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Can demography affect inflation and monetary policy?[1]

Mikael Juselius[2] and Előd Takáts[3]

Abstract

Several countries are concurrently experiencing historically low inflation rates and ageing populations. Is there a connection, as recently suggested by some senior central bankers? We undertake a comprehensive test of this hypothesis in a panel of 22 countries over the 1955–2010 period. We find a stable and significant correlation between demography and low-frequency inflation. In particular, a larger share of dependents (ie young and old) is correlated with higher inflation, while a larger share of working age cohorts is correlated with lower inflation. The results are robust to different country samples, time periods, control variables and estimation techniques. We also find a significant, albeit unstable, relationship between demography and monetary policy.

Keywords: demography, ageing, inflation, monetary policy

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1. Motivation

Why was inflation high in the 1960s and 1970s and why is it low today? According to a widespread view, central banks made mistakes which allowed inflation to rise higher and higher. Only when they started to combat inflation in the early 1980s did it moderate. Yet controlling inflation has proven to be difficult once more as many advanced economies face what many regard as uncomfortably low inflation today.

Given these developments, some senior central bankers have suggested an alternative to the "pure mistake" view, arguing that low-frequency inflation may be linked to demographic change. Governor Shirakawa of the Bank of Japan (2011a, 2011b, 2012 and 2013) has argued that population ageing can lead to deflationary pressures by lowering expectations of future economic growth. While people might ignore the implications of an ageing population for a while, they revise their expectations when they recognise the extent of the economic impact. The resulting loss of demand and investment might not be easily offset by monetary policy, especially if inflation is already low and policy rates are close to the zero lower bound. President Bullard of the St Louis Federal Reserve Bank has suggested a different explanation focusing on the political economy of central banking. Bullard et al (2012) argue that the old might prefer lower inflation than the young due to the redistributive effects of inflation. Thus, to the degree their policies reflect voter preference, central banks might engineer lower inflation when populations age.

The potential connection between demography and inflation has also sparked interest from researchers at policy institutions such as the International Monetary Fund. Motivated by the experience of Japan, for example, Anderson et al (2014) find that ageing causes deflationary pressures, mainly via slowing growth. Imam (2013) finds that it can weaken monetary transmission. Yoon et al (2014) find, based on a panel regression, that ageing is deflationary.

Though unconventional, if right, a link between demography and inflation may have significant implications for monetary policy. Global ageing further underlies the need to understand the effects of changing age structure. Yet comprehensive empirical evidence on this potential link is missing: can we observe such a link? Is it robust? Can it be explained away by more traditional variables?

To inform the policy debate, we undertake a systematic empirical analysis of the potential link between demography and inflation. Specifically, we investigate the extent to which such a link is present in data from 22 advanced economies over the 1955–2010 period. Throughout the analysis we place emphasis on robustness: we try different samples, add time effects, include a wide variety of controls and use increasingly sophisticated estimation techniques to secure non-spurious results. To keep the analysis structured, we gradually escalate our investigation from simple panel regressions to more involved specifications.

We find a statistically and economically significant stable relationship between the age structure of a population and low-frequency inflation. Our benchmark specification controls for the real interest rate, the output gap and the two oil crises – but the results do not depend on these or several other controls. In fact, the demographic impact seems to be complementary to these factors. Only survey-based inflation expectations can crowd out this impact, but expectations themselves are, in turn, explained by demography. Hence, demography is linked to inflation either directly or through inflation expectations. Most important, the results do not depend on any specific time period: the relationship is present in the post-1980 or even in the post-1995 period. Moreover, the relationship remains intact when time fixed effects are added, and, hence, it is not spuriously related to global factors, such as oil price developments.

According to our estimates, demography accounts for around one-third of the variation in inflation and for the bulk of the deceleration between the late 1970s and early 1990s. Furthermore, our estimates reveal a stable U-shaped pattern: a larger share of dependents (ie young and old) is correlated with higher inflation, and a larger share of working age cohorts is correlated with lower inflation.

The statistically robust correlation between demography and inflation is puzzling and raises the question of why central banks have not offset it. In order to shed some light on this question, we extend our analysis to monetary policy. We find a significant relationship between demography and monetary policy but, in contrast to inflation, this relationship is not stable over time. Before the mid-1980s, monetary policy reinforced the demographic impact of inflation: real interest rates were low precisely when demographic inflationary pressure was high. However, this pattern reversed after the mid-1980s as monetary policy mitigated the demographic pressures, albeit not fully. In other words, in this later period real interest rates were low when demographic inflationary pressure was also low. Given that demographic pressures are estimated to have been inflationary in the first half of the sample and disinflationary in the second half, central banks applied relatively low real interest rates throughout. In particular, they only mitigated the demographic pressure when it did not require high real interest rates.

Our results are relevant for economic theory and policy. From a theoretical perspective, the link between the age structure of the population and low-frequency inflation clearly deviates from the traditional textbook models and calls for further research. From a policy perspective, understanding the relationship could help forecast low-frequency inflationary pressures and calibrate monetary policy accordingly. This might also help us to think about how changing demographics affect monetary regimes: for instance, would inflation targets remain optimal if the underlying demographic inflationary pressures shift dramatically?

Furthermore, our results suggest that ageing might eventually lead to higher, not lower, inflationary pressures – contradicting the prevailing view. However, this result should be read with caveats: our estimates are less precise at the two extreme ends of the age distribution, ie the very young and the very old, and it is precisely the share of very old which is expected to increase very fast. Hence, the mechanical application of our results to future demographic trends should be treated with caution.

In addition to documenting the empirical link between demography, monetary policy and inflation, our results also shed some light on potential drivers. Two competing possibilities suggest themselves: the impact can work through economic channels (as, for instance, suggested by Governor Shirakawa) or through political channels (as President Bullard has argued). Though our findings differ from both theories in concluding that ageing is inflationary, they are more supportive of an economic explanation: monetary policy does not appear to fully explain the demographic impact because demography affects inflation even after controlling for real interest rates. Furthermore, we find that country-specific demographic impacts are apparent in small euro area countries in spite of centralised policy rate setting by the European Central Bank.

Our paper is related to some previous work on inflation forecasting. McMillan and Baesel (1990) used the correlation between demographics and inflation in the United States to predict the moderation of inflation in the 1990s. Using data from 20 OECD countries over the 1960–1995 period, Lindh and Malmberg (2000) also found a strong correlation between the age structure and inflation which they used to forecast inflation rates. In line with our results, both papers report a positive inflationary impact from dependents (ie the young and the old) and a negative impact from working age cohorts. However, our paper differs from theirs both in terms of substance and in technical aspects. In terms of substance, we go beyond analysing the correlation between inflation and demography and set the question in a broader monetary policy context. In terms of technical aspects, we use a larger sample, employ a variety of estimation techniques, such as population polynomials from Fair and Dominguez (1991), and try several controls – among them standard monetary policy variables. We also allow for country heterogeneity and estimate dynamic heterogeneous panels in error correction form to avoid spurious results.

The rest of the paper is organised as follows. The second section describes the data. The third section investigates the link between inflation and demography. The fourth examines the link between demography and monetary policy. The fifth discusses the findings. The final section concludes.

2. Data

We include the largest possible available sample. In terms of time coverage, we use almost the full postwar sample: from 1955 to 2010. We do not use the years right after World War II, because of the impact of the postwar reconstruction – and, to a smaller extent, that of the Korean war.[4] The sample covers 22 advanced economies 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.

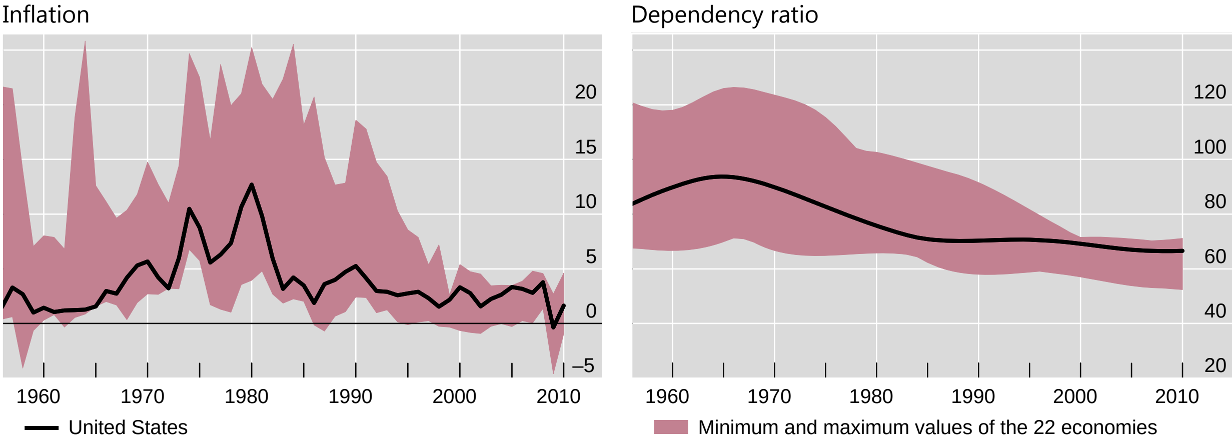
The main variable of interest is the yearly inflation rate obtained from Global Financial Data and national data sources. Given that we are interested in low-frequency inflation dynamics, yearly data are sufficient. In the following, we denote yearly inflation as π_{jt}, where $j=1,\dots,N$ is a country index and $t=1,\dots,T$ is a time index. A cursory look at the inflation data confirms the substantial variation both across time and countries (Graph 1, left-hand panel). The United States highlights a typical time trend: inflation rose in the late 1960s and started to moderate rapidly after the late 1970s peak (black line). However, there is also substantial heterogeneity across countries (red band): inflation did not always moderate in lockstep with the US, and there are many idiosyncratic jumps in many countries.

4 Technically, observations are available from 1950 onwards. However, many economies, including the US, experienced abnormal hikes in inflation between 1950 and 1955 following the onset of the Korean war. Similarly, we exclude the years following the 2008–09 financial crisis where low growth went hand-in-hand with low inflation in a number of countries. However, this sample choice does not drive our results: using data from the full post-war years yields results both quantitatively and qualitatively similar to using the 1955–2010 sample with the precision of the estimates only marginally reduced.

The other key variable of interest is the age structure of the population, which we obtain from the UN population database. Besides historical data we also use the medium fertility version of the population forecast up until 2050. The total population (denoted as N_{jt} for each country and year) is divided into 17 five-year age cohorts (denoted by N_{kjt} where $k = 1, \ldots, 17$) where the N_{kjt} shows the number of people in cohorts 0–4, 5–9, 10–14, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79 and 80+. We also denote the share of cohort k in the total population, N_{kjt}/N_{jt}, by n_{kjt}. Fur future use we also define the share of young (0–19 years old), $n_{jt}^{young} = \sum_{j=1}^{4} n_{kjt}$, working age (20–64 years) $n_{jt}^{working} = \sum_{j=5}^{13} n_{kjt}$, and old population (65 years and older), $n_{jt}^{old} = \sum_{j=13}^{17} n_{kjt}$.

Inflation and dependency ratio

In per cent Graph 1



The dependency ratio, ie the young and old population divided by the working age population ($depr_{jt} = 100 * (n_{jt}^{young} + n_{jt}^{old})/n_{jt}^{working}$) provides a summary statistic for demographic change. As its name suggests, the dependency ratio approximately captures the share of the population which is economically dependent in the sense that its members do not earn labour income. For example, a value of 50 for this ratio implies that the working age population is twice as large as the dependent population. The dependency ratio has generally declined in the sample as the baby boomers typically had fewer children than their parents. However, there is quite a bit of heterogeneity in this decline (Graph 1, right-hand panel). Interestingly, the United States (black line) had a typical dependency ratio in the early part of the sample, but now has one of the highest ratios.

In addition to the inflation rate and the population variables, we use a number of control variables. Given that inflation is a monetary phenomenon, it should also be related to the real interest rate, r_{jt}. In most of our analysis we use the ex-post real interest rate given by $r_{jt} = i_{jt} - \pi_{jt}$, where i_{jt} is the nominal overnight interbank interest rate. To get full time coverage, we collect the nominal interest rates from several different sources: national data, Datastream and Global Financial Data.

One problem with using the ex-post real interest rate as an explanatory variable is that it is endogenous. Moreover, including it makes inflation appear on both sides of the econometric equation, albeit in constrained form on the right-hand side. This can artificially increase the statistical significance of the real rate if there are outliers in the inflation rate which do not appear in the nominal interest rate. Furthermore, unexpected events, such the two oil crises in the 1970s, would make ex-post inflation an imperfect measure of what economic actors expected. For these reasons we also use one-year ahead inflation forecasts from Consensus Forecasts, π_{jt}^{e}, to construct an ex-ante real interest rate, $r_{jt} = i_{jt} - \pi_{jt}^{e}$. Unfortunately, this ex-ante real interest rate is only available for the post-1990 period.

Standard models would also suggest that inflation is related to the output gap, $\hat{y}_{jt} = y_{jt} - y_{jt}^{*}$, where y_{jt} is real GDP and y_{jt}^{*} is potential GDP. Given the length of the sample, we obtain real GDP figures from a variety of sources: national data, the OECD's *Economic Outlook*, the IMF's *World Economic Outlook* (WEO), Datastream and Global Financial Data. We then construct a measure for the output gap with full sample coverage, by using the deviations in real GDP from a Hodrick-Prescott filtered trend (with λ set to 100, the standard value for yearly frequency).

We use seven additional control variables which may be particularly relevant for low-frequency inflation. We use three labour variables. The first is the share of wages in national income (w_{it}/y_{it}), which we obtain by combining data from the OECD *Economic Outlook*, Datastream and national data. These data are available from 1960 at the earliest onwards. The second is labour productivity per hour worked (y_{it}/h_{it}) in constant 2013 dollars, and the third is hours worked per person (h_{it}/l_{it}). Both are obtained from the Conference Board Total Economy Database. We also consider the fiscal balance and fiscal debt as a share of GDP (denoted as $(\tau_{jt} - g_{jt})/y_{jt}$ and d_{it}/y_{it}, respectively) that we obtain from the IMF WEO. The sample for the fiscal variables starts in 1980 at the earliest, but some countries do not have any observations before 1995. We also try two measures of asset price inflation: residential property price inflation, π_{jt}^{H}, from the BIS residential property price database, and equity price inflation, π_{jt}^{E}, from Datastream. They are generally available from 1970 onwards. Finally, we examine various money measures based on the broad money stock ($m2_{jt}$), which we obtain from several sources: national data, the ECB, the OECD *Economic Outlook*, the IMF *International Financial Statistics*, and Global Financial Data. The time coverage of the money stock varies from country to country, but starts in all but three countries before the 1980s.

3. Demography and inflation

We provide a comprehensive empirical analysis of the potential connection between inflation and demography in this section. We first try a simple univariate measure of the demographic structure, the dependency ratio, as a regressor. We find that it is significant both in statistical and economic terms, even controlling for time fixed effects. We then gradually extend the analysis, taking the entire population structure more fully into account. Along the way, we continuously subject the findings to numerous robustness checks to see if we can make the connection between inflation and demographics disappear. Our overarching conclusion is that it is very hard to refute this connection in the data.

3.1 First glance at the data

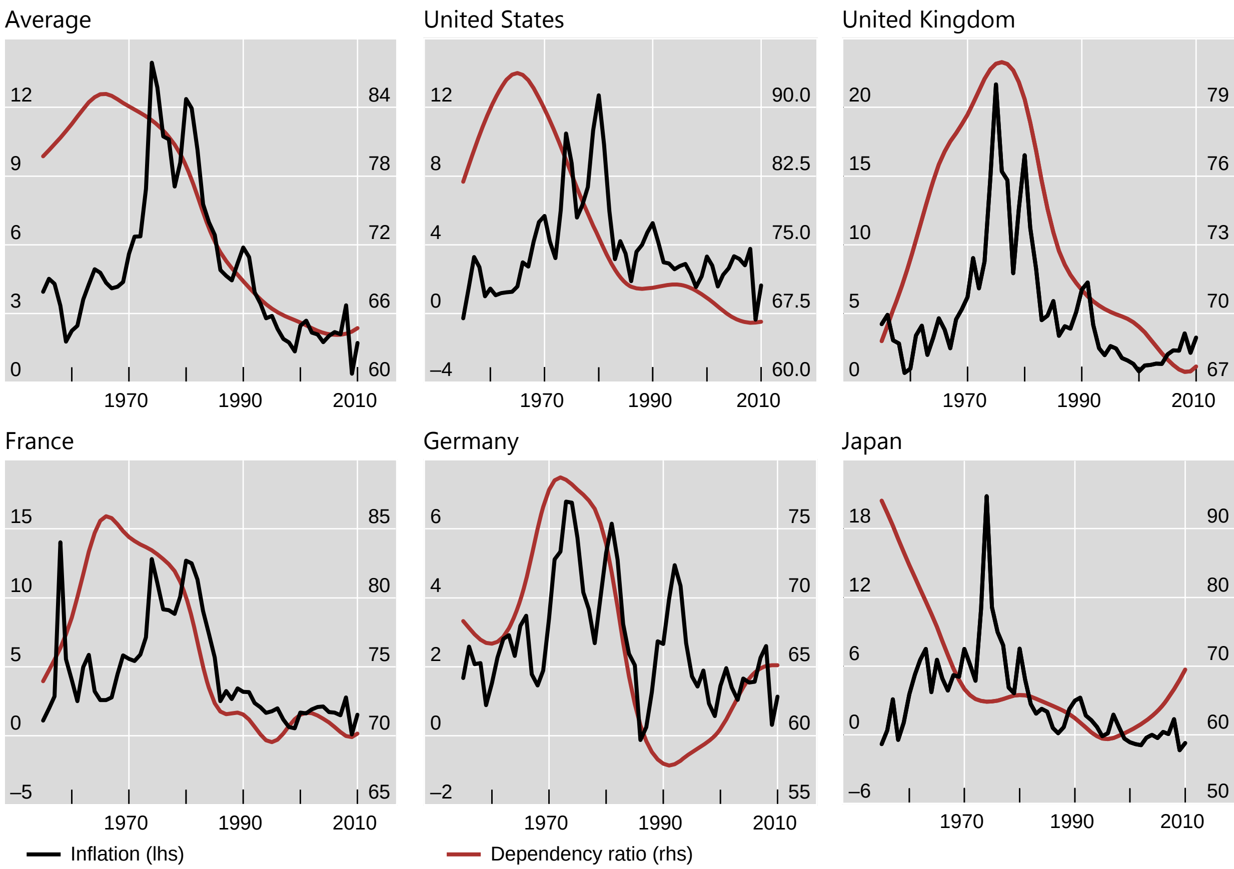
We begin by graphically comparing a common univariate summary measure of the demographic structure – the dependency ratio – with inflation. This ratio is often used in studies examining the impact of demographic change and is a good starting point for our investigation.

Indeed, there seems to be positive correlation between inflation and the dependency ratio for the average of our sample, and separately for five major advanced economies (Graph 2). Interestingly, the correlation seems to be weakest for Japan, the country for which some policymakers and researchers see demography as a prominent potential explanation for inflation. In short, a first look at the data does not refute the possibility that there might be some relationship between inflation and demography.

Inflation and dependency ratio

In per cent

Graph 2



However, the graph also reveals that both demographic and inflationary time patterns have been fairly similar across countries even if the magnitudes of the series have differed. This raises the suspicion that the time correlation between the two variables is purely coincidental, with inflation being driven by some common factor across countries, such as oil prices during certain phases. In the following analysis we address this possibility by replicating each specification with time fixed effects to make sure that we do not mistakenly identify some common trends.

To get a more formal sense of the connection shown in Graph 2, we regress inflation on the dependency ratio:

$$\pi_{jt} = \mu + \mu_{j0} + \beta_3 depr_{jt} + \varepsilon_{jt} \tag{1}$$

where μ is the constant and μ_{j0} is a country-specific fixed effect. Large endogeneity issues should not arise in specification (1) given that demography is reasonably exogenous to most economic variables, including inflation.

The dependency ratio appears to be strongly correlated with inflation (Table 1). It alone explains around 16% of the variation of inflation (Model 1). Controlling for time fixed effects (Model 2) leads to a slight drop in the estimated coefficient on the dependency ratio, but the coefficient nevertheless remains both economically and statistically significant. Hence, our fist simple specifications do not immediately reject a relationship between inflation and demography.

Demography and inflation

Dependent variable is π_t

Table 1

Model	1	2	3	4	5	6
$\mathrm{depr}_{\mathrm{it}}$	0.17 (11.16)	0.11 (4.10)				
$\mathrm{n}_{\mathrm{it}}^{\mathrm{young}}$			0.31 (10.61)	0.22 (3.42)		
$\mathrm{n}_{\mathrm{it}}^{\mathrm{working}}$			–0.23 (–7.67)	–0.14 (–5.89)		
$\mathrm{n}_{\mathrm{it}}^{\mathrm{old}}$			0.31 (4.25)	0.01 (0.11)		
$\tilde{\mathrm{n}}_{1\mathrm{kt}}(\times 1)$					1.95 (14.15)	0.12 (0.87)
$\tilde{\mathrm{n}}_{2\mathrm{kt}}(\times 10)$					–4.62 (–14.97)	–1.09 (–3.29)
$\tilde{\mathrm{n}}_{3\mathrm{kt}}(\times 10^2)$					3.90 (14.62)	1.38 (4.84)
$\tilde{\mathrm{n}}_{4\mathrm{kt}}(\times 10^3)$					–1.07 (–13.92)	–0.48 (–5.93)
Dem. Insig. F-test					0.000	0.000
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	Yes	No	Yes	No	Yes
R^2	0.16	0.57	0.16	0.57	0.30	0.61
Obs.	1276	1276	1276	1276	1276	1276
Max sample	1955–2010	1955–2010	1955–2010	1955–2010	1955–2010	1955–2010

The estimates of the regression constant and fixed effects are omitted here and in later tables for the sake of brevity, but are available upon request. The displayed R^2 includes the impact of the time fixed effect (when applied) but not that of the country fixed effect. We obtain valid R^2 estimates for Models 3 and 4 from a model with the constant included and $\mathrm{n}_{\mathrm{it}}^{\mathrm{old}}$ excluded.

Next, we allow for slightly more flexible demographic effects. In particular, the dependency ratio implicitly assumes that the young and the old have identical effects and that these effects have the opposite sign but the same absolute size as the effect of the working age cohorts. To explore the robustness of this implicit assumption, we extend the estimation to allow these three age cohorts to have different effects, ie we formally estimate the regression below:

$$\pi_{jt} = \mu_{j0} + \beta_1 n_{jt}^{young} + \beta_2 n_{jt}^{working} + \beta_3 n_{jt}^{old} + \varepsilon_{jt} \tag{2}$$

where we drop the constant, because the three population shares sum to one.

Allowing for more flexibility vis-à-vis the effects of different age groupings does not alter the picture substantially (Table 1, Models 3 and 4). First, note that the explanatory power hardly increases compared to Models 1 and 2. The likely reason is that the implicit assumption behind the dependency ratio is roughly satisfied: the young and the old have approximately the same impact on inflation, and the working age population has the same absolute size impact with the opposite sign. Furthermore, using these population cohorts reveals that the two dependent population categories increase inflation whereas the working age cohorts decrease it – ie a U-shaped inflationary pattern arises. This cohort-specific finding is not visible from the estimation using only the dependency ratio. Adding time effects again does reduce significance levels, in particular for the old age category, which now becomes statistically insignificant. However, time fixed effects do not eliminate the overall demographic impact.

In sum, based on our first look at the data we cannot refute a puzzling correlation between the age structure of the population and inflation – which motivates us to examine the relationship using a finer age distribution.

3.2 Population polynomials

It is possible to go further and allow for an even finer age distribution – notwithstanding the seemingly even effects from the young and old populations. A motivation for such an extension is that the inflationary impact of a person is unlikely to shift dramatically the instant that he moves from young to working age or from working age to old age – but this is what equation (2) implicitly assumes. To address this concern, one would, in essence, need to estimate a regression like:

$$\pi_{jt} = \mu_{j0} + \textstyle\sum_{k=1}^{17} \beta_{1k} n_{kjt} + \varepsilon_{jt} \tag{3}$$

However, estimating equation (3) directly involves three problems. First, the precision of the estimates is lost if the number of population cohorts gets large compared to the number of time periods. Second, the finer the division of the total population, the larger the correlation between consecutive age cohorts becomes. Third and last, the unconstrained coefficient estimates may jump back and forth between close age cohorts in an economically puzzling fashion. For instance, the estimates could show cohorts 30–34 and 40–44 to be highly disinflationary, while cohort 35–39 is inflationary.

A way of overcoming the estimation problems associated with (3) is suggested by Fair and Dominguez (1991) and applied later by Higgins (1998) and more recently by Arnott and Chaves (2012). The idea is to limit the differences between the estimated effects of consecutive age cohorts by restricting the population coefficients, β_{1k}, to lie on a P:th degree polynomial ($P < K$) of the form

$$\beta_{1k} = \textstyle\sum_{p=0}^{P} \gamma_p k^p \tag{4}$$

where the gammas are the coefficients of the polynomial. We show in the Appendix that (3) and (4) together with the restriction $\sum_{k=1}^{17} \beta_{3k} = 0$, which removes the perfect colinearity between the constant and the age shares, yield

$$\pi_{jt} = \mu + \mu_{j0} + \sum_{p=1}^{P} \gamma_p \tilde{n}_{pjt} + \varepsilon_{jt} \tag{5}$$

where $\tilde{n}_{pjt} = \sum_{k=1}^{17} \left(k^p n_{kjt} - k^p/17 \right)$. Once estimates of the γ_p coefficients have been obtained, the β_{3k} coefficients can be directly obtained from (4). In addition, since the β_{3k}:s are linear transforms of the γ_p:s, their standard errors can be calculated using standard formulas (see the Appendix for a formal derivation).

Allowing different age cohorts to have different effects through a population polynomial substantially increases the explanatory power of demography. Estimating equation (5) almost doubles the explained variation from 16% to 30% – a respectable number for a large country panel (Table 1, Model 5). Moreover, the polynomial terms are highly significant, both individually (as the t-tests show) and even more important, jointly (as the F-test shows). As before, the inclusion of the time fixed effects weakens the estimated demographic impact somewhat, but does not remove it (Model 6).

Both Model 5 and Model 6 are based on a fourth degree polynomial which produces better fit than second and third degree polynomials but very similar ones to fifth or higher degree polynomials.[5] Given this good general fit, we use fourth degree polynomials as a baseline in the subsequent analysis – but we subject this choice to careful robustness tests in connection with our benchmark model below.

3.3 Benchmark model

The obvious concern with the results so far is that they do not control for real interest rates and the business cycle. For instance, central banks persistently kept real interest rates low in many countries throughout the 1970s – and this is the mainstream explanation for the high inflation rates experienced at the time. Similarly, if central banks do not correctly take into account output gaps, that could also affect inflation – though higher-frequency business cycles are less likely to be able to explain low-frequency inflation movements.

In order to control for these two variables, we augment equation (5) with the real interest rate and an output gap. Furthermore, we add two dummy variables, *d74*, and *d80*, to the model to account for the impact of the two oil crises in the 1970s.[6] These modifications yield our benchmark specification:

$$\pi_{jt} = \mu + \mu_{j0} + \sum_{p=1}^{P} \gamma_p \tilde{n}_{pjt} + \beta_1 r_{jt} + \beta_2 \hat{y}_{jt} + \beta_3 d74 + \beta_3 d80 + \varepsilon_{jt} \tag{6}$$

We introduce the elements of equation (6) step-by-step to check the impact of the individual variables. First, we establish that adding the two oil crisis dummies

[5] The fit is somewhat less precise for the very young (0–4 years old) or the very old (80 years and older). One potential reason is that lower child mortality and increased old age life expectancy affect the economic impact of these categories. Another is that the polynomial order can affect the endpoint estimates.

[6] These crises are associated with huge positive outliers in the ex-post inflation rate, but not in the nominal interest rate. This implies that the ex-post real interest rate would be negatively correlated with inflation if the outliers are not blocked.

does not alter our previous results: the variation explained by demographics remains roughly the same as before (Table 2, Model 7). Next, we add the real interest rate and the output gap and remove the demographic terms. Without time fixed effects, the real interest rate is very significant, but the output gap is not (Model 8). The two more traditional economic variables jointly explain around one-third of the total variation – roughly as much as demography explains. Notably, when we add time fixed effects the output gap also becomes significant and now over two–thirds of the variation in the data is accounted for (Model 9).

Demography, inflation, real interest rates and the output gap

Dependent variable is π_t

Table 2

Model	7	8	9	**10**	11	12
$\tilde{n}_{1kt}(\times 1)$	1.72 (12.68)			**1.91** **(18.43)**	0.66 (5.38)	1.73 (16.55)
$\tilde{n}_{2kt}(\times 10)$	–4.10 (–13.49)			**–4.16** **(–17.66)**	–2.11 (–7.58)	–3.68 (–15.52)
$\tilde{n}_{3kt}(\times 10^2)$	3.46 (13.21)			**3.26** **(16.01)**	2.11 (8.70)	2.83 (13.70)
$\tilde{n}_{4kt}(\times 10^3)$	–0.95 (–12.59)			**–0.84** **(–18.13)**	0.63 (–9.28)	–0.72 (–11.97)
r_{it}		–0.56 (–14.46)	–0.63 (–17.59)	**–0.59** **(–18.13)**	–0.63 (–17.82)	–0.51 (–8.81)
$\hat{y}_{it}$		0.08 (1.78)	0.12 (2.49)	**0.15** **(3.94)**	0.15 (3.65)	0.21 (2.86)
D_{74}	6.95 (6.45)	4.79 (8.89)		**2.37** **(3.49)**		3.03 (3.66)
D_{80}	5.36 (6.07)	6.67 (11.20)		**3.87** **(5.56)**		4.57 (5.54)
Dem. Insig. F-test	0.000			**0.000**	0.000	0.000
Country effects	Yes	Yes	Yes	**Yes**	Yes	Yes
Time effects	No	No	Yes	**No**	Yes	No
R^2	0.36	0.39	0.76	**0.62**	0.80	0.63
Obs.	1276	1232	1232	**1232**	1232	1232
Estimator	FE	FE	FE	**FE**	FE	GMM
Max sample	1955–2010	1955–2010	1955–2010	**1955–2010**	1955–2010	1955–2010

The estimates of the benchmark specification (Equation 6) indicate that the population polynomial, real interest rates and the output gap contain complementary information for inflation (Model 10). Strikingly, both the output gap and the real interest rates become even more significant when the population polynomial is added. Demography taken together with the two economic variables explains almost two-thirds of the variation. Furthermore, comparing Model 10 with Model 8 shows that adding demography to the more traditional variables increases the explanatory power by almost one-quarter of the total variation.

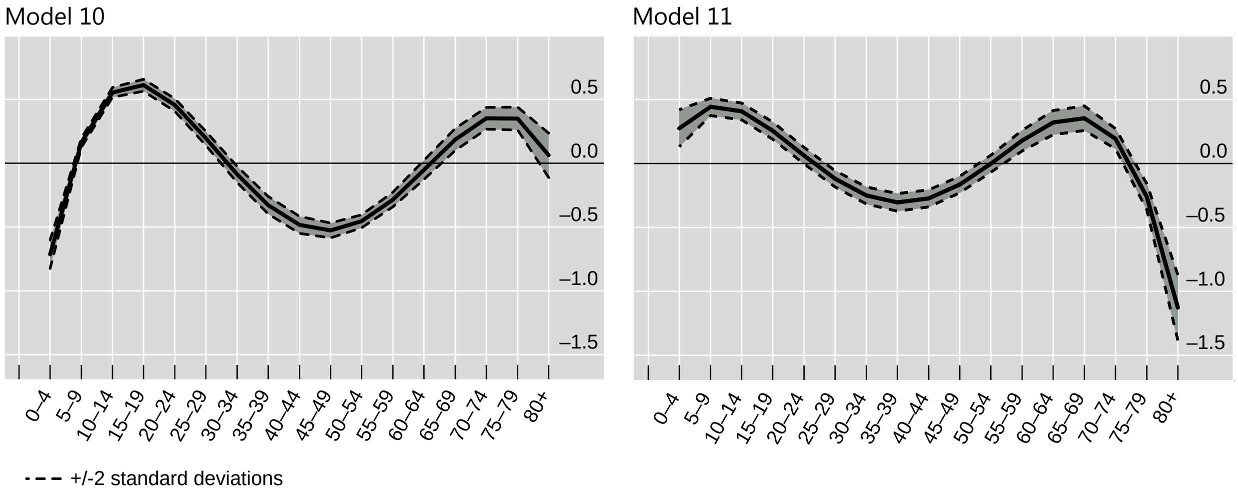
In the following we will use Model 10 as our benchmark specification when discussing additional robustness tests. Having such a benchmark makes it easier to assess the value added of the large number of different alternative specifications that we try in the following. Moreover, since Model 10 accounts for a large fraction of the variation in the data, as well as the most standard monetary policy variables, only alternative specifications that truly matter will be able to improve upon it. While we subject the benchmark specification to robustness testing by adding time fixed effects, we do not apply time fixed effects in the benchmark model in order to be able to estimate the time variation.

To ensure that the benchmark regression does not capture global factors, such as oil prices, we also add time fixed effects to check robustness (Model 11). In this case the demographic coefficients change somewhat, but this is not surprising as the time fixed effects remove time variation and only the cross-section part of the demographic effect is estimated. We also instrument the real interest rate and the output gap variable with their lags to show that endogeneity does not drive our results (Model 12). This might be particularly relevant for the real interest term which embeds inflation, the dependent variable. While the significance of the real interest term drops somewhat, its magnitude and general impact remain stable. Most important, the size of demographic coefficients remains largely unchanged.

When we compute from the population polynomial the impact of each age cohort on inflation, a U-shaped relationship appears (except, as we discussed earlier, for the two extreme tails of the age distribution): the young and the old age cohorts have a positive impact on inflation, whereas the working age population has a negative impact (Graph 3). This is true irrespective of whether one excludes time fixed effects (left-hand panel) or includes them (right-hand panel).

Age cohort effects on inflation

In per cent　　　　Graph 3

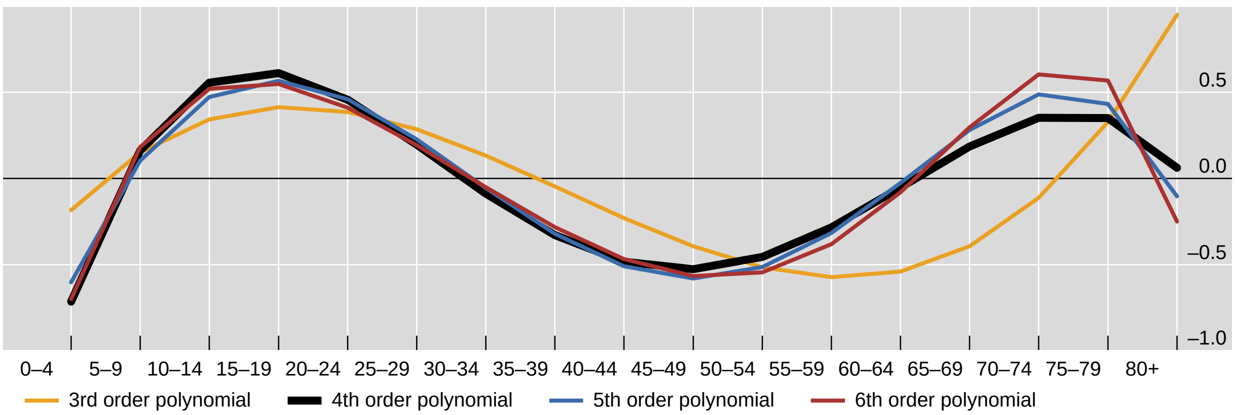


In fact, the extreme tails of the age distribution, ie the very young and the very old, seem to be less stable: the very old shifts from slightly inflationary (Graph 3, left-hand panel) to strongly deflationary when we include time fixed effects (right-hand panel). This shift is not solely related to the treatment of time fixed effects: the extreme tails of the age distribution seem to be less robust than the middle of it in general. There are two potential drivers of this lower precision. First, the data might be noisier at the endpoints: survival rates increased in particular for the very young (due to lower infant mortality) and for the very old (due to increased longevity in old age). This raises the possibility that the economic meaning of the share of very young and very old, which our estimates implicitly assume to remain constant, could have also changed. Second, the polynomial technique, more precisely the choice of polynomial order, can further affect the endpoint estimates. The noise at the endpoints explains why we focus on the inner age cohorts in our analysis and treat the less stable extreme ends of full age cohort distribution cautiously.

Investigating alternative polynomial specifications suggests that the choice of fourth degree polynomial is appropriate. Starting from a sixth degree polynomial, we examine whether an additional polynomial term can be excluded by using an F-test at the 1% level (Appendix Table A1). We cannot reject the hypothesis that the last polynomial coefficient is zero in the sixth and also in the fifth degree polynomial, but we have to reject it for the fourth degree polynomial. This result rules out using a third degree polynomial. Furthermore, we opt against using fifth or sixth degree polynomials because their fit and predictions are not materially different from those of the fourth degree polynomial (Graph 4). In particular, re-estimating the benchmark specification with fifth and sixth degree polynomials (red and blue lines, respectively) gives very similar age cohort impact effects to the fourth degree polynomial (thick black line). If anything, the age cohort impact is stronger for the old in the higher degree polynomials. Thus, our choice of using a fourth order polynomial, ie the benchmark specification, if anything weakens the estimation of the link between demography and inflation. Furthermore, as the robustness tests later will show, the U-shaped pattern below also arises if one uses large age categories instead of the population polynomial.

Age cohort effects with different polynomials

Graph 4



Benchmark specification.

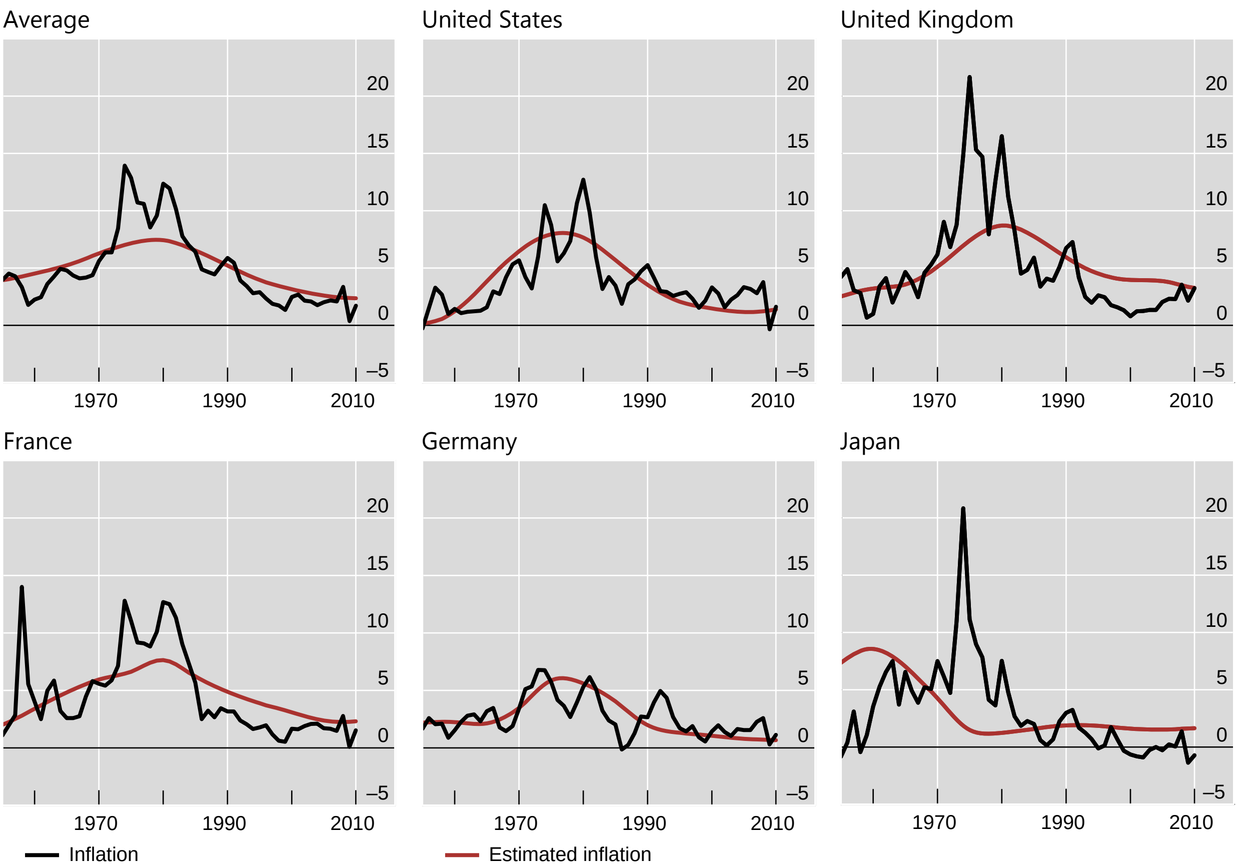
The estimated demographic effects from the benchmark model explain the low-frequency evolution of inflation well, not only on average, but even in individual country cases (Graph 5). This is striking because we have used the panel coefficients to calculate the estimated demographic impact on inflation for each individual country. The graph shows this impact for the panel average and for the same five individual countries that appeared in Graph 2 (the remaining countries appear in Graph A1 of the Appendix). As can be seen, the fitted demographic effects align surprisingly well with actual inflation in most cases, in terms of both pattern and magnitude.

In contrast, the fitted demographic effects from the model with fixed time effects (Model 11) are, on their own, less well aligned with actual inflation (see Graph A2 in the Appendix). This is hardly surprising given that the time fixed effects remove much of the common time variation from the data. In other words, if part of the low-frequency dynamics in inflation is related to demography, it cannot be fully revealed from cross-country variation alone.

The estimated demographic impact is also highly significant economically (Graph 5). On average, in the benchmark model (without time fixed effects) demography accounts for around a five percentage point reduction in the rate of inflation from the late 1970s to the early 2000s, ie it explains around half of the total average reduction in inflation from its peak (upper left-hand panel). The strength of the impact is particularly strong in the United States: demography accounts for a reduction of around six percentage points in the inflation rate (upper middle panel). Furthermore, demographic developments seem to explain much of the cross-country variation in low-frequency inflation. For instance, the larger swings in US low-frequency inflation compared to German movements (lower left-hand panel) mostly reflect larger demographic changes in the United States. Interestingly, the estimates do not suggest a substantial change in the inflationary pressures for Japan over the past two decades (lower right-hand panel).

Actual inflation and estimated demographic impact

Benchmark specification: Model 10, in per cent Graph 5



The fitted demographic effects are normalised to have the same mean as actual inflation.

3.4 Robustness tests

We undertake extensive sensitivity tests to ensure that the puzzlingly strong relationship between demography and inflation does not arise because of overlooked factors. First, we restrict attention to various sub-periods, including those after 1980 and after 1995. Second, we add a large number of additional control variables. Third, we investigate the role of inflation expectations. Fourth, we replicate the analysis using large age categories instead of the population polynomial. Fifth, we add dynamic structure to the model to ensure that the results are not spurious. Last, we allow for varying degrees of heterogeneity in the panel. None of these tests removes the demographic impact.

3.4.1 Different time periods

An obvious concern is that our result is specific to a particular time period. For example, most countries experienced high inflation in the 1970s: might it be a coincidence that demographics shifted at the same time? If so, the effects should disappear later. While time fixed effects should have addressed this problem at least partly, here we examine the relationship in different sub-periods explicitly.

The demographic impact remains present in all three sub-periods we investigate (Table 3). The demographic effect is clearly present in the 1955–1979 sub-period, when estimating it both without time fixed effects (Model 13) and with time fixed effects (Model 14). Furthermore, the demographic effect remains present in the 1980–2010 sub-period (Models 15 and 16) and even in the 1995–2010 sub-period (Models 17 and 18). Though the estimated coefficients and the explanatory

Robustness over time

Benchmark model, dependent variable is π_t

Table 3

Model	13	14	15	16	17	18
$\tilde{n}_{1kt}(\times 1)$	1.22 (6.58)	0.79 (3.55)	0.93 (5.95)	–0.18 (–1.17)	0.92 (3.32)	0.89 (4.41)
$\tilde{n}_{2kt}(\times 10)$	–2.82 (–5.77)	–2.59 (–4.52)	–0.29 (–9.04)	–0.49 (–1.56)	–1.99 (–3.71)	–1.78 (–4.50)
$\tilde{n}_{3kt}(\times 10^2)$	2.33 (4.98)	2.70 (5.05)	2.87 (10.50)	0.97 (3.79)	1.55 (3.90)	1.30 (4.08)
$\tilde{n}_{4kt}(\times 10^3)$	–0.61 (–4.26)	–0.87 (–5.40)	–0.88 (–10.95)	–0.39 (–5.38)	–0.40 (–3.95)	–0.31 (–3.50)
r_{it}	–0.71 (–16.00)	–0.66 (–18.48)	–0.47 (–9.11)	–0.47 (–7.44)	–0.12 (–1.62)	–0.12 (–1.56)
$\hat{y}_{it}$	0.17 (4.42)	0.10 (2.28)	0.24 (5.57)	0.15 (2.51)	0.19 (5.10)	0.06 (1.13)
Dem. Insig. F-test	0.000	0.000	0.000	0.000	0.000	0.000
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	Yes	No	Yes	No	Yes
R^2	0.80	0.86	0.68	0.78	0.22	0.45
Obs.	550	550	682	682	352	352
Max sample	1955–1979	1955–1979	1980–2010	1980–2010	1995–2010	1995–2010

power of the benchmark regression decline somewhat in the more recent periods, the demographic effect remains significant both statistically and economically.

Moreover, even the age cohort-specific effect is similar to the benchmark model (Graph A3 in the Appendix). The benchmark model (left-hand panel) and the 1995–2010 subsample (right-hand panel) show the same U-shaped pattern for the inner age cohorts. As expected, the statistical significance is slightly weaker in the shorter subsample. Perhaps due to this decreased precision, the economic impact is also slightly lower. In any case, demography remains both statistically and economically significant in all periods.

3.4.2 Additional controls

The previous subsection found that the demographic impact remains robust to the choice of sample period. However, questions remain as to whether demography picks up the impact of some other observable variables. In order to control for such factors, we expand the benchmark model (equation 6) with additional variables:

$$\pi_{jt} = \mu + \mu_{j0} + \sum_{p=1}^{P} \gamma_p \tilde{n}_{pjt} + \beta_1 r_{jt} + \beta_2 \hat{y}_{jt} + \beta_3 d74 + \beta_4 d80 + \beta_5 x_{jt} + \varepsilon_{jt} \qquad (7)$$

where x_{jt} is a vector that collects the controls.

Table 4 shows the results for additional control variables. First, we apply the labour share in GDP because in the absence of real marginal cost data, the labour share of income has been used as a proxy in a number of empirical applications (Gali et al (2001)). Indeed, higher labour share is associated with significantly higher inflation, as one would expect (Model 19). However, its inclusion does not materially change the demographic coefficient. When we extend the analysis with other labour market indicators, such as labour productivity (Model 20) and hours worked per person (Model 21), the demographic coefficients still remain largely unchanged. However, in itself labour productivity has the wrong sign, ie higher productivity is associated with higher inflation, which suggests a potential omitted variable. In fact, combining all labour sector variables seems to address this omitted variable bias: the signs for all variables become consistent with theory (Model 22). In sum, the labour variables do not materially affect the estimated demographic impact.

Furthermore, the inclusion of fiscal variables, such as government budget balance or government debt (Models 23 and 24), does not materially affect the demographic coefficients. The coefficients on fiscal balance are significantly negative: as expected, higher fiscal deficits are associated with higher inflation. Yet higher government debt is associated with lower inflation – suggesting potential omitted variables in this specification.

Finally, we include asset price inflation, ie residential property price growth and equity price growth, to implicitly account for wealth transfers between population cohorts. The inclusion of asset prices is complicated by the fact that demography might also drive real asset prices, as, for instance, Takáts (2012) finds. Thus, the demographic impact might work through asset prices. However, the inclusion of the two asset price growth rates leaves the demographic impact intact (Model 25). In fact, only equity price inflation comes out significant with a slightly surprising negative sign: ie stock market booms are associated with lower inflation. These results suggest that the United States' experience in the early 2000s, with booming stock markets and low inflation, was not unique.

Controlling for labour sector variables, fiscal indicators and asset prices

Benchmark model, dependent variable is π_t

Table 4

Model	19	20	21	22	23	24	25
$\tilde{n}_{1kt}(\times 1)$	1.63 (13.41)	1.97 (18.54)	1.86 (18.20)	1.49 (11.84)	1.04 (6.69)	0.91 (5.44)	0.98 (6.24)
$\tilde{n}_{2kt}(\times 10)$	–3.35 (–12.82)	–4.38 (–17.24)	–4.24 (–18.17)	–3.17 (–11.45)	–2.98 (–9.37)	–2.73 (–8.01)	–2.35 (–7.66)
$\tilde{n}_{3kt}(\times 10^2)$	2.52 (11.44)	3.51 (15.22)	3.47 (16.70)	2.42 (10.23)	2.73 (10.30)	2.51 (8.93)	1.99 (8.03)
$\tilde{n}_{4kt}(\times 10^3)$	–0.63 (–9.99)	–0.93 (–13.40)	–0.93 (–15.13)	–0.62 (–8.99)	–0.79 (–10.26)	–0.72 (–8.88)	–0.55 (–7.91)
r_{it}	–0.53 (–12.35)	–0.59 (–17.27)	–0.56 (–16.86)	–0.52 (–12.43)	–0.39 (–7.86)	–0.36 (–6.84)	–0.30 (–6.16)
$\hat{y}_{it}$	0.28 (7.38)	0.14 (3.75)	0.15 (3.98)	0.30 (8.16)	0.27 (6.09)	0.20 (4.31)	0.21 (6.01)
w_{it}/y_{it}	0.19 (5.78)			0.20 (6.58)			
y_{it}/h_{it}		0.04 (3.04)		–0.03 (–1.70)			
h_{it}/l_{it}			–0.01 (–5.99)	–0.01 (–7.09)			
$(\tau_{it}-g_{it})/y_{it}$					–0.07 (–2.74)		
d_{it}/y_{it}						–0.02 (–3.32)	
π^H_{jt}							–0.00 (–0.02)
π^E_{jt}							–0.01 (–2.70)
Dem. Ins. F-test	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Country effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	No	No	No	No	No	No
R^2	0.67	0.62	0.63	0.70	0.69	0.69	0.68
Obs.	780	1232	1232	780	603	578	740
Max sample	1960–2010	1955–2010	1955–2010	1960–2010	1980–2010	1980–2010	1970–2010

The coefficient estimates on the constant and the two oil crisis dummies are available upon request

Next, we turn to various monetary measures and investigate whether the inclusion of money can break the link between demography and inflation. Given that money is clearly endogenous, the loss of statistical significance of demographic variables would not be strong evidence in itself against the demographic impact. In fact, there is some evidence, for instance in Nishimura and Takáts (2012), that demography might affect money holdings which could imply that demography affects inflation via the behaviour of monetary aggregates. However, in spite of these concerns, the inclusion of money, irrespective of the precise specification, does not materially affect the demographic coefficient estimates.

In all specifications, demographic coefficients remain statistically and economically significant, and the demographic impact maintains the U-shaped pattern seen earlier after controlling for money (Table 5). In particular, the inclusion of nominal money growth (Model 26), real money growth (Model 27), money growth in excess of nominal and real GDP growth (Models 28 and 29, respectively) does not affect the demographic estimates meaningfully. To further confirm robustness, we take the best fitting model (Model 29: money growth in excess of real GDP growth) and apply time fixed effects (Model 30), and run the specification in the pre-1980s (Model 31) and post-1980s part of the sample (Model 32): again, the demographic coefficient remains robust. Furthermore, the demographic coefficient remains robust for similar extensions in Models 26–28.

Controlling for money

Benchmark model, dependent variable is π_t

Table 5

Model	26	27	28	29	30	31	32
$\tilde{n}_{1kt}(\times 1)$	1.26 (11.21)	1.17 (10.37)	1.27 (11.16)	1.24 (11.24)	0.19 (1.56)	0.66 (2.51)	0.79 (5.58)
$\tilde{n}_{2kt}(\times 10)$	–2.74 (–10.96)	–2.60 (–10.69)	–2.80 (–11.21)	–2.68 (–10.88)	–0.93 (–3.40)	–1.39 (–2.10)	–2.48 (–8.50)
$\tilde{n}_{3kt}(\times 10^2)$	2.12 (9.96)	2.01 (9.93)	2.17 (10.30)	2.08 (9.83)	1.04 (4.48)	1.03 (1.67)	2.46 (9.93)
$\tilde{n}_{4kt}(\times 10^3)$	–0.54 (–8.85)	–0.51 (–8.89)	–0.55 (–9.19)	–0.53 (–8.72)	–0.34 (–5.15)	–0.24 (–1.25)	–0.76 (–10.44)
r_{it}	–0.45 (–11.05)	–0.41 (–10.23)	–0.45 (–10.98)	–0.43 (–10.71)	–0.51 (–11.87)	–0.63 (–12.10)	–0.40 (–8.30)
$\hat{y}_{it}$	0.14 (3.15)	0.21 (5.10)	0.18 (4.06)	0.17 (4.23)	0.18 (4.27)	0.23 (4.00)	0.21 (5.28)
$\Delta\ln(\mathrm{m2}_{it})$	0.11 (5.73)						
$\Delta\ln(\mathrm{m2}_{it}) - \pi_{it}$		–0.15 (–8.16)					
$\Delta\ln(\mathrm{m2}_{it}/y_{it})$			–0.03 (–2.43)				
$\Delta\ln(\mathrm{m2}_{it}/y_{it}^r)$				0.17 (9.10)	0.13 (8.28)	0.12 (3.90)	0.13 (8.13)
D_{74}	3.34 (4.44)	2.29 (3.33)	2.99 (3.96)	3.26 (4.56)		2.69 (5.13)	
D_{80}	3.82 (5.50)	3.12 (4.45)	3.75 (5.15)	3.48 (5.36)			0.87 (1.25)
Dem. Ins. F-test	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Country effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	No	No	No	Yes	No	No
R^2	0.58	0.61	0.57	0.62	0.81	0.74	0.71
Obs.	981	981	981	981	981	313	668
Max sample	1955–2010	1955–2010	1955–2010	1955–2010	1955–2010	1955–1979	1980–2010

The coefficient estimates on the constant and the two oil crisis dummies are available upon request

Furthermore, the coefficients on nominal money growth (Model 26) and money growth in excess of real economic growth (Model 29) are positive as expected:

higher money growth is associated with higher inflation. Yet real money growth (Model 27) has a negative sign: this can arise due to having inflation on both sides of the equation. A positive inflationary shock, for instance, can drive inflation up and thereby real money growth down at the same time – creating a negative correlation.

In sum, none of the additional control variables remove the demographic impact: in all specifications the population polynomial remains statistically and economically significant and the U-shaped pattern across age cohorts is also stable.

3.4.3 Inflation expectations

Another question is whether including inflation expectations overturns the results. Ideally one would use expectations more generally, but inflation expectation data for the countries in the panel are only available for the post-1990 period, which limits their use to robustness tests.

First, we modify the benchmark model by using the ex-ante expected real interest rate instead of the ex-post real rate (Table 6, Model 33). This means that we use expected not realised inflation to deflate the nominal policy rate. In this specification, the demographic coefficient remains highly significant and the estimates remain broadly consistent with the benchmark model. However, the expected real interest rate takes a surprising positive sign, ie higher real interest rates are associated with higher inflation. As it turns out, this is the artefact of a simultaneous decline of inflation and ex-ante real interest rates during the early

Controlling for expected inflation

Dependent variable: Models 33–36: π_{it} , Models 37–38: π_{it}^{e} — Table 6

Model	33	34	35	36	37	38
$\tilde{n}_{1kt}(\times 1)$	0.57 (2.80)	0.45 (1.98)	0.13 (0.85)	0.08 (0.48)	0.48 (4.48)	0.17 (1.28)
$\tilde{n}_{2kt}(\times 10)$	–1.40 (–3.47)	–0.97 (–2.15)	–0.27 (–0.91)	–0.17 (–0.52)	–1.19 (–5.66)	–0.58 (–2.71)
$\tilde{n}_{3kt}(\times 10^{2})$	1.21 (3.80)	0.78 (2.27)	0.24 (1.05)	0.16 (0.68)	0.99 (5.64)	0.58 (3.79)
$\tilde{n}_{4kt}(\times 10^{3})$	–0.34 (–3.96)	–0.21 (–2.36)	–0.07 (–1.19)	–0.05 (–0.86)	–0.27 (–5.22)	–0.19 (–4.19)
$\hat{y}_{it}$	0.24 (6.44)	0.22 (4.97)	0.13 (5.87)	0.13 (5.93)		
r_{it}^{e}	0.17 (3.64)	0.29 (3.94)		0.04 (1.83)		
π_{it}^{e}			1.19 (18.60)	1.17 (17.64)		
Dem. Insig. F-test	0.000	0.000	0.033	0.004	0.000	0.000
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	No	No	No	No	Yes
Estimator	FE	GMM	FE	FE	FE	FE
R^2	0.43	0.53	0.75	0.76	0.50	0.65
Obs.	441	419	441	441	441	441
Max sample	1990–2010	1990–2010	1990–2010	1990–2010	1990–2010	1990–2010

1990s: in the post-1995 sample, for instance, the negative sign on the expected real interest rate disappears (results available upon request). Furthermore, the demographic impact remains intact when instrumenting the ex-ante real interest rate (Model 34) to avoid endogeneity problems.

Second, and perhaps more interestingly, we include inflation expectations explicitly in our benchmark estimation. Irrespective of whether inflation expectations are rational or backward looking, they should incorporate any slow moving low-frequency change, such as demographic change. If so, demographics would disappear as an *unexpected* driver of inflation. Indeed, this is the case in our estimates: including inflation expectation makes the demographic coefficients individually insignificant and only barely significant jointly, both without controlling for real interest rates (Model 35) and controlling for them (Model 36). The more relevant question is whether demography remains an *expected* driver of inflation.

We test for this explicitly, exploring what explains inflation expectations, ie treating inflation expectations as the dependent variable in the regressions. We indeed find that demography is a highly statistically significant driver of inflation expectations (Model 37). Furthermore, the age structure affects inflation expectations in the same way as it affects inflation, ie in the same U-shaped age cohort pattern. Remarkably, the population polynomial alone can explain one-half of the total variation in inflation expectations. These results also hold when controlling for time fixed effects (Model 38). Hence, the age structure of the population explains the evolution of inflation expectations, which in turn seems to explain the evolution of inflation.[7] In short, using inflation expectations does not overturn the demographic effect on inflation.

3.4.4 Large age categories

The question can arise whether the population polynomial technique drives the results. In order to address this question we re–estimate our main regressions using seven large age categories.

The results confirm that the demographic effect is not dependent on the population polynomial technique (Table 7). First, we re-estimate the benchmark regression on the full sample with the seven age cohorts instead of the population polynomial (Model 39). All age categories are highly significant, except for the very old (80 years and older). Furthermore, abstracting from the extreme ends of the distribution (0–4 years and 80 years and older), the familiar U-shaped age cohort impact arises with a slight shift: the young, along with the young working age (5–34 years) are inflationary, the older working age cohorts (35–64 years) deflationary and the old (65–79 years) again inflationary. This basic U-shaped pattern remains robust throughout various estimations: when controlling for time fixed effects (Model 40), constraining the sample for the earlier, 1955–79 period (Model 41) or the later, 1980–2010 period (Model 42) or even for the post-1995 period (Model 43) – though coefficient estimates of some age cohorts occasionally lose statistical significance. Estimating a dynamic version of the same specification that allows for full

[7] Strictly speaking, the evidence could also be consistent with backward looking expectations formation, where current and past inflation drive the bulk of inflation expectations. In such a case, inflation expectations could not explain inflation, but demography would still explain inflation and inflation expectations.

heterogeneity, similar to equation (8) in the next section, also shows a similar U-shaped pattern for age cohort impact (Model 44).

However, the estimates at the extreme ends remain somewhat volatile, exactly as in the case of population polynomials: the coefficients on the very young (0–4 years) and the very old (80 years and older) swing from significance to insignificance and between positive and negative values depending on the specification.

Large age categories

Dependent variable is π_t in 39–43 and $\Delta\pi_t$ in 44

Table 7

Model	39	40	41	42	43	44
n_{it}^{0-4}	–0.87 (–9.05)	0.44 (3.79)	–0.65 (–5.26)	0.84 (4.32)	–0.48 (–1.57)	–0.01 (–0.01)
n_{it}^{5-19}	0.56 (13.57)	0.38 (9.12)	0.19 (3.31)	0.53 (8.33)	0.42 (3.65)	1.20 (4.20)
n_{it}^{20-34}	0.31 (9.20)	–0.06 (–1.73)	–0.05 (–0.72)	–0.06 (–1.31)	0.16 (2.72)	–0.07 (–0.35)
n_{it}^{35-49}	–0.47 (–11.82)	–0.33 (–8.21)	–0.61 (–5.94)	–0.42 (–8.43)	–0.15 (–2.54)	–1.65 (–3.07)
n_{it}^{50-64}	–0.30 (–6.24)	0.18 (3.80)	0.12 (1.58)	0.11 (1.30)	–0.15 (–1.91)	–1.57 (–3.16)
n_{it}^{65-79}	0.59 (6.84)	0.32 (3.71)	1.66 (4.56)	0.45 (4.32)	–0.20 (–1.89)	3.34 (4.04)
n_{it}^{80+}	–0.15 (–1.09)	–1.55 (–6.94)	–1.88 (–1.61)	–2.07 (–6.29)	0.55 (2.54)	4.07 (1.30)
r_{it}	–0.59 (–17.82)	–0.63 (–17.97)	–0.68 (–17.58)	–0.45 (–8.48)	–0.13 (–1.75)	–0.60 (–7.34)
$\hat{y}_{it}$	0.14 (3.78)	0.14 (3.48)	0.13 (3.50)	0.23 (5.12)	0.18 (4.40)	0.79 (8.49)
D_{74}	2.31 (3.27)		2.27 (4.18)			
D_{80}	3.39 (4.72)					
$-\alpha$						–0.53 (14.15)
Δr_t						–0.58 (–12.31)
$\Delta\hat{y}_t$						0.21 (4.95)
Estimator	FE	FE	FE	FE	FE	MG
Dem. Insig. F-test	0.000	0.000	0.000	0.000	0.000	NA
Country effects	Yes	Yes	Yes	Yes	Yes	NA
Time effects	No	Yes	No	No	No	NA
R^2	0.68	0.83	0.85	0.75	0.51	NA
Obs.	1232	1232	550	682	352	1276
Max sample	1955–2010	1955–2010	1955–1979	1980–2010	1995–2010	1955–2010

3.4.5 Model dynamics

Given that we are matching low-frequency variation in inflation with equally low-frequency demographic movements, it is reasonable to check that the correlations presented are not spurious. We show in this subsection that demography remains statistically and economically significant after allowing for dynamics and transforming the data to make them stationary.

To address concerns of spurious regression, we add lags of inflation, real interest rate and output gap to the right-hand side of the benchmark model (equation 6), lag the polynomial terms by one period and rewrite the result in error correction form in equation (8) below:

$$\Delta\pi_{jt} = \mu + \mu_{j0} + \varphi_1 \Delta\hat{y}_{jt} + \varphi_2 \Delta r_{jt}$$

$$-\alpha(\pi_{j,t-1} - \lambda_1 \hat{y}_{j,t-1} - \lambda_2 r_{j,t-1} - \textstyle\sum_{p=1}^{P} \gamma_p \tilde{n}_{pj,t-1}) + \varepsilon_{jt} \quad (8)$$

The term in parentheses captures deviations from an empirical steady-state relationship between inflation and the real interest rate, the output gap and the population polynomial. This part of the equation has the same interpretation as the specifications that we have so far been estimating. The adjustment coefficient α describes how fast deviations from the estimated steady-state translate into inflation growth. The remaining terms capture short-run dynamics. Note that we do not allow the population terms in (8) to have any short-term effects since we did not add lags of the population polynomial to the equation.

The benefit of the specification in (8) is that the left-hand side variable is now clearly stationary. Consequently, only stationary right-hand side variables can be relevant for explaining it. For example, if it turned out that the regressions that we have so far conducted were spurious, the steady-state deviations would be non-stationary and, hence, α should be zero.

Using the dynamic fixed effects (DFE) specification to estimate equation (8) does not change the estimated demographic impact meaningfully (Table 8). The coefficient estimates for the polynomial terms are highly significant statistically and are still in line with the benchmark results both without time fixed effects (Model 45) and with them (Model 46). Adding time fixed effects also has approximately the same effects as before, ie somewhat weakening but not eliminating the demographic impact. Moreover, in both cases the adjustment coefficient α is both significant and negative, indicating that deviations from the long-run equilibrium error correct into inflation movements and that the errors are mean-reverting. Taken together, these results indicate that the population effects are not spurious.

However, the large coefficients on the output gap in Models 45 and 46 might be puzzling at first glance. When interpreting this finding one should consider that the magnitude of the effect on per-period inflation growth should be multiplied by α and that this multiple is much smaller and more in line with what we had before. Yet there is an indication that the output gap might not belong to the long-run relationship, because the output gap captures cyclical fluctuations of a much higher frequency than demography or low-frequency inflation. In other words, the swings in the output gap are so fast that the estimated large long-run effect never has time to materialise. This argument is further reinforced by the fact that the coefficients on the output gap in Models 45–50 seem to fluctuate inversely with the adjustment coefficient α.

Dynamics and heterogeneity

Dependent variable: $\Delta\pi_t$

Table 8

Model	45	46	47	48	49	50
Estimator	DFE	DFE	PMG	MG	PMG	PMG
$\tilde{n}_{1kt}(\times 1)$	2.17 (7.22)	0.31 (1.15)	1.86 (8.36)	1.95 (2.55)	4.15 (4.24)	2.16 (10.82)
$\tilde{n}_{2kt}(\times 10)$	–5.16 (–6.25)	–1.53 (–3.07)	–4.24 (–8.01)	–4.24 (–2.02)	–9.80 (–4.41)	–4.98 (–10.14)
$\tilde{n}_{3kt}(\times 10^2)$	4.35 (5.46)	1.72 (4.26)	3.43 (7.23)	2.83 (1.37)	8.06 (4.13)	4.13 (9.13)
$\tilde{n}_{4kt}(\times 10^3)$	–1.20 (–4.89)	–0.57 (–4.08)	–0.91 (–6.51)	–0.53 (–0.80)	–2.15 (–3.69)	–1.12 (–8.29)
r_{it}	–0.72 (–5.18)	–0.66 (–8.97)	–0.63 (–10.18)	–0.72 (–4.83)	–1.77 (–5.05)	–0.41 (–6.02)
$\hat{y}_{it}$	1.68 (4.07)	0.85 (6.84)	1.57 (9.47)	0.99 (5.22)	3.22 (3.78)	1.20 (9.06)
$-\alpha$	–0.16 (–3.73)	–0.24 (–5.45)	–0.19 (–13.28)	–0.46 (–11.40)	–0.07 (–6.32)	–0.26 (–10.58)
Δr_t	–0.66 (–20.67)	–0.66 (–21.10)	–0.59 (–15.97)	–0.57 (–12.55)	–0.70 (–12.44)	–0.53 (–10.83)
$\Delta\hat{y}_t$	0.21 (5.63)	0.09 (2.88)	0.25 (7.64)	0.18 (4.44)	0.22 (3.02)	0.26 (7.16)
Dem. Insig. F-test	0.000	0.000	0.000	0.000	0.000	0.000
Country effects	Yes	Yes	NA	NA	NA	NA
Time effects	No	Yes	NA	NA	NA	NA
R^2	0.73	0.81	NA	NA	NA	NA
Obs.	1232	1232	1232	1232	448	784
Max sample	1955–2010	1955–2010	1955–2010	1955–2010	1955–2010	1955–2010

3.4.6 Country heterogeneity

An additional concern is whether the homogeneity assumptions underlying the panel regressions are approximately satisfied. To address these concerns, we show that country heterogeneity does not meaningfully affect the demographic impact. We first allow all short-run coefficients and the adjustment coefficient of equation (8) to vary with the country index, ie we estimate these models by the pooled mean group (PMG) estimator derived in Pesaran and Smith (1995). We then allow for full heterogeneity with respect to all the coefficients, ie we use the mean group (MG) estimator derived in Pesaran et al (1999).

The demographic impact remains both statistically and economically significant after adding country heterogeneity, ie applying PMG and MG estimators (Table 8, Models 47 and 48, respectively). Again the coefficients are similar to those of the benchmark model and are highly significant. Moreover, the PMG estimator generates a U-shaped age cohort effect on inflation very similar to the benchmark model (Graph A4 in the Appendix, left-hand panel). The basic U-shaped pattern also

Country-specific estimates

Dependent variable: π_t

Table 9

	$\tilde{n}_{1kt}(\times 1)$	$\tilde{n}_{2kt}(\times 10)$	$\tilde{n}_{3kt}(\times 10^2)$	$\tilde{n}_{4kt}(\times 10^3)$	$-\alpha$	F(4,1250)
Austria	0.02 (0.04)	–0.40 (–0.38)	0.32 (0.36)	–0.05 (–0.18)	–0.66 (–5.42)	0.000
Australia	5.98 (5.99)	–13.82 (–5.48)	12.88 (5.05)	–4.05 (–4.79)	–0.60 (–4.90)	0.000
Belgium	2.03 (0.88)	–4.61 (–0.83)	3.80 (0.73)	–1.03 (–0.65)	–0.42 (–3.15)	0.000
Canada	1.25 (1.47)	–2.24 (–0.86)	1.20 (0.39)	–0.14 (–0.12)	–0.40 (–3.01)	0.000
Denmark	–0.66 (–0.81)	0.55 (0.35)	–0.86 (–0.64)	0.49 (1.21)	–0.76 (–4.95)	0.000
Finland	0.57 (1.04)	–0.20 (–0.15)	–0.63 (–0.54)	0.35 (0.87)	–0.38 (–3.00)	0.000
France	4.26 (1.41)	–9.01 (–1.31)	7.32 (1.20)	–2.01 (–1.11)	–0.34 (–2.70)	0.000
Germany	0.18 (0.31)	–0.66 (–0.49)	0.53 (0.44)	–0.11 (–0.32)	–0.45 (–4.74)	0.000
Greece	9.92 (3.19)	–29.51 (–3.71)	26.82 (3.79)	–7.45 (–3.66)	–0.11 (–1.74)	0.002
Ireland	4.41 (1.40)	–10.47 (–1.35)	9.21 (1.24)	–2.69 (–1.14)	–0.54 (–4.22)	0.000
Italy	8.04 (2.55)	–18.05 (–2.86)	14.08 (2.66)	–3.53 (–2.14)	–0.12 (–0.99)	0.037
Japan	–0.47 (–0.74)	1.78 (1.19)	–1.98 (–1.44)	0.66 (1.56)	–0.54 (–3.95)	0.000
Korea	–7.67 (–1.70)	24.31 (1.75)	–27.45 (–1.80)	9.71 (1.82)	–0.33 (–3.80)	0.000
Netherlands	–1.56 (–1.09)	3.72 (1.13)	–4.06 (–1.28)	1.48 (1.42)	–0.43 (–3.34)	0.000
New Zealand	3.99 (5.10)	–8.96 (–4.48)	8.18 (3.88)	–2.57 (–3.46)	–0.72 (–5.70)	0.000
Norway	2.36 (4.35)	–4.75 (–5.13)	3.42 (4.69)	–0.82 (–3.74)	–0.66 (–4.58)	0.000
Portugal	2.86 (0.64)	–5.59 (–0.51)	1.14 (0.09)	0.95 (0.19)	–0.08 (–0.98)	0.211
Spain	–0.55 (–0.45)	1.29 (0.39)	–3.43 (–0.86)	1.83 (1.22)	–0.48 (–4.37)	0.000
Sweden	3.30 (4.03)	–6.83 (–4.89)	4.67 (4.22)	–1.00 (–3.08)	–0.49 (–3.35)	0.000
Switzerland	1.10 (2.26)	–2.35 (–2.12)	1.77 (1.78)	–0.44 (–1.47)	–0.64 (–5.17)	0.000
United Kingdom	2.24 (3.25)	–5.00 (–3.19)	3.75 (2.54)	–0.90 (–1.97)	–0.52 (–4.25)	0.000
United States	1.26 (1.87)	–2.41 (–1.65)	1.61 (1.15)	–0.35 (–0.76)	–0.39 (–2.58)	0.000

remains in the MG estimator, but the form moves closer to a second order polynomial (right-hand panel). Again, one should treat this result cautiously because the impact of the very young and the very old cohorts are less precisely estimated.

The results from the MG estimator also produce country-specific estimates of the steady-state (Table 9). Two general patterns arise. First, going from the lower order polynomial terms to the higher order ones, the coefficients tend to alternate in sign. In the vast majority of countries, the first coefficient is positive, the next negative, and so on. The pattern is reversed in five countries (Denmark, Japan, Korea, the Netherlands and Spain), and the alternation is broken in two countries (Finland and Portugal). Second, the coefficients on the second and third order terms are approximately twice as large as the coefficients on the first and fourth order terms. Furthermore, the steady-state deviations appear to be significantly mean-reverting in most countries. The adjustment coefficients are insignificant in only three countries (Greece, Italy and Portugal) – and even in these cases, it should be kept in mind that the estimate for each country is based on at most 55 observations. The population polynomial is only insignificant in the case of Portugal.

Despite the similarities across countries, it might be worthwhile to split the sample and apply the PMG estimator to different groups as an additional robustness check (Table 8, Models 49 and 50). In order to obtain two country sets as different as possible in terms of demographic impact, we split the sample into one group consisting of the countries where the results seem to be the weakest (Greece, Italy and Portugal) or where the parameter sequence deviates from the dominant pattern (Denmark, Finland, Japan, Korea, the Netherlands and Spain) and another consisting of the remaining countries. That is, we separately estimate the population polynomial for the set of countries where results are likely to be the weakest (Group 1 – Model 49) and for the set where results can be expected to be the strongest (Group 2 – Model 50). Nevertheless, the long-run relationship between demographics and inflation appears to be almost identical between the two groups, aside from different scaling. Again, the polynomial coefficients are very significant and show a similar pattern. Hence, re-estimating our regression on the group of countries which differ most in terms of the population polynomial estimates does not yield meaningfully different results from the benchmark model.

Thus, individual country estimates suggest that heterogeneity across countries is moderate and does not drive the demographic estimates. In fact, the relative similarity of country estimates might explain why the predicted demographic impact derived from the panel estimate fits country inflation data so well (as shown in Graph 5).

4. Demography and monetary policy

The evidence presented so far suggests that demographic change affects low-frequency inflation beyond the impact of other factors, including that of short-term real interest rates. This pattern raises questions about how and through which mechanism the age structure of the population could affect inflation.

In order to provide further evidence for thinking about potential mechanisms, we examine whether the age structure is also related to the conduct of monetary policy, ie to real interest rate setting and to deviations from Taylor rules. The age cohort impact on monetary policy variables can also inform us whether monetary policy mitigated or reinforced the demographic impact on inflation. Consider the case when monetary policy reinforces the demographic impact: then those age cohorts where the demographic pressures are inflationary should be associated with relatively lower real policy rates or downward deviations from Taylor rules. Thus, given that the demographic impact on inflation shows the U-shaped age cohort pattern, one would expect to see an inverse U-shaped pattern for real interest rates and Taylor deviations. Conversely, when the central bank mitigates the demographic inflationary pressure, then those age cohorts where the demographic pressures are inflationary should be associated with relatively higher real policy rates or upward deviations from Taylor rules. Thus, in this case a similar U-shaped pattern should arise for real interest rates and Taylor deviations, as we have seen for inflation.

We first show that the age structure of the population also affects short-term real interest rates. We use the population polynomial to estimate the following specification for the ex-post real interest rate:

$$r_{jt} = \mu + \mu_{j0} + \sum_{p=1}^{P} \gamma_p \tilde{n}_{pjt} + \varepsilon_{jt} \tag{9}$$

The regression results confirm that demography affects the real interest rates (Table 10). In the full sample, demography is statistically and economically significant – and it accounts for more than one-eighth of the total variation of low-frequency movements in real interest rates (Model 51).

Demography and monetary policy — Table 10

Model	51	52	53	54
Dependent variable	r_{it}	$i_{it} - 1.5\pi_{it} - 0.5\hat{y}_{it}$	$i_{it} - \beta_{0i} - \beta_1\pi_{it} - \beta_2\hat{y}_{it}$	$i_{it} - \beta_{0i} - \beta_{1i}\pi_{it} - \beta_{2i}\hat{y}_{it}$
$\tilde{n}_{1kt}(\times 1)$	0.10 (0.63)	–0.88 (–3.91)	–0.49 (–2.54)	–0.75 (–2.80)
$\tilde{n}_{2kt}(\times 10)$	0.42 (1.23)	2.77 (5.71)	1.83 (4.45)	2.44 (4.35)
$\tilde{n}_{3kt}(\times 10^2)$	–0.77 (–2.64)	–2.76 (–6.66)	–1.95 (–5.58)	–2.43 (–5.14)
$\tilde{n}_{4kt}(\times 10^3)$	0.29 (3.55)	0.85 (7.05)	0.62 (6.12)	0.74 (5.43)
Dem. Insig. F-test	0.000	0.000	0.000	0.000
Country effects	Yes	Yes	Yes	Yes
Time effects	No	No	No	No
R^2	0.13	0.13	0.14	0.14
Obs.	1232	1232	1232	1232
Sample	1955–2010	1955–2010	1955–2010	1955–2010

Furthermore, one also would like to go beyond real interest rates and control for those factors that monetary policy should have taken into account – and investigate the deviations from such an optimal policy. For our analysis, we apply versions of the widely used Taylor rule to proxy optimal monetary policy, because it is straightforward to calculate and can be used throughout the sample. However, we acknowledge that central bank decision-making is complex, and such rules are just crude proxies for optimal policies. Investigating the demographic effects on other monetary policy rules is a natural future extension of our work.

Deviations from Taylor rules are also statistically significantly correlated with demography (Table 10, Models 52–54). We consider three Taylor rules. First, we investigate deviations from the specific normative rule that Taylor (1993) suggested originally to describe US policy rates (Model 52). Next, we look at deviations from empirically estimated Taylor rules. In the first version, we estimate a single Taylor rule for all countries in the sample (Model 53), and in the second version we allow the Taylor coefficients to vary across countries (Model 54). We estimate the Taylor coefficients on the 1985–2010 period, because there is more agreement that central banks broadly followed such rules in that period compared to earlier ones. Demography is again significant: deviations from normative and estimated Taylor rules all correlate statistically significantly with demography. The impact of age structure on both the real interest rate and the deviation of real interest rates from Taylor rules follows a similar inverse U-shaped pattern (Graph A5 in the Appendix).[8]

However, a closer examination of the results reveals that the conduct of monetary policy has undergone a significant change around the mid-1980s. In particular, re-estimating real interest rates and deviations from Taylor rules for the 1955–1984 and the 1985–2010 periods separately yields very different results (Table 11). In the first half of the sample, we see the same qualitative picture emerging as for the full sample both for real interest rates and the Taylor rule (Models 55 and 56, respectively).[9] However, this pattern reverses completely in the second half of the sample (1985–2010): the coefficient estimates for both the real interest rate and deviations from the Taylor rule have the opposite sign (Models 57 and 58, respectively). Note that the link does not disappear in the later period: the coefficient remains highly significant statistically – only the sign changes.

In the first half of the sample (1955–1984), the demographic impact on monetary policy reinforced the demographic pressures on inflation (Graph 6). The young and the old are associated with lower real interest rates, and the working age cohort with higher real interest rates (left–hand panel). Similarly, the young and the old are associated with below Taylor rule rates, and the working age cohort with above Taylor rule rates (right-hand panel). Given that the demographic impact was mostly inflationary in the first half of the sample, reinforcing it implies that central banks kept real interest rates relatively low.

8 Adding time fixed effects has similar results as in the case of inflation. In particular, it does not qualitatively change the demographic impact on real interest rates or the deviations from Taylor rules, but weakens the statistical significance and reduces the economic impact by removing time variation. For the sake of brevity, the results with time fixed effects are not shown here, but are available upon request.

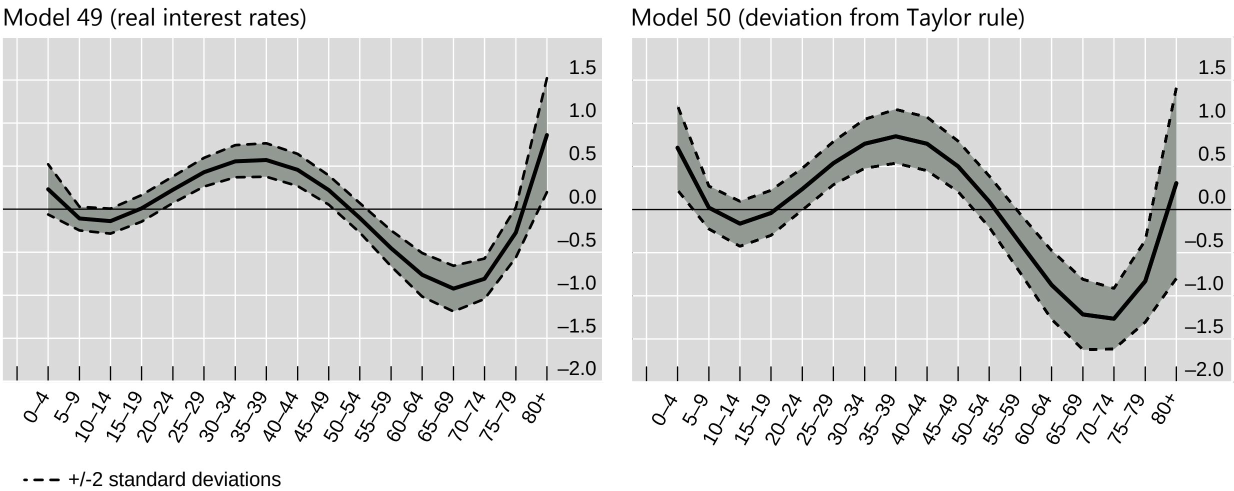
9 For the sake of brevity, Table 11 shows the results for real interest rate and the deviations from the Taylor rule relying on country-by-country coefficient estimates. Estimates for the other two Taylor rules (as in Models 52 and 53) are not materially different and are available upon request.

Demography and monetary policy: a shift in the mid-1980s — Table 11

Model	55	56	57	58
Dependent variable	r_{it}	$i_{it} - \beta_{0i} - \beta_{1i}\pi_{it} - \beta_{2i}\hat{y}_{it}$	r_{it}	$i_{it} - \beta_{0i} - \beta_{1i}\pi_{it} - \beta_{2i}\hat{y}_{it}$
$\tilde{n}_{1kt}(\times 1)$	–1.09 (–4.00)	–1.87 (–4.06)	1.27 (7.04)	0.51 (2.70)
$\tilde{n}_{2kt}(\times 10)$	3.20 (4.94)	4.91 (4.51)	–2.44 (–6.73)	–0.77 (–2.03)
$\tilde{n}_{3kt}(\times 10^2)$	–3.16 (–5.40)	–4.53 (–4.64)	1.66 (5.57)	0.29 (0.93)
$\tilde{n}_{4kt}(\times 10^3)$	0.97 (5.56)	1.32 (4.57)	–0.37 (–4.37)	0.00 (0.05)
Dem. Insig. F-test	0.000	0.000	0.000	0.000
Country effects	Yes	Yes	Yes	Yes
Time effects	No	No	No	No
R^2	0.05	0.07	0.49	0.27
Obs.	660	660	572	572
Sample	1955–1984	1955–1984	1985–2010	1985–2010

Age cohort effects on monetary policy

1955–1984, in per cent — Graph 6

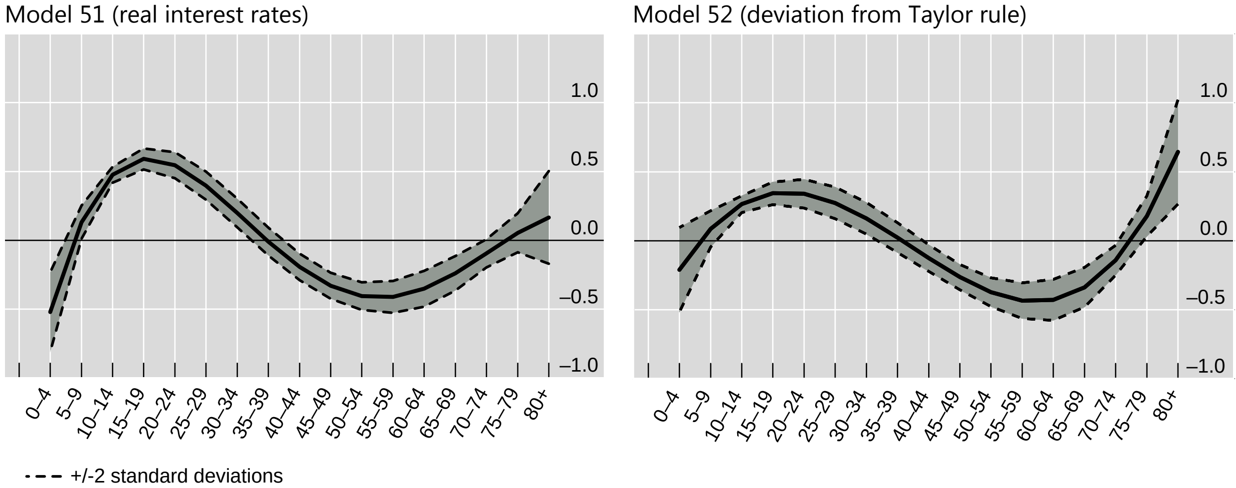


In the second half of the sample (1985–2010), the reversal in estimated coefficients implies that the demographic impact on monetary policy mitigated the demographic pressure on inflation (Graph 7). A U-shaped age cohort pattern emerges: real interest rates are higher when the demographic pressure on inflation is strong and lower when the demographic pressure is weak, ie the young and old are associated with higher real rates and the working age population with lower real rates (left-hand panel). The deviations from the Taylor rule follow a similar pattern: the young and the old are associated with upward deviations from the rule, and the working age cohort with downward deviations (right-hand panel). Given that demographic impacts were mostly disinflationary in the post-1985 period, mitigating them implies that central banks kept real rates relatively low.

Age cohort effects on monetary policy

1985–2010, in per cent

Graph 7



In sum, our investigation suggests that demography affected not only inflation but also the conduct of monetary policy. However, this impact was not stable. Up until the mid-1980s, monetary policy reinforced demographic effects on inflation, but after the mid-1980s it mitigated them. Given that before the mid-1980s demographic pressures tended to be inflationary and after the mid-1980s disinflationary, the results also imply that central banks tended to keep real interest rates relatively low throughout the whole sample.

5. Discussion

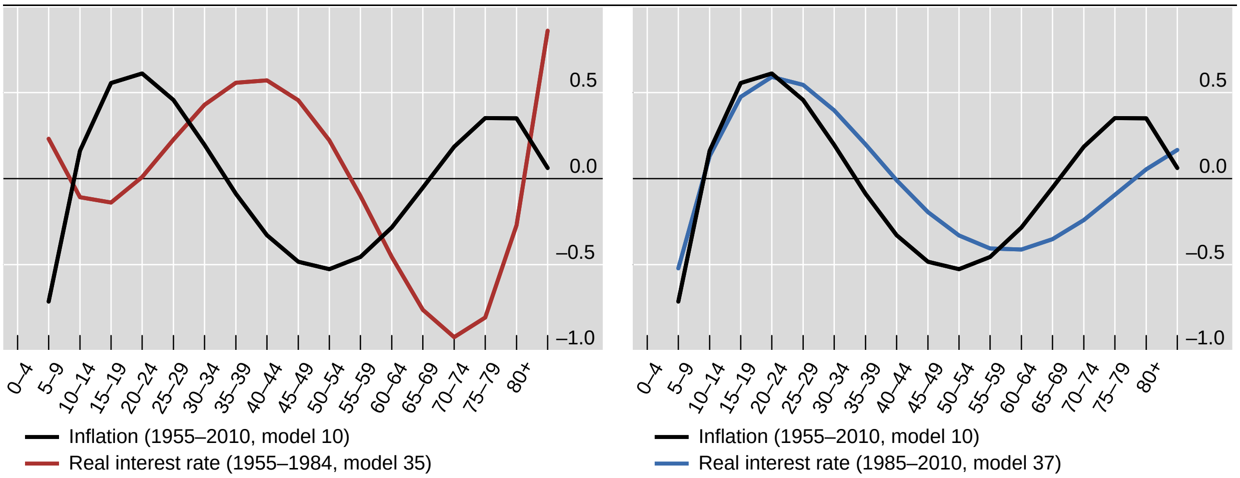
In this section, we discuss some implications of the empirically uncovered robust and stable link between demography and inflation. First, we summarise the main takeaways from our empirical investigation. Second, we show why the data seem to be more consistent with economic factors driving the relationship between demography and inflation as opposed to political factors. Third, we quantify the demographic pressure implied by our results for future inflation. Fourth, we show that using low-frequency population effects helps obtain more precise and stable estimates of higher-frequency inflation drivers. Last, but not least we discuss the caveats.

5.1 Main findings

Our results suggest a robust correlation between demography and inflation and a shifting correlation between demography and monetary policy (Graph 8). As for the relationship between demography and inflation, the same stable U-shaped pattern arises irrespective of the precise period or empirical technique chosen: the dependents (ie the young and the old) are associated with higher rates of inflation, while the working age cohorts are associated with lower inflation rates (black line). Thus, our results suggest that ageing would eventually lead to higher inflation, which is somewhat surprising because most arguments, including those that motivated our study, have concluded the opposite.

Age cohort effects on inflation and monetary policy

Graph 8



As for monetary policy, we see a major shift around the mid-1980s – irrespective of whether we measure monetary policy by real interest rates or by deviations from a Taylor rule. Before the mid-1980s, the dependents (ie the young and the old) are associated with lower real interest rates, while the working age cohorts are associated with higher real interest rates (Graph 8, left-hand panel, red line). In other words, monetary policy reinforces the demographic impact: the real interest rate is low when the demographic pressure is inflationary and vice versa. This pattern reverses after the mid-1980s, as then the dependents are associated with higher real interest rates, while the working age cohorts are associated with lower interest rates (right-hand panel, blue line). Thus, in the later sample monetary policy mitigates demographic disinflationary pressures, albeit not fully.

5.2 Politics vs economics

In very broad terms, either economic or political factors can drive the demographic impact on inflation. The mechanism presented in Shirakawa (2011a, 2011b, 2012 and 2013) is economic: demography affects inflationary pressures directly. Such a pressure could work through, for instance, the balance of demand and supply or the equilibrium real interest rate. The mechanism presented in Bullard et al (2013) models a political driver. In such a setup, different age groups might have different inflationary preferences – and the central bank could take social or voter preferences into account when setting the interest rate.

Our results lend support to an economic explanation. Most important, the demographic impact on inflation remains even after controlling for real interest rates. If the demographic impact simply reflected central bank decisions, then the real interest rate would include all the demographic impact and be a sufficient statistic for inflation movements. In principle, the results also contradict the specifics of the Bullard et al (2013) model. First, central banks' reaction to inflation changes mid-sample suggesting that age groups do not have well defined inflation preferences or are not able to transmit these preferences consistently to central banks. Second, the significant impact of the non-voting young is inconsistent with a voting model. Finally, the empirical findings suggest that the old are inflationary and the working age are disinflationary – the opposite of the model.

The creation of the euro provides a natural experiment to test whether economic or political channels are at work. If demography affects inflation through a political process, then after the creation of the euro area demography should not explain the country–specific variation in inflation. For instance, demographic developments in Belgium should not affect Belgian inflation – as Belgian political pressures could not reasonably sway the European Central Bank's decisions.

To test this hypothesis, we run our benchmark model on the 1999–2010 period (Table 12). Without time fixed effects, ie without focusing solely on the cross-country variation in inflation, the demographic impact is significant for both the full country sample and the euro area (Models 59 and 60). Incidentally, this provides another robustness test for our benchmark specification. Furthermore, the demographic impact remains significant even if we focus on the cross-country variation in inflation, ie when we introduce time fixed effects. In this case, demography remains significant for all countries (Model 61), for non-euro area countries (Model 62) and also for the euro area (Model 63) – suggesting that more is at work than simple political pressure. The significance remains even if we exclude the three largest euro area economies (France, Germany and Italy), who might be considered as more likely candidates to influence the central bank's decisions (Model 64).

Demographic impact and the euro area

Benchmark model, 1999–2010 dependent variable is π_t

Table 12

Model	59	60	61	62	63	64
$\tilde{n}_{1kt}(\times 1)$	1.23 (5.34)	0.79 (3.41)	1.08 (4.12)	1.41 (5.17)	0.51 (2.68)	0.58 (1.95)
$\tilde{n}_{2kt}(\times 10)$	–2.19 (–4.62)	–1.45 (–4.50)	–1.74 (–3.47)	–2.36 (–5.06)	–0.81 (–2.71)	–0.93 (–1.83)
$\tilde{n}_{3kt}(\times 10^2)$	1.45 (3.79)	0.96 (4.60)	0.99 (2.74)	1.44 (4.43)	0.36 (1.49)	0.46 (1.05)
$\tilde{n}_{4kt}(\times 10^3)$	–0.32 (–3.04)	–0.21 (–3.76)	–0.18 (–1.97)	–0.28 (–3.42)	–0.02 (–0.29)	–0.06 (–0.39)
r_{it}	–0.37 (–3.64)	–0.27 (–2.47)	–0.41 (–3.33)	–0.48 (–4.52)	–0.31 (–1.62)	–0.29 (–1.49)
$\hat{y}_{it}$	0.27 (4.52)	0.21 (2.71)	0.07 (1.38)	0.19 (3.08)	–0.02 (–0.72)	0.01 (0.41)
Dem. Insig. F-test	0.000	0.000	0.000	0.000	0.006	0.011
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	No	Yes	Yes	Yes	Yes
R^2	0.51	0.41	0.73	0.77	0.79	0.57
Sample	All countries	Euro area	All countries	Non-euro area	Euro area	Euro area (w/out DE, FR and IT)
Obs.	264	120	264	144	120	84

However, some caution is warranted. The demographic coefficients are weaker in the euro area than outside – and even weaker in the euro area sample excluding the three largest economies. This weakening of the coefficient estimates might simply reflect less precise estimates as our sample size shrinks – but it might also signal the existence of some political drivers.

Taken together, the empirical results, particularly the test on the euro area, suggest that demography affects inflation primarily through economic and not political factors. However, this does not imply that political pressures are irrelevant – our results only suggest that economic drivers might be more relevant.

Given the robust results and the evidence pointing towards an economic explanation, the question arises of precisely what economic mechanism might explain the observed empirical pattern. While this is clearly an area of further research, the different effects of dependents (ie the old and the young) and working age cohorts suggest a possible demand channel. More precisely, those cohorts which consume more goods and services than they produce (ie the dependents) could exert an inflationary pressure through excess demand while those who produce more than what they consume (ie the working age cohorts) could exert a disinflationary pressure through excess supply. It is straightforward to formalise such an intuition in an overlapping generation model with exogenous money, which would reproduce our qualitative findings. However, even in this case more research needs to be done to understand what factors shape central banks' response to such pressures. Finally, there might be other potential theoretical explanations which should be explored and evaluated in the light of empirical evidence.

5.3 Implications for the future

Combining the estimated coefficients with the UN demographic projections allows us to show some preliminary estimates of how demography might alter inflation pressures in the future. We highlight these results to place our estimates in the context of the ongoing policy debate about the inflationary impact of population ageing, and not to provide standalone projections. As we discussed earlier, our results are less precise at the two extreme ends of the age distribution: for the very young and the very old. Given that in the future the share of the very old is expected to grow fast, the predictions should be treated cautiously. In contrast, estimates for past inflationary pressures rely more on the cohorts in the middle of the distribution, where our estimates are the most stable.

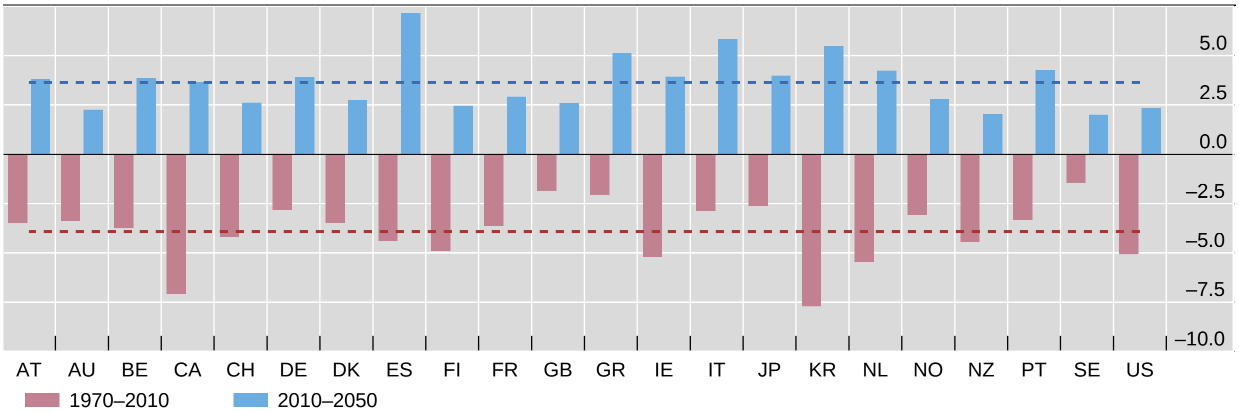
Taking our estimates at face value, the demographic pressure on inflation would be expected to reverse almost fully over the coming decades, from benign to more challenging (Graph 9). Our results imply that the increase in the relative share of working age population has lowered inflationary pressures by around four percentage points on average over the past forty years (red dotted line). However, over the next forty years the growing share of the old could raise average inflationary pressures by around four percentage points (blue dotted line).

Furthermore, individual country estimates show a similar reversal from demographic tailwinds pushing down inflation in the past (red bars) to demographic headwinds pushing up inflation in the future (blue bars). However, there are important cross-country differences. For instance, favourable demographics in the United States imply more pronounced than average reduction in inflationary pressures over the past forty years – and over the next forty years, US inflationary pressures could be expected to rise less than the average. Faster-ageing countries, such as Japan or Germany, have already lost some of the earlier reduction in inflation pressures – and the future inflationary pressures there are not higher than the average. Finally, the highest inflationary pressures would be expected in countries which are forecasted to age fastest: Greece, Italy, Korea and Spain could see a more than five percentage point increase in inflationary pressures.

Past and future inflationary pressures

Model 10, in per cent

Graph 9



AT = Austria; AU = Australia; BE = Belgium; CA = Canada; CH = Switzerland; DE = Germany; DK = Denmark; ES = Spain; FI = Finland; FR = France; GB = United Kingdom; GR = Greece; IE = Ireland; IT = Italy; JP = Japan; KR = Korea; NL = Netherlands; NO = Norway; NZ = New Zealand; PT = Portugal; SE = Sweden; US = United States.

The dashed lines show averages of the above economies.

It is also important to emphasise that we discuss inflationary pressures here, and not inflation forecasts: central banks, as our analysis also confirms, can always offset these inflationary pressures by raising policy rates. Thus, stronger inflationary pressures imply either higher inflation or higher real interest rates – and the choice remains with central banks.

To conclude, our results would suggest that the demographic environment is turning from benign to challenging. In the recent past demographic trends kept a lid on inflation, which allowed for rapid disinflation and, more recently, for low real interest rates. Over the course of the next forty years, this could change: central banks might need to apply higher real interest rates to contain growing inflationary pressures. In other words, our results suggest that the ageing under way is inflationary.

5.4 Long-run inflation estimation

Our results suggest that the evolution of inflation can be decomposed to low-frequency demographic and relatively high-frequency cyclical components. This decomposition would explain why estimates of cyclical components often work in the short run but not in the long run (see Sophocles et al (2014), for instance).

The inclusion of the population polynomial makes the coefficient estimates on the output gap statistically significant and more meaningful economically – and improves the overall fit of the regression. This can already be seen from the benchmark model estimates (see Table 2). Consider first the regression estimating a

Philips curve type relationship without the population polynomial (Model 8): though the real interest rate coefficient is highly significant, the output gap is insignificant. However, once we add the population polynomial (Model 10), the coefficient estimate on the output gap doubles in size and becomes statistically significant.

The estimates for the post-1980 period illustrate the point further (Table 13). When estimating the benchmark model without the population polynomial the output gap is insignificant – a typical problem of long-run estimates (Model 68). However, adding the population polynomial makes the output gap highly significant with the right sign (Model 69). Furthermore, the population polynomial also greatly improves the fit: the R^2 jumps from 0.02 to 0.68. In fact, it seems that in this period demography accounts for most of the low-frequency variation in inflation (Model 70). However, the results for the first half of the sample show smaller improvement for the inclusion of the demographic terms (Models 65–67). The reason might be that central banks in this period reinforced the demographic impact in their real interest rate setting, implying that the real interest rate already incorporates a sizeable demographic impact.

In sum, the real interest rate alone, or its combination with the output gap, often cannot explain the low-frequency shifts in inflation. We find that the inclusion of the population polynomial can explain these low-frequency shifts and thereby enables us to estimate inflation drivers correctly even in the long run.

Demography, inflation, real interest rates and the output gap

Benchmark model, dependent variable is π_t Table 13

Model	65	66	67	68	69	70
$\tilde{n}_{1kt}(\times 1)$		1.18 (6.56)	1.80 (5.98)		0.93 (5.95)	0.47 (2.31)
$\tilde{n}_{2kt}(\times 10)$		–2.74 (–5.76)	–4.29 (–5.55)		–2.92 (–9.04)	–2.25 (–5.57)
$\tilde{n}_{3kt}(\times 10^2)$		2.27 (4.97)	3.73 (5.13)		2.87 (10.50)	2.58 (7.59)
$\tilde{n}_{4kt}(\times 10^3)$		–0.60 (–4.27)	–1.04 (–4.68)		–0.88 (–10.95)	–0.86 (–8.62)
r_{it}	–0.76 (–13.12)	–0.69 (–17.04)		–0.17 (–2.11)	–0.47 (–9.11)	
$\hat{y}_{it}$	0.21 (4.32)	0.14 (3.66)		0.01 (0.11)	0.24 (5.57)	
Dem. Insig. F-test		0.000	0.000		0.000	0.000
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	No	No	No	No	No
R^2	0.70	0.81	0.38	0.02	0.68	0.57
Obs.	550	550	550	682	682	682
Max sample	1955–1979	1955–1979	1955–1979	1980–2010	1980–2010	1980–2010

The estimates for the two oil crisis dummies are available upon request.

5.5 Caveats

The results, and especially the projections, are subject to a number of caveats. Most important, while our sample is quite long by traditional macroeconomic standards, it is relatively short for analysing very slow moving demographic change – hence, the results should be treated cautiously. The fact that many countries experienced a similar demographic transition, a version of baby boom and bust, calls for further caution.

The implicit assumption that the impact of age cohorts is unchanged through the sample would require some attention. As an example, the analysis implicitly assumes that the 20–24 age cohort had the same demographic impact in 1960 and in 2010. However, the typical economic behaviour of people in these age cohorts has evolved over time: the young study longer and start careers and families later now than fifty years ago – so the economic profile of the 20–24 age cohort in the 1960s is likely to differ somewhat from the impact of the same cohort today. However, this shift is unlikely to drive our results meaningfully. The reason is that it concerns only a few years, at most moving the economic impact from one five-year age cohort to a neighbouring cohort. Such a limited move would not affect the results much as the population polynomial technique ensures that the estimated impact of nearby cohorts is similar.

However, the demographic change affecting the very young and very old cohorts, in particular decreased infant mortality and longer old age life expectancy, is likely to affect our estimates, as we have already discussed above. While this should not affect the main results, as we always focus on the inner cohorts, we would caution against relying on the estimates concerning the very young (0–4 years) or the very old (80 years and older). This is particularly relevant for future projections due to the strong expected increase in the number of very old. Hence, these projections should be treated cautiously.

Furthermore, the long-run projections should also be treated cautiously not only because of econometric concerns but also because of inherent uncertainty. Not surprisingly, the track record of longer-term predictions is dismal. Technology can develop with complex and unforeseen second round economic and social effects. Even demographic trends can change unexpectedly, so the current consensus and projections might prove to be wrong. True, demography has a very strong momentum; in Drucker's (2003) words it is "the future that has already happened". However, it is not written in stone. For instance, both the American and British baby booms were largely unexpected. The prevailing consensus, expressed in Keynes (1937) and Schumpeter (1943), expected low and falling birth rates on the eve of the boom. Similarly, the recent rapid increase in Russian fertility rates after 2005 also surprised the experts. Finally, the projected scale of population ageing is unprecedented, which suggests caution in extrapolating past, more modest, trends.

6. Conclusion

This paper has found a statistically and economically significant relationship between demography and low-frequency inflation: dependents (ie the young and the old) are inflationary while working age cohorts are disinflationary. This result holds in different sample periods, using different controls and estimation techniques. In other words, our results suggest that population ageing is inflationary. While this contradicts the prevailing view, it is consistent with the findings of an earlier inflation forecasting literature.

We also find that the age structure of the population is associated with the conduct of monetary policy. However, there seems to be a structural break in this link during the mid-1980s: monetary policy reinforced demographic pressures on inflation in the earlier part of the sample, and it started to mitigate them afterwards. Our findings also suggest that demography affects inflation more through economic than political economy channels.

Identifying demography as a potential driver of low-frequency inflation might be relevant for monetary policy makers by helping to fine tune monetary policy and eventually to anticipate the evolution of low-frequency inflationary pressures. In addition, including demography in empirical models could help construct more reliable estimates of, say, the impact of output gaps on inflation.

Yet there is much left for future research. On the theoretical side, more research is needed to identify how and through which channels demographic change can affect inflationary pressures. On the empirical side, more needs to be done to precisely estimate the inflationary impact of the very young and the very old. This is particularly relevant for gauging the inflationary impact of the global ageing under way: projections about future inflation developments rely disproportionately on the estimate of the impact of the very old, because their number is expected to rise sharply – and this is in fact the age category for which our estimates are less precise.

In sum, we find a sizeable and statistically stable demographic impact on low-frequency inflation. This result should motivate further research. As Alvin Hansen (1939) said in his presidential address to the American Economic Association, "Understanding how to adjust economic policy with respect to future demographic change will be a crucial question for policy makers in the aging industrial countries." We also believe that understanding these policy questions is crucial, perhaps not only for advanced economies, but also for ageing emerging economies.

Appendix

Population polynomial

Consider the population regression in equation (3) that we, for ease of exposition, reproduce for *K* age shares and without time fixed effects:

$$\pi_{jt} = \mu_{j0} + \sum_{k=1}^{K} \beta_{1k} n_{kjt} + \varepsilon_{jt} \tag{A1}$$

As mentioned earlier, there are at least three difficulties associated with this regression. First, correlation between consecutive age shares is typically large. Second, given that consecutive age shares are likely to have similar effects, it is inefficient to estimate their coefficients completely freely. Third, both the country fixed effects and the age shares sum to one and are, hence, perfectly correlated.

The first two problems can be addressed by restricting the population coefficients, β_{1k}, to lie on a *P*:th degree polynomial (*P* < *K*) of the form

$$\beta_{1k} = \sum_{p=0}^{P} \gamma_p k^p \tag{A2}$$

where the γ_p:s are the coefficients of the polynomial. Substituting A2 into A1 yields

$$\begin{aligned} \pi_{jt} &= \mu_{j0} + \sum_{k=1}^{K} \sum_{p=0}^{P} \gamma_p k^p \, n_{kjt} + \varepsilon_{jt} \\ &= \mu_{j0} + \sum_{p=0}^{P} \gamma_p \sum_{k=1}^{K} k^p \, n_{kjt} + \varepsilon_{jt} \\ &= \mu_{j0} + \gamma_0 + \sum_{p=1}^{P} \gamma_p \sum_{k=1}^{K} k^p \, n_{kjt} + \varepsilon_{jt} \end{aligned} \tag{A3}$$

where the last step uses $\sum_{k=1}^{K} k^0 \, n_{kjt} = 1$.

The third issue can be resolved by imposing the restriction $\sum_{k=1}^{K} \beta_{1k} = 0$. Substituting (A2) in the sum $\sum_{k=1}^{K} \beta_{1k}$ yields

$$\sum_{k=1}^{K} \beta_{1k} = \sum_{k=1}^{K} \sum_{p=0}^{P} \gamma_p k^p = \gamma_0 K + \sum_{p=1}^{P} \gamma_p \sum_{k=1}^{K} k^p \tag{A4}$$

where the last line uses the fact that $\sum_{k=1}^{K} k^0 = K$. Setting this expression to zero yields

$$\gamma_0 = -\sum_{p=1}^{P} \gamma_p \sum_{k=1}^{K} (k^p / K) \tag{A5}$$

and substituting into (A3) yields

$$\pi_{jt} = \mu_{j0} + \sum_{p=1}^{P} \gamma_p \sum_{k=1}^{K} (k^p \, n_{kjt} - k^p / K) + \varepsilon_{jt} \tag{A6}$$

which is as in the main text if we define $\tilde{n}_{pjt} = \sum_{k=1}^{K} \left(k^p n_{kjt} - k^p / K\right)$ and set *K* = 17.

Given estimates of the $\gamma_p{:}s$ one can easily calculate the $\beta_{1k}{:}s$ directly from (A2). It is also possible to calculate the variance of the β_{1k} estimates. To do this we substitute A5 into A2 to get

$$\beta_{1k} = \sum_{p=1}^{P} \gamma_p (k^p - \sum_{h=1}^{K} h^p / K) \tag{A7}$$

where we have changed the index from *k* to *h* on the sum in the parentheses to avoid ambiguity. Equation A7 shows that the $\beta_{1k}{:}s$ are linear transforms of the estimated $\gamma_p{:}s$. Collecting all the $\beta_{1k}{:}s$ and $\gamma_p{:}s$ in vector format, we can write A7 as

$$\beta_1 = \Psi \gamma \tag{A8}$$

where Ψ is a $K \times P$ matrix with typical element $\Psi_{kp} = (k^p - \sum_{h=1}^{K} h^p / K)$. From A8 we have

$$var(\beta_1) = var(\Psi \gamma) = \Psi \, var(\gamma) \, \Psi' \tag{A9}$$

applying the standard formula.

Appendix table

F-test results for polynomials — Table A1

Null: $\gamma_i = 0$	$i = 1$	$i = 2$	$i = 3$	$i = 4$	$i = 5$	$i = 6$
6th degree	4.62 (0.0317)	5.48 (0.0043)	83.55 (0.0000)	134.44 (0.0000)	111.52 (0.0000)	139.33 (0.0000)
5th degree	6.36 (0.0118)	123.21 (0.0000)	211.98 (0.0000)	162.83 (0.0000)	204.27 (0.0000)	
4th degree	206.95 (0.0000)	299.77 (0.0000)	204.36 (0.0000)	218.58 (0.0000)		
3rd degree	445.13 (0.0000)	229.17 (0.0000)	209.13 (0.0000)			

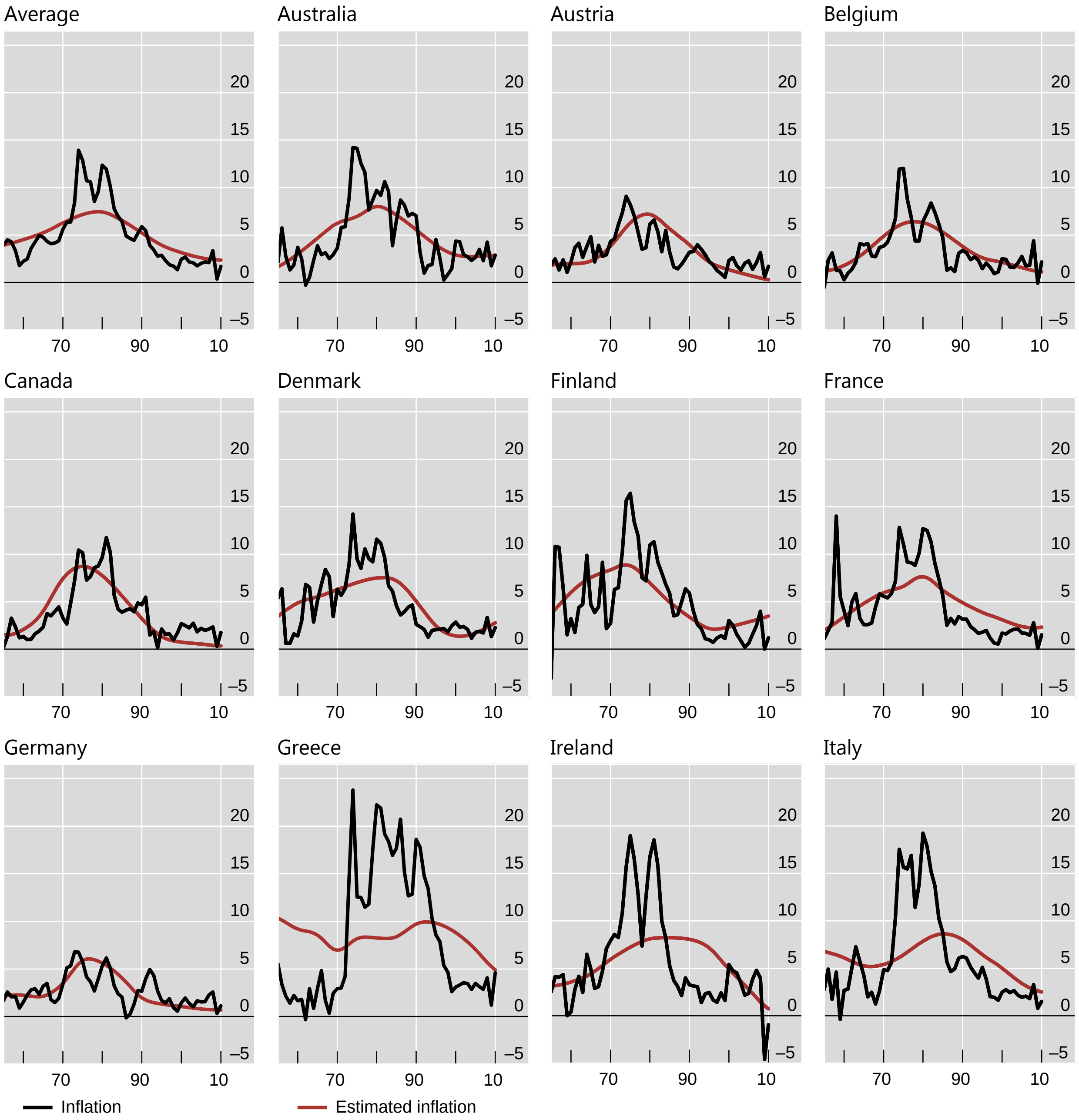
F-test on the null hypothesis that last i polynomial coefficients are zero (eg 4th degree i=2 tests $\gamma_4 = \gamma_3 = 0$).
Probability in parentheses.

Appendix graphs

Actual and estimated inflation from the benchmark model

Model 10: population polynomial without time effects, in per cent

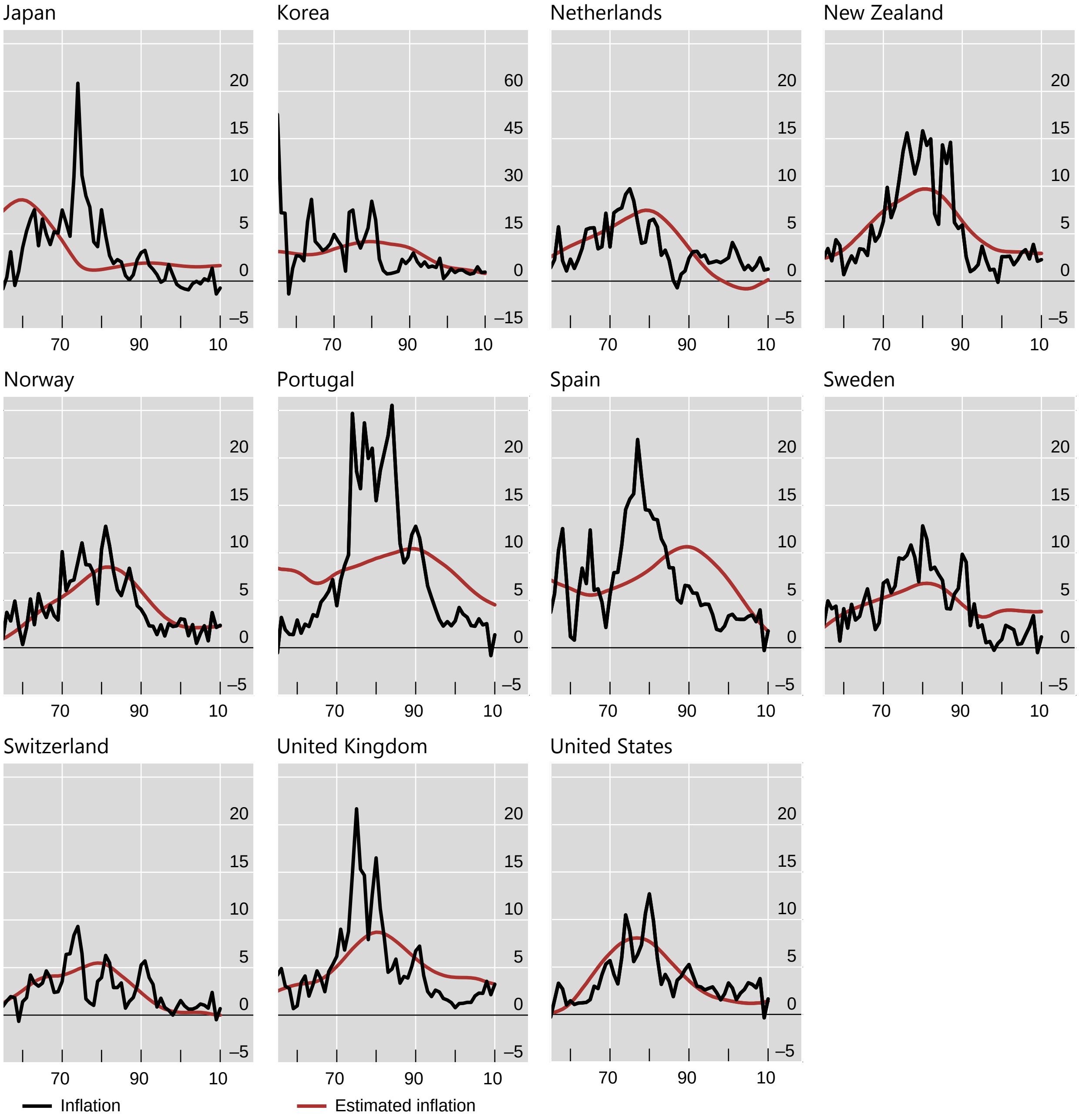
Graph A1



The fitted demographic effects are normalised to have the same mean as actual inflation.

Actual and estimated inflation from the benchmark model (cont)

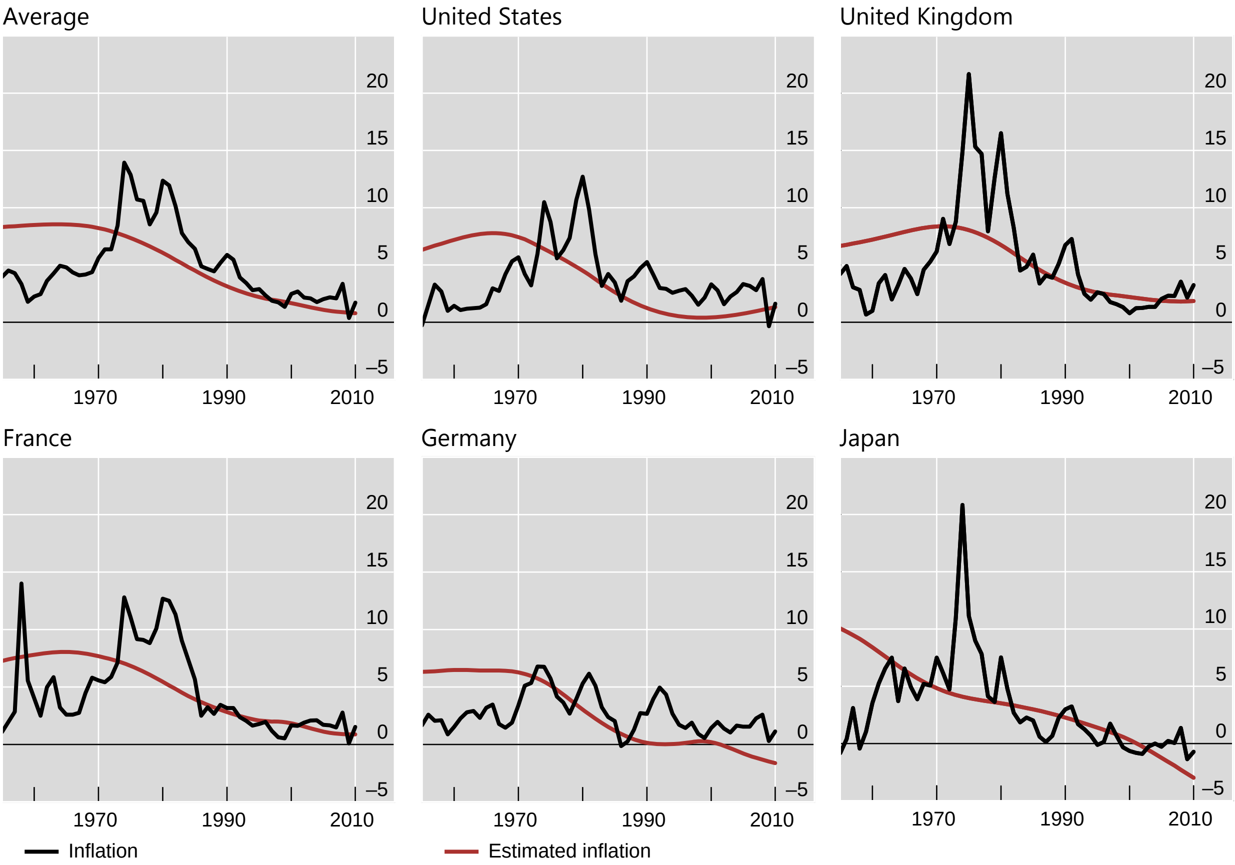
Model 10: population polynomial without time effects, in per cent — Graph A1



The fitted demographic effects are normalised to have the same mean as actual inflation.

Actual and estimated inflation from population polynomial with fixed time effects

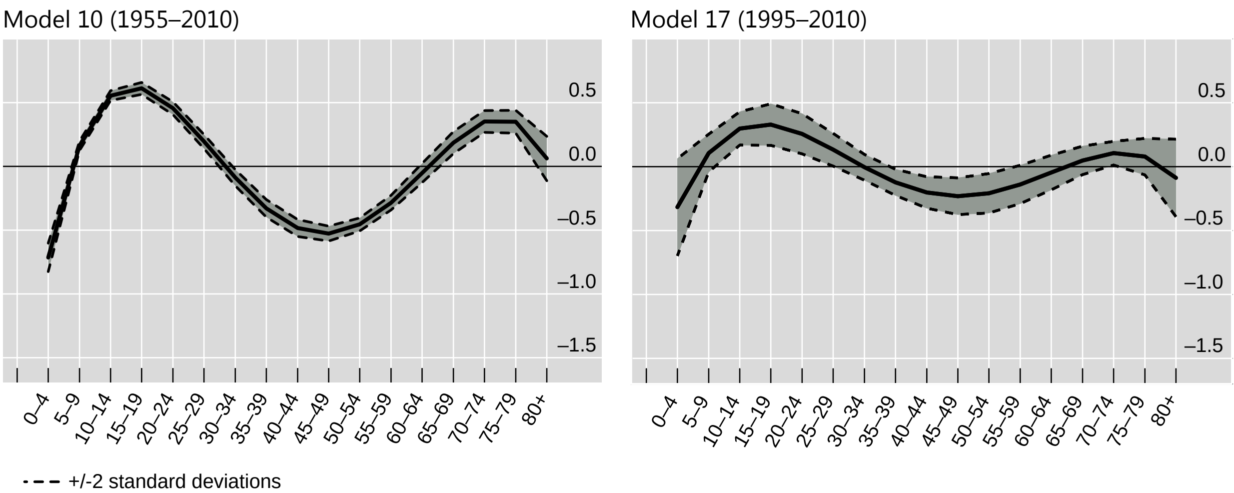
Model 11, in per cent | Graph A2



The fitted demographic effects are normalised to have the same mean as actual inflation.

Age cohort effects on inflation

Benchmark mode, in per cent | Graph A3

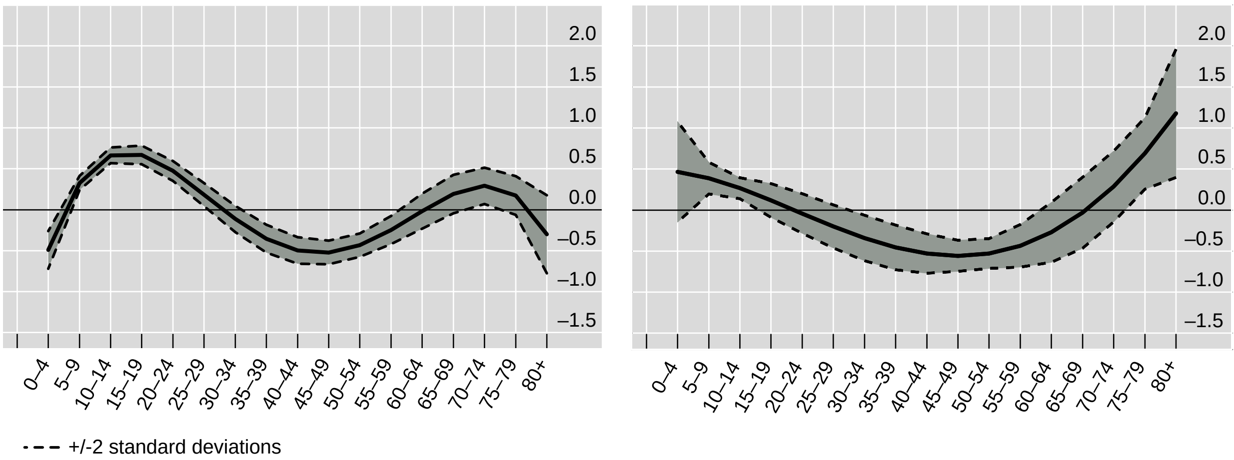


Age cohort effects on inflation

In per cent

Graph A4

Model 41 (PMG estimator) | Model 42 (MG estimator)

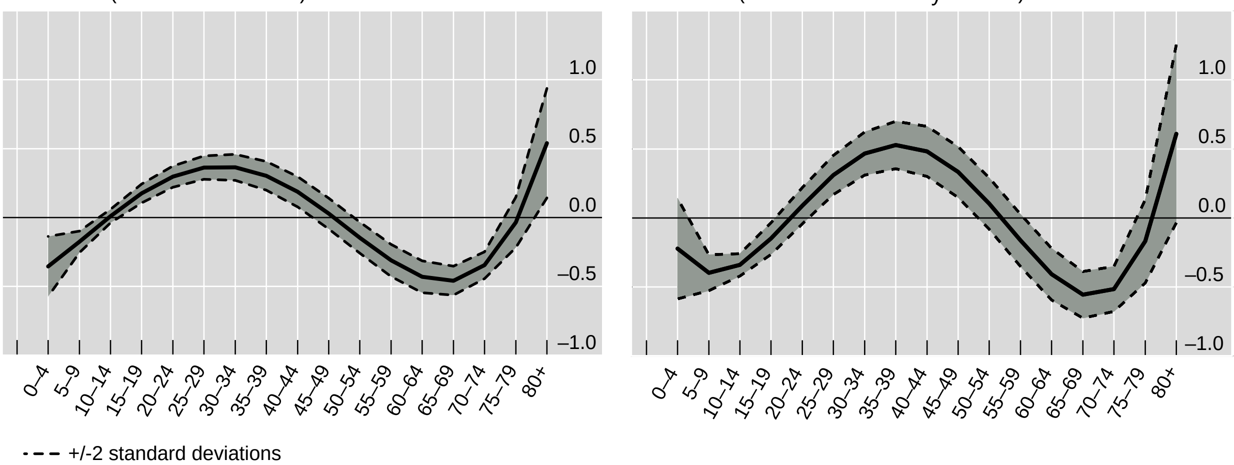


Age cohort effects on monetary policy

1955–2010, in per cent

Graph A5

Model 45 (real interest rates) | Model 48 (deviation from Taylor rule)



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