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Okay Boomer... Excess Money Growth, Inflation, and Population Aging

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Abstract

What determines the strength of the relationship between money growth rate and inflation? A large literature suggests that it has weakened since the 1980s, without a definitive explanation of the cause. In this paper, I explore the extent that population age structure explains changes in the pass through of money growth rates to inflation. I first show that the quantity theory of money holds over long time horizons in a long run annual panel of countries, with substantial effects of money growth rates in the shorter-to-medium term. I then estimate state dependent local projections at five year horizons, showing that various measures of population age structure have significant effects on the strength of the money growth-inflation relationship. These demographics can account for a substantial increase in the effect of money on prices in the 1970s, as well as a subsequent decline throughout the great moderation. I find that the baby boomer generation, now in the age group around retirement, are applying upward pressure on this relationship again, with ambiguous effects in the future as low fertility and rising longevity continue to play a role.

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1. Introduction

In this paper I explore the role that population age structure plays on the pass through of money growth rates to inflation. I first establish evidence in support of the long run relationship implied by the quantity theory of money. Estimating this in a historical panel of 16 developed countries since 1870, I find that money growth has significant effects over short-to-medium horizons, and converges to a one-to-one relationship after twelve years. My primary contribution is to estimate state dependent effects, conditional on population age structure. I show that progression the baby boomer cohort through the life-cycle, in addition to long run trends in old and young dependents, can explain a strengthening of the money growth-inflation relationship during the 1970s, as well as a subsequent weakening throughout the great moderation.

A recent shift in central bank policy is the diminishing importance of money. While monetary aggregates are still nominally used as one of the "two pillars" of European Central Bank analysis, their importance has substantially waned. Early critics of money growth pointed to an apparent instability in the money-inflation relationship during the turbulent period of the 1970s and early 1980s.[1] The great moderation has further minimized money's role, with low and stable inflation seeming to react weakly to changes in monetary aggregates. The empirical evidence is fairly clear: Money growth has a weaker effect on inflation. Less clear is *why* this weakening has taken place. This paper shows that aging may be one important channel driving this shift.

Why does population age structure matter for money and prices? Population aging has gained a great deal of attention as a potential source of future inflation. This is one of the primary theses of Goodhart and Pradhan (2020), and is supported by a number of papers.[2] Separately, a large literature has identified demographics as potentially important for secular trends in equilibrium interest rates and asset prices.[3] These papers show that life-cycle demand for assets can drive secular trends as households stockpile during working life and spend them down in retirement, with relative asset prices affected by evolution of portfolio allocation across the life-cycle. Aoki, Michaelides, and Nikolov (2019) estimate a quantitative model of this type. Unlike other work, they include money as one of three assets held by households. Their model shows that money holdings (as a share of financial wealth) are generally high early in working career, before falling dramatically throughout mid-to-late career, and rebounding in retirement. This is broadly consistent with Survey of

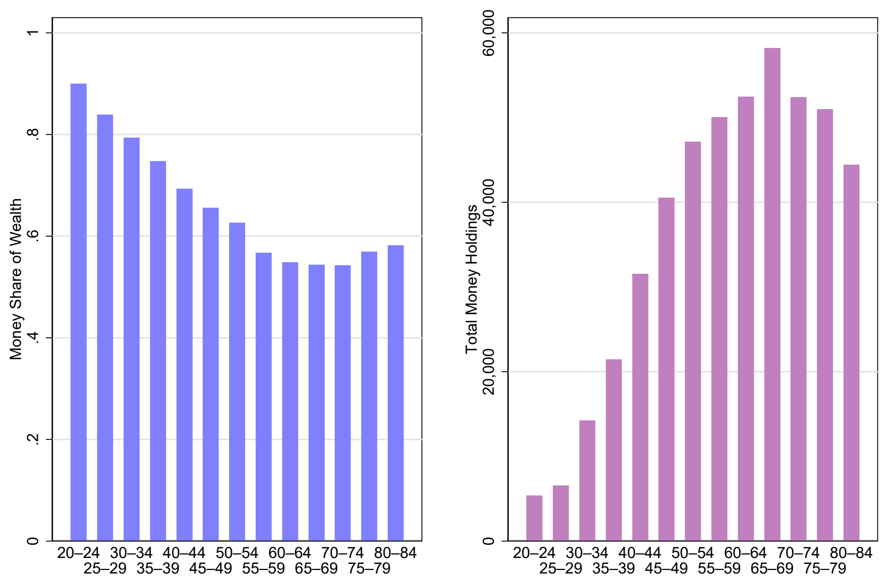
[1] For a thorough treatment of this policy discussion at the time see Goodhart (1989).

[2] See for example: Bobeica, Nickel, Lis, and Sun (2017), de Albuquerque, Caiado, and Pereira (2020), Aksoy, Basso, Smith, and Grasl (2019), Edo and Melitz (2019), and Juselius and Takáts (2021)

[3] See fore example: Gagnon, Johannsen, and Lopez-Salido (2021), Eggertsson, Mehrotra, and Robbins (2019), Kopecky and Taylor (2020)

Figure 1: *U.S. Survey of Consumer Finances: Money Holdings by Age*

(a) *Money As Share of Financial Assets* **(b)** *Total Money Assets*



Notes: Survey of Consumer Finance Data pooled from 2001, 2004, and 2007, 2010, 2013, and 2016 surveys. Money defined as sum of checking, savings, and money market mutual fund accounts. Financial assets defined as sum of all non-housing financial assets excluding trusts and , life insurance. Averages are calculated by five year age group for all respondents with less than $2,000,000 in total assets.

Consumer Finance data on money holdings, which I show in Panel A of Figure 2.

Aoki et al. (2019) are interested in money holdings as a share of assets, as their work focuses on life-cycle portfolio decisions. More relevant for aggregate money demand is the life-cycle nature of total money holdings, which I plot in Panel B of Figure 2. This relationship suggests that one may expect economies with relatively more households in the years surrounding retirement to have significant upward pressure on money demand. This relationship is explored somewhat in Wang and Zhu (2021), who show that the share of old age (> 65) populations have a negative impact on the velocity of money. They interpret this result as population aging leading to increases in money demand, and suggest that aging may be a channel for structural changes in money demand throughout the great moderation. I seek to contribute by providing an empirical estimate of how much of the change in money growth's pass through to inflation may be accounted for by population change, while also providing a deeper empirical understanding of this relationship across the entire age distribution.

My average estimates of money growth on inflation (those independent of the age distribution) lend support to existing estimates showing a robust medium-to-long term effect. This is in line with a recent literature[4] supporting the long run Friedman and Schwartz (1963) relationship. Meanwhile, my heterogeneous effects (those conditional on age), provide an explanation for weakening of this relationship suggested in work such as: Teles, Uhlig, and Valle e Azevedo (2016), Benati (2005), and Gertler and Hofmann (2018). This literature finds a significant change in the quantity theory relationship since the 1980s. My conclusions are not mutually exclusive of other structural explanations. It is entirely possible that in addition to aging, changing central bank policies have caused structural breaks in money-inflation relationships by grounding expectations.[5] Here I suggest that aging may be an additional channel and should be taken into account when trying to understand the low frequency relationship between money and inflation. Establishing a strong inflation anchor[6] likely plays a role in the decline of money growth's importance, but demography may provide winds to pull on that anchor. Recent criticism of inflation expectations by Rudd (2021) has gained substantial attention. While in my view this critique undervalues evidence in favor of expectations, I agree that this is an area where causal evidence is scarce, and we should be careful when enshrining conventional wisdom as unassailable truth. This paper provides a different perspective.

Methodologically, I use a tool developed in Cloyne, Jordà, and Taylor (2020), who study the effect of monetary accommodation of fiscal multipliers. They suggest a parsimonious way of dealing with decomposition of heterogeneous policy effects in the local projections estimations of Jordà (2005) by implementing a Blinder (1973)-Oaxaca (1973) decomposition.

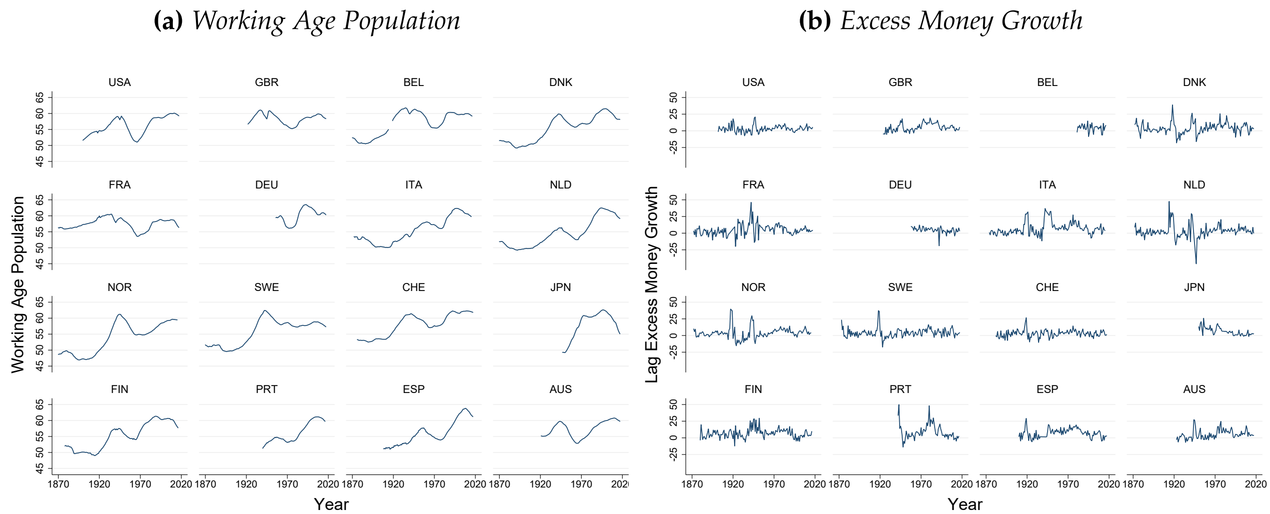
The paper proceeds as follows. In Section 2, I discuss the data and my methodological approach. Section 3 establishes a baseline effect of money growth on inflation over this sample period, showing substantial short and medium run effects of money growth with long run effects approaching unity. Section 4 performs the Blinder-Oaxaca estimation and decomposition proposed by Cloyne et al. (2020), and demonstrates quantitatively how large the effect of aging may have been on this transmission of money growth. Section 5 concludes.

[4]See Assenmacher-Wesche and Gerlach (2007) and Fratianni, Gallegati, and Giri (2021). As well as Belongia and Ireland (2016) who show that much (though not all) of the weakening is due to mismeasurement and fixed using a Barnett (1980) Divisia measure of money.

[5]For two papers who discuss regime shifts to "anti-inflationary" policy as changing this relationship see: Sargent and Surico (2011) and Benati (2005)

[6]See Reis (Reis) for a very recent discussion of historical anchoring as well as a present view on movements in expectations.

Figure 2: *U.S. Survey of Consumer Finances: Money Holdings by Age*



2. Data and Empirical Strategy

2.1. Data

Population data come primarily from the Human Mortality Database (2019). I use their data on population by age to construct various population shares across the age distribution. In addition, I use US Census National Intercensal Tables to extend the United States demographic series to 1900. I consider two methods for controlling for the population age structure. The first is to use the working age population, defined as the number of individuals aged 20-64, as a percentage of the overall population. The second relies on demographic variables to cover the full age distribution as in Fair and Dominguez (1991).

In Figure 2a, I plot the working-age population for the full panel of countries used in my estimations. This highlights an advantage of such a long sample. While a great deal of work is limited to either a single country, or to panels that include only the period since the baby boomer generation entered the workforce,[7] I can take advantage of a large amount of variation both across countries, as well as in the period before the boomer cohort. While all of the countries in this sample have some sort of baby boom, the severity and timing are all slightly different.

I merge this population data with the macrohistory dataset of Jordà, Schularick, and Taylor (2017) (JST) which provides information on price levels and a wide range of macroeconomic variables of interest. With the addition of Jordà, Knoll, Kuvshinov, Schularick, and Taylor (2019) this also contains useful information on asset returns and credit market

[7]From roughly 1970 onward

conditions. It will be crucial to control for a broad set of macroeconomic and financial controls from these data, which have been shown to be important. While the dataset contains 18 developed countries, my preferred specification drops two[8] as they lack the financial variables used as controls. For the remaining 16 countries[9] data go back as far as 1870 with information on population age, macroeconomic controls, and financial variables. The shortest panel is 32 years (Belgium) due to lack of data on broad money, but all other series are more than 50 years, with the average in the panel spanning 85 years of data.

The simple quantity theory of money states the growth rate of inflation should be the growth rate of money less growth in output and velocity. I take as my measure of *excess money growth* the difference between broad money growth rates and growth of output. Assuming a constant velocity the quantity theory then suggests a coefficient of one. Figure 2b shows my measure of excess money growth. It is important to note that part of the weakening of money is due to mismeasurement issues around official aggregates. Belongia and Ireland (2016) show that by using the Divisia monetary aggregates of Barnett (1980) that there has been a lengthening of the lag time for money to affect output and prices, but that the effects remain strong. This is in line with Barnett, Offenbacher, and Spindt (1984), and many others who show that these Divisia aggregates generally outperform official measures. While these measures are not available for the long run panel I study, it seems plausible that they might reflect a faster convergence to quantity theory convergence than I find using official measures from the JST data.

2.2. Estimation Strategy

My objects of interest are cumulative impulse response functions for the change in price levels, given changes in the excess money growth rate. I estimate these using the local projections method of Jordà (2005). To do this for the standard average effects, without heterogeneity, I estimate the impulse responses described in Equation 1:

$$\pi_{i,t+h} - \pi_{i,t-1} = \mu_i^h + m_{i,t-1}\beta^h + (x_{i,t} - \bar{x})\gamma^h + D_{i,t}\gamma_d^h + \epsilon_{i,t+h}\;; \quad \textit{for } h = 0, \ldots, H \tag{1}$$

The outcome, $\pi_{i,t+h} - \pi_{i,t-1}$, is the cumulative growth rate of price levels from the current period to the h annual horizon. The key independent variable, $m_{i,t-1}$ is the measure of excess[10] money growth. Estimates of horizon $\beta^{h=0}$ are therefore one-year effects of

[8] Ireland and Canada

[9] For ease of comparability I present all results only on this truncated sample. Including them has no effect on overall results for specifications where data is available.

[10] Growth in broad money less growth in output.

a change to the excess money growth rate on inflation. Estimates at this horizon might be considered an estimate of the short run impacts of these policies, as they reflect the current inflationary impact of a money growth policy taken a year prior. I include in the vector $x_{i,t}$ for a broad set of macroeconomic and financial controls. In keeping with the Blinder-Oaxaca interpretation I will discuss later these are all taken as deviations from their sample mean. In the baseline specification, I populate $x_{i,t}$ with: growth rate of real output, growth of real consumption per-capita, the change in the ratio of investment to gdp, change in the current account-to-gdp ratio, change in government debt-to-gdp ratio, real equity prices, growth in total loans to the household sector, population growth rates, and the change in the short term bill rate.[11] Two lags are included in the regression specification for each control. Additionally, three lags of inflation are included. I include dummy variables for both world wars, which are interacted with demographics to avoid allowing large demographic swings related to wartime periods to impact estimates. I also include global GDP growth as a means of controlling for global time varying trends. This captures much of the variation of time fixed effects in the same way as similar long-run studies[12] on this data without the need to add an additional 143 controls as time fixed effects. Use of time fixed effects yields qualitatively identical results for my demographic transmission effects, with larger error bands, and a smaller[13] (though still sizable) response of inflation to money growth over reported horizons. These time fixed effects can bias estimates in the presence of unobserved time trends that are not uniform across countries. Since it is quite easy to imagine such trends in this context,[14] I opt to consider my baseline estimates without such effects. They are included in Appendix C for reference. I include country fixed effects with μ_i^h. The term $D_{i,t}$ represents the set of controls for population age structure. This is either the working age population (WAP), or constructed as in Fair and Dominguez (1991) to control for the entire population structure.

To transform the above specification to one with heterogeneous effects I instead estimate a regression specification interacting my vector of demographic variables (and controls) with the lag of excess money growth. This can be seen in Equation 2. This estimation procedure is described in great detail in Cloyne et al. (2020). The idea is: having calculated the impulse responses function with this series of equations, I obtain a direct effect of lagged excess money growth on inflation at any horizon h with β^h, as before. However,

[11]Results are robust to the inclusion of house prices data, but due to missing data including this variable is akin to dropping most of the information for a handful of countries and therefore not used.

[12]See Jordà, Schularick, and Taylor (2020), for example.

[13]All of my main results on the interaction between money growth and aging remain significant at the relevant horizons.

[14]For example differences in structural changes to monetary policy framework, which are implemented differently and at different times.

now I can also decompose the *indirect effect* of a change in one of the covariates through the interaction term. The strength of this is estimated by θ^h. The demographics term, θ^h_D, is split out from the remaining covariates in Equation 2 for clarity.

$$\begin{aligned} \pi_{i,t+h} - \pi_{i,t-1} = \mu_i^h + m_{i,t-1}\beta^h + (x_{i,t} - \bar{x})\gamma^h + m_{i,t-1}(x_{i,t} - \bar{x})\theta^h \\ + D_{i,t}\gamma_D^h + m_{i,t-1}D_{i,t}\theta_D^h + \epsilon_{i,t+h}\ ; \quad \textit{for } h = 0, \ldots, H \end{aligned} \tag{2}$$

The estimates of γ^h terms yield what I call *composition effects*. That is, those effects of a given set of covariates on the outcome directly, unrelated to money growth. This specification is convenient in that it handles empirical estimation of state dependence of estimated effects in a straightforward way. Much of the literature estimating such effects will opt to estimate coefficients on split samples.[15] It should however be emphasized that this is not a magic wand for identification. In principle, for a causal interpretation of these indirect effects one should have a defensible identification strategy for *both* the policy shock, and for the interactive control, as any endogeneity via other regressors could contaminate results. While it might be possible to find a somewhat compelling instrument for monetary policy interest rate shocks, there is not, to my knowledge, a readily available instrument for exogenous change in monetary aggregates suitable for this sample. For this reason, although I will work hard to show that these results are fairly robust, I am cautious of causal interpretation. However, with the importance of the question at hand I believe an exercise that explores this relationship is still worthwhile. Much of the conventional wisdom around the structural shift in money's effect on prices also lacks clean empirical causal identification, to my mind increasing the need for understanding additional channels that are consistent with empirical data.

2.3. Controlling of Population Structure: an Augmented Fair and Dominguez (1991) Methodology

Before moving on to results I must first describe how I will control for demographics in Equation 2 using the entire population age structure. One of my two main demographic specifications will be to use a methodology similar to that of Fair and Dominguez (1991), who fit the estimated effects for population age shares across the *entire* age distribution with a low order polynomial. A naive regression might split the population into J bins and add all of these population age shares in the estimating equation. This is problematic

[15]See for example many papers on state dependent fiscal multipliers: Ilzetzki, Mendoza, and Végh (2013), Gechert and Rannenberg (2014), Jordà and Taylor (2016) and others.

for two reasons. The first problem is that all of the population shares sum to one, making it impossible to jointly estimate all of the coefficients along with a regression constant. Additionally, as the number of age bins increases, the population shares become increasingly colinear. This latter point often results in significant parameter instability as one splits the age structure into finer and finer groups. The work of Fair and Dominguez (1991) suggests two assumptions:

1. Letting α_j be the be the regression coefficient on population share $p_{j,i,t}$ of age group j in country i and time t. Assume that all of the effects of these coefficients across the age distribution sum to zero. In other words:

$$\sum_{j}^{J} \alpha_j = 0$$

2. Assume that the estimated age coefficients α_j can be fitted with a K order polynomial. In other words:

$$\alpha_j = \sum_{k}^{K} \gamma_k j^k \tag{3}$$

The first point makes the coefficients estimable without dropping the constant from the equation. The second forces that the effects across the age distribution be relatively smooth, and reduces the number of parameters that need be estimated, while still allowing for quite a bit of variation[16] across the life-cycle. A notable, but not substantial, difference between my approach is that instead of using population age shares to construct these variables I will be using these shares less their population mean to keep the interpretation similar to the rest of my demeaned variables in the Blinder-Oaxaca approach suggested in Cloyne et al. (2020). By putting these deviations of population age shares from long run means into Equation 1 and applying the two assumptions above I construct demographic variables that estimate the γ_k parameters of the fitted polynomial. These demographic controls are given by:

$$D_{k,i,t} = \left[\sum_{j}^{J} (p_{j,i,t} - \bar{p}_{i,t}) j^k \right] \tag{4}$$

I construct these for a fourth order polynomial in my baseline specification so that I will create $D_1 - D_4$ of these population age variables to include in my analysis. For a detailed derivation of Equation 4, as well as a discussion of the Fair and Dominguez (1991) see Appendix A.

[16] Increasing the order of the polynomial allows for more turning points in the estimated effect across ages.

2.4. Validity of Non-Stationary Demographic Controls

Most of the controls used above are growth rates or first differenced variables, and all non-demographics controls pass an augmented Dickey-Fuller test for stationary. These variables are generally included with the intention of accounting for the shorter run factors that may be important for determining inflation. However, my demographic controls described above are non-stationary, $I(1)$ series. There may be some concern that results below represent a spurious relationship with cumulative inflation, which though stationary in changes at very short[17] horizons is itself $I(1)$. Olea and Plagborg-Møller (2020) show that lag-augmented local projections provide valid estimations over long horizons with both stationary and non-stationary data. Thus as a first protection against spurious relationships, all estimations will include three lags inflation as controls. The number of lags used here, or indeed specifications with no lagged inflation, have little impact on my coefficients of interest.

Additionally, I find that the working age population as well as the set four of demographic controls described in Section 2.3 are co-integrated with cumulative inflation,[18] which is used to construct my local projections outcome horizons. This is consistent with existing work (Bobeica et al., 2017) who study the cointegrated relationship between inflation and age structure. In the presence of a cointegrating relationship the estimations performed in Equation 2 should be *super*-consistent, with coefficients of interest converging faster than they would if the series were stationary. As a final check, for all estimated models in the paper I run an augmented Dickey-Fuller test on predicted residuals post-estimation with a unit root rejected in all cases with extremely strong (< 0.0001) significance.

3. Money Growth and Inflation: The Long Run Evidence

To set a baseline result, I estimate the direct effect of excess money growth on inflation rates through Equation 1. This serves as an average effect without heterogeneity for the effect of excess money growth on inflation. In Table 1, each column shows the cumulative impulse response function five years after a change in excess money growth. This window gives an idea of the *medium-to-long term* effects on inflation.

The specifications in Table 1 show how this relationship changes from a naive univariate

[17] For outcomes at horizons $h > 3$, the cumulative change is also $I(1)$

[18] For these test results, see Appendix B

Table 1: *Inflation and Money Growth: Five Year Cumulative Effect*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L.m	1.305***	0.664***	0.634***	0.750***	0.624***	0.636***	0.552**
	(0.379)	(0.217)	(0.203)	(0.180)	(0.202)	(0.210)	(0.196)
dmWAP			-0.833*			-0.190	
			(0.435)			(0.348)	
D1				4.764***			4.452***
				(1.149)			(1.050)
D2				-1.315***			-1.330***
				(0.312)			(0.274)
D3				0.134***			0.140***
				(0.031)			(0.027)
D4				-0.004***			-0.005***
				(0.001)			(0.001)
Macro X_i,t	No	Yes	Yes	Yes	Yes	Yes	Yes
Financial X_i,t	No	No	No	No	Yes	Yes	Yes
R^2	0.137	0.466	0.474	0.645	0.488	0.594	0.640
Observations	1354	1354	1354	1354	1354	1354	1354

Standard errors are reported in parenthesis and clustered at the country level. $*p < 0.10, **p < 0.05, ***p < 0.01$. Each column is the impulse response function at the five year horizon

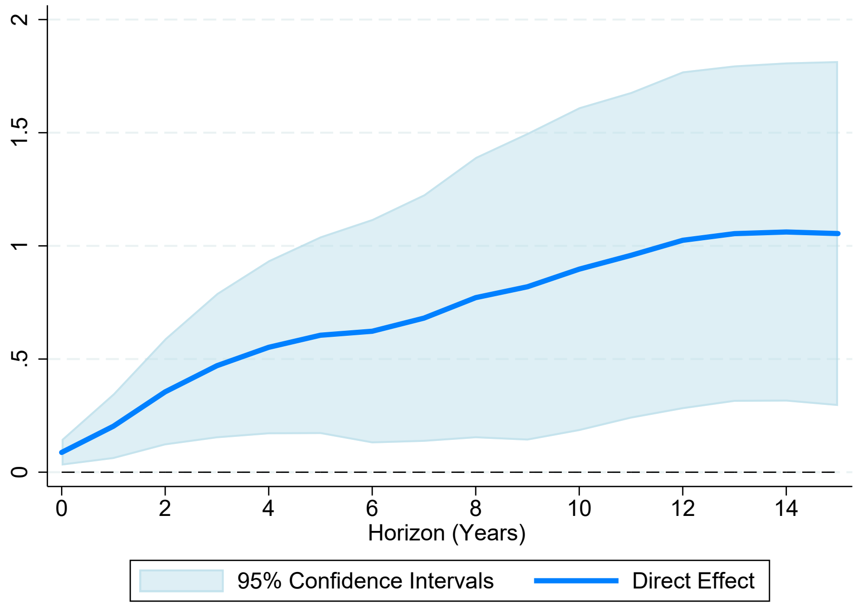
panel fixed effects specification after the inclusion of macroeconomic,[19] financial,[20] as well as my two sets of demographic controls. Standard errors are clustered at the country level. While both sets of controls lower point estimates, the effect of money growth remains large in the full specification. Roffia and Zaghini (2007) show that accommodation of money growth by financial variables is important in the short run. Given the importance of longer run credit trends (as described in Schularick and Taylor (2012) and others) these are likely also important also for the long run transmission. My preferred specification throughout the rest of this paper will include all of these controls. To see how these effects evolve over time, I plot the impulse response function for the specification in Column 7 over a fifteen year window in Figure 3.

There are two things worth noting in Figure 3. The first is that including the full set of macro, financial, and demographic controls, there appears to be a convergence to the unity relationship implied by the quantity theory in the historical data over about twelve years. Documenting this fact in a long sample is one contribution of the paper. The second

[19] Two lags of the demeaned values of: GDP growth, per capita consumption growth, change in investment as a share of GDP, population growth rate, change in current account to GDP ratio, log change in debt to GDP ratio, dummies for WW1 and WW2, as well as interactions between WW1/WW2 and money growth and demographic vars (when included).

[20] Two lags of demeaned values of: change in log equity prices, dummy for financial crises, growth in credit per GDP, and the change in the short term bill rate.

Figure 3: *Lagged Excess Money Growth and Inflation : Full Set of Controls*

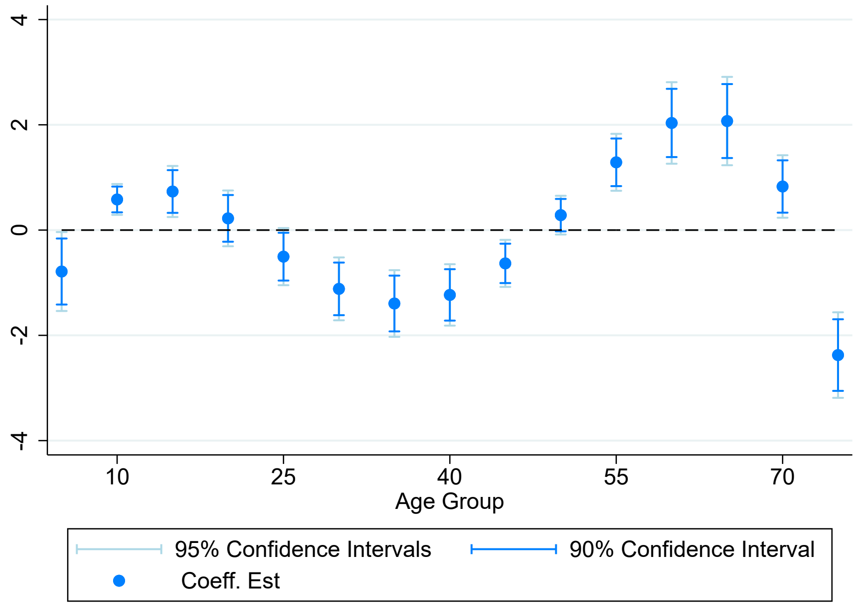


takeaway is that the effect of money growth over the short-to-medium horizon is substantial. The current year impact of a lagged percentage point change in money growth is small, but economically significant implying that each percentage point of money growth will contribute to about 0.09 percentage points of inflation in the next year. This rises persistently for over a decade and is nearly 0.50 within four years. While it takes quite a long time to reach the predictions of long run theory, there are non-trivial short-to-medium term effects of money growth rates for all horizons, across all specifications listed in Table 1.

The first demographic control, dmWAP, is the deviation of the working age population from its long run mean. The working age population has the expected sign. More workers loosen labor markets and reduce wage/price pressure, while consumption associated with dependents may put upward pressure on prices. However, in my specification with financial controls all statistical significance disappears. The more flexible estimation of the age structure is highly significant, lending some suggestive evidence that there is more variation in age structure that is missed by a single statistic.

The downside of using Fair and Dominguez (1991) demographic controls are that the coefficients have little meaning alone. The coefficient D1 represents the sensitivity of the linear (k=1) term in Equation 3, which is difficult to interpret directly in the estimating equation. However, the effect of each of the J the individual demeaned population shares can be backed out by calculating:

Figure 4: *Inflation Response to Population Share:* $h = 4$



$$\alpha_j = \gamma_0 + \gamma_1 j + \gamma_2 j^2 + \gamma_3 j^3 + \gamma_4 j^4$$

Where the γ terms above are the coefficients of this estimation. In Figure 4, I plot these point estates as well as confidence bands calculated via the delta method. These results are fairly closely aligned with what might be expected by theory. Young and old age groups have generally positive effects on inflation, while early-mid career workers have significantly negative. The negative values for the very youngest and the very oldest groups are slightly puzzling, but for the eldest age group are consistent with prior findings of Juselius and Takáts (2021), who's work[21] generally focus on static effects, but find quite similar picture across the age spectrum.

It is important to note that these results tell us nothing about the effect of aging on transmission of money growth. While an age composition effect is undoubtedly important for understanding inflationary pressures, it is not the primary focus of this paper. Since much prior work has suggested that low inflation regimes have different transmission it is possible that, by providing disinflationary pressure, this direct effect may be important for supporting low inflation monetary regimes during the great moderation. It is also useful here to see that aged 55-65 individuals appear to have opposite sign effects than 20-45 year olds, suggesting that population age structure effects might not be well approximated by

[21] They use a similar methodology and the same data. Figure 4 is essentially a replication of their headline results at a five year horizon.

the working age population, which is commonly used as a proxy for age structure. Having established this baseline, I move to estimating the *indirect effects* from Equation 2 with interactive terms.

4. Population Age Structures and Monetary Transmission

I now present results on the effect of population aging on the transmission of money growth to inflation. I estimate the impulse response functions defined in Equation 2 as suggested by Cloyne et al. (2020). My baseline specifications will be the full set of macroeconomic and financial controls, but now also control for interaction of the lag of excess money growth and each of these covariates. My primary outcome of interest is not the direct effect of aging on inflation (though these can still be seen), but rather this interactive term.

4.1. Working Age Population

I first present results for working age population. While this is a crude estimate of the age structure, and evidence from Figure 4 might suggest that it misses important turning points, it allows for quite simple interpretation and therefore provides useful introduction to age effects on monetary transmission. In Table 2, I show the impulse response function at up to five year horizons for these estimates. The direct effect of lagged excess money growth accumulated over this whole horizon (0.49) is of similar magnitude, though slightly smaller than the equivalent estimate in Table 1 (0.552), after adding interactions money growth with WAP, as well as with all other covariates.

Table 2: *Inflation, Money Growth, and WAP: Impulse Response Horizons*

	0	1	2	3	4
L.m	0.08**	0.18**	0.32***	0.42***	0.49***
	(0.03)	(0.07)	(0.10)	(0.13)	(0.16)
dmWAP	0.09**	0.41***	0.74***	0.95***	0.97***
	(0.04)	(0.11)	(0.20)	(0.26)	(0.31)
L.m x dmWAP	-0.02***	-0.10***	-0.17***	-0.23***	-0.25***
	(0.01)	(0.02)	(0.04)	(0.05)	(0.05)
Macro X_i,t	Yes	Yes	Yes	Yes	Yes
Finance X_i,t	Yes	Yes	Yes	Yes	Yes
Interact X_i,t	Yes	Yes	Yes	Yes	Yes
R^2	0.693	0.644	0.673	0.676	0.665
Observations	1354	1354	1354	1354	1354

Standard errors are reported in parenthesis and clustered at the country level. $*p < 0.10, **p < 0.05, ***p < 0.01$. Each column is the impulse response function at the h year horizon

The direct coefficients on the WAP now tell a different story. This composition effect of aging is now positive and quite large. This seems contradictory as theories connecting WAP to inflation through labor market tightness[22] suggest a negative effect. A potential explanation could be that hump shaped life-cycle consumption, peaking late in working life might explain some inflationary relationship of the WAP. It seems plausible that some of the estimated effects many have found could work through indirect channels like these. In any case these results suggest that one should be wary of explanations of aging and inflation that use WAP alone. In the following section, where I use the entire age distribution, my results for the composition effect of age structure on inflation directly will be more or less in line with the inflationary aging hypothesis in the literature.

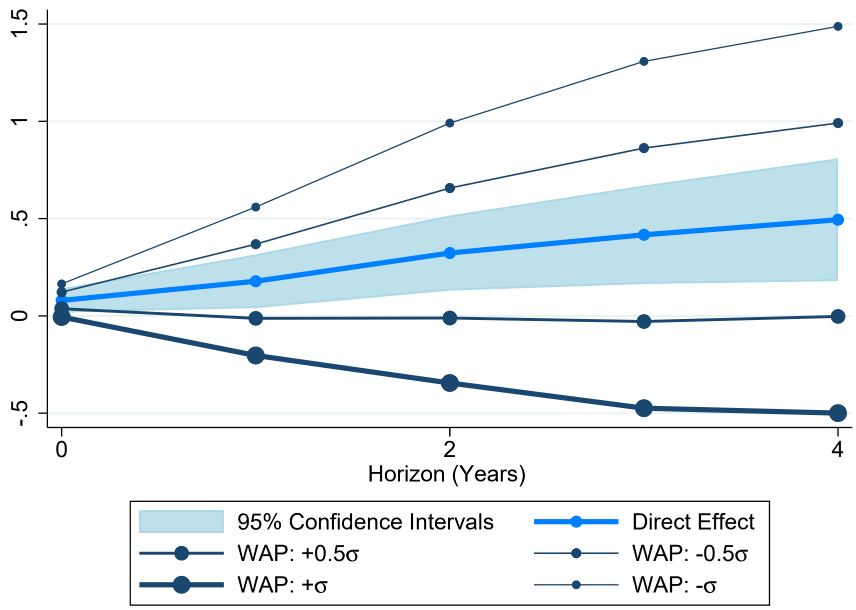
How large are these transmission mechanisms? Figure 5 shows the effect of increasing/decreasing the demeaned WAP by one-half and one standard deviations. The thickest line represents an increase of working age population to 3.93 percentage points above its long run mean, while the smallest lines/markers show a symmetric decrease. The point estimates suggest that a high working age population (thicker curves/markers) brings this effect of money growth down substantially. Taking the United States as an example the WAP has been persistently above its long run mean starting from 1977 and remains so today (though notably not persistently increasing over that period). In the latest year of the sample, 2017, the working age population in the united states is about 3.06 percentage points larger than the historical average of 56.7% in the sample, but has begun falling somewhat rapidly off a peak that occurred in 2011.

Such effects are better understood in context by plotting similar variation to Figure 5, while feeding empirical values for a given country rather than standard deviations. In Figure 6, I present this age decomposition for three countries: the United States, France, and the United Kingdom. Each left-hand panel contains impulse responses of inflation to money growth conditional over a five year window for one of these countries. For reference the *direct effect*, which is an average effect of money growth is plotted, along with effects conditional on the age distribution of that country on three historical periods: 1970, 1990, and 2017; and two future projections: 2030 and 2050. I also plot the evolution of the demeaned working age population of each country in the right-hand panels.

In Panel 6b I show the demeaned value of the WAP for the United States to get a clearer idea of what drives the conditional results in Panel 6a. In particular, the effect of the baby boomer cohort who represented an unprecedented (in this sample) increase of young dependents (pushing WAP down) in the 1950s and 60s, a dramatic reversal with

[22]The WAP and its effect on increasing/decreasing labor market competition is one of the key theoretical explanations of the aging inflation hypothesis put forward by Goodhart and Pradhan (2020)

Figure 5: *Heterogeneous Effect of Excess Money Growth and Inflation: WAP*

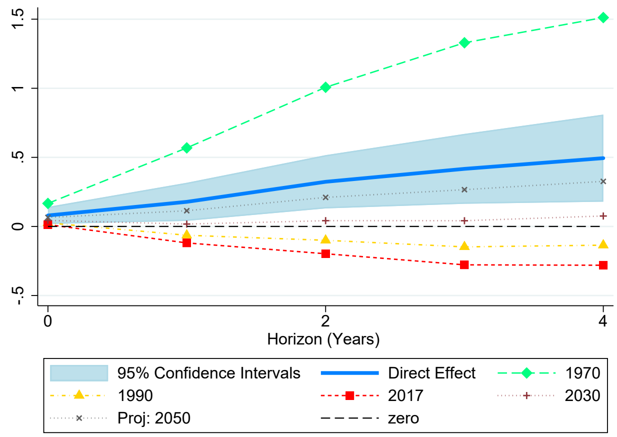


elevated working age population over the course of the period of the great moderation. In the decades to come a slow return toward the mean effect will still be weak. One thing worth noting is that a persistent decrease in young dependents in the years following the boomer cohort both exaggerated the rise of WAP during the great moderation, and slows the speed of decline as boomers enter retirement. Similar historical evidence can be seen in France and the UK, though in France working age population has already reached the mean value in the sample, and both countries will see declines much more rapidly than the United States. Increasing longevity will provide negative pressure on the working age population for all of these countries going forward, further increasing estimated money pass through to inflation.

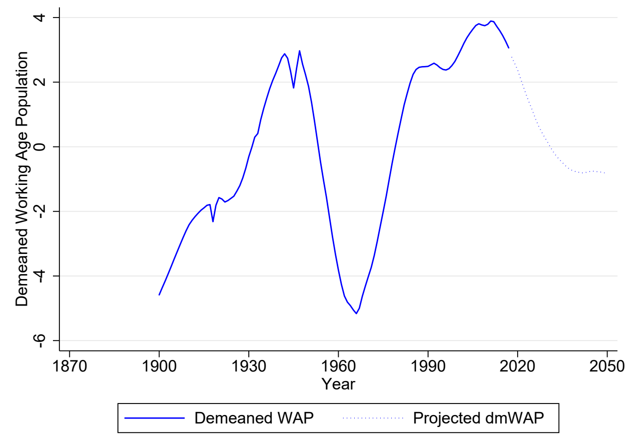
This provides suggestive evidence that population age structure may have strengthened the transmission of money to prices in the 1970s, significantly reduced if over the subsequent decades, and is primed to strengthen it again after 2030 as even the youngest of the baby boomers, who have already started to retire, will have fully left the WAP. However the WAP is an imprecise measurement of aging. Using just one statistic for population age structure assumes a number of things. First, it forces any transmission effects to be constant across the life-cycle. We know from work such as Wong (2019) that this is unlikely to be the case with interest rate policy, and Figure 2 suggests it is unlikely the case for life-cycle variation in money demand. Additionally, using working age population forces old age dependents and young age dependents have symmetric effects. This seems unlikely, especially in the

Figure 6: *Blinder Oxaca Decomposition: Working Age Population*

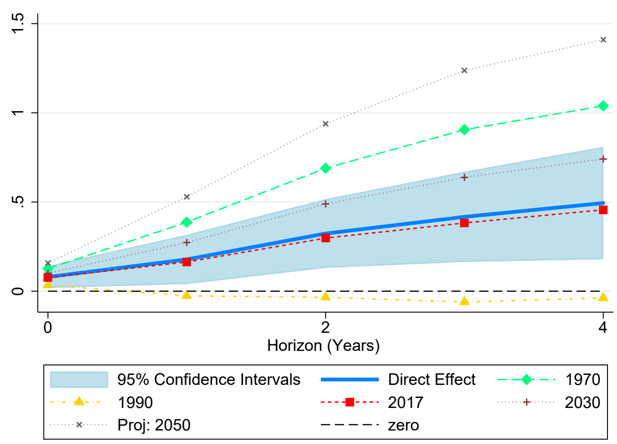
(a) *Conditional IRF: USA*



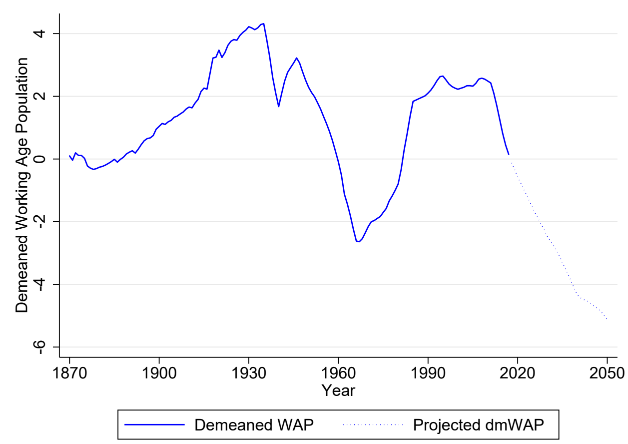
(b) *Demeaned WAP: USA*



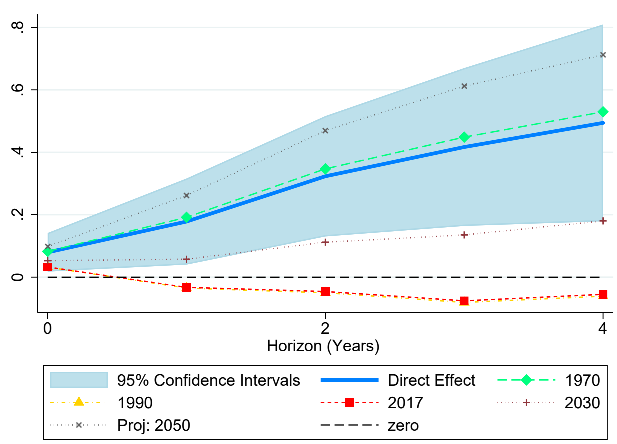
(c) *Conditional IRF: France*



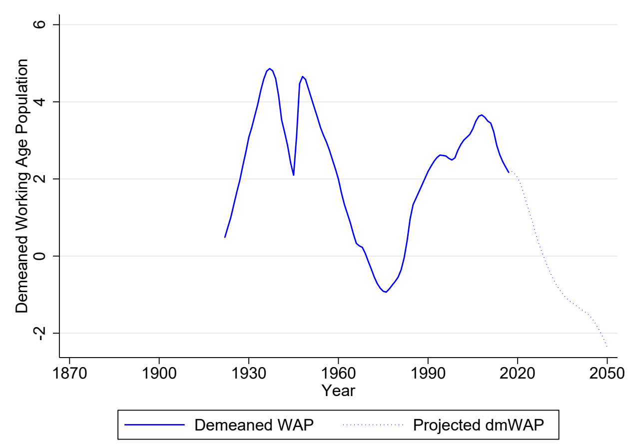
(d) *Demeaned WAP: France*



(e) *Conditional IRF: United Kingdom*



(f) *Demeaned WAP: United Kingdom*



Notes: Direct effects are the average effect of money growth on inflation when population is at long run sample mean. Conditional IRFs are effects of money growth rates conditional on age distribution of each country in a given year.

face of lengthening of time-span in retirement which itself might affect the consumption of older retirees.

4.2. Estimates Over the Full Age Distribution

I now present estimates that control for the entire age distribution. The goal is to allow for a more flexible approach than is allowed by using a single variable to capture population age structure dynamics. The strong significance of all four Fair and Dominguez (1991) demographic variables in Table 1 suggests that this variation is likely informative of *something*. The estimates of impulse response functions controlling for age in this way are are presented in Table 3. As before, I present the estimation including all covariates, and country fixed effects. This specification now includes interactive effects not only for the four demographic variables, but also for the entire vector of controls.

Table 3: *Inflation and Money Growth Full Age Specification: Impulse Response Function*

	0	1	2	3	4
L.m	0.10***	0.27***	0.48***	0.60**	0.67***
	(0.03)	(0.09)	(0.16)	(0.21)	(0.22)
D1	0.14	0.69*	1.54**	2.35***	3.29***
	(0.14)	(0.32)	(0.56)	(0.77)	(0.97)
D2	-0.29	-1.55	-3.66**	-5.74**	-8.32***
	(0.42)	(1.00)	(1.59)	(2.13)	(2.71)
D3	0.24	1.37	3.31*	5.28**	7.82**
	(0.44)	(1.06)	(1.63)	(2.17)	(2.76)
D4	-0.07	-0.41	-1.00*	-1.61**	-2.43**
	(0.15)	(0.36)	(0.54)	(0.73)	(0.92)
L.m× D1	0.07***	0.12**	0.17*	0.20	0.20
	(0.02)	(0.04)	(0.08)	(0.12)	(0.13)
L.m× D2	-0.22***	-0.45***	-0.65***	-0.82**	-0.88**
	(0.05)	(0.12)	(0.21)	(0.31)	(0.35)
L.m× D3	0.23***	0.52***	0.77***	1.00***	1.10***
	(0.05)	(0.12)	(0.21)	(0.31)	(0.36)
L.m× D4	-0.08***	-0.18***	-0.28***	-0.37***	-0.41***
	(0.02)	(0.04)	(0.07)	(0.10)	(0.12)
Macro X_i,t	Yes	Yes	Yes	Yes	Yes
Finance X_i,t	Yes	Yes	Yes	Yes	Yes
Interact X_i,t	Yes	Yes	Yes	Yes	Yes
R^2	0.698	0.654	0.659	0.660	0.672
Observations	1354	1354	1354	1354	1354

Standard errors are reported in parenthesis and clustered at the country level. $*p < 0.10, **p < 0.05, ***p < 0.01$. Each column is the impulse response function at the h year horizon. Coefficients on Demographic polynomials as well as interactions are scaled by 1/10/100/1000 respectively for clarity.

Unlike the case of estimation with the WAP the cumulative effect at $h = 4$, five years after the change in excess money growth, is larger than the equivalent specification in Table 1, with money transmission at nearly 70% by the fifth year. While the regression coefficients in Table 3 on both the demographic variables directly and their interactions are not easily interpretable economically (as before), it's clear that the inclusion of these interactive term between my constructed age variables and money growth are strongly significant.[23]

The direct effects of population age structure on inflation are significant over longer horizons, but are generally insignificant in the short run. This is in contrast to strong significance of demographics in the specification of Table 1 Column 7. Short horizons are omitted from that table for exposition, but all four demographic variables were significant at the 1% level at all fifteen horizons pictured in Figure 3. While it is perhaps reasonable that aging takes time to influence inflation directly, much of the variation picked up by population age structure coefficients in Table 1 are indirect effects of aging. The sensitivity of inflation to money, conditional on age structure, is strongly significant at all horizons for all but one of these variables.

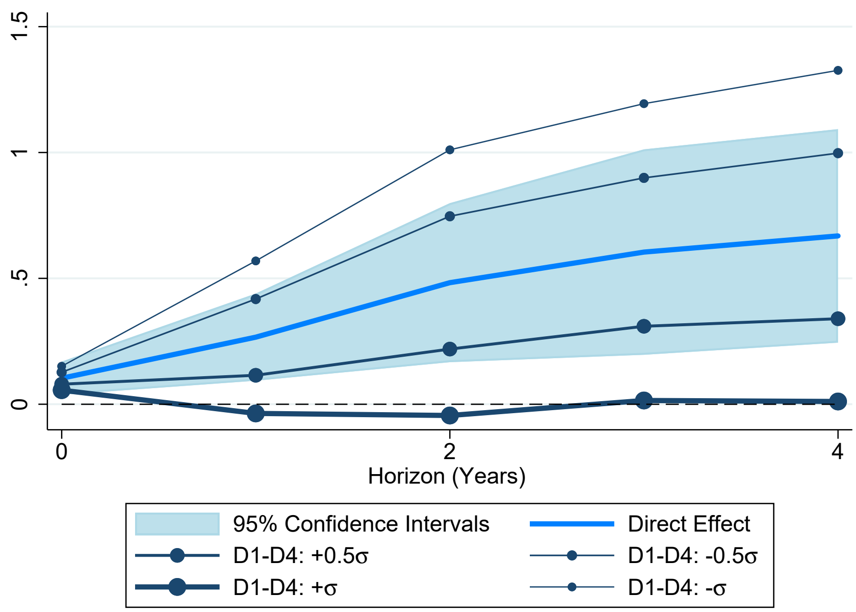
As before it is useful to understand the scale of this heterogeneous effect relative to the direct effect of excess money growth on inflation. Since unlike the earlier exercise there are now four demographic variables I scale all four of these and plot the joint heterogeneous effect. One might wish to do this separately for each individual demographic control (as they might have offsetting effects), but because the constructed variables, being weights of underlying population shares, have little interpretation the marginal value of doing so is likely low given that it is clear from the results of Table 1 that the effects are significant. In Figure I show these heterogeneous effects relative to the direct effect of excess money growth on inflation.

Figure 7 suggests that the heterogeneity is not only statistically significant (ie: measurably different from the direct effect), but also economically quite meaningful. The average cumulative effect over a five year horizon of a one percentage point increase in lagged excess money growth is a 0.67 percentage point increase in inflation. Increasing the demographic variables jointly by one standard deviation leads to a net effect of nearly zero, while a symmetric increase would double estimates over a five year horizon. Unlike the case of the WAP we cannot say that an increase in these constructed variables is linearly one directional. So it is even more important to understand what this means for observed age structures.

Once again I can plot the *compositional effects* of age on inflation across the life cycle

[23] Some intuition on these parameters is that significance across all four degrees suggests that the model found usefulness in each term of the polynomial in improving the fit of the prediction across the age distribution.

Figure 7: *Heterogeneous Effect of Excess Money Growth and Inflation: Fair and Dominguez (1991) Age Vars*

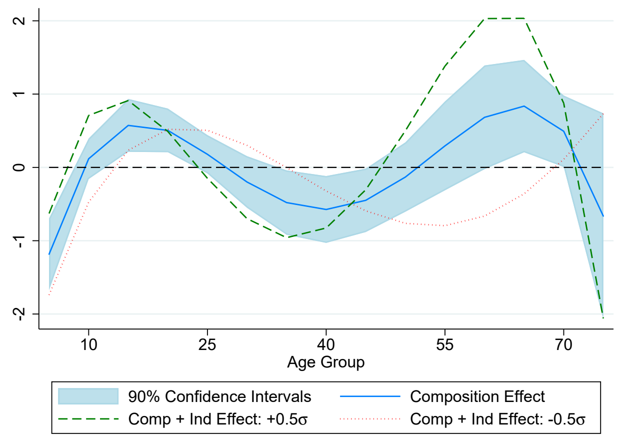


by backing out the implied coefficients using the same methodology described above to generate Figure 4. However now in addition to direct effects there are indirect effects coming from the interaction term. In Figure 8a, the blue line represents the *compositional effects*; the effects when excess money growth is zero. Though some significance is lost, the overall effect by age group is roughly the same as in Figure 4.[24] In addition to this I show the net effect of adding *indirect effects*. This takes these direct effects by age and add/subtract a half standard deviation shift in excess money growth. Panel 8b simply shows the *Indirect Effect* alone for the positive shock and is the difference between the dashed green and solid blue lines in Panel 8a.

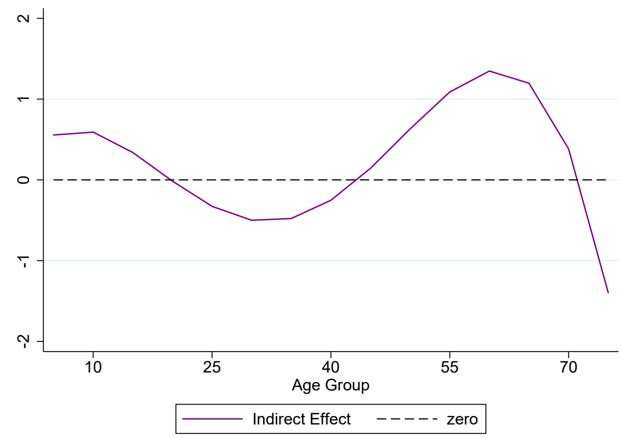
The total effect of aging, including indirect effects, shows that the indirect effects more or less reinforce the age specific coefficients. This is somewhat easy to see from the fact that each interaction in Table 3 has the same sign as it's non-interactive counterpart. We can somewhat interpret these indirect effects as being positive for young dependents and very early workers, negative for early-to-mid career workers and then strongly positive again for late career (> 55) workers and retirees. Moving from a population structure with lots of weight in young or old populations, to one with weight in the early working ages population will of course reduce transmission, even leading to a negative net effect, as will be the case below.

[24]Also quite similar to results from Juselius and Takáts (2021) who, as discussed above, estimate these direct effects.

Figure 8: *Age Specific Coefficients at H = 4: Composition + Indirect Effects*



(a) *Composition + Indirect Effect*



(b) *Indirect Effect* $+0.5\sigma$ *L.m Shock*

Another takeaway from Panel 8b is that the indirect effect bottoms out for young-to-middle aged workers and then begins to sharply rise for workers in mid-to-late career, with a peak in the five year groups on either side of retirement. This quite similar to the stylized picture of money holdings by age from the SCF in Figure 2. Here though I also see the effect of young dependents, who might exert pressure on money demand through spending needs of their parents. A theory of money, needed to finance consumption, may explain these dynamics. Fernández-Villaverde and Krueger (2007) show that consumption has a dramatic hump-shape, peaking somewhere in the mid-late fifties and remaining high throughout early retirement before falling during later retirement years. This is more or less the same picture I see for the indirect effect in the second half of life here. My empirical findings suggest that more theoretical work should be done to investigate how late career workers and early retirees might be an important conduit for monetary transmission to inflation, by generating these life-cycle profiles. It seems likely based on these pictures that some wealth + consumption dynamics, which match these shapes must play some role.

There may be other mechanisms at work. If more experienced workers are more important for the wage pressures through bargaining, that might act as a push factor for inflation. This is a main hypothesis regarding inflationary aging, but may be important for priming the monetary transmission if these wages affect money demand. Other explanations that have been put forth, focused on interest rate policy, suggest that households with large accumulation of wealth become *more* sensitive to changes in interest rates and therefore more likely to strengthen the effect of policy. However, this is the opposite of the effect expected in work such as Wong (2019),[25] where young households are more sensitive via

[25]Notable of course is that in her work it is not money, but interest rate policy that matters, which perhaps

a different, borrowing constraint, channel. One could imagine such mechanisms for safe interest rate transmission to potentially operate similarly to money if it was modeled as a competing asset as in Aoki et al. (2019).

The visualizations in Figure 8 are useful, but do not yet provide a clear idea of how recent demographic trends have contributed to monetary transmission. I conduct the same Blinder-Oaxaca decomposition as above. As before these are the impulse response functions for a one percentage point increase in excess money growth conditional on the age distribution of the United States, France and the United Kindom. These results are plotted in Figure 9.

In Panel 9a each line represents a particular realization of the population age distribution in the United States. These then correspond to four values for the constructed demographic variables, which capture movements in deviations of population age shares from their long run mean. As such, each impulse response represents the *direct effect* of a change in excess money growth (plotted by the blue line) plus the contribution from each of these four indirect effects through the four demographic interaction terms. The first twenty years of this exercise offer the same, though more dramatic, picture of the change in this relationship than those seen in the previous section. The great inflation of the 1970s are a time when the estimated effect of aging on the money-inflation relationship is strongly positive, with changes in excess money growth rate accommodated by aging such that a one-to-one relationship materialized within three years. During the great moderation, represented here by the estimated effects in 1990 (and similar though not plotted 2000) this relationship completely disappears, as demographic headwinds create an almost puzzlingly strong negative money-inflation relationship.

What is causing this dramatic shift from 1970 to 1990? To understand more clearly I show the demeaned population shares for each of the years in the left hand panels of Figure 9. Looking at the United States in Panel 9b there are a few large swings from the 1970s (green diamonds) to the 1990s (gold triangles). The first is that the population moves from one with a large share of young dependents, by historical standards, to one with relatively few. These swing from higher than historical sample averages (here the zero line) when the boomers make up this group in the 1970s,[26] to lower for all but the youngest group.[27] Looking back on the indirect effect across age groups plotted in Figure 8b, these are groups with quite a strong positive effect on the money-inflation relationship so this reduction should shrink the effect. Additionally, there is an increase on the younger

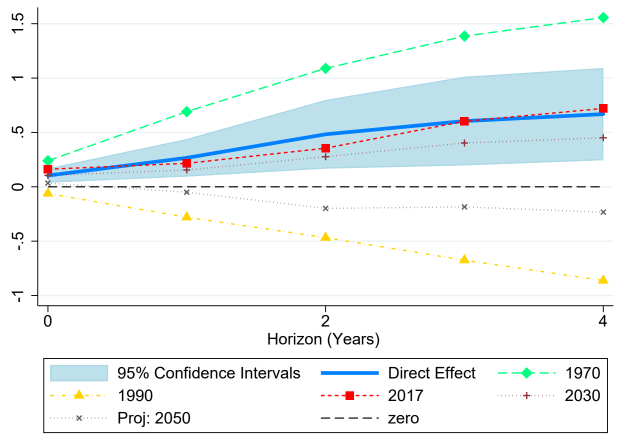
could have different transmission effects.

[26]Their cohort is aged between 6 and 24 at that point.

[27]In 1990 young dependents are populated by the relatively small Generation X and the eldest of the larger millennial cohort.

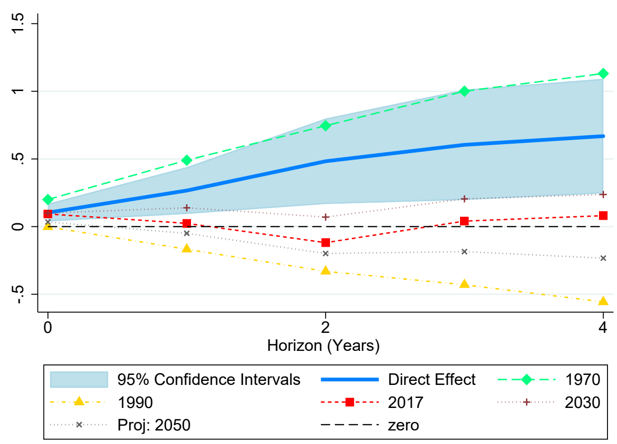
Figure 9: *Blinder Oaxaca Decomposition: Fair and Dominguez (1991) Controls*

(a) *Conditional IRF: United States*



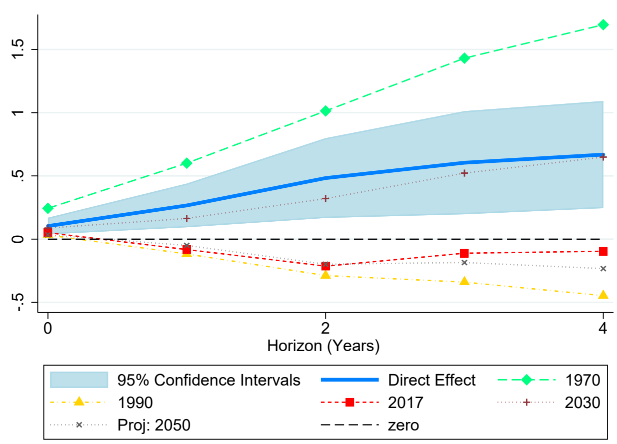
(b) *Population Shares: United States*

(c) *Conditional IRF: France*



(d) *Population Shares: France*

(e) *Conditional IRF: United Kingdom*



(f) *Population Shares: United Kingdom*

Notes: Direct effects are the average effect of money growth on inflation when population is at long run sample mean. Conditional IRFs are effects of money growth rates conditional on age distribution of each country in a given year.

working aged group as the boomer generation has moved into this category. At this stage they are between 26 and 44 years old, occupying the early-mid life trough in Figure 8b. Meanwhile population aging has not yet begun to take off in the United States, with a relatively small silent generation make up late career workers with the strongest positive effect on the money-inflation relationship. The great moderation, it would seem, was the perfect demographic storm for a movement from strong to weak money pass through to prices, largely due to the size of the boomers.

By 2017, the boomer cohort is at the peak of the money growth relationship aged 53-71. In the United States this would suggest a resurgence of money transmission. This effect is limited by the massive increase in the oldest age cohorts, who contribute negatively, due to continued increases in life expectancy over this period, as well as the still small groups of young dependents. According to the OECD, life expectancy at age 65 for men in the United States increased by 2.9 years from 1990 and 2017 from 15.1 to 18 years. This increase is even more dramatic in the United Kingdom (14 to 18.8 years) and France (15.7 to 19.6 years). So the combination of having relatively fewer young dependents and relatively more old age retirees, leads the effects in these two countries to remain quite low in the most recent data. Projecting forward it is indeed the increasing importance of the eldest age cohort and continued decreasing share of young dependents that drive further downward pressure on money-inflation estimates.

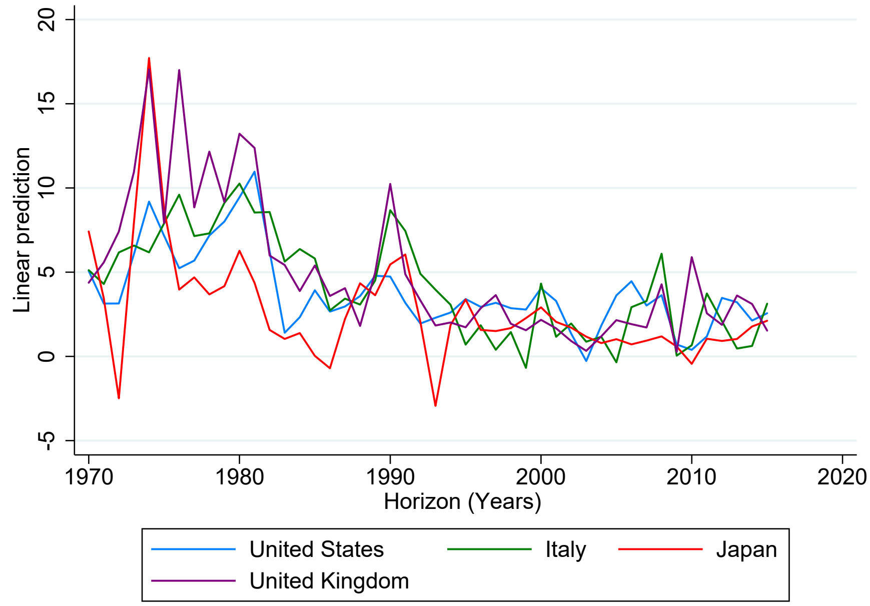
It's clear from the left hand panels of Figure 9 that the 75 age group has an outsized effect on future projections. As a result, I wish to caution putting too much weight on point estimates. A known issue of using demographic controls is that over-fitting of the polynomial over the age distribution can tend to lead to extreme values for the youngest and oldest age groups. While a decreasing money demand in old age is consistent with the stylized picture in Figure 2, the reversal for the oldest group is significantly more dramatic. It is true that the extreme shift of the estimated effects presented in Figure 8b may be subject to such over-fitting. In Appendix D, I present estimates and projections using lower order versions of this polynomial. These have poorer fit of the age relationship,[28] but present a broadly consistent story of the effects from 1970 to present. The notable difference is that the conditional effects of older age groups appear to have less singular effect with aging, with the money-inflation relationship seeing less dramatic declines in future projections.

4.3. Where is the Missing Inflation?

Where is the missing inflation? My two separate demographic controls paint similar pictures over a long run view, but give conflicting answers in the years since the global

[28] Interestingly the second order appears to fit better than the third, for reasons I discuss briefly.

Figure 10: *Prediction of Current Inflation*



financial crisis. If one thinks that my estimates in Section 4.2 are potentially over-fitting the age data, then you might be content with the idea that working age population suggests that demographic headwinds have still been in place over the last decade, perhaps reconciling seemingly weak inflation in response to relatively loose monetary policy. However it is *possible* that the age distribution has already become accommodating and that other forces have been working in the other direction.

Coibion, Gorodnichenko, and Ulate (2019) suggest that an expectations-augmented Phillips curve can account for inflation weakness post global financial crisis in a wide range of countries. With the deflationary pressures of the Great Recession lasting until about 2018. Part of the inability of standard Phillips curves to show this, is that economic slack not well accounted for by traditional measures such as unemployment rates. Falling participation for example might signify more slack in the economy that would be missed otherwise. My present analysis isn't able to account for such expectations, nor even for dynamics in employment. As a result if I were to try to forecast inflation using my model I would, like the traditional Phillips curve, significantly overestimate inflation.

To get a sense of this I plot the predicted current year inflation rate using my specification from Table 3 for a subsample of countries in Figure 10. To be clear I expect this to be a poor estimate of inflation. This paper is not making any attempts at forecasting, and has explicitly focused on attempting to estimate long term effects. However, many of my macroeconomic and financial controls are quite important in determining inflation at shorter horizons and can give some sense as to whether my estimated age-structure transmission mechanism which is quite strong by 2017 in the analysis of Section 4.2 would have counter-factually predicted a large inflation takeoff. It's clear from Figure 10 that in spite of my sharp predicted increase in the transmission of money growth to inflation over this period, my model has not predicted any takeoff from inflation levels from what might have been expected during the great moderation.

These results are reassuring in that they provide some context such that the dramatic transmission mechanisms plotted for the United States in Figure 9a do not necessarily imply a takeoff of inflation in their own right. Rather they suggest that age structure has shifted toward accommodation of money transmission ceteris paribus. Of course many factors might be working against this in the short run and those discussed in Coibion et al. (2019) suggest that an overhang from the global financial crisis is plausible. However, with inflation response to the Covid crisis appearing more robust than many expected my results suggest that policy makers should be careful to disregard monetary aggregates as a potential driver, particularly in the United States where demographics suggest a robust relationship at present and where Fed interventions have led to incredible spikes in M3.

5. Conclusion

Age structure does an excellent job accounting for a boom-bust cycle of the medium-to-long transmission of excess money growth rates to inflation over the past fifty years. This appears to be a feature of three forces: falling fertility (leading to smaller shares of young dependents), increasing old age dependents through increased life expectancy, and the movement of the baby boomer cohort through the age distribution. If the results outlined above are to be taken seriously then policy makers should be cautious to with the idea that the policy environment of the last thirty years is the norm. While decreased fertility and increasing longevity are likely going to continue in advanced economies, the aging of the boomers may be allowing for a slight return of the money-inflation relationship at present.

There are a number of caveats that should be made clear. While my results appear to be quite robust, this analysis falls short of causal identification. Finding an identification strategy that combines exogenous monetary shocks with plausibly exogenous demographic shocks would add credibility to any such estimates, but are not readily available. Because of this, I see these results as also calling for further theoretical work to explore potential mechanism more concretely, while allowing for a robust quantitative analysis. These of course can work together, as clearer ideas as to the mechanisms that might explain the aggregate data should help point to areas where micro data may shed light on how such mechanisms may operate.

While I provide some evidence in support of the theses presented in Goodhart and Pradhan (2020), I do not focus specifically on how aging affects inflation directly, rather exploring how population aging may work through indirect channels of money transmission. These indirect channels appear important, and should not be ignored in this broader discussion of the effects of aging. While all estimates explain the transition from great inflation to great moderation, the implications for the future are nuanced. If we consider working age population, there is some time before the United States would face money driven inflation, but aging will continue to push toward more money transmission. Using more information from the age distribution, it is possible that the United States is already experiencing positive demographic pressure on the money-inflation relationship, but that significant aging beyond this may actually reduce this effect as the group of individuals over 75 grows substantially. Policy makers should ignore money at their own risk. While the widely accepted notion that a low inflation policy regime has removed the need to carefully track monetary aggregates, this paper suggests that aging may just as easily explain some of this shift. If this is indeed true, then we cannot expect the relationship to remain constant over the coming decades.

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A. Construction of Demographic Controls

My estimates for effects across the entire age distribution build on the methodology of Fair and Dominguez (1991). Suppose one wanted to estimate the following relationship:

$$y_{i,t} = X_{i,t}\beta + \sum_{j}^{J} \alpha_j p_{j,i,t} + \mu_i + \nu + \epsilon_{i,t} \tag{5}$$

Where $y_{i,t}$ is any outcome of interest, $X_{i,t}$ is an arbitrary vector of controls, $\epsilon_{i,t}$ is error, μ_i country fixed effects, and ν a constant. The variables $p_{j,i,t}$ are shares of the population, divided into J bins. This is inestimable due to the perfect colinearity of the population shares $p_{j,i,t}$. Additionally while one would prefer to take a granular approach to modeling population shares ()allowing for a large number of, J, groups), these shares are highly colinear with one another, more so as their number increases. Finally in smaller samples it may be undesirable to fit such a large number of coefficients, particularly as in my case when interaction terms would also be needed. Fair and Dominguez (1991) proceeds by making the following two assumptions:

1. Letting α_j be the be the coefficient on population share $p_{j,i,t}$ of age group j in country i and time t. Assume that all of the effects of these coefficients across the age distribution sum to zero. In other words:

$$\sum_{j}^{J} \alpha_j = 0$$

2. Assume that the age coefficients α_j can be fitted with a K order polynomial. In other words:

$$\alpha_j = \sum_{k}^{K} \gamma_k j^k \tag{6}$$

All three problems are addressed. First it transforms the problem of estimating J coefficients into one of estimating K, as I will show in a moment. Second, the assumption that all age effects, α_j, sum to zero makes them jointly estimable, without having to drop the regression constant. Finally, by forcing the age effects to lie on a polynomial, the model requires that there be relatively smooth transitions from the effect of one age group to another. If one were to take only the first assumption (or omit the constant of the regression) it would be possible to estimate the effects in Equation 5. The results of such estimations when using five or ten year population age groups often lead to highly unstable coefficients that alternate signs quickly from one age group to the next. This is due to the high degree of colinearity between one age group and those immediately around it, which increases in J.

To see how this methodology works. Substitute α_j into Equation 5. I will assume in what follows a third order polynomial for exposition. This yields:

$$y_{i,t} = X_{i,t}\beta + \sum_{j}^{J} \left[(\gamma_0 + \gamma_1 j + \gamma_2 j^2 + \gamma_3 j^3) p_{j,i,t} \right] + \mu_i + \nu + \epsilon_{i,t} \tag{7}$$

The summing over both sides of Equation 3, and using the assumption that the sum of α_j must be zero, it can easily be shown that γ_0 is equal to:

$$\gamma_0 = -\frac{1}{J} \left[\gamma_1 \sum_j j + \gamma_2 \sum_j j^2 + \gamma_3 \sum_j j^3 \right]$$

Thus far I have followed exactly the methodology of Fair and Dominguez (1991). From here one simply plugs the above expression for γ_0 into Equation 7, and given the fact that the first term, $\sum_j \gamma_0 p_{j,i,t} = \gamma_0$ by the fact that the population parameters sum to one, then this can be rearranged as:

$$y_{i,t} = X_{i,t}\beta + \gamma_1 \sum_{j}^{J} \left(p_{j,i,t} j - \frac{\sum j}{J} \right) + \gamma_2 \sum_{j}^{J} \left(p_{j,i,t} j^2 - \frac{\sum j^2}{J} \right) + \gamma_3 \sum_{j}^{J} \left(p_{j,i,t} j^3 - \frac{\sum j^3}{J} \right) + \mu_i + \nu + \epsilon_{i,t} \tag{8}$$

With the terms in parenthesis being the demographic variables. Because I wanted my estimates to follow the demeaned structure and interpretability of for the Blinder-Oaxaca decomposition. I opted to instead estimate

$$y_{i,t} = X_{i,t}\beta + \sum_{j}^{J} \alpha_j (p_{j,i,t} - \bar{p}_{j,t}) + \mu_i + \nu + \epsilon_{i,t} \tag{9}$$

The first few steps are exactly the same so I don't replicate them here. The problem however is just to rearrange terms slightly differently in order to construct the correct demographic variables for estimation. In principle this simplifies to:

$$Dk_{i,t} = \left[\sum_{j}^{J} (p_{j,i,t} - \bar{p}_{i,t}) j^k - \sum_{j}^{J} j^k \sum_{j}^{J} (p_{j,i,t} - \bar{p}_{i,t}) \right] \tag{10}$$

But only this first term is needed given that $sum_j \gamma_0 (p_{j,i,t} - \bar{p}_{j,t}) = 0$, and not γ_0 as before. So rather the estimation becomes

$$y_{i,t} = X_{i,t}\beta + \gamma_1 \sum_{j}^{J}(p_{j,i,t} - \bar{p}_{j,t})j + \gamma_2 \sum_{j}^{J}(p_{j,i,t} - \bar{p}_{j,t})j^2 + \gamma_3 \sum_{j}^{J}(p_{j,i,t} - \bar{p}_{j,t})j^3 + \mu_i + \nu + \epsilon_{i,t} \tag{11}$$

Where these $\sum_j (p_{j,i,t} - \bar{p}_{j,t})j^k$ terms are the demographic controls used in the estimations in the paper.

B. Cointegration of Population Age Structures and Inflation

In this appendix section I present results of a cointegrating relationship between inflation and age structure in my data. All controls besides my two demographic specifications are stationary. Notably neither the demeaned working age population series, nor the Fair and Dominguez (1991) style demographic controls are stationary. I show this in Table 4, which reports the inverse χ^2 statistic for both Phillips-Perron and augmented Dickey-Fuller, Fisher-type panel unit root tests. P-values for these are shown in parentheses. The first half of this table shows that indeed I cannot reject a unit root for the cumulative inflation (my dependent variable used to construct local projection horizons), nor for any of the age structure variables. The lone exception is the Phillips-Perron statistic on the demeaned working age population series. All other controls are not reported as they are strongly stationary for all tests.

These variables are however appear to be stationary in differences as is shown by the reported. This is strongly rejected in the Phillips-Perron in all tests, failing to reject for D3 and D4 for the augmented Dicky-Fuller.

The purpose of the above was to show that my dependent variable and demographic controls are I(1) processes. As mentioned in the text, there have been a number of papers showing that there is a long run, cointegrating, relationship between population age structure and inflation. I now show that indeed this appears to be the case. In the effort of transparency I will report nine different tests of panel cointegration. I report the test statistics, and corresponding p-values in Table 5. I show these for my two specifications for demographic controls. In seven out of nine of these tests I reject the null hypothesis of no cointegration.

The existence of such a relationship should ease concerns of spurious results in my estimates as well as imply that coefficients are *super*-consistent.

Table 4: *Unit Root Test: Cumulative Inflation and Age Structure Controls*

	Phillips-Perron	Augmented Dickey-Fuller
Cumulative Inflation	21.11	10.29
	(0.98)	(1.00)
dmWAP	69.30	13.51
	(0.00)	(0.99)
D1	4.30	3.46
	(1.00)	(1.00)
D2	2.52	2.84
	(1.00)	(1.00)
D3	2.11	2.93
	(1.00)	(1.00)
D4	1.68	3.33
	(1.00)	(1.00)
First Difference		
d.(Cumulative Inflation)	456.22	247.93
	(0.00)	(0.00)
d.(dmWAP)	123.61	97.95
	(0.00)	(0.00)
d.(D1)	95.17	62.89
	(0.00)	(0.00)
d.(D2)	94.62	50.97
	(0.00)	(0.00)
d.(D3)	92.07	44.81
	(0.00)	(0.15)
d.(D4)	88.39	40.63
	(0.00)	(0.27)

Table 5: *Test of Cointegrating relationship between cumulative inflation and and Demographic variables*

	Pedroni			Kao					Westerlund
	mPP	PP	aDF	mDF	DF	aDF	umDF	uDF	VR
dmWAP	4.70	6.88	11.29	3.15	4.27	0.40	4.60	8.56	1.25
	(0.00)	(0.00)	(0.00)	(0.001)	(0.00)	(0.34)	(0.00)	(0.00)	(0.11)
D1-D4	0.58	4.09	10.64	1.88	1.94	-0.63	3.84	5.30	-2.61
	(0.28)	(0.00)	(0.00)	(0.03)	(0.03)	(0.27)	(0.00)	(0.00)	(0.01)

C. Estimations With Time Fixed Effects

As discussed in Section 2 I attempt to control for time fixed effects using a global measure of output. This is used in a number of papers with this JST data, notably Jordà et al. (2020), as the addition of time fixed effects requires a large number of covariates. However in this particular context there is also a compelling argument that there are non-uniform trends present in my panel which could in principle bias estimates if a single time trend is used. In particular the conventional story of a structural change in the money-inflation relationship suggests that changes in the underlying monetary policy framework are important for policy pass through. Since central banks have not adopted uniform policies (and have not done so with uniform timing) across my 16 countries it would appear that time fixed effects are likely inappropriate in this context.

However, given the ubiquitous use of these time trends, I provide them in this appendix to show that their inclusion do not change any of my results qualitatively. Though they have sizable impacts on the point estimates of the money growth-inflation relationship, decreasing them and increasing the error bands. In Table 6 I show the coefficients for both my working age population and Fair and Dominguez (1991) controls with the inclusion of these time fixed effects. The signs of the demographic interactions are identical to those in the paper, and in the preferred specification (with three demographic controls) the effect of lagged money growth remains significant (and sizable) at all horizons. Notably the demographic interactions, though jointly significant at all levels are much weaker in this estimation than in Table 3. Here I use a third order polynomial as it appears to fit slightly better in this specification, but qualitatively the demographic effects in the country specific Blinder-Oaxaca decomposition are the same across both estimations and are jointly significant in second and forth order specifications.

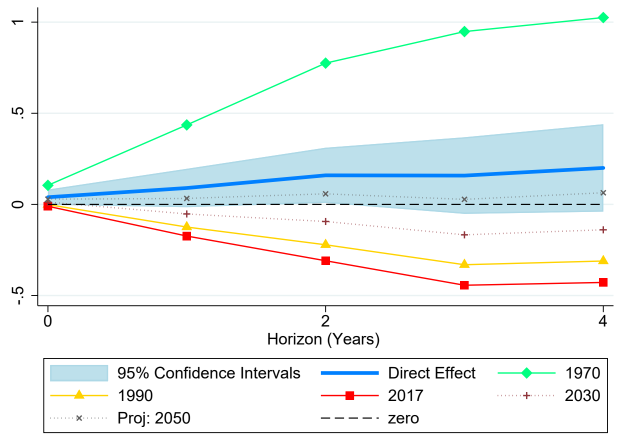
Figure 11 plots the same Blinder-Oaxaca decomposition for the three countries as in the main text of the paper. As before the dramatic shift from 1970 to 1990 is present. For working age population it will take longer for declines to reverse this trend, while the point estimates for 2017 over the full age distribution are similar to those in the main text, though slightly smaller for the United States.

Table 6: *Inflation, Money Growth, and WAP: Impulse Response Horizons*

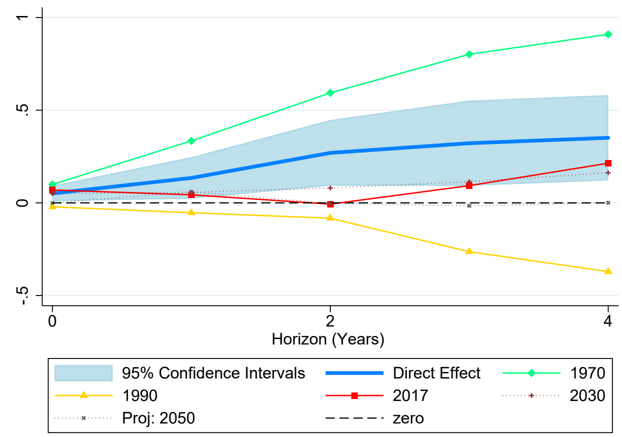
	WAP Control: Horizon					D1-D3 Controls: Horizon				
	0	1	2	3	4	0	1	2	3	4
L.m	0.04*	0.09	0.16*	0.16	0.20	0.05**	0.13*	0.27**	0.32**	0.34**
	(0.02)	(0.05)	(0.08)	(0.11)	(0.12)	(0.02)	(0.06)	(0.10)	(0.13)	(0.12)
dmWAP	0.11**	0.47***	0.80***	0.95***	0.87***					
	(0.05)	(0.14)	(0.25)	(0.30)	(0.28)					
L.m x dmWAP	-0.02*	-0.09***	-0.15***	-0.20***	-0.21***					
	(0.01)	(0.02)	(0.04)	(0.05)	(0.05)					
D1						0.01	0.14	0.03	-0.15	-0.38
						(0.10)	(0.25)	(0.38)	(0.56)	(0.71)
D2						0.00	-0.14	0.05	0.35	0.72
						(0.16)	(0.41)	(0.64)	(0.94)	(1.20)
D3						-0.01	0.04	-0.04	-0.18	-0.34
						(0.07)	(0.18)	(0.29)	(0.42)	(0.54)
L.m× D1						-0.01	-0.06*	-0.09**	-0.13**	-0.15**
						(0.01)	(0.03)	(0.04)	(0.06)	(0.06)
L.m× D2						0.02	0.08	0.14*	0.18*	0.21**
						(0.02)	(0.05)	(0.07)	(0.09)	(0.09)
L.m× D3						-0.01	-0.03	-0.06*	-0.08*	-0.08**
						(0.01)	(0.02)	(0.03)	(0.04)	(0.04)
Macro X_i,t	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finance X_i,t	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interact X_i,t	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.693	0.644	0.673	0.676	0.665	0.827	0.799	0.807	0.824	0.851
Observations	1354	1354	1354	1354	1354	1354	1354	1354	1354	1354

Figure 11: *Blinder Oxaca Decomposition: Including Time Fixed EFfects*

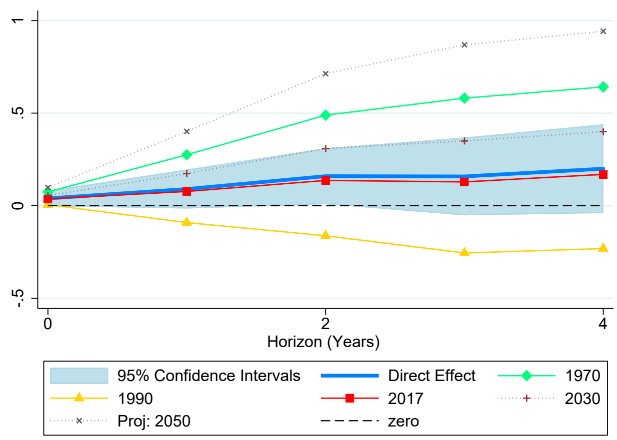
(a) *Conditional IRF, WAP: United States*



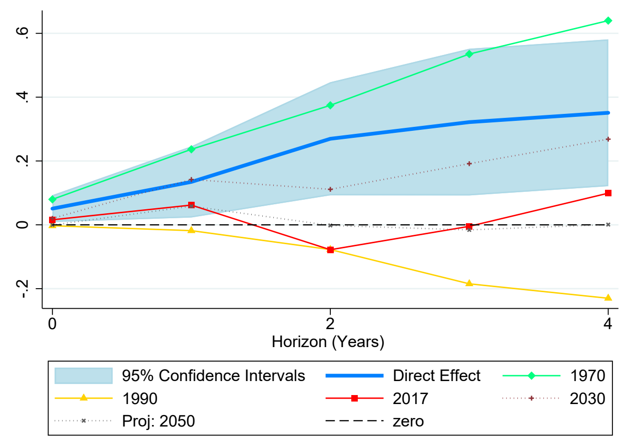
(b) *Conditional IRF, Full Age Distribution: United States*



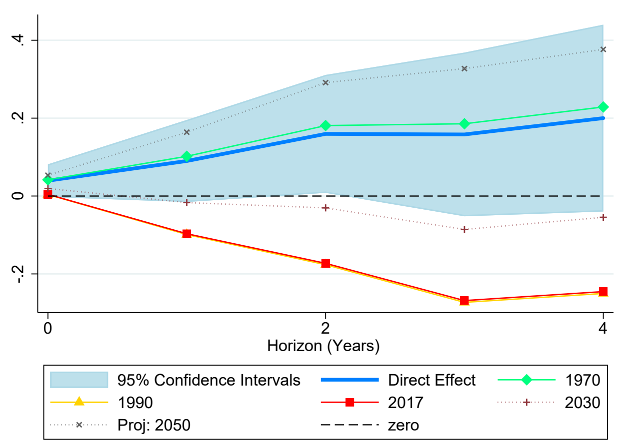
(c) *Conditional IRF, WAP: France*



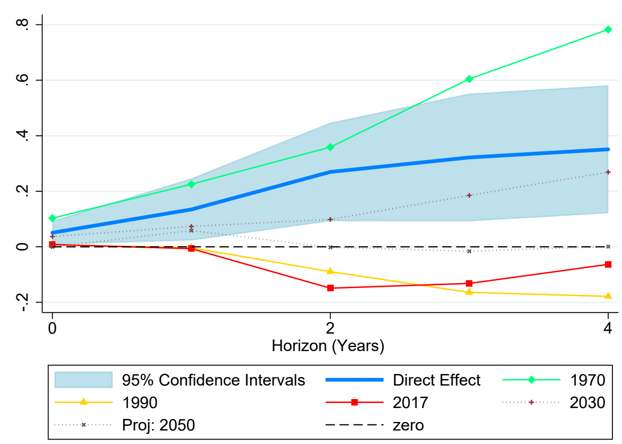
(d) *Conditional IRF, Full Age Distribution: France*



(e) *Conditional IRF, WAP: United Kingdom*



(f) *Conditional IRF, Full Age Distribution: United Kingdom*



Notes: Direct effects are the average effect of money growth on inflation when population is at long run sample mean. Conditional IRFs are effects of money growth rates conditional on age distribution of each country in a given year.

D. Effects Across the Age Distribution: Lower Order Polynomials

There might be concern that using a fourth degree polynomial might over-fit the data, leading to extreme effects for the youngest and oldest age group. This is a common issue with this methodology and while adding additional degrees to the polynomial should help improve the fit of the age process, but may not be useful for out of sample projections. It's clear from the right hand panels of Figure 9 that the fall in < 10 and rise in > 75 age groups is having a large effect in projections to 2050.

The first thing to note is that removing the fourth order demographic term does reduce significance substantially. While many of my interaction terms remain significant,[29] it is clear that the fourth order estimation fit substantially better. This is to be expected, and even by design, as the goal was to mitigate some of the over-fitting that allowed for the oldest cohort to have such a singular effect on estimates in the post-baby boom retirement period. In addition to this, some of the weakness seems to stem from modeling an even number of turning points across age. This can be seen when instead I use a second order polynomial which I include in appendix Table 7, where again these interactions are strongly significant at every horizon. My intuition is that the best fit for the data requires oldest retirees and young dependents to have same signed direct effects, but that the third order effect struggles to accommodate this while also fitting working age. The direct effect of excess money is larger at every horizon, suggesting perhaps that the better fit of demographic data was explaining some of this direct money transmission.

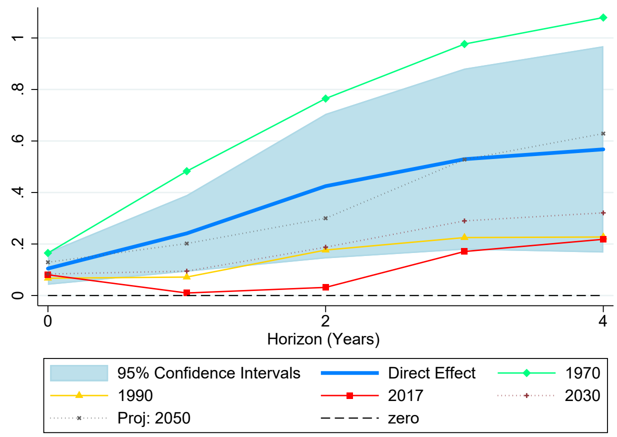
To see that these changes in coefficients, though substantial, imply quite similar demographic forces, I repeat the Blinder-Oaxaca exercise from the prior section using the same empirical population values. As before each economy experiences quite strong money transmission to prices in the 1970s, with substantial weakening by 1990. There are three differences from this specification. First, the strong negative values for 1990 populations are now more like zero effects. This seems more plausible as it's hard to come up with a strong theoretical intuition for a negative money effect. Second, the predictions for the United States and other countries don't look quite as different in the present year. This is due to the positive effects from late carrer and early retiree boomers not being as strongly offset in France and the United Kingdom, by already large groups of older retirees. Finally, while projections suggest a strengthening through 2030, and a weakening beyond there is substantially less extreme movement of point estimates.

The point of this exercise is to show that while aging continues to give the same qualitative picture about monetary transmission in past data, that one should be cautious

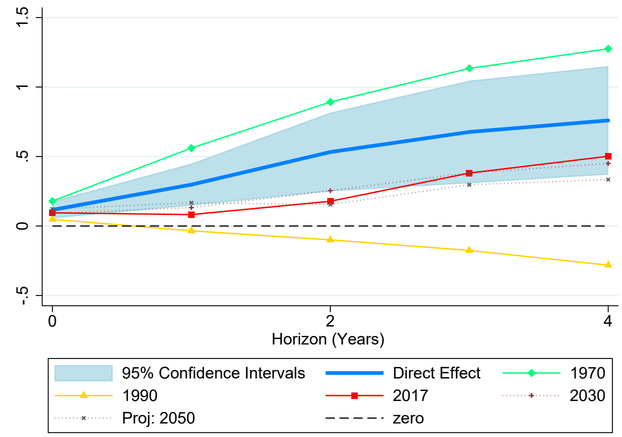
[29] Indeed the age structure is jointly significant at all horizons including $h = 0$ at the 5% level.

Figure 12: *Blinder Oxaca Decomposition: Lower Order Polynomials*

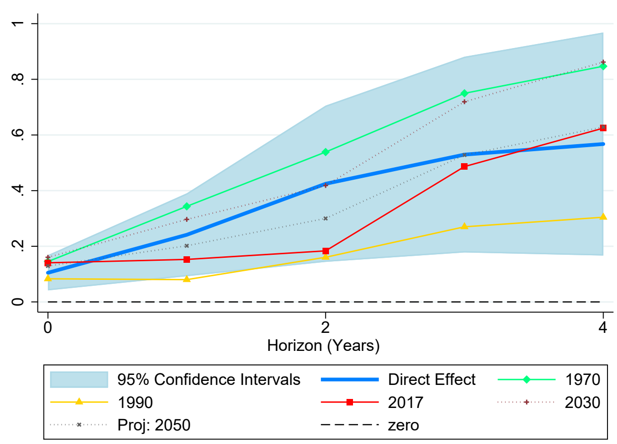
(a) *Conditional IRF 2nd Degree: United States*



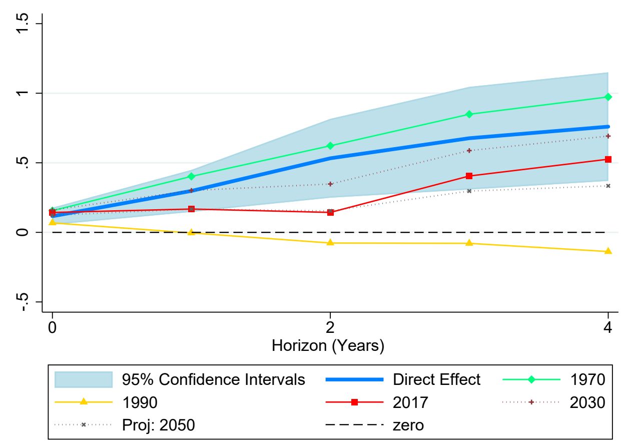
(b) *Conditional IRF 3rd Degree: United States*



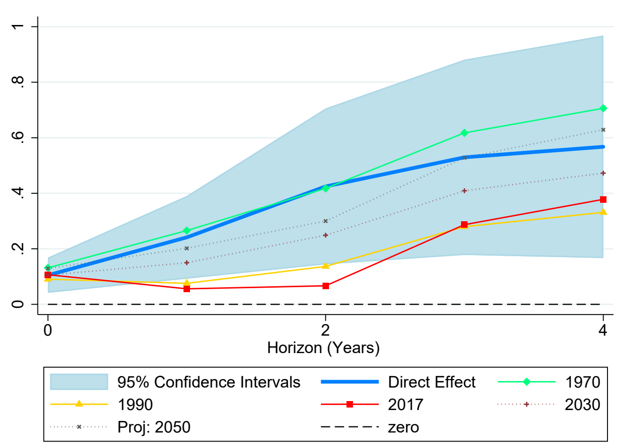
(c) *Conditional IRF 2nd Degree: France*



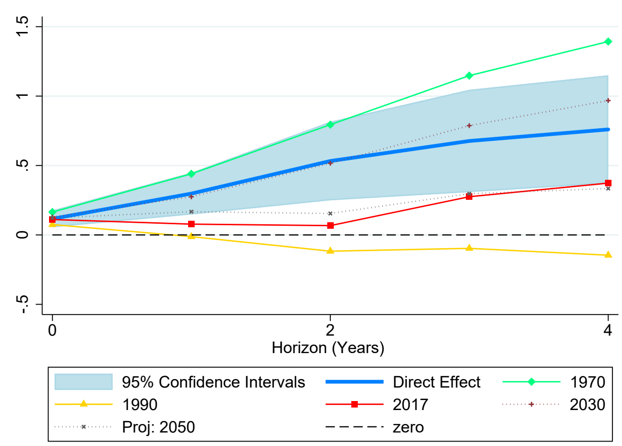
(d) *Conditional IRF 3rd Degree: France*



(e) *Conditional IRF 2nd Degree: United Kingdom*



(f) *Conditional IRF 3rd Degree: United Kingdom*



Notes: Direct effects are the average effect of money growth on inflation when population is at long run samsple mean. Conditional IRFs are effects of money growth rates conditional on age distribution of each country in a given year.

Table 7: *Inflation and Money Growth Full Age Specification: Impulse Response Function*

	Second Order Estimation					Third Order Estimation				
	0	1	2	3	4	0	1	2	3	4
L.m	0.10***	0.24***	0.42***	0.53***	0.57**	0.12***	0.30***	0.53***	0.68***	0.76***
	(0.03)	(0.08)	(0.14)	(0.18)	(0.20)	(0.03)	(0.08)	(0.14)	(0.19)	(0.20)
D1	0.01	0.09*	0.14*	0.18*	0.20	0.05	0.23**	0.45***	0.59***	0.65**
	(0.02)	(0.04)	(0.07)	(0.09)	(0.12)	(0.04)	(0.10)	(0.14)	(0.19)	(0.23)
D2	-0.01	-0.05	-0.08	-0.11	-0.12	-0.07	-0.29	-0.64**	-0.86**	-0.95**
	(0.01)	(0.03)	(0.05)	(0.07)	(0.08)	(0.06)	(0.18)	(0.28)	(0.38)	(0.44)
D3						0.03	0.10	0.26*	0.35*	0.39*
						(0.03)	(0.09)	(0.14)	(0.19)	(0.22)
L.m× D1	-0.01**	-0.03***	-0.04***	-0.05***	-0.06***	-0.02	-0.07**	-0.13**	-0.19**	-0.24***
	(0.00)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.03)	(0.05)	(0.07)	(0.07)
L.m× D2	0.01**	0.02***	0.02**	0.03**	0.04**	0.02	0.08	0.19**	0.27**	0.35***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.08)	(0.11)	(0.12)
L.m× D3						-0.01	-0.03	-0.07*	-0.11*	-0.14**
						(0.01)	(0.02)	(0.04)	(0.05)	(0.05)
Macro X_i,t	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finance X_i,t	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interact X_i,t	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.688	0.634	0.627	0.620	0.624	0.690	0.643	0.642	0.639	0.649
Observations	1354	1354	1354	1354	1354	1354	1354	1354	1354	1354

about the predictions going forward with any one specification for the age distribution. These results should not call for a dramatic change in how policy makers view money, but rather a caution that aging may have been an important factor and a call for work to better understand the underlying mechanisms that may allow for population age structure to be important for the transmission of monetary aggregates to inflation.