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Abstract

We examine the impact of demographic structure, the proportion of the population in each age group, on growth, savings, investment, hours, interest rates and inflation using a panel VAR estimated from data for 20 OECD economies, mainly for the period 1970-2007. This flexible dynamic structure with interactions among the main macroeconomic variables allows us to estimate long-run effects of demographic structure on the individual countries. Our estimates confirm the importance of these effects.

JEL-Code: E320, J110.

Keywords: demographic changes, macroeconomic variables, business cycle.

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1 Introduction

Demographic structure matters for the economy. The proportion of the population in each age group have different savings behaviour, according to the life-cycle hypothesis; different age groups have different productivities, according to the age profile of wages; different age groups work different amounts, the very young and very old tend not to work, with implications for labour input; and different age groups provide different investment opportunities, as firms target their different needs. These adjustments of savings and investment in response to demographic changes will impact on real interest rates, inflation and real output.

As Figure 1 illustrates, the demographic structures of developed economies are changing. The average proportion of the population aged 60+ across our sample is projected to increase from 16% in 1970 to 29%, with most of the corresponding decline experienced in the $0 - 19$ group. Though the proportion of the population in the "working age" group ($20 - 59$) is similar in the two years at 50% and 48% respectively, it initially increased to around 56% in 2003 before starting to decline again. In this paper we investigate the economic impact of these changes in demographic structures using a panel VAR estimated on data from 20 OECD countries over the last four decades. We consider a relatively wide range of variables and allow for flexible dynamics to capture a range of possible macroeconomic adjustment processes. The endogenous variables we consider are growth, investment, savings, hours worked, interest rates and inflation. There are other impacts of demographic structure that we do not consider, such as the political economy issues of how societies adjust to the tensions caused by having a large proportion of very old people to support.

While theoretical models, calibrated for instance on the age profile of savings, and most economic commentary on policy strongly emphasize the importance of demographic structure, the econometric evidence for its importance is less

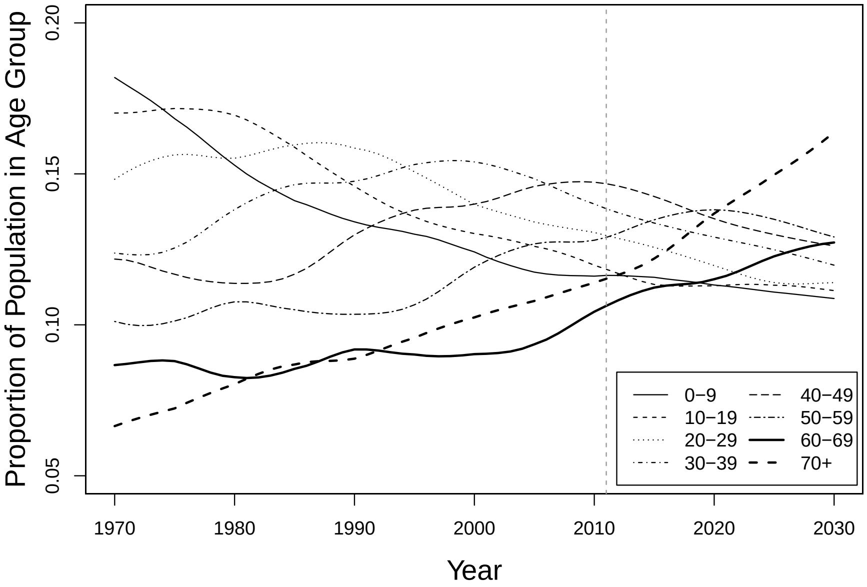

Figure 1: (Unweighted) Sample Mean Proportions in each Age Group by Year (Source: United Nations, 2011)

compelling. There are a number of reasons for this. Changes in demographic structure are low frequency phenomena, difficult to distinguish from the other low frequency trends that dominate economic time series. The vector of proportions in each age group is inevitably highly collinear, making precise estimation of the effect of each age group difficult. Hence it is common to impose very strong restrictions on the effect of the age structure, for instance through the use a single variable, the dependency ratio. Estimation of the coefficients of low frequency collinear determinants will be inevitably sensitive to the exact specification of the equations and the estimation method used. Endogeneity is a serious problem because although the proportions in each age group are plausibly exogenous (the high birth rate that produced the baby boomers after 1945 is unlikely to be influenced by growth rates 30 years later) the other variables in the system are likely to be responding to the low frequency demographic impacts, reducing the marginal contribution of the demographic variables. Finally, general equilibrium effects are likely to be important, as other variables adjust. In particular, crucial intervening variables in the transmission of demographic structure to growth and savings are years in education; the age, sex and skill specific labour force participation rates and pension wealth. Although there are difficult measurement issues associated with each of these factors, all seem to have shown large variations over our sample.

In this paper, we deal with these econometric issues by using a large panel of OECD countries, over the period 1970-2007 for most countries, controlling for the interaction between the main variables of interest. In particular, we ask how much of the variation of long-run growth in these countries can be explained by the evolution of their demographic structure, allowing for the interactions between growth, savings, investment, aggregate labour supply, interest rates and inflation. However, the lack of good comparable data on participation rates means that we do not explicitly model this channel. We employ a panel VAR technique to uncover long-run association between key macroeconomic variables, that are, real output, investment, savings, hours worked, nominal short term interest rates, and price inflation, and the slowly changing demographic profile. Although we provide a straightforward theoretical motivation for our analysis, our objective is not to estimate a tight theoretical model; such a model would need to abstract from a lot of considerations that our estimates show are important in practice and require strong identification assumptions. Rather, we aim to provide estimates of the impact of demographic structure on the main macroeconomic indicators that may help inform the development of the theory.

We first find that the changing age profile across OECD countries has economically and statistically significant impact on key macroeconomic variables, that are real output growth, investment, savings, hours worked, interest rates and inflation, in both the long and short-run next to autoregressive components and oil prices as control variables. When we isolate direct and indirect long-run effects of the changing age profile on all variables of concern, we find that the impact is strong on all variables except for the hours worked. We also find that the changing age profile impact roughly follows a life-cycle pattern; that is, dependant cohorts in general have a negative impact on real macroeconomic variables and add positive inflationary pressures in the long-run. Secondly, we test for the robustness of our results to the use of time effects, to the exclusion of individual countries and structural breaks. We find that our model that allows for the demographic transition is robust to time effects and exclusion of individual countries. However, while real output, investment, savings and hours worked do not suffer from structural breaks, inflation and nominal interest rate equations may do so in the early 1990's. Thirdly, we investigate the impact of the baby-boomers entering the labour market in 1970's and approaching retirement in late 2000's in individual countries analyzed. We find that given our model, Japan should have been most affected by changes in age profile; including a very large negative adjustment in hours worked, while various other countries would have responded through an adjustment in hours worked. Fourthly, our model suggests that, ceteris paribus, the changing age profile will have significant negative growth impact on future real output growth in the 2010-19 decade in our sample of countries. When compared to 2000-09 decade the decline in average annual real output growth will range from .45% in Japan to 1.34 % in the U.S. Finally, we report that while our model with demographic structure cannot improve on a simple random walk model in terms of out of sample forecast accuracy over the short-term, it does significantly improve on the VAR that excludes demographic variables, and provides more accurate predictions for growth over the long horizon.

The paper is organized as follows. Section 2 presents the background: in Section 2.1 we discuss related literature and Section 2.2 provides the econometric framework for the panel VAR. Section 3 presents the panel VAR estimates and provides a series of robustness tests. Section 4 presents results for individual countries. Section 5 presents the out-of-sample forecasting accuracy of our model with demographic transition changes vis-a-vis a simple random walk and the model without demographic transition. Finally, Section 6 concludes.

2 Background

2.1 Literature

There is a large literature on the effects of demography, in particular the age structure of the population, on macroeconomic variables, which arise through life cycle influences on savings and the differences in productivity, arising from the fact that different age groups have different participation rates and different human capital. Standard macroeconomic theory is not helpful in this respect because representative agent models, by definition, cannot allow for such effects, and overlapping generations models allow for them in quite a restricted way. (See, for instance, Auerbach and Kotlikoff, 1992).

Fair and Dominguez (1991) examine the effect of demographics on various US macro variables. They have a careful discussion of the aggregation issues and use a low order polynomial function for the coefficients of the vector of 55 age distribution shares. They find that the impact of US age distribution on consumption, money demand, housing investment and labour force participation is highly significant. Higgins and Williamson (1997) study the dependency hypothesis for Asia and argue that the significant increase in the Asian saving rates can be explained by the significant decline in youth dependency ratios that is associated with increased investment and reduced foreign capital dependency. Higgins (1998) examines the relationship between age-distribution, savings investment and thus the current account for a panel of countries, using 5 year averages for the variables. He also uses a low order polynomial function for the coefficients of 15 age distribution shares. He shows that demographic effects, i.e. increases in both youth and old-age dependency ratios, can explain different levels of decline in savings and investments and increase in capital imports. Miles (1999) has a careful discussion of the advantages and disadvantages of the use of different types of evidence to assess the impact of demographic change and argues for the use of calibrated general equilibrium models. Acemoglu and Johnson (2007) study a panel of 75 countries. They argue that increase in life expectancy due to advancements in medicine against infectious diseases led to a significant increase in population, as birth rates did not decline sufficiently to compensate for the increase in life expectancy. They argue that the increases in life expectancy (and the associated increases in population) appear to have reduced income per capita. Bloom et al. (2007) find that inclusion of life expectancy and the initial working-age share improves per capita income growth forecast performance for the period of 1980-2000 for a panel of 67 economies.

(See also Bloom et al., 2010, and references therein.) Jaimovich and Siu (2009) examine the impact of demography on business cycle volatility in the G7 countries. The young and old have more volatile hours and employment than the prime-age workforce and thus an increasing share of prime-age workforce may have contributed to the great moderation. Park (2010) examines the impact of age distribution on stock market price-earnings ratios in the US, using a Fourier flexible form, rather than a polynomial.

Gómez and Hérnandez de Cos (2008) find that the proportions of 'mature' (15-64 year olds) and 'prime age' (34-54 year olds) people in the population can explain more than half of global growth since 1960, and that 'maturation' is also responsible for the continuing divergence of rich and poor countries as age structure in the former has improved more dramatically than in the latter.

With the exception of Fair and Dominguez (1991), studies mentioned so far take the issue of aging population either as a change in the ratio of working age population in an economy (or dependency ratios) or as the aggregate impact of changes in life expectancy. In contrast, Lindh and Malmberg (1999) consider age structure in a transitional growth regression on a panel of 5-year periods in OECD countries. They find that growth of GDP per worker is strongly influenced by the age structure, with 50-64 year olds having a positive influence and the 65-plus age group a negative one. Feyrer (2007) considers the age structure of the workforce, rather than the population as a whole, and its impact on productivity and hence output. He also finds a strong demographic effect, with the 40-50 year age-group having the most positive impact. Our approach differs from these in three significant ways: first, we consider one-year periods rather than 5-year ones, and can hence adopt a panel time-series approach to estimation. Second, we allow for interaction effects between a number of important macro-variables by estimating a VAR rather than an individual equation. And third, we make no assumptions about the underlying economic processes and hence impose less structure on the data. We provide a straightforward theoretical motivation in the spirit of Acemoglu and Johnson (2007) in the Appendix.

2.2 Data and econometric model

The annual dataset covers the period 1970-2007. The demographic data was obtained from the United Nations (2011). The annual data on savings and investment rates were calculated from Nominal GDP, Investment and Savings series obtained from the OECD (2010), which also supplied the data on hours worked. Annual data on policy rates and the Consumer Price Index (CPI) were obtained from the IMF (2010). Per-capita GDP growth rates were calculated from per-capita real GDP obtained from Penn World Tables (Heston et al., 2009).

The twenty countries covered by the data are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Sweden, Switzerland, United Kingdom, United States. For some countries there data is not available over the whole period, so the panel is unbalanced. Data on hours are only available for Austria from 1995-2007, for Greece from 1983-2007 and for Portugal from 1986-2007. Savings and investment rates for Switzerland are only available from 1990-2007. All other countries have full datasets.

Though it would also be desirable to include Germany, Spain and Turkey as mature OECD economies, we exclude Germany due to reunification and Spain and Turkey due to incomplete demographic data.

We have data for countries, $i = 1, 2, \ldots, N$, for years $t = 1, 2, ..., T$. For data on age structure Park (2010) uses age by year, and restricts the shape of their effect, but given the lack of data for many countries we use age by decade. With only 7 demographic proportions and a fairly large panel we chose not to restrict the age coefficients. Denote the share of age group $j = 0, 1, ..7$

$(0-9,\ 10-19,\ldots,70+)$ in total population by w_{jit} and suppose the effect on the variable of interest, say x_{it}, takes the form:

$$x_{it} = \alpha + \sum_{j=0}^{7} \delta_j w_{ji,t} + u_{it}.$$

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

The six endogenous variables of the system are the growth rate of the real GDP, y_{it}, the share of investment in GDP, I_{it}, the share of personal savings in GDP, S_{it}, the logarithms of hours worked H_{it}, the nominal short interest rate, R_{it} and the rate of inflation π_{it}. We denote the vector of these six variables as $Y_{it} = (y_{it}, I_{it}, S_{it}, H_{it}, R_{it}, \pi_{it})'$. As exogenous variables we have W_{it} and two lags of the logarithm of the real oil price.[1]

There are likely to be complicated dynamic interactions between the six economic variables and there is relatively little literature suggesting an appropriate model for panel data. For instance Bond et al. (2010) consider the relationship between y_{it} and I_{it} in detail, but one may also expect interaction with the other variables because of the other theoretical linkages as discussed above.

Ideally one would like to estimate an identified structural system between these six variables allowing for expectations. Suppose, ignoring oil prices, that such a structural system took the form:

$$\Phi_0 Y_t = \Phi_1 E_t(Y_{t+1}) + \Phi_2 Y_{t-1} + \Gamma W_t + \varepsilon_t. \tag{1}$$

Then there is a unique and stationary solution if all the eigenvalues of A and $(I - \Phi_1 A)^{-1}\Phi_1$ lie strictly inside the unit circle, where A solves the quadratic matrix equation:

$$\Phi_1 A^2 - \Phi_0 A + \Phi_2 = 0. \tag{2}$$

In that case the solution is:

$$Y_t = AY_{t-1} + \Phi_0^{-1}\Gamma W_t + \Phi_0^{-1}\varepsilon_t. \tag{3}$$

Identifying the structural system is likely to be difficult, If there are m endogenous variables, identifying (1) requires $2m^2$ identifying restrictions (see the discussion in Koop et al., 2011; Komunjer and Ng, 2011). Therefore we estimate the solution or reduced form of such a structural system and assume that conditional on the exogenous variables it can be written as a VAR, like (3). Notice that since A will be a complicated function of all the structural parameters, as (2) makes clear, it may be difficult to interpret the coefficients. However, our objective is primarily to provide predictions of the long-run effect of the demographic variables and the same predictions would be obtained from any just identified structural model as from (3) . Over-identifying restrictions, if available and correct, would increase the efficiency of the estimation, but given that we have a large panel that seems a secondary consideration.

We allow for intercept heterogeneity through a_i but assume slope homogeneity and estimate a one way fixed effect augmented panel VAR(2) of the form:

$$Y_{it} = a_i + A_1 Y_{i,t-1} + A_2 Y_{i,t-2} + DW_{it} + u_{it},$$

plus two lags of the oil price. D is the 6×7 matrix of coefficients of the demographic variables. Our estimate of the effect of the demographic variables is then the marginal effect after having controlled for lagged Y_{it} and the oil price Implicitly we are assuming either that all the variables are stationary or that a flexible unrestricted VAR will capture stationary combinations by differencing or cointegrating linear combinations. Bond et al. (2010) discuss this issue with respect to the investment share and Phillips and Moon (1999) and Coakley et al. (2006) suggest that spurious regression may be less of a problem in panels.

Slope heterogeneity is undoubtedly important and it can have unfortunate consequences in dynamic panels. Pesaran and Smith (1995) show that it biases the coefficient of the lagged dependent variable towards one and the coefficient of the exogenous variable towards zero, though these two biases may offset each other in the calculation of the long-run effects, the focus of our interest. However, we adopt a fixed effect estimator which imposes slope homogeneity across countries, partly because we are estimating 21 slope parameters and partly because the demographic variables show very low frequency variation relative to annual time-series and the elements are highly correlated. Thus heterogeneous estimates based on relatively few degrees of freedom may be poorly determined and likely to produce outliers. We found this to be the case when we experimented with VARs for each country. In addition, Baltagi and Griffin (1997) and Baltagi et al. (2000) show that the homogeneous estimators tend to have better forecasting properties. Thus since our main aim is to predict the variables conditional on demographics, the homogeneous estimators may provide better predictors of this demographic contribution.

The long-run moving equilibrium for system is then given by:

$$Y_{it}^{*} = (I - A_1 - A_2)^{-1} a_i + (I - A_1 - A_2)^{-1} DW_{it},$$

where the effect of the demographic variables is given by $(I - A_1 - A_2)^{-1} D$ which reflects both the direct effect of demographics on each variable and the feedback between the endogenous variables. This allows, for instance, the effects of demography on savings to influence growth through the effect of savings on growth. We can isolate the long-run contribution of demography to each variable in each country by:

$$Y_{it}^{D} = (I - A_1 - A_2)^{-1} DW_{it}. \tag{4}$$

This is the demographic attractor for the economic variables at any moment in time. Notice this is a long-run estimate in the very specific sense of being the long run forecast for the economic variables conditional on a particular vector of demographic shares after the completion of the endogenous adjustment of the economic variables. But over time the shares would also change as people get older, so this is not a long-run steady state which would also allow for the extra adjustment of the demographic shares to their equilibrium, which we do not model. We will examine the movements of elements of this vector, Y_{it}^{D}, over time to indicate the low frequency contribution of demographics to the evolution of a particular variable in a particular country.

3 Panel VAR estimates

We chose between possible specifications on the basis of the Schwarz Bayesian information criterion, SBC. On that basis, a one way fixed effect model with country intercepts was preferred for every equation to a two way fixed effect model with country and year intercepts, but without the oil price. This suggests that cross-section dependence or common trends is not a major problem with the model, but we investigate the robustness of our results to this below. A VAR(1) and a VAR(2) had almost identical SBCs. We used a VAR(2) to allow for more flexible dynamics and to deal with potential non-stationarity. Full estimates are given in an appendix Tables 10 and 11, together with HAC robust standard errors.

We report below, in Table 1, the $A_1 + A_2$ matrix, where each row represents an equation in the panel VAR representation. We note that hours are highly persistent and investment, savings, nominal interest rates and inflation rate are moderately so. There is evidence that all our endogenous variables are Granger causal for some other variables in the system, except in the case of savings which is not a significant influence on any other variable. Lagged growth significantly influences all the variables except savings and interest rates. Investment significantly influences growth, inflation and savings. Hours significantly influences interest rates and inflation. Interest rates significantly influence growth, investment and hours. Inflation significantly influences interest rates. Oil prices significantly influence everything except investment. Perhaps the most surprising feature is that lagged investment has a negative effect on growth, though as noted below there is a strong positive contemporaneous correlation between the growth and investment residuals. For OECD countries Bond et al. (2010) found a small positive effect in the bivariate relationship. The nominal interest rate has a negative effect on all the other variables, and although inflation has a positive effect, the coefficients are very small, indicating that this is not picking up a real interest rate effect.

Table 2 gives the D matrix of short term demographic impacts on the six variables. As expected the individual coefficients are not well determined because of collinearity, but the hypothesis that the coefficients of the demographic variables are all zero is strongly rejected for all equations except hours worked (see tables 10 and 11). One would expect demographic structure to have significant impacts on hours worked and the fact that it does not may be because there are offsetting adjustments in labour force participation rates. Generally the results look plausible, though there are some unexpected results. For instance there seems to be a negative effect of the 30-39 age group on growth and a positive effect of teenagers on savings and 60-70 years cohort on investment.

Table 3 gives the $(I - A_1 - A_2)^{-1} D$ matrix. Allowing for the dynamics and interactions makes a strong difference, the long-run effects are much larger. The effect on hours is particularly marked, perhaps because these are highly persistent.

Table 4 gives the matrix of correlations between the residuals of each equation of the VAR. There are very strong contemporaneous correlations between the residuals of some of the equations, perhaps reflecting business cycle effects. The correlation coefficient between the residuals from the growth equation and the residuals from the investment equation is .54, the savings equation .45 and the hours equation .43. These are the three largest correlations. All the correlations are positive, except for a very small negative correlation between savings and interest rates.

3.1 Robustness to the use of time effects

As mentioned above the model chosen using SBC assumes one-way fixed effects and includes oil prices as a measure of technology shocks across countries. One potential drawback of this approach concerns trends: if there are shared, cross-country, factors driving the trend in the dependent variable as well as the demographic variables, this trend may be wrongly attributed to the demographic variables in the one-way, country, fixed effect model. A two-way effects model avoids this issue by removing any common cross-country factors from all variables prior to estimation.

Table 5 shows the long-term impact of demographic variables under a two-way fixed effects model. Comparison with Table 3 reveals that though the impact does change significantly for inflation, hours and savings, the impact on GDP growth is remarkably robust to the chosen effect. We conclude that the impact of demographic variables on growth and investment identified by the model is not merely a spurious correlation.

3.2 Robustness to exclusion of individual countries

We test the robustness with respect to the selected countries by re-estimating the model on a dataset with each country excluded in turn. The results are very stable with respect to these exclusions, as are the tests as to whether the demographic variables are significant in each equation.

3.3 Structural Change

We also test for potential structural change by estimating the model on subperiods of the entire dataset, and selecting the preferred model using the SBC. A single model over the whole period was preferred over models with structural breaks in any given year for the first four equations in the VAR - growth, investment, savings and hours worked. For the last two equations, interest rates and inflation, models with breaks in 1992 and 1989 respectively were optimal under the SBC.

Estimating the model over two subsets spanning 1970-1990 and 1990-2007 respectively yields results that differ from the full-period estimation as well as each other, indicating the possible presence of structural instability. The ranges of the demographic variables for the two periods are also somewhat different, however, and the second period has a vastly reduced variation in interest rates since the euro member countries in our sample shared a common rate for much of the period.

4 Impact on individual countries

We now consider what light our results shed on the question of whether the baby boomers squandered the demographic dividend. For this purpose we conduct a counterfactual analysis. Table 6 shows, for the countries with available data, the impact on the six variables of the change in demographic structure between 1970, when the baby boomers were entering the labour market and 2007, when they were approaching retirement. This is calculated using equation (4) and the long-run estimates from the one way fixed effect model.

The estimated impact of demographic changes on GDP varies across countries, but given our model 2007 real GDP growth would have been 2.91% *less* for Japan as compared to 1970 and .69% less for the U.S. In general, given our estimated model Japan in 2007, as compared to 1970, would have been most affected by the changes in the age profile, as all variables would have been sizably depressed including the hours worked. It appears, that given our model, while in various countries there would have been some form of contrarian adjustment in the hours worked as a response to demographic pressures, Japanese and, to a limited extent, Finnish and Swedish labour markets would not have followed such a pattern.

Interestingly, the estimated impact of demographic changes on both the interest rate and inflation is strongly negative and of quite similar orders of magnitude, consistent with real interest rate effects. Since the 1970s were the decade when the baby boomers entered the labour force, we might have expected the supply side effect to be deflationary, the arrival of such a large cohort depressing wages, but the demand side effects might have been inflationary. Although both interest rates and inflation did tend to be higher around 1970 than in 2007, the change over the period is not as large as predicted by demographic factors. However, the two way fixed effects estimates above suggest that the demographic effects on these two variables might be overstated.

The estimated model can also be applied to the predicted future demographic structure. Using both historic data and forecasts for the demographic structure, Table 7 provides forecasts of the average impact of demographic structure on average annual per-capita GDP growth over the current decade, and compares it to that over 2000-2009. It suggests that in all countries in our sample, as well as Germany, the impact of demographic factors over this decade will put downward pressure on GDP growth. The magnitude of this pressure is economically highly significant: for the US, for example, it is -1.34%.

5 Forecast Accuracy

An important measure of the usefulness of any economic model is the degree to which it can forecast future events. With this in mind we re-estimated the model using the data available up to 1997 and used that model to forecast the path of the economy over the following ten years, 1997-2007. As a baseline we also performed a random walk forecast for each variable.

Table 8 presents the results from a series of one-year-ahead forecasts, where period t realised values are used to forecasts period $t+1$ outcomes. The VAR model forecasts are less accurate than those from the baseline model. Adding demographic variables to the VAR provides slightly better accuracy in this sample for all variables other than savings and hours worked, but does not improve on the random walk.

Table 9 displays results from ten years rolling forecasts. Here, the forecasts for the current year are used as inputs to forecast the next year, as would be required of a long-range forecaster. Again the random walk model provides more accurate forecasts in most cases, though for both growth and hours worked the error of the cumulative forecast over the ten years period is markedly lower for the VAR models. The demographic variables improve the forecasts of inflation and interest rates over the VAR without demographics, but do not outperform the random walk.

6 Conclusions

We present a parsimonious econometric model that aims to capture the impact of demographic changes that currently affect nearly all developed economies on key macroeconomic variables of interest. The use of a panel VAR in six main macroeconomic variables, for 20 OECD countries over the period 1970-2007 allows us to obtain estimates of the long-run impact of demographic structure on the economy. Our results indicate that the age profile of the population has both economically and statistically significant impact on output growth, investment, savings, hours worked, interest rates and inflation. The magnitude of the long term impact is large. Demographic factors are predicted to depress average annual GDP growth over the current decade, 2010-2019, at .94% in our sample of OECD countries, with the strongest predicted negative impact in the US at 1.34%. This impact also appears to be robust to various changes in the model and dataset. We report that our model is robust to time effects and exclusion of individual countries. We find that our model with demographic structure cannot improve on a simple random walk model in terms of forecast accuracy over the short-term, though it does significantly improve on a VAR that excludes demographic variables, and provides more accurate predictions for growth over the long term.

A Theoretical Motivation

In this Appendix we provide a simple theoretical framework that justifies the inclusion of demographic variation in a reduced form econometric analysis. To do so, we follow Acemoglu and Johnson (2007) approach in providing a justification for the role of dynamic interactions between the variables of interest and the evolution of the demographic profile.[2] Suppose that the economy i has the following production function:

$$Y_{it} = \left(A_{it} H_{it}\right)^{\alpha} K_{it}^{\beta}, \tag{5}$$

where $\alpha + \beta \leq 1$, Y_i denotes output produced, K_i denotes capital and H_i denotes the effective units of labour given by $H_{it} = h_i N_i$, where h_i is the human capital per person and N_i is the total population. Let us assume that changes in the age profile may affect output via changes in the human capital accumulation or via technology.

To accommodate these possible age related impacts we assume the following isoelastic relationships:

$$A_{it} = \bar{A}_i \sum_{j=0}^{7} w_{ji,t}^{\gamma_j}, \tag{6}$$

$$h_{it} = \bar{h}_i \sum_{j=0}^{7} w_{ji,t}^{\eta_j}, \tag{7}$$

where $\bar{A}_i$ and $\bar{h}_i$ represent the baseline differences across countries, $w_{ji,t}$ denote the share of age group $j = 0, 1, \dots 7$, (between 0-9, 10-19, ..,70 and over), in total population. Substituting (6) and (7) into (5) , and taking logarithms we obtain the following specification for per capita income $y_{it} = \log\left(\frac{Y_{it}}{N_{it}}\right)$:

$$y_{it} = \alpha \log \bar{A}_i + \alpha \log \bar{h}_i - (1-\alpha)\log N_{it} + \beta \log K_{it} + \alpha \sum_{j=0}^{7} (\gamma_j + \eta_j) \log w_{ji,t}. \tag{8}$$

As the capital stock will likely adjust to changes in the demographic structure in the long run we would like to control for this. Controlling for the depreciation of capital by δ and economy-wide saving rate by s_i, we write the evolution of capital as:

$$K_{it+1} = s_{it}Y_{it} + (1-\delta)K_{it}$$

At the steady state, the capital stock will be given by $K_i = \dfrac{s_i Y_i}{\delta}$. Substituting this value into (8) we have a long term relationship between the changes in the demographic structure (the age profile), key macroeconomic variables and per-capita real output:

$$\begin{aligned} y_{it} = {} & \frac{\alpha}{1-\beta}\log \bar{A}_i + \frac{\alpha}{1-\beta}\log \bar{h}_i - \frac{(1-\alpha)}{1-\beta}\log N_{it} + \frac{\beta}{1-\beta}\log s_i \\ & - \frac{\beta}{1-\beta}\log \delta + \frac{\alpha}{1-\beta}\sum_{j=0}^{7}(\gamma_j + \eta_j)\log w_{ji,t}. \end{aligned} \tag{9}$$

The model outlined so far is for a closed economy, in which savings is equal to investment. In open economies this need not be the case, even in the presence of home bias and Feldstein-Horioka effects. (See for instance Bai and Zhang, 2010). Thus in our econometric model we will include both savings and investment.

Notes

[1] In a dynamic stochastic general equilibrium setting, savings (hence consumption) should be subject to both substitution and wealth (income) effects. In our savings analysis we include nominal short term policy rates and inflation to capture intertemporal consumption preferences. We also experimented with a specification with two measures of wealth (financial and housing) to capture the wealth effects. The data for this was taken from Slacalek (2009) and was only available for a sub-sample of the data we use. On the sub-sample, the Schwarz Bayesian information criterion indicated that the specification excluding wealth gives a better fit, therefore the main analysis is performed on the full range of data and excludes wealth.

[2] Note that while Acemoglu and Johnson (2007) develop a relationship between increased life expectancy and its impact on real output, we focus on the impact of a changing age profile on real output and other macro variables.

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	y	I	S	H	R	π
y	0.27	-0.26	0.01	0.01	-0.29	-0.00
I	0.18	0.73	0.00	0.03	-0.11	0.01
S	-0.11	-0.14	0.78	-0.00	-0.11	0.03
H	0.24	-0.08	-0.00	0.93	-0.14	0.03
R	0.21	0.02	-0.04	0.04	0.75	0.05
π	0.38	0.18	0.07	-0.02	-0.16	0.72

Table 1: Sum of VAR coefficients $A_1 + A_2$

	δ_1	δ_2	δ_3	δ_4	δ_5	δ_6	δ_7	δ_8
y	-0.03	0.21	0.18	-0.05	0.04	0.04	-0.00	-0.40
I	0.06	-0.04	0.09	-0.07	0.01	0.04	0.23	-0.32
S	-0.06	0.14	0.02	0.10	0.12	0.21	0.03	-0.56
H	-0.01	-0.07	0.06	0.09	0.02	0.12	0.09	-0.31
R	0.16	0.04	-0.04	-0.18	-0.09	0.07	0.22	-0.19
π	0.46	0.10	-0.14	-0.45	-0.26	-0.04	0.18	0.14

Table 2: Short run Demographic impacts. δ_8 is derived from restrictions as described in section 2.2.

	δ_1	δ_2	δ_3	δ_4	δ_5	δ_6	δ_7	δ_8
y	-0.20	0.23	0.09	0.11	0.08	-0.04	-0.33	0.06
I	-0.21	-0.16	0.43	0.23	0.30	0.11	0.32	-1.01
S	-0.19	0.52	-0.25	0.39	0.42	0.78	-0.12	-1.56
H	-1.09	-0.44	0.54	1.95	0.63	0.81	-1.02	-1.37
R	0.54	0.31	0.03	-0.58	-0.30	0.23	0.51	-0.73
π	0.98	0.53	-0.21	-1.00	-0.38	-0.11	0.15	0.04

Table 3: Long-Run Demographic Impact

	y	I	S	H	R	π
y	1.00	0.54	0.45	0.43	0.20	0.28
I	0.54	1.00	0.01	0.29	0.11	0.20
S	0.45	0.01	1.00	0.25	-0.01	0.06
H	0.43	0.29	0.25	1.00	0.19	0.16
R	0.20	0.11	-0.01	0.19	1.00	0.28
π	0.28	0.20	0.06	0.16	0.28	1.00

Table 4: Residual Correlation Matrix

	δ_1	δ_2	δ_3	δ_4	δ_5	δ_6	δ_7	δ_8
y	-0.24	0.25	0.07	0.12	0.11	-0.04	-0.30	0.03
I	-0.32	-0.25	0.38	0.20	0.53	0.06	0.54	-1.15
S	-0.08	0.91	-0.01	0.44	0.21	0.25	0.05	-1.77
H	-1.53	-0.07	0.48	2.12	0.94	0.46	-0.68	-1.72
R	0.48	0.12	-0.10	-0.70	0.03	0.39	0.18	-0.41
π	0.38	0.39	-0.42	-0.69	-0.01	-0.07	-0.13	0.54

Table 5: Long-Run Demographic Impact in a Model with Two-way Fixed Effects

	y	I	S	H	R	π
Australia	-0.38	-0.17	-4.34	7.87	-7.99	-11.47
Austria	1.37	-0.42	-0.85	11.99	-9.20	-11.71
Belgium	0.17	-2.90	-4.98	4.16	-7.08	-7.25
Canada	-1.13	0.62	-3.45	11.13	-9.64	-15.07
Denmark	-0.46	-1.77	-1.89	1.63	-5.50	-6.39
Finland	-1.72	-4.76	-9.01	-4.02	-7.25	-7.00
France	-0.27	-2.62	-4.69	3.68	-6.31	-7.02
Germany	0.96	-3.88	-6.77	2.22	-9.66	-8.83
Greece	0.21	-3.54	-9.87	4.92	-11.07	-11.66
Iceland	-0.18	2.37	-0.78	16.00	-8.73	-14.69
Ireland	0.83	5.01	0.82	23.96	-9.91	-17.17
Italy	0.10	-5.45	-10.37	1.16	-11.76	-11.15
Japan	-2.91	-10.22	-17.47	-16.80	-9.98	-7.00
Netherlands	-0.76	-0.83	-2.11	6.21	-7.81	-10.88
New Zealand	0.02	0.88	-2.84	11.38	-9.04	-13.34
Norway	0.45	0.09	-0.81	9.17	-6.78	-9.15
Portugal	0.15	-1.97	-8.85	10.49	-13.27	-16.41
Sweden	-0.06	-3.19	-4.80	-1.41	-5.44	-4.44
Switzerland	0.20	-2.68	-3.19	3.61	-8.35	-9.10
United Kingdom	0.90	-1.40	-4.06	5.38	-7.42	-8.10
United States	-0.69	0.82	-2.43	9.20	-6.49	-10.09

Table 6: Difference in Predicted Impact of Demographic Factors between 2007 and 1970 (in percentage points, except H where it is a percentage).

This was calculated by applying the estimated long-run demographic coefficients to the demographic structure in each country as it was in 1970 and in 2007, and subtracting the result of the former from the latter.

	2000 - 2009	2010 - 2019	*Change*
Australia	1.91	0.89	-1.02
Austria	1.62	0.94	-0.68
Belgium	1.38	0.35	-1.04
Canada	2.13	0.47	-1.66
Denmark	0.75	0.28	-0.47
Finland	0.97	-0.36	-1.34
France	1.50	0.32	-1.18
Germany	0.93	0.41	-0.52
Greece	1.48	0.69	-0.79
Iceland	2.24	1.01	-1.23
Ireland	2.19	0.97	-1.21
Italy	1.05	0.49	-0.56
Japan	0.34	-0.10	-0.45
Netherlands	1.33	0.26	-1.07
NewZealand	1.97	0.77	-1.19
Norway	1.55	0.57	-0.97
Portugal	1.40	0.86	-0.55
Sweden	1.14	0.20	-0.94
Switzerland	1.57	0.70	-0.86
UnitedKingdom	1.45	0.64	-0.81
UnitedStates	1.97	0.63	-1.34

Table 7: Average Predicted Impact on GDP Growth by Country, in percentage points.

These results were calculated by applying estimated long-run demographic impacts on growth to the demographic structure of the population each year, and averaging the results over each period. The latter period is based on demographic forecasts from United Nations (2011).
We use the long-run impact to allow for interaction effects; the same calculation with short-run impacts also yields suggests a strongly negative development in GDP growth in all cases other than Norway.

	RW^a	*Without Demographics*				*With Demographics*			
	$RMSE^b$	$RMSE$	*bias*	$corr.^c$	$cum.corr.^d$	$RMSE$	*bias*	*corr.*	*cum.corr.*
y	0.020	0.029	0.011	0.209	0.189	0.025	-0.000	0.320	0.420
I	0.012	0.014	0.003	0.878	0.925	0.013	-0.001	0.884	0.930
S	0.016	0.020	0.003	0.942	0.990	0.032	-0.010	0.828	0.859
H	0.016	0.014	0.001	0.373	0.492	0.017	-0.006	0.353	0.584
R	0.013	0.021	0.006	0.708	0.763	0.019	-0.001	0.725	0.792
π	0.011	0.039	0.014	0.233	0.253	0.032	0.006	0.130	0.110

[a] The baseline random-walk model

[b] Root mean square error

[c] The correlation between forecast and actual outcomes

[d] The correlation between the sum of forecast and actual outcomes over the entire period; since each cumulative outcome is the outcome for a single country, this indicates how well the model forecasts cross-country differences.

Table 8: 1-Year-Ahead Forecast, 1997-2007

	RW^a		$Without\ Demographics$		$With\ Demographics$	
	$RMSE^b$	$cum.\ RMSE^c$	$RMSE$	$cum.\ RMSE$	$RMSE$	$cum.\ RMSE$
y	0.028	0.022	0.027	0.013	0.026	0.013
I	0.025	0.019	0.042	0.032	0.041	0.031
S	0.031	0.023	0.079	0.053	0.076	0.054
H	0.021	0.017	0.017	0.007	0.017	0.007
R	0.028	0.023	0.050	0.044	0.039	0.028
π	0.016	0.012	0.074	0.072	0.034	0.028

[a] The baseline random-walk model

[b] Root mean square error

[c] The root mean square error of the cumulative forecast over the entire period

Table 9: Rolling Forecast, 1997-2007

	Growth (y)		*Investment* (I)		*Savings* (S)	
	Estimate	*Std. Error*$^{(a)}$	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*
y_{t-1}	0.26	0.05 *	0.13	0.04 *	-0.07	0.07
I_{t-1}	-0.31	0.11 *	0.92	0.07 *	0.06	0.08
S_{t-1}	0.08	0.07	0.05	0.04	0.99	0.05 *
H_{t-1}	0.02	0.07	-0.02	0.03	0.01	0.04
R_{t-1}	-0.22	0.09 *	-0.09	0.03 *	-0.05	0.05
π_{t-1}	-0.06	0.05	0.02	0.04	0.01	0.03
y_{t-2}	0.01	0.04	0.06	0.03 *	-0.04	0.04
I_{t-2}	0.06	0.11	-0.19	0.05 *	-0.20	0.08 *
S_{t-2}	-0.06	0.06	-0.05	0.03	-0.21	0.07 *
H_{t-2}	-0.01	0.07	0.05	0.03	-0.01	0.04
R_{t-2}	-0.06	0.09	-0.02	0.03	-0.06	0.04
π_{t-2}	0.05	0.06	-0.01	0.04	0.02	0.02
$POIL_{t-1}$	-0.02	0.01 *	0.00	0.00	-0.01	0.00 *
$POIL_{t-2}$	0.02	0.01 *	0.00	0.00	0.00	0.00
δ_1	-0.03	0.08	0.06	0.04	-0.06	0.07
δ_2	0.21	0.10 *	-0.04	0.05	0.14	0.05 *
δ_3	0.18	0.07 *	0.09	0.03 *	0.02	0.06
δ_4	-0.05	0.07	-0.07	0.04	0.10	0.08
δ_5	0.04	0.08	0.01	0.04	0.12	0.07
δ_6	0.04	0.08	0.04	0.05	0.21	0.11
δ_7	-0.00	0.14	0.23	0.10 *	0.03	0.10
R^2	0.29		0.87		0.82	
$\Pr(\delta_j = 0)^{(b)}$	0.00		0.00		0.00	
obs	630		630		630	

$^{(a)}$ The entries marked with a $*$ are significant at the 5% level.

$^{(b)}$ This row reports the joint significance of the 7 demographic variables in the equation.

Table 10: Results for Growth, Investment and Savings

	Hours (H)		*Interest Rate* (R)		*Inflation* (π)	
	Estimate	*Std. Error*$^{(a)}$	*Estimate*	*Std. Error*	*Estimate*	*Std. Error*
y_{t-1}	0.20	0.04 *	0.15	0.18	0.25	0.08 *
I_{t-1}	0.00	0.09	-0.18	0.17	-0.39	0.17 *
S_{t-1}	0.06	0.04	0.00	0.06	0.03	0.18
H_{t-1}	1.12	0.05 *	0.28	0.05 *	0.15	0.08
R_{t-1}	-0.14	0.03 *	0.36	0.17 *	-0.12	0.15
π_{t-1}	0.01	0.03	0.12	0.08	0.54	0.22 *
y_{t-2}	0.04	0.03	0.06	0.03	0.13	0.09
I_{t-2}	-0.08	0.09	0.20	0.20	0.58	0.40
S_{t-2}	-0.06	0.04	-0.04	0.05	0.04	0.09
H_{t-2}	-0.19	0.04 *	-0.24	0.05 *	-0.16	0.08 *
R_{t-2}	-0.00	0.03	0.38	0.21	-0.04	0.12
π_{t-2}	0.02	0.04	-0.07	0.03 *	0.19	0.05 *
$POIL_{t-1}$	-0.01	0.00 *	-0.01	0.00	-0.02	0.00 *
$POIL_{t-2}$	0.01	0.00 *	0.01	0.00 *	0.02	0.01 *
δ_1	-0.01	0.07	0.16	0.14	0.46	0.18 *
δ_2	-0.07	0.08	0.04	0.09	0.10	0.16
δ_3	0.06	0.06	-0.04	0.06	-0.14	0.13
δ_4	0.09	0.06	-0.18	0.12	-0.45	0.22 *
δ_5	0.02	0.06	-0.09	0.11	-0.26	0.20
δ_6	0.12	0.09	0.07	0.15	-0.04	0.21
δ_7	0.09	0.09	0.22	0.13	0.18	0.29
R^2	0.92		0.73		0.75	
$\Pr(\delta_j = 0)^{(b)}$	0.10		0.00		0.00	
obs	630		630		630	

$^{(a)}$ The entries marked with a $*$ are significant at the 5% level.

$^{(b)}$ This row reports the joint significance of the 7 demographic variables in the equation.

Table 11: Results for Hours, Interest Rate and Inflation