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Demography and Inflation: An International Study

Doug Andrews[1], Jaideep Oberoi[2], Tony Wirjanto[3], Chenggang Zhou[4]

Abstract

Changes in the relative share of different age groups in the population may present inflationary, disinflationary or even deflationary tendencies. We find evidence that increases in the share of the very old (age 80 and older) may be associated with deflation. The analysis is based on an international dataset over a long time period. Classifying age groups into young, working, younger old and older old, we find that the shares of the young and the younger old groups are inflationary, while those of the working group disinflationary, and those of the very old group seemingly deflationary.

JEL Classification: E31, E37, J11, J14.

Keywords: Demographic Changes, Population Aging, Inflation, Macroeconomic Impacts.

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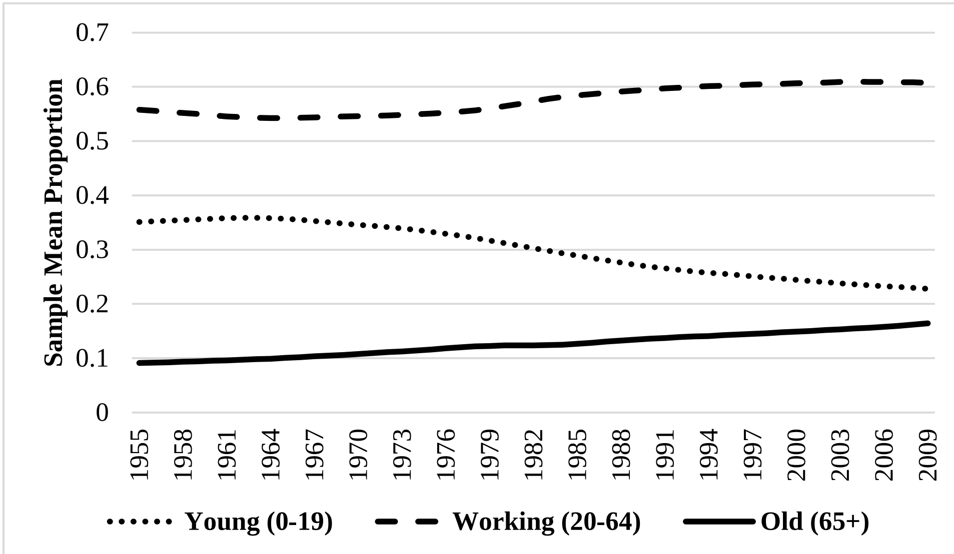
1 INTRODUCTION

In many countries, the population is aging. Actuaries are aware of the financial impact that increasing old-age dependency ratios will have for PayGo pension schemes and other unfunded social support systems, such as health and long-term care. But what impact will a changing demographic structure have, if any, on economic factors such as inflation? This question is also of vital importance to actuaries who use demographic and economic projections in the pricing and valuation of products, design of risk management solutions, and in opinions regarding the sustainability of social programs. Many actuarial products are priced and valued using nominal interest rates. The profitability of such products is directly affected by the level of inflation. Actuarial present values of future income streams are lower the higher the inflation rate used for valuation. Should our models account for any association between ageing and the level of inflation? This paper examines the above question using an international dataset, to offer insights that may be of use to practicing actuaries.

The world population has experienced a drastic shift in terms of both size and composition in the past few decades. Figure 1 depicts the (unweighted) mean proportions of three age groups (the Young 0-19, Working Age 20-64, and the Old 65+) across 22 OECD countries, over the period 1955-2010. In this sample, the average proportion of the Old group has increased from 9% in 1955 to 16% in 2010, with most of the decline in share occurring in the Young group. The average proportion of the population in the Working Age group increased from 57% in 1955 to 60% in 1993, and remained level thereafter.

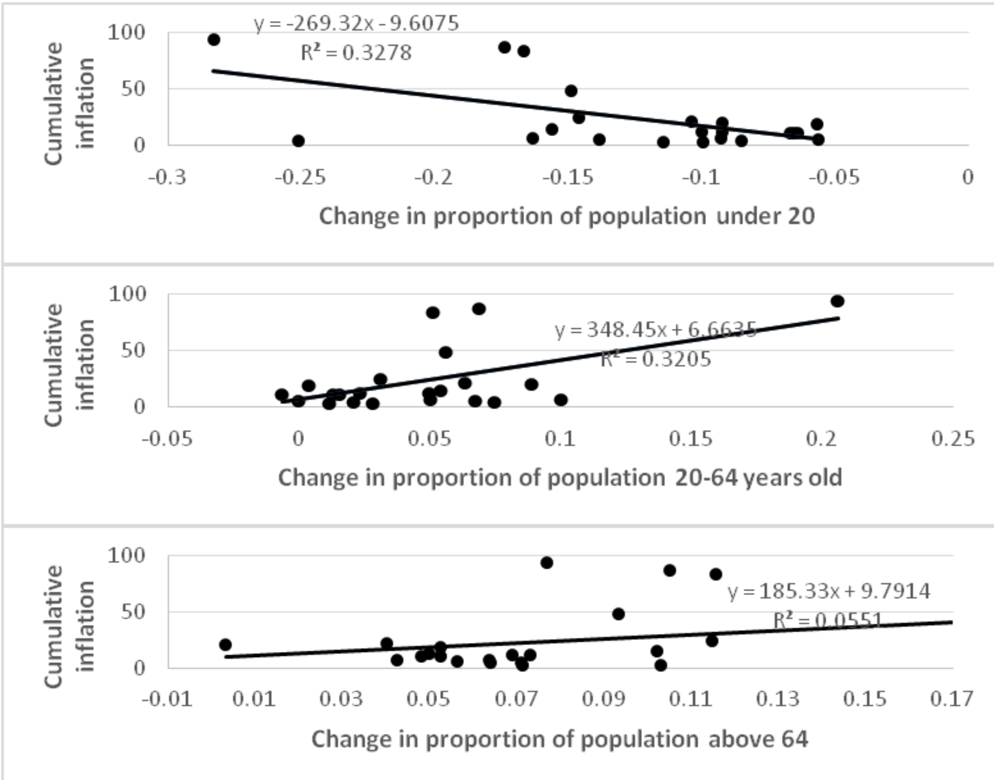
Figure 1: Unweighted cross-country average population shares



Note: The sample consists of 22 OECD countries. For the purpose of this chart, we divide the population into three age groups: the Young (0-19 years), Working Age (20-64 years) and Old (65 years and over). We plot the cross-country average of the share in population of each age group for each year from 1955 to 2010. The data source is the United Nations World Population Prospects (2013).

Currently, several aging countries are also experiencing historically low inflation and, in some instances, even deflation. Given the projected global aging, it is important to understand the link between the two (if it exists), since it may have significant implications for actuarial practice. In three panels in Figure 2, we plot the cumulative inflation against the change in the proportion of the population of Young 0-19, Working Age 20-64, and the Old 65+, respectively, over the period 1955 – 2010 for our sample of 22 countries. These plots suggest that countries with a smaller decrease in the share of the Young experienced lower inflation while those with a greater increase in the share of the Working Age experienced higher inflation. On the other hand, the association with the Old is unclear. Without controlling for other factors, this is contrary to recent findings that higher shares of working age population are associated with lower inflation. This suggests that the question of association is worth studying further.

Figure 2: Cumulative Inflation (1955 – 2010) vs. Changes in the proportions of age groups



Note: The sample consists of 22 OECD countries. For each country, we calculate the change between 1955 and 2010 in the share of each of three age groups: the Young (0-19 years), Working Age (20-64 years) and Old (65 years and over). We plot this change against the cumulative inflation over the same period in each of the countries, presenting one scatter plot for each age group. Note the horizontal axis scales are different.

With respect to the relation between the Old group and inflation, recent studies by Yoon et al. (2014) and Juselius and Takáts (2015, 2016a, 2016b) arrive at opposing conclusions although they use similar datasets in their studies. In particular, while Yoon et al. predict that an increase in the share of the older age groups relative to those under 15 years old will potentially introduce deflationary pressures on the economy, Juselius and Takáts find that the older age group exerts inflationary pressures.[5] We hypothesize that to reconcile these two opposing findings, a finer decomposition of the older age group will be required.

We present analyses using both, an age grouping similar to that used in the literature, and one in which the older ages are separated into two groups. A typical time trend of inflation among the OECD countries is that it rose in the late 1960s and after peaking in the late 1970s it gradually declined and stayed relatively low in the 1990s and thereafter. To avoid conflating the possibly independent trends in demography and inflation, we also analyze the relationship over two sub-periods, 1955-1979 and 1980-2010.

Juselius and Takáts (2015) introduced a polynomial specification for the relationship between population age share and inflation, reporting a large variation of specifications and tests based on this structure. We first implemented the apparently most robust version of their regression model, with a fourth degree polynomial in demographics, fixed effects, and various controls as regressors. We do this for the total period and the two sub-periods 1955-79 and 1980-2010.[6] We find that older ages have a disinflationary or deflationary association. However, Juselius and Takáts (2015, 2016a, 2016b) did not elaborate on somewhat similar findings in their paper, instead they focussed on the U-shape of the "pre-tail" portion of their polynomial estimates.

We believe that the tail is in fact important and significant, and may perhaps offer an opportunity to reconcile conflicting findings. To show this, we extended the number of age groupings in our second investigation. Using OECD data for a shorter sub-period, 1990-2010, we

[5] Although the sign is negative, the significance of the relationship between the old age group and inflation is not entirely clear from the results reported by Yoon et al. (2014), while Juselius and Takáts (2015, 2016a, 2016b) use an alternative methodology, ignoring the tail end of their estimates. We discuss this in more detail in Section 2.

[6] We are grateful to an anonymous referee for suggesting this exercise. It is worth noting that including time fixed effects in the model makes the demographic variables similar across the two sub-periods.

made use of a finer breakdown of the old age group available for this period. We found that the relationship at older ages is strongly deflationary for this latter period, but not so for the younger old. This is also consistent with the findings of studies on Japanese data (see Anderson et al., 2014; Muto et al., 2012; Shirakawa, 2012). Our findings also remain qualitatively the same when we estimate panel regressions for the entire sample period of 56 years and the two major sub-periods, this time separating the older age groups into younger old (65-74 years) and older old (75+).

The above analyses do not provide evidence of causation, but rather of association, which is the goal of this paper. However, as a complementary analysis, we estimated a reduced-form panel-data Vector Autoregression (VAR) model to capture dynamic interactions among some key macroeconomic variables and shares of age groups. Our aim was to determine how much of the variation in inflation can be explained by the evolution of the demographic structure, when allowance is made for interactions among these other key macroeconomic variables. We found that the changing age profile across selected countries does have an economically and statistically significant impact on inflation, after controlling for oil prices. However, the short period of appropriate data availability for this exercise means that we again observe a life-cycle pattern; i.e., dependent cohorts in general have an inflationary impact. Our conclusion is that only more advanced aging shows a deflationary association, thereby explaining some of the contradictions in the literature.

The remaining parts of this paper are organized as follows. In Section 2, we present a selected review of literature. In Sections 3 and 4, we provide two investigations, including analyses on the OECD panel over different sub-periods, and on the OECD panel with more age groupings in the older tail. In Section 5, we provide analysis using the reduced form panel-data VAR to provide a form of robustness check on our analysis. Section 6 concludes

2 RELATED LITERATURE

There is considerable literature regarding the effects of demography, in particular the age structure of the population, on economic growth, and other leading macroeconomic variables. In particular, the link between age structure and growth has been widely studied in recent times.[7] Evidence of the economic significance of the impact of the age structure on the economy has not been clear cut. On the one hand, theoretical macroeconomic models, which are typically calibrated on the age profile of savings, have highlighted the importance of demographic structure, as have many commentaries on economic policy. On the other hand, the econometric evidence assembled has been seen to be less compelling. There are a number of reasons for this.

In particular, most of the changes in demographic structure have occurred at low frequencies. This renders it difficult to distinguish the impact of demographic structure from the other low frequency trends that typically dominate economic time series. In addition, the vector of proportions in each age group is also inevitably highly collinear, making precise estimation of the effect of each age group a difficult, if not impossible, task. Faced with these difficulties, it has become a common practice in this literature simply to impose strong restrictions on the effect of the demographic structure, for instance, through the use of a single proxy, known as the dependency ratio. However, the balance of the evidence suggests that one cannot rule out the risk that an older age structure has a negative impact on economic growth. Given this evidence, it is reasonable to expect that an economy with an aging population, when accompanied by high debt

[7] For studies on this subject, see Acemoglu and Johnson (2007), Arnott and Chaves (2011), Bloom et al. (2007), Bloom et al. (2010), Callen et al. (2004), Feyrer (2007), Gomez and Hernandez de Cos (2008), Jaimovich and Siu (2009), Katagiri (2012), Konishi and Ueda (2013), Lindh and Malmberg (1999), McMorrow and Roeger (1999).

and low employment, may give rise to an environment that has a tendency to have low inflation or even deflation.

Japan has the most rapidly aging population in the world and experienced persistent deflation over the past two decades. Various channels through which demographic changes affect inflation in Japan have been examined in the past few years. Using a deterministic life-cycle economic model with capital, Bullard et al. (2012) find that the optimal inflation rates suggest that aging population structures like those in Japan may contribute to observed low rates of inflation or even deflation. Katagiri (2012) investigates the effects of changes in demand structure caused by population aging on the Japanese economy using a multi-sector Keynesian model with job creation/destruction. He finds that such demand shocks caused around 0.3 percentage point deflationary pressure on year-to-year inflation from the early 1990s to the 2000s in Japan. Katagiri (2012) shows that the repetition of such upward revisions made those effects look more persistent.

Based on simulation of a calibrated IMF Global Integrated Fiscal and Monetary (GIMF) model, Anderson et al. (2014) find that substantial deflationary pressures arise from population aging, mainly from declining growth and falling land prices. In addition, the repatriation of foreign assets by the elderly leads to real exchange rate appreciation, which exerts a downward pressure on inflation because of increased demand for relatively cheaper foreign goods and services[8]. By embedding the fiscal theory of the price level[9] into an OLG model, Katagiri et al. (2014) find that the effects of aging critically depend on its causes. Aging is deflationary when caused by an increase in longevity but inflationary when caused by a decline in birth rate. In the

[8] There is a considerable increase in the proportion of imported foreign goods in domestic consumption in Japan over the last decade. According to World Bank national account data, this ratio was 9.8% in 2001 and continuously increased to 19.0% in 2013.

[9] Fiscal theory of the price level states that the government will reduce the impact of its (debt) obligations of an unsustainable policy through inflation.

case of Japan, they believe that it is unexpected longevity, not simply aging, that has induced a deflationary pressure. In addition, Societe Generale (2016) provides an overview for consequences of aging for price dynamics. It argues that the graying of the population could potentially influence price dynamics through a wide-ranging set of key macroeconomic variables and therefore it is hard to tell from the purely theoretical perspective how changes in demographics will ultimately shape the inflation rate behavior.

Our paper is focused on the empirical aspects of the relationship between population aging and inflation. In recent studies, Juselius and Takáts (2015, 2016a, 2016b) and Yoon et al. (2014) have estimated the effect of demographic changes on inflation using post-war panel data of developed countries. However, they reached opposing conclusions.

On the one hand, using a panel dataset covering 30 OECD economies for the period of 1960-2013, Yoon et al. (2014) find that population growth is inflationary, while aging is potentially deflationary. On the other hand, looking at a similar panel of 22 OECD countries from 1955 – 2010, Juselius and Takáts (2015, 2016a, 2016b) find that aging is inflationary rather than deflationary. That is, a larger share of dependents (both young and old) is correlated with higher inflation, whereas having more working population leads to lower inflation. Both papers extend their arguments based on the relative speed of adjustment of aggregate supply and aggregate demand to provide some intuition for their findings.

To compare the two papers, we identify a panel regression in each paper that can be directly compared with its counterpart in the other paper. Table 4, Specification 3 in Yoon et al. (2014), and Table 1, Specification 4 in Juselius and Takáts (2015) are as follows:

$$\pi_{it} = \mu_0 + \mu_i + \beta_1 s_{it}^w + \beta_2 s_{it}^o + \varepsilon_{it}, \qquad [1]$$

$$\pi_{it} = u_i + \theta_1 s_{it}^y + \theta_2 s_{it}^w + \theta_3 s_{it}^o + \epsilon_{it}. \quad [2]$$

where s_{it}^y, s_{it}^w, and s_{it}^o are the shares of young, working age and old, respectively. μ_0 is a constant and μ_i is the country-specific fixed effect. Note that there is no constant in Equation [2] because the three population shares sum to unity. The difference between them lies in their treatment of trend inflation: while one uses a quadratic filter to remove the trend, the other incorporates time fixed effects in the model. Overall, the net effect of the old age group on inflation according to Yoon et al. (2014) is estimated as $\frac{\mu_0}{100} + \beta_2 = -0.0406$, but the statistical significance of this net effect is not reported in their paper. In both papers, the coefficient on the share of the working age group is also found to be negative, although it is statistically significant only in the study by Juselius and Takáts (2015). Their findings agree on the inflationary tendency of the young (dependents) group. In the rest of the paper, we conduct analyses that help show the importance of incorporating distinct groups for older ages in the dataset.

3 ANALYSIS OF OECD DATA FOR VARIOUS TIME PERIODS

In this section, following Juselius and Takáts (2015), we examine the relationship between inflation and demographic structure for various time periods using panel analysis. The full panel covers the period of 1955 – 2010, but we also examine the relationship for shorter sub-periods. In terms of country coverage, we use 22 OECD countries for which good quality data are available: Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the United States.

The annual inflation rate is obtained from OECD, World Bank Indicators and national data. We denote the inflation rate as π_{it}. We index country by$i$ where, $i = 1,2, \ldots, N$, and year by

t where, $t = 1,2, \ldots, T$. The demographic data was obtained from the United Nations (2012). In this analysis, we use finer demographic proportions: the total population (0 – 80+) is divided into 17 five-year age groups (denoted by N_{kit} where$k = 1, \ldots, 17$). The corresponding share of group k in a country's total population is given by $n_{kit} = N_{kit}/N_{it}$.

In addition to inflation rate and age structure variables, we use the following control variables. First, the real interest rate $\mathrm{r_{it}}$, is used to roughly proxy the monetary policy. We define the ex-post real interest rate as the difference between the average nominal overnight rate and the inflation rate during the same year. We collect and compile nominal interest data from various sources, including OECD, IMF's World Economic Outlook (WEO) and national data. Second, the inflation rate may also be affected by the output gap, as suggested by standard monetary models. To compute the output gap y_{it}, we use the deviation in real GDP from a Hodrick-Prescott filtered trend (with λ set to 100, the standard value for yearly frequency). Finally, data of real GDP is obtained from OECD and WEO.

The panel-regression model is written as

$$\pi_{it} = \mu_0 + \mu_i + \mu_t + \sum_{p=1}^{4} \gamma_p \tilde{n}_{pit} + \beta_1 r_{it} + \beta_2 \hat{y}_{it} + \varepsilon_{it}. \qquad [3]$$

where μ_0 is a constant, μ_i and μ_t are the country-specific and time fixed effects, respectively. $\tilde{n}_{pit}$ are the fourth order population polynomials[10], which are used to overcome the estimation problems associated with direct use of age groups. Once estimates of the γ_p have been obtained, the corresponding coefficients on age groups can be directly computed.

We examine the age patterns on inflation for the OECD panel with various sub-periods, including those years before and after 1980. Results are reported in Table 1. The first column

[10]See Fair and Dominguez (1991), Higgins (1998), and Arnott and Chaves (2011) for details.

presents the estimates of our panel regression over the whole period. The second and third columns are for the sub-period of 1955 – 1979 and the sub-period of 1980-2010, respectively. The last column lists the estimates for the model with more refined age groups over the period of 1990-2010 (discussed below in Section 4).

Table 1: The relationship between demography and inflation for various periods

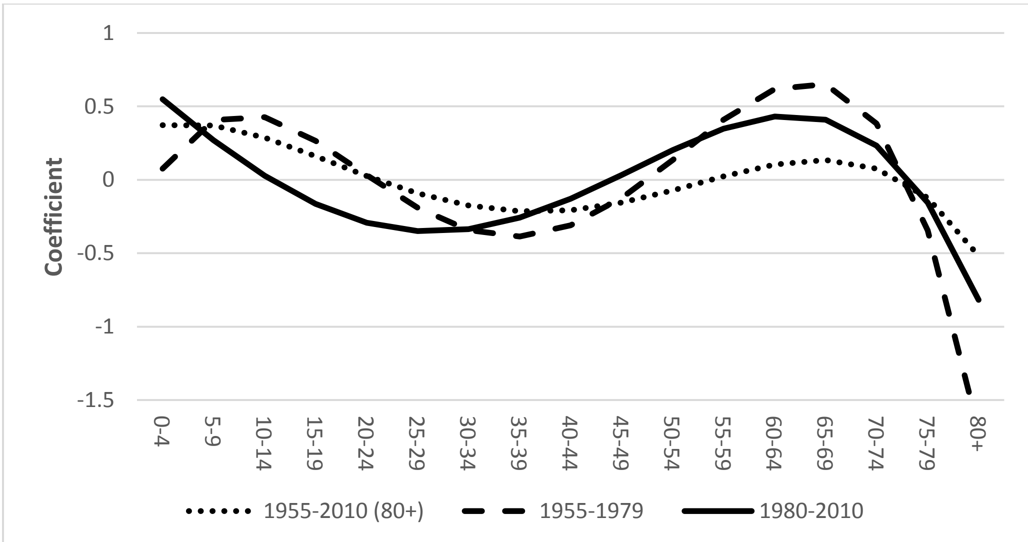
(Dependent variable: inflation rate π_{it})

Model	**22 OECD 1955-2010**	**22 OECD 1955-1979**	**22 OECD 1980-2010**	**22 OECD 1990-2010 (100+)**
Polynomial n1	**0.21**	**1.09*** **	**-0.28**	**0.26**
Polynomial n2 (×10)	**-0.92** **	**-3.22*** **	**-0.11**	**-0.84*** **
Polynomial n3 ($\times 10^2$)	**0.98*** **	**3.18*** **	**0.57** **	**0.81*** **
Polynomial n4 ($\times 10^3$)	**-0.31*** **	**-0.99*** **	**-0.26*** **	**-0.24*** **
Real interest rate	**-0.54*** **	**-0.65*** **	**-0.52*** **	**-0.41*** **
Output gap	**0.04*** **	**0.07* **	**0.03*** **	**0.02*** **
R-squared	**0.80**	**0.88**	**0.77**	**0.71**
Observations	**1023**	**367**	**656**	**451**

Note: We report the results of panel regressions of inflation on an age polynomial and control variables controlling for country fixed effects and time fixed effects (not included here for ease of reading). The dataset represents annual observations for a panel of 22 OECD countries. The final column uses data for a shorter period, but with a finer distribution of population age shares in the older age groups. * denotes significance at the 10% level; ** denotes significance at the 5% level; and *** denotes significance at the 1% level.

Estimated coefficients of the population polynomials are statistically significant in most cases, with the weakest results for the period 1980-2010. The age group effects on inflation are computed using estimates of γ_p and presented in Figure 3. The dotted, dashed and solid curves are derived from the panel regressions over the whole period, the sub-period of 1955 – 1979 and the sub-period of 1980-2010, respectively. The relationship exhibits a U-shape until approximately age 70, but then reverses downward again for later ages. The young and the younger old age groups have a positive impact on inflation, whereas the working age population and the older age groups have a negative effect.

Figure 3: Age group impacts on inflation: Complete data and sub-periods



Note: The dotted, dashed and solid curves are produced from the age polynomials in the panel regressions (Equation 3) over the whole period, the sub-period of 1955 – 1979 and the sub-period of 1980-2010, respectively.

Compared with the full period benchmark model (the dotted line), the effects in the two sub-periods appear more pronounced, but they follow roughly the same pattern.

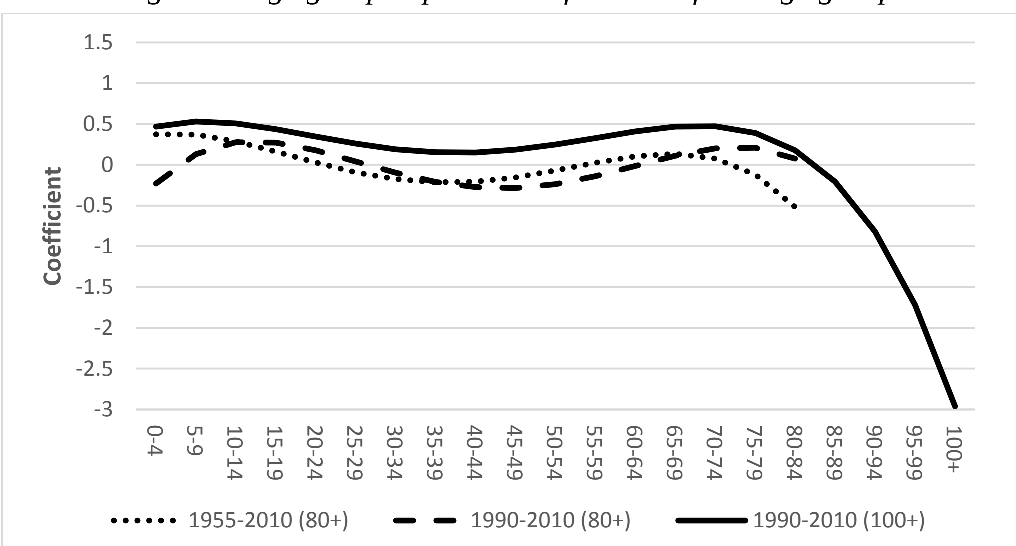
In addition, in each regression, the real interest rate has a significant negative effect, while the output gap also affects inflation. These support the suggestion in Juselius and Takáts (2015) to include these variables as regressors.

4 Analysis of the very old

From observing the relationship between the age patterns and inflation, it is reasonable to hypothesize that the “younger old” may be inflationary but the “older old” are deflationary. Since the U.N. population table does provide more refined demographic data for “older old” from 1990, i.e. data on 80-84, 85-89, 90-94, 95-99, 100+ age groups, we can test the hypothesis using an OECD panel over the period of 1990 – 2010. The estimation results are listed in the last column of Table 1. All estimated coefficients are statistically significant, even though the use of the short period (1990 – 2010) decreases the explanatory power of the covariates.

Figure 4 shows the age group effects on inflation. The solid curve represents the age pattern derived from the new sub-period panel regression with finer demographic data. The dashed line is for the same sub-period panel but with the original age group definition. The dotted line is again for the benchmark model with full panel. From the graph, it is obvious that our hypothesis is supported. That is, for the old population, the older the age, the more deflationary the age group is. In addition, the U shape is less pronounced for the new sub-period panel.

Figure 4: Age group impacts on inflation: refined age groups



Note: The dotted and dashed curves are derived from the panel regressions over the whole period, the sub-period of 1990 – 2010, respectively. The solid curve represents the age pattern derived from the sub-period 1990-2010 panel regression with finer demographic data on people over 80 years old.

It is important to recognise that period 1990-2010 was characterized by low and declining inflation, so although we include time fixed effects in the regression, the estimates over this period should be interpreted with caution. A referee has suggested that we seek more evidence of our hypothesis by conducting a further sub-period analysis, by breaking the sample into a higher inflation period (1955-1979) and a declining inflation period (1980-2010). To this end, we estimate further panel regressions of inflation on demographic structure, this time using shares of age groups as regressors. However, we break the older age group into two parts. The model specifications are as follows.

$$\pi_{it} = \mu_i + \mu_t + s_{it}^{y} + s_{it}^{w} + s_{it}^{yo} + s_{it}^{vo} + \beta_1 r_{it} + \beta_2 \hat{y}_{it} + \varepsilon_{it}. \qquad [4]$$

where (s_{it}^{y}, s_{it}^{w}, s_{it}^{yo}, s_{it}^{vo}) are the shares of age groups in total population for the young (0-19), the working age (20-64), the younger old (65-74) and the very old (75+) respectively. The estimation results are presented in Table 2.

Table 2: Demographic structure and inflation: Sub-period analysis

(Dependent variable: inflation rate π_{it})

	Sub-period 1955 - 1979		**Sub-period 1980 - 2010**	
Model	**(1)**	**(2)**	**(3)**	**(4)**
Share of young (0-19)	**0.12**	**0.17*** **	**0.35*** **	**0.34*** **
Share of working (20-64)	**-0.06**	**-0.02**	**0.03**	**-0.01**
Share of young old (65-74)	**3.33*** **	**0.67**	**0.18**	**0.58*** **
Share of very old (75+)	**-5.70*** **	**-2.23** **	**-0.48* **	**-0.47** **
Real interest rate		**-0.63*** **		**-0.55*** **
Output gap		**0.08** **		**0.03*** **
R-squared	**0.858**	**0.954**	**0.833**	**0.882**
Observations	**550**	**367**	**682**	**656**

Note: We report the results of panel regressions (Equation 4) of inflation on shares of age groups and control variables, with fixed effects (not included here for ease of reading). The dataset represents annual observations for a panel of 22 OECD countries. * denotes significance at the 10% level; ** denotes significance at the 5% level; and *** denotes significance at the 1% level.

For both periods, the share of the young old is associated with positive coefficients, although they are statistically significant in only two out of four cases. The coefficient on the share of the very old is significant and negative in all four regressions. In the sub-period 1955-1979, controlling for the real interest rate and the output gap leads to a drop in the size of the estimate but it retains its significance. The estimate is still much larger than that in the sub-period 1980-2010. While controlling for conditions through the real interest rate and the output gap would plausibly reduce the size of the estimate in the first sub-period, the difference between the two sub-periods requires some consideration. One possible explanation for this difference is that both the level and variability of inflation were much higher in the first sub-period than the second. This is especially plausible because the regressions also include time fixed effects to control for factors such as the change in the relative size of the older age groups over time. Overall, we can see that the inclusion of the older age group helps in clarifying the association between age and inflation.

5 VECTOR AUTOREGRESSIVE MODEL AND SUMMARY OF MAIN RESULTS

We carry out additional work to incorporate dynamics in our analysis using a VAR model. While VAR is a more robust approach to use since it is model free, changes in data definitions affect the ability to model the cross-country panel time series in this way. After reviewing changes in methods in compiling the OECD data, there is only a relatively short period of data that we could use. Since we are investigating the long term impact of demographics, which may have low frequency impacts, the short period of consistent data is a limitation for this methodology. Hence, we use the results obtained from the VAR analysis mainly as a robustness check on our previous analysis.

The approach undertaken in this section has three important characteristics. First, we consider one year period and adopt a panel time-series approach to estimation of our VAR models. Second, we allow for interaction effects among a number of leading macroeconomic variables by estimating a VAR model instead of an individual equation. Third, we make no assumptions about the underlying economic processes and hence impose a minimal structure on the data.

5.1 Data and econometric model

The annual dataset covers the period 1999-2010 covering twenty countries. Because of differences in data sources, in this analysis Iceland has been added, but Korea, Portugal and Spain have been excluded.

The demographic data was obtained from the United Nations (2012). The annual data on savings and investment rates were calculated from Nominal GDP, Investment and Savings series obtained from the OECD (2012), which also supplied the data on hours worked. Annual data on policy rates and the Consumer Price Index (CPI) were obtained from the IMF (2012). Per-capita GDP growth rates were calculated from per-capita real GDP obtained from Penn World Tables 7.1.

We index country by i where, $i = 1,2, \ldots, N$, and year by t where,$t = 1,2, \ldots, T$. In the empirical analysis, we are faced with two challenging problems. First we have at our disposal a relatively small number of time-series observations at the annual frequency. Second for each country, we also have a large number of macroeconomic control variables which are low frequency and, hence, likely to be highly co-linear. Both factors can contribute to low precision of the parameter estimates of the panel-data VAR regressions. As a result, we decide on relatively coarse demographic proportions by ten-year age bands. Denote the share of age group

$j = 0,1,\ldots,7$(0 -9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70+) in total population by w_{jit} and suppose the effect on the variable of interest, say x_{it}, takes the form:

$$x_{it} = \alpha + \sum_{j=0}^{7} \delta_j w_{jit} + u_{it}. \qquad [5]$$

As $\sum_{j=0}^{7} w_{jit} = 1$, there is perfect collinearity among the demographic proportions if all the demographic shares are included. To deal with this, we restrict the coefficients to sum to 0, use $w_{jit} - w_{7it}$ as explanatory variables and recover the coefficient of the oldest age group from $\delta_7 = -\sum_{j=0}^{6} \delta_j$. We denote the 7 ($j = 0,1,\ldots,6$) elements' vector of $w_{jit} - w_{7it}$ as W_{it}.

The six endogenous variables of the system are:

1. the growth rate of the real GDP, y_{it};
2. the share of investment in GDP, I_{it};
3. the share of personal savings in GDP, S_{it};
4. the logarithm of hours worked[11], H_{it};
5. the nominal short interest rate, R_{it}; and
6. the rate of inflation, π_{it}.

We denote the vector of these six variables as $Y_{it} = \left(y_{it}, I_{it}, S_{it}, H_{it}, R_{it}, \pi_{it}\right)$. The exogenous variables are: W_{it} and two lags of the logarithm of the real oil price.[12] We allow for intercept

[11] It is customary in empirical studies to take the logarithm of *continuous* variables in order to (i) stabilize the variance of the variables a bit, to capture potential nonlinearities in the variable; (ii) to render residuals more symmetrically distributed; and (iii) to facilitate interpretation of the coefficient estimates of parameters as elasticities.

[12] The reason we use two lags on the oil price, rather than one, is because the second lag is statistically significantly different from 0.

heterogeneity through a_i but assume slope homogeneity and estimate a one-way fixed-effect augmented-panel VAR (2) of the form[13]:

$$Y_{it} = a_i + A_1 Y_{i,t-1} + A_2 Y_{i,t-2} + DW_{it} + u_{it}. \qquad [6]$$

plus two lags of the oil price. In Equation [6], D is the matrix of coefficients of the demographic variables. The long-run moving equilibrium for the system is then given by:

$$Y_{it}^{*} = (I - A_1 - A_2)^{-1} a_i + (I - A_1 - A_2)^{-1} DW_{it}. \qquad [7]$$

where $(I - A_1 - A_2)^{-1} D$ captures the effect of the demographic variables. This reflects both the direct effect of demographics on each variable and the feedback between the endogenous variables. This allows, for instance, the effects of demography on savings to influence growth through the effect of savings on growth.

We can isolate the long-run contribution of demography to each variable in each country by:

$$Y_{it}^{D} = (I - A_1 - A_2)^{-1} DW_{it}. \qquad [8]$$

This is the demographic attractor for the economic variables at any given time. In this analysis, we will examine the movements of elements of this vector, Y_{it}^{D}, over time, to indicate the contribution of demographics to the evolution of a particular variable in a particular country.

5.2 Results of Panel-data VAR regressions

We examine both the short and long term impacts. By exploring the D matrix of short term demographic impacts on the six endogenous variables, we find that the individual coefficients are not very well determined due to high collinearity among the variables in the VAR

[13] We use a VAR (2) specification primarily to allow for more flexible dynamics and to deal with potential non-stationarity. Moreover, working with a VAR (2) specification (instead of VAR(1) specification) reduces the potential of spurious regression although we believe that spurious regression is less of a problem in the panel data setting, in particular when the cross-section dimension is large relatively to the dimension of time series.

specification. However, the hypothesis that the coefficients of the demographic variables are jointly not significantly different from zero is strongly rejected for all equations except hours worked (see Table 4 and Table 5).

Table 4: VAR Results for Growth, Investment and Savings

	GDP growth (*y*)			**Share of investment (*I*)**			**Share of savings (*S*)**		
	Estimate	**Std. Err**	**|t-stat|**	**Estimate**	**Std. Err**	**|t-stat|**	**Estimate**	**Std. Err**	**|t-stat|**
y_{t-1}	0.277***	0.058	4.775	0.138*	0.041	3.366	-0.071**	0.051	0.062
I_{t-1}	-0.310***	0.116	2.672	0.929***	0.072	12.903	0.056	0.082	0.683
S_{t-1}	0.084	0.074	1.135	0.048	0.038	1.263	0.954***	0.057***	16.737
H_{t-1}	0.027	0.015	1.800	-0.024	0.018	1.333	0.011*	0.041	0.268
R_{t-1}	-0.225	0.101	2.228	-0.090	0.029	3.103	-0.052	0.051	1.020
π_{t-1}	-0.063*	0.051	1.235	0.021	0.041	5.122	0.013	0.032	0.406
y_{t-2}	0.011***	0.037	0.297	0.062***	0.032	1.937	-0.047	0.042	1.119
I_{t-2}	0.059	0.011	5.364	-0.194	0.048	4.042	-0.203*	0.082**	2.476
S_{t-2}	-0.065	0.060	1.083	-0.051	0.029	1.759	-0.210	0.075***	2.800
H_{t-2}	-0.009	0.065	0.138	0.047	0.035	1.343	-0.129*	0.040***	3.225
R_{t-2}	-0.062	0.012	5.167	-0.021	0.031	0.677	-0.064*	0.041	1.561
π_{t-2}	-0.052*	0.014	3.714	-0.012*	0.041	0.293	0.020	0.022	0.909
$POIL_{t-1}$	-0.019***	0.014	1.357	0.003	0.000	2.717	-0.011	0.000**	2.245
$POIL_{t-2}$	0.021	0.015	0.140	0.001***	0.000	1.988	0.001	0.000*	1.929
δ_0	-0.029	0.081	0.358	0.062*	0.041	1.512	-0.065**	0.072	0.903
δ_1	0.217	0.101	2.148	-0.040	0.051	0.784	0.139	0.052	2.673
δ_2	0.182	0.071	2.563	0.093*	0.030	3.100	0.020	0.063	0.317
δ_3	-0.004*	0.006	0.667	-0.067**	0.041	1.634	0.102***	0.083	1.229
δ_4	0.040	0.082	0.488	0.010	0.040	0.250	0.124	0.073*	1.700
δ_5	0.045	0.082	0.549	0.040	0.051	0.784	0.210*	0.010**	2.100
δ_6	-0.000	0.101	0.004	0.230	0.101	2.277	0.031	0.102	0.304
δ_7	-0.455			-0.240			-0.314		
R^2	0.29			0.79			0.70		
$\Pr(\delta_j = 0)$	0.000			0.00			0.000		
OBS	238			238			238		

Note: 1. The row for $\Pr(\delta_j = 0)$ reports the joint significance of the 7 demographic variables in the equation. 2. * denotes significance at the 10% level; ** denotes significance at the 5% level; and *** denotes significance at the 1% level.

Table 5: VAR Results for Hours, Interest Rate and Inflation

	Log of hours (*H*)			**Nominal interest rate (*R*)**			**Inflation (*π*)**		
	Estimate	**Std. Err**	**|t-stat|**	**Estimate**	**Std. Err**	**|t-stat|**	**Estimate**	**Std. Err**	**|t-stat|**
y_{t-1}	0.204***	0.041	4.976	0.150	0.162	0.926	0.252***	0.084	3.000
I_{t-1}	0.002	0.081	0.025	-0.195	0.168	1.161	-0.390**	0.170	2.294
S_{t-1}	0.064	0.040	1.600	0.006*	0.063	0.095	0.031	0.182	0.170
H_{t-1}	1.128***	0.055	20.509	0.241***	0.049	4.918	0.153*	0.072	2.100
R_{t-1}	-0.140	0.032	4.375	0.033	0.378	0.087	-0.123***	0.155	0.793
π_{t-1}	0.010	0.031	0.322	0.124	0.132	0.939	0.541*	0.227**	2.383
y_{t-2}	0.041	0.033	1.242	0.062*	0.034	1.823	0.133	0.083	1.602
I_{t-2}	-0.083	0.091	0.912	0.209	0.206	1.015	0.573	0.408	1.404
S_{t-2}	-0.062	0.039	1.589	-0.038	0.054	0.703	0.040	0.084	0.476
H_{t-2}	-0.192***	0.045	4.267	0.386*	0.214	1.800	-0.159	0.077**	2.467
R_{t-2}	-0.002	0.032	0.062	0.383*	0.211	1.815	-0.048	0.122	0.393
π_{t-2}	0.021	0.040	0.525	-0.071**	0.031	2.290	0.019	0.047	0.404
$POIL_{t-1}$	-0.010***	0.003	3.333	-0.011	0.003	0.367	-0.018***	0.002	9.000
$POIL_{t-2}$	0.010***	0.003	3.333	0.001	0.003	0.333	0.018***	0.012	1.500
δ_0	-0.010	0.073	0.136	0.161***	0.011	14.636	0.460	0.017***	27.059
δ_1	-0.070	0.082	0.853	0.041	0.091	0.450	0.100	0.158	0.633
δ_2	0.060*	0.064	0.937	-0.040	0.061	0.656	-0.140	0.129	1.085
δ_3	0.090	0.065	1.384	-0.181	0.121	1.496	-0.450	0.210**	2.143
δ_4	0.020	0.062	0.323	-0.090	0.110	0.818	-0.261	0.203	1.286
δ_5	0.120	0.094	1.277	0.070	0.151	0.463	-0.041	0.211*	0.194
δ_6	0.090	0.091	0.989	0.220*	0.131	1.679	0.181	0.293	0.618
δ_7	-0.240			0.200			0.151		
R^2	0.95			0.89			0.87		
$\Pr(\delta_j = 0)$	0.101			0.001			0.001		
OBS	238			238			238		

Note: 1. The row for$\Pr(\delta_j = 0)$ reports the joint significance of the 7 demographic variables in the equation. 2. * denotes significance at the 10% level; ** denotes significance at the 5% level; and *** denotes significance at the 1% level.

Note that the estimate of the coefficient δ_6 (age group 60-69) on growth rate y is not significantly negative, and that on the oldest age group ($\delta_7 = -\sum_{j=0}^{6} \delta_j$) is negative at -0.455, although it is not statistically significant. That is, an increase in the share of old age group (70+) appears to induce a negative impact on economic growth rate. This is consistent with the conclusion given in Bloom et al. (2010), which analyses the implications of population aging for economic growth. They argue that for OECD countries, projected aging population causes drops in both labor force participation and labor-force-to-population ratios and therefore suggests modest declines in the pace of economic growth.

In theory, we would expect that the demographic structure has significant impacts on hours worked. That it does not in our empirical results may indicate that there are likely to be offsetting adjustments in the labor force participation rates. Generally the results are plausible, although there are some unexpected results. For instance there is a negative effect of the 30-39 age group on growth and a positive effect of teenagers on savings and of the 60-69 years group on investment.

Table 6 gives the $(I - A_1 - A_2)^{-1} D$ matrix. By comparison, we note that by allowing for rich dynamics and interactions among the macroeconomic variables, the long-run effects are found to be much larger. In particular, we notice that the effect on hours is markedly more pronounced in our empirical results, perhaps due to this variable being highly persistent over time. The VAR analysis supports the U-shape hypothesis found in Juselius and Takáts (2015, 2016a, 2016b) and in our results. However, the lack of statistical significance of parameters again supports the motivation of our analysis in including older age groups to clarify the relation between demographic structure and inflation.

Table 6: Long-Run Demographic Impact: Variable Values by Age Group

	y **(GDP growth)**	***I*** **(share of invest)**	***S*** **(share of saving)**	***H*** **(log of hours)**	***R*** **(nominal int)**	***π*** **(inflation)**
δ_0	-0.267	-0.190	-0.185	-0.109	0.575	0.975
δ_1	0.268	-0.170	0.591	-0.420	0.281	0.518
δ_2	0.088	0.432	-0.246	0.535	0.432	-0.213
δ_3	0.112	0.231*	0.361	1.864	-0.540	-1.002
δ_4	0.082	0.049	0.411	0.610	-0.553	-0.584
δ_5	-0.037	0.139	0.802	0.822	0.261	-0.1341
δ_6	-0.314	0.310	-0.141	-1.015	0.470	0.172
δ_7	0.0611	-1.021	-1.538	-1.433	-0.755	0.043

Note: 1. * denotes significance at the 10% level

The VAR analysis also enables us to perform further country-specific analysis. We consider how the results obtained in our study may shed some light on the question of whether the baby boomers squandered the demographic dividend. For this purpose, we conduct a counterfactual analysis. Table 7 shows, for the countries with available data, the impact on the six variables of the change in demographic structure between 1970 when the baby boomers were participating in the labor market, and 2010, when they were approaching retirement.[14] This is calculated using Equation [7] and the long-run estimates from the one way fixed effect model (Equation [6]).

[14] Note that only for the purpose of conducting a counterfactual exercise do we include observations starting from 1970 in our empirical analysis. In all other analysis, the estimation starts from 1999. This is because our experiment suggests that the panel-data VAR regressions exhibit major structural instabilities when the earlier samples from 1970 to 1998 are included in the estimation, producing highly biased estimates of the parameters.

Table 7: Difference in Predicted Impact of Demographic Factors between 1970 and 2010 (in percentage points, except H where it is a percentage)

	y **(GDP growth)**	***I*** **(share of invest)**	***S*** **(share of saving)**	***H*** **(log of hours)**	***R*** **(nominal int)**	***π*** **(inflation)**
Australia	-0.357	-0.174	-4.336	7.829	-7.911	-11.816
Austria	1.448	-0.555	-0.879	11.041	-9.522	-11.895
Belgium	0.183	-2.579	-4.962	4.187	-7.059	-7.250
Canada	-1.251	-0.655	-3.922	11.694	-9.639	-15.141
Denmark	-0.496	-1.781	-1.833	1.758	-5.675	-6.256
Finland	-1.750	-4.393	-9.207	-3.667	-7.590	-7.433
France	-0.261	-2.498	-4.292	3.896	-6.580	-7.627
Germany	1.404	-7.101	-10.007	-8.796	-12.773	-9.584
Greece	0.215	-3.587	-9.478	5.017	-11.058	-11.411
Iceland	-0.18340	2.065	-0.752	16.220	-8.736	-14.764
Ireland	0.830	5.093	0.934	22.338	-9.908	-17.299
Italy	0.105	-5.575	-11.659	1.1865	-11.069	-11.576
Japan	-2.884	-10.418	-17.562	-16.961	-9.913	-7.166
Netherlands	-0.751	-0.852	-2.051	5.855	-7.690	-10.916
New Zealand	0.018	0.883	-3.149	13.266	-9.063	-13.647
Norway	0.455	0.095	-0.817	9.392	-6.475	-9.083
Sweden	-0.052	-3.631	-4.885	-1.390	-5.488	-4.262
Switzerland	0.240	-2.626	-3.188	3.862	-8.473	-9.169
United Kingdom	0.985	-1.32	-4.075	5.238	-8.327	-8.425
United States	-0.686	0.822	-2.501	9.120	-6.426	-10.331

Note: This was calculated by applying the estimated long-run demographic coefficients to the demographic structure in each country as it was in 1970 and in 2010, and subtracting the result of the former from the latter. Updated April 20, 2015 to include Germany based on same parameter estimates as used for other countries.

The estimated impact of demographic changes on inflation varies across countries. We find that the estimated impact of demographic changes on both the interest rate and inflation is strongly negative and of quite similar orders of magnitude, consistent with real interest rate effects. Since the 1970s was the decade when the baby boomers entered the labor force strongly, we might have expected the supply-side effect to be deflationary, the arrival of such a large cohort depressing wages, but the demand-side effects might have been inflationary. Although both interest rates and inflation are expected to be higher around 1970 than in2010, the change over the period is not expected to be as large as predicted by demographic factors. However, caution regarding the actual, as opposed to the relative, magnitude is warranted, because the two-way fixed-effects estimates suggest that the demographic effects on these two variables might be overstated.

We further tested the robustness of our results with respect to the selected countries by re-estimating the specification in the panel-data VAR (2) regression on a dataset with each country excluded in turn. We obtain results that are relatively stable with respect to these exclusions, as are the tests as to whether the demographic variables are significant in each equation.

We also performed a number of other robustness checks with respect to the matrix of correlations between residuals, the presence of trends in the data, and removal of time effects. The results of these checks were all satisfactory. They are not reported here for the sake of brevity, but are available on request.

The panel VAR analysis had several limitations. Firstly, the short period of data necessitated analysis at the annual frequency, though it would be reasonable to assume that demography affects the economy in more subtle ways over longer periods of time. Secondly, both age structure and inflation exhibit long memory and there is a risk of detecting spurious relationships if the possibility of co-integration is not properly tested. Thirdly, estimation of the coefficients of low frequency and highly collinear determinants is highly sensitive to the specification of the model and the estimation method used. Lastly, although the proportions in each age group are plausibly exogenous, the other leading macroeconomic variables in the system are likely to be responding to the low frequency demographic impacts. This endogeneity has the effect of reducing the marginal contribution of the demographic variables to the overall performance of the economy.

6 CONCLUSION

In this paper, we analyze OECD panel data over the full period and sub-periods to investigate the impact of population aging on inflation. Our analysis suggests that it is the sub-period, rather than the panel sample, that shapes the pattern of the impact of aging on inflation. In addition, we believe that, as supported by the study on OECD data after 1990, a finer adjustment to age categories is needed to capture the potentially different effects of the older and younger of the 65+ age group. That is, for the old population, the older the age, the more deflationary the cohort is. This finding suggests that studies on the old should use a greater number of age groups. This is particularly important because the size and the length of this age group is increasing due to increasing longevity.

As for the OECD panel analysis, the challenge of determining the link between aging and inflation is that demographic changes exert (according to theory) opposing forces on price levels. Keeping population size constant, aging causes reduced expectations of growth and consumption (deflationary), while also reducing the resources available for production. This latter effect can take place directly or through structural transformation, which are both inflationary. An empirical examination of the relationship suffers from the danger of failing to control for other more salient factors that affect inflation. Moreover, the data appears to be a source of another problem – there is very little evidence of deflationary episodes in our sample period, making it difficult to analyze the prospects for deflation as opposed to disinflation, or inflation falling to low levels.

Given the limitations in getting a long period of consistently maintained data, we use a cross-country panel VAR model as a type of robustness check on our analysis. Several key variables were modelled jointly to be able to identify the effect of the age distribution on inflation. Our results indicate that the age profile of the population can have both an economically and a statistically significant impact on output growth, investment, savings, hours worked, interest rates and inflation. However, the panel VAR analysis suggests that the older age group is slightly inflationary. This result may be caused by coarse demographic groups and short period studied. Based on robustness checks conducted on the VAR analysis we believe that using such a model should provide more accurate predictions for growth and inflation over the long term horizon.

In conclusion, this paper demonstrates that demographic structure does affect economic factors such as inflation. However, the measurement and quantification of this impact remain challenging problems worthy of further research. This effect has significant implications for actuaries who make and rely on projections of demographic and economic effects in their work because demographic and economic assumptions are often set independently. The actuarial profession should stay informed regarding developing research in this area.

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