France	57	Sweden	26
Germany	7	Switzerland	25
Ireland	2	UK	24

The table reports the number of observations per country used in the state-dependent local projections analysis.

Appendix A.3. Model Appendix

Full set of model aggregate equilibrium conditions

Aggregation, a symmetric equilibrium and market-clearing conditions yield the following equations which characterize the model.

$$x_t = c_t - \tilde{\theta} c_{t-1} \tag{A.1}$$

$$h_t^{\kappa} = x_t^{-\sigma} w_t \tag{A.2}$$

$$x_t^{-\sigma} = \tilde{\beta}_t R_t \mathbb{E}_t x_{t+1}^{-\sigma} \pi_{t+1}^{-1} \tag{A.3}$$

$$\tilde{\beta}_t = (1-g^d)\beta \psi_t \psi_{t-1}^{-1} \tag{A.4}$$

$$\lambda_{i,t} + \lambda_{d,t} = 1 + \tilde{\theta}\tilde{\beta}_t \mathbb{E}_t \left[\frac{x_{t+1}}{x_t}\right]^{-\sigma} \lambda_{d,t+1} \tag{A.5}$$

$$\lambda_{d,t} = c_t/(\eta x_t) \tag{A.6}$$

$$\lambda_{i,t}/\lambda_{i,t-1} = \pi_{m,t}/\pi_t \tag{A.7}$$

$$w_t = A_t \lambda_{h,t} \tag{A.8}$$

$$\lambda_{m,t} + \lambda_{h,t} = \lambda_{i,t} \tag{A.9}$$

$$\begin{aligned} y_t(1-\gamma\frac{\lambda_{m,t}}{\lambda_{i,t}}) &= \delta c_t \pi_{m,t}(\pi_{m,t}-\pi^*) \\ &\quad - \delta\tilde{\beta}_t \mathbb{E}_t \left[\frac{x_{t+1}}{x_t}\right]^{-\sigma} c_{t+1}\frac{\lambda_{i,t+1}}{\lambda_{i,t}}\pi_{m,t+1}(\pi_{m,t+1}-\pi^*) \end{aligned} \tag{A.10}$$

$$c_t = y_t - \frac{\delta}{2} c_t (\pi_{m,t} - \pi^*)^2 \tag{A.11}$$

$$y_t = A_t h_t \tag{A.12}$$

where $\pi_{m,t} = P_{m,t}/P_{m,t-1}$, $w_t = W_t/P_t$, $h_t = \int h_{i,t} di = \sum h_{j,t} f(j)$, and $y_t = \int y_{i,t} di$. Equations 34 and A.1 to A.12 along with the laws of motion for productivity and discount factor shocks (equations 9 and 30) complete the description of equilibrium.

Table A.7: Model calibrated parameters

Parameter		**Symbol**	**Value**	**Target**
	Discount factor	β	0.99	Annual real rate of 4%
	Risk aversion	σ	3.0	Following Ravn et al. (2010)
	Inverse labor elasticity	κ	1.0	Following Fernandez-Villaverde et al. (2015)
	Demand elasticity	η	56.91	Match average markups in Japan over 1980-1985
	Production elasticity	γ	59.85,4.97	Match average markups in Japan over 1980-1985 and 2011-2016
	Price rigidity	δ	187	Average Phillips curve slope equivalent to Calvo parameter of 0.75
	Maximum habits	θ	1.02	Average deep habits of 0.85 as in Ravn et al. (2010)
	Deep habits rate	s	0.03	Deep habits flatten out at age 55 years
	Birth rate	gb	0.011,0.002	Population growth in Japan over 1980-1985 and 2011-2016
	Death rate	gd	0.004-0.0037	Life expectancy in Japan over 1980-1985 and 2011-2016
Monetary policy rule				
	Persistence	ρ_r	0.70	Following Fernandez-Villaverde et al. (2015)
	Inflation coefficient	α_π	1.5	Conventional values
	Output coefficient	α_y	0.0	Conventional values
	Inflation target	π^*	1.00	Conventional values
Productivity shock				
	Mean	$\bar{A}$	exp(4.3)	Steady state labor (h) of 0.33
	Persistence	ρ_A	0.96	Fernald (2014)
	Volatility	$\bar{\sigma}_A$	0.008	Fernald (2014)
Preference shock				
	Mean	$\bar{b}$	0	Steady state discount factor is $(1-gd)\beta$
	Persistence	ρ_b	0.96	Matched to productivity shock persistence
	Volatility	$\bar{\sigma}_b$	0.008	Matched to productivity shock volatility

Appendix A.4. Alternative model without deep habits

In this section I consider the implications of aging on the conduct of monetary policy when the elasticity of substitition parameter in households' preferences is directly affected by aging and without deep habit formation. In this setting, population aging will not induce additional persistence in the economy but will nevertheless affect both steady state markups and the slope of the New Keynesian Phillips Curve.

I make two changes relative to the model in the main text. First, in lieu of deep habits, I have the elasticity of substitution as a direct function of age. Second, to allow both the elasticities of substitution for consumption and production using intermediate inputs to directly affect the output cost of disinflationary monetary policy, I assume *Rotemberg* price adjustment costs for both the consumer goods and intermediate inputs layers of production.

Households

As in the main text, households are born and die following the *Blanchard-Yaari* overlapping generations framework with an age distribution given by $f(j) = g(1-g)^(j-1) \quad for\ j \in [1,\infty]$. Households choose consumption baskets and labor provision by maximizing the discounted utility from producing and working given by the following program,

$$\begin{aligned}
max \qquad & \mathbb{E}_t \sum_{t'=0}^{\infty} \tilde{\beta}^{t'} U(\{c_{i,j,t+t'}\}, h_{j,t+t'}) && \text{(A.13)}\\
\text{subject to:} & \\
U &= \frac{x_{j,t}^{1-\sigma}}{1-\sigma} - \frac{h_{j,t}^{1+\kappa}}{1+\kappa} && \text{(A.14)}\\
x_{j,t} &= \left[\int_0^1 c_{i,j,t}^{\frac{\eta_j-1}{\eta_j}} di\right]^{\frac{\eta_j}{\eta_j-1}} && \text{(A.15)}\\
\int_0^1 P_{i,t} c_{i,j,t} di + B_{j,t} &= R_{t-1} B_{j,t-1} + W_t h_{j,t} + \Phi_t \quad \forall t && \text{(A.16)}
\end{aligned}$$

where $\eta_j = \underline{\eta} + (\bar{\eta} - \underline{\eta})(1-s)^{j-1}$ and bonds are in zero net supply.[23]

Production

I modify the consumer goods producers' problem relative to the main text by adding *Rotemberg* price rigidities such that consumer goods producers solve the following problem,

$$\begin{aligned}
max \qquad & \mathbb{E}_t \sum_{s=0}^{\infty} q_{t+s} \Phi_{i,t+s} && \text{(A.17)}\\
\text{subject to:} & \\
\Phi_{i,t} &= P_{i,t} c_{i,t} - \int_{m=0}^1 P_{m,t} Y_{m,t} dm - \frac{\delta_c}{2} P_t c_t \left(\frac{P_{i,t}}{P_{i,t-1} - \pi^*}\right)^2 && \text{(A.18)}\\
c_{i,t} &= \sum_{j=1}^{\infty} x_{j,t} \left[\frac{P_{i,t}}{P_t}\right]^{-\eta_j} f(j) && \text{(A.19)}\\
c_{i,t} &\leq y_{i,t} = \left[\int_{m=0}^1 Y_{m,t}^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}} && \text{(A.20)}
\end{aligned}$$

where q_t is the households' discount factor as before and demand is given by aggregating the solution to the households' problem.

[23] I do not include discount factor shocks in this setup.

The intermediate goods producers' problem is unchanged relative to the main text (equations 26 to 29). The price adjustment cost parameter is denoted with δ_m to distinguish it from the price adjustment cost parameter in consumer goods production.

Aggregation and monetary policy

I use the same monetary policy rule as in the main text (equation 34). I take the symmetric equilibrium, log-linearize around the zero-inflation deterministic steady state and simplify terms to arrive at the following set of equations characterizing the alternative model.

$$\hat{r}_t = \rho_r \hat{r}_{t-1} + (1-\rho_r)[\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t] + \varepsilon_{r,t} \tag{A.21}$$

$$\hat{y}_t = \tilde{\beta}\mathbb{E}_t \hat{y}_{t+1} - \frac{1}{\sigma}(\hat{r}_t - \mathbb{E}_t \hat{\pi}_{t+1}) \tag{A.22}$$

$$\hat{\pi}_t = \tilde{\beta}\mathbb{E}_t \hat{\pi}_{t+1} + \frac{\tilde{\eta}-1}{\delta_c}\hat{\lambda}_{i,t} \tag{A.23}$$

$$\hat{\pi}_{m,t} = \tilde{\beta}\mathbb{E}_t \hat{\pi}_{m,t+1} + \frac{\gamma-1}{\delta_m}\hat{\lambda}_{h,t} \tag{A.24}$$

$$\hat{\lambda}_{i,t} + \hat{\lambda}_{h,t} = (\kappa+\sigma)\hat{y}_t - (1+\kappa)\hat{A}_t \tag{A.25}$$

$$\hat{\pi}_{m,t} - \hat{\pi}_t = \hat{\lambda}_{i,t} - \hat{\lambda}_{i,t-1} \tag{A.26}$$

where the age distribution enters through the average elasticity of substitution $\tilde{\eta}$ given by,

$$\tilde{\eta} = \underline{\eta}\frac{g\frac{\bar{\eta}}{\underline{\eta}} + s(1-g)}{g + s(1-g)} \tag{A.27}$$

where as before aging (a decrease in g) lowers the average elasticity of substitution and thus the average price sensitivity of consumers. The steady state markup in this alternative model is given by the following.

$$\mu = \left[\frac{\gamma}{\gamma - 1}\right]\left[\frac{\tilde{\eta}}{\tilde{\eta} - 1}\right] \tag{A.28}$$

As with the model in the main text, an increase in aging raises steady state markups as well as lowers the slope of the consumer goods price New Keynesian Phillips Curve (equation A.23).

Calibration and the output cost of disinflation

I calibrate the model to Japan in the 1980s and 2010s, focusing on population growth, life expectancy, and markups. As there is an extra parameter in this alternative model, I am able to calibrate the parameters such that 10% of the increase in markups is attributed to aging.[24] I then simulate the response of inflation and output to a monetary surprise and calculate the cumulative change in output given a monetary surprise that reduces inflation by one percent on a given horizon. Table A.8 reports the cumulated response of output across various scenarios.

Table A.8: Response of output to monetary policy surprises

Horizon	2 year	5 year	20 year
1980-1985 Baseline	-1.746	-1.740	-1.740
2011-2016 with no demog. change	-5.988	-5.778	-5.778
2011-2016 All changes	-6.708	-6.238	-6.236

[24] I assume that the two elasticity of substitution parameters are equal in the 1980s and then calibrate the rest of the parameters such that 10% of the increase in steady state markups is due to the change in the consumer elasticity of substitution.

The table reports the model-implied cumulative response of output over a 2, 5, and 20 year horizon to a monetary policy surprise shock when the model is calibrated to match Japan for the periods 1980-1985 and 2011-2016. The size of the shock is calibrated to generate a cumulative response of inflation of one percent at the specified horizon. The first row reports cumulative responses using the 1980-1985 calibration. The second row reports results when the production elasticity of substitition is calibrated to 2011-2016 while demographic parameters are kept to 1980s levels. The third row allows for both demographics and production elasticity parameters to change to 2011-2016 levels.

The results indicate that the output cost of disinflation is almost four times larger in the 2010s than in the 1980s. Further, and in contrast to the results in the main text where the model had deep habits, the relative contribution of aging to the increase in the output cost is fairly similar across horizons at about 10% which is also the share of the increase in markups attributed to aging.

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