

Semedo Leite, Duarte Nuno; Härtl, Klaus

Conference Paper

The Aging-Inflation Puzzle: on the Interplay between Aging, Inflation and Pension Systems

Beiträge zur Jahrestagung des Vereins für Socialpolitik 2019: 30 Jahre Mauerfall - Demokratie und Marktwirtschaft - Session: Macroeconomics IV, No. E23-V1

Provided in Cooperation with:

Verein für Socialpolitik / German Economic Association

Suggested Citation: Semedo Leite, Duarte Nuno; Härtl, Klaus (2019) : The Aging-Inflation Puzzle: on the Interplay between Aging, Inflation and Pension Systems, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2019: 30 Jahre Mauerfall - Demokratie und Marktwirtschaft - Session: Macroeconomics IV, No. E23-V1, ZBW - Leibniz-Informationszentrum Wirtschaft, Kiel, Hamburg

This Version is available at:

<https://hdl.handle.net/10419/203514>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

The Aging-Inflation Puzzle: on the Interplay between Aging, Inflation and Pension Systems

Klaus Härtl^{a,b}, Duarte N. Leite^{a,c}

^a Munich Center for the Economics of Aging at the Max-Planck-Institute for Social Law and Social Policy

^b Technical University of Munich (TUM)

^c Center for Economics and Finance at the University of Porto (CEF.UP)

This version: February 2019

Abstract

This paper focuses on the empirically observed relationship between demographic change and inflation and explores the theoretical nature of the puzzling link between the two. It puts the existent disparate empirical findings in the literature into perspective by formalizing an overlapping-generations (OLG) model containing many of the underlying mechanisms that link demographic change and inflation dynamics. We are the first to formally disentangle the two components of demographic change: population size and structure, and determine how they separately affect inflation. We find that changes in population size are a main driver of inflationary pressures, but changes in population structure play a fundamental role in dampening or boosting inflationary dynamics since size effects are quite stable across the several scenarios tested. The main conclusions show a negative effect of demographic change/aging on inflation. We also conclude that the introduction of a public pay-as-you-go (PAYG) pension system has a negative impact on inflation, but these effects are dampened under general equilibrium conditions and when individuals can respond to changes in their income by adapting their labor supply. A simulation of different stages of demographic change and size of pension systems is carried out for a selected sample of individual countries. Findings suggest that aging countries with generous PAYG pension systems face strong deflationary pressures while countries that face aging but with higher fertility and immigration rates, such as the US, will experience the same deflationary pressures but much later in time. These results reinforce the hypotheses that we are entering a period of stagnation and they warn policy makers about the impact of demographic change on the foreseeable effects of monetary policy.

Keywords:

Population aging, inflation, life-cycle behavior, pension systems, labor supply, money

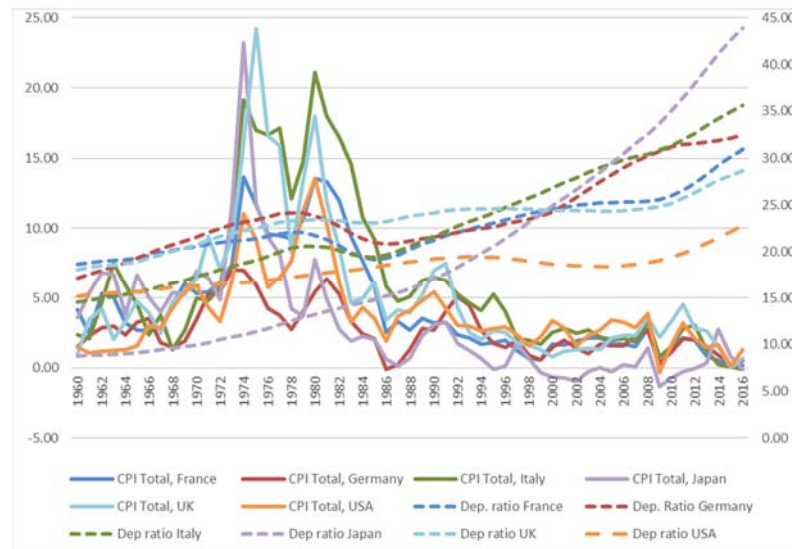
JEL classification: C68, D15, E27, E31, J11

1. Introduction

“Low inflation has been the major surprise of the era” – James Bullard¹

James Bullard’s statement in his President’s Message in 2015 mirrors both the concerns and astonishment that the last decade of low inflation has triggered in most economists as well as the understanding that this may be the “new normal” (Summers, 2014) for the years to come. Indeed, inflation has slowed down in many countries not only after its peak in the 1970s but, more surprisingly, also in comparison to 1990 levels (see Figure 1). Even more strikingly, the US is not even the country with the most modest inflation dynamics - European countries and Japan have been suffering from more persistent lower levels of inflation, which strongly indicates that there are reasons to question the time and location of this phenomenon.

Figure 1.1 – Consumer price index versus old-age dependency ratio



Source: authors’ own calculations

Several theories have been put forward by the literature and most of them are connected with the secular stagnation hypothesis. This hypothesis points to different explanations for slow growth, such as a fall in new great inventions, stagnant aggregate demand, or that a lack of new infrastructures and effects of the great recession may have permanently reduced the supply side of the economy (Summers, 2014; Eggertsson, et al., 2019; Gordon, 2014). As originally pointed out by Alvin Hansen, slower population growth was one of the main underlying causes for the stagnant levels observed back in the 1930s (Hansen, 1939), and nowadays is one of the four headwinds hypothesis that slow down growth as argued by Gordon (2014). It is, then, exactly from this hypothesis that our paper comes in to explain the slowdown on inflation dynamics. It is indeed no

¹ At this time President of the Federal Reserve Bank of St. Louis.

secret that the demographic structure in developed countries has been changing in the last decades. As observed in Figure 1, as the baby-boom generation ages, we observe that the age dependency ratio has steadily been increasing and, at the same time, inflation has steadily been declining since its peak in the 1970s. These twin patterns seem to fit in with the idea of Gordon, Hansen and Summers that slower population growth and change of population structure are connected and are one of the causes for lower inflation and stagnant growth². Despite these compelling patterns and the agreement of many authors that demographic change is no doubt a root for today's macroeconomic trends, a general perusal of the literature quickly ascertains that there is no concrete consensus and instead more of a mix of puzzling and contradicting empirical findings. Several studies exactly show these contradictory findings, see e.g. McMillan and Baesel (1990), Nishimura and Takáts (2012), Yoon, et al. (2014), Anderson et al. (2014), Juselius and Takáts (2016), and Bobeica et al. (2017)³.

Given this state of literature, this paper steps back from a strict empirical approach and formalizes some of the underlying mechanisms that explain how demographic change influences inflation using a Computational General Equilibrium (CGE) model based on an OLG-MIU (Money in the Utility) theoretical framework à la Auerbach and Kotlikoff (1987) and Sidrauski (1967)⁴. We concentrate our analysis on the aggregate demand side of the economy, following the literature that argues that changes in total savings and consumption patterns affect aggregate demand for money and, hence, determine (de-)inflationary pressures in the economy, see e.g. Lindh and Malmberg (2000). Since aggregate demand depends on demographics, we focus primarily on clearly defining demographic change as a combination of two phenomena: a change in population growth (size) and structure. Since a significant part of the literature concentrates on only one of these phenomena, to our knowledge, this paper is the first to address this shortcoming and identify the impacts they have individually on inflation.

Our main conclusion is that population growth is a main driver on inflationary pressures since aggregate demand is firstly determined by the level of population. We find that in a shrinking society, deflationary pressures will prevail, while in a society with an expanding population, inflationary pressures will emerge. This stems from the consumption and money demand decisions in the economy and is in accordance with empirical results by Shirakawa (2012), Yoon, et al. (2014) and Bobeica et al. (2017). However, changes in population structure play a fundamental role on the

² From the most basic relationship between cumulative inflation and age dependency ratios for different age groups, we observe that these two variables seem to be correlated depending on the structure of the population (see Figures A.1-A.3 in the appendix). Note that these figures do not aim to provide an answer to the relationship between demographic change and inflation it is used only as a motivation.

³ Besides the strict relationship between aging and inflation, different strands of the literature follow a political economy approach. For instance, Doepke and Schneider (2006), Bullard et al. (2012) and Katagiri et al. (2014) show how different structures of a population can influence decisions and plans of policy makers/governments, e.g. through voting behavior.

⁴ Introducing a MIU framework into an OLG model is one of the most used approaches to introduce a monetary economy into a neoclassical framework (Walsh, 2010). See further details in Subsection 4.1.

intensity of these (de-)inflationary pressures. In fact, (de-)inflationary pressures due to the population growth effect can be bolstered or dampened depending on the structure of population. Size effects are quite stable across the different scenarios we test but the structure of the population is much stronger and can be the difference between an earlier or later entrance in a period of deflationary pressures. As a consequence, we show that countries that still have a young population structure (as China and India) or that have already had a baby boom generation enter the retirement phase but still have high fertility or immigration rates (as France and the US) will experience the negative effects of demographic change on inflation later. In contrast, countries whose baby boom generation is entering the retirement phase now (as Germany or Japan) and are not compensated by higher fertility rates or enough immigration flows are already facing the impact of deflationary pressures due to aging.

We strip down our model such that different mechanisms and its effects can be clearly defined and quantified. Firstly, we identify the pure demographic effects by leaving aside all general equilibrium effects and possible endogenous decisions of individuals except for the classical consumption/savings decisions. The first outcomes show that population size is the major driver for inflation dynamics and population structure only has a residual impact. We then include labor supply decisions and a pension system sequentially, this being the first time that the role of pension systems is analyzed in such a framework. We show that in this scenario a PAYG pension system is an important vehicle through which aging affects inflation via aggregate demand⁵. According to our findings, the presence of a pension system reduces savings of individuals at working age and influences consumption of both workers and retirees, and, consequently, on money demand. The introduction of a pension system reinforces the effects of demographic change by producing deflationary pressures. This works mostly via the structure effect, even though it has a small negative impact of around 15% relative to the steady state inflation equilibrium. Labor supply does not account for a significant change of the results since the non-existence of general equilibrium effects hampers its impact.

In a second stage, where general equilibrium effects on wages and real interest rates are at work, we observe a major change in results. Population size is still the main driver of inflation dynamics but it has much less weight on total inflation. On the contrary, population structure assumes a much stronger role. For the period of 2015-2025, for an example of an aging population, the change of the structure of population accounts for around 50% reduction of inflation relative to the equilibrium steady-state. When we introduce the previous channels in a systematic basis, both labor supply and

⁵ Although it is well-known that in some economies financing additional social expenditures in pension systems by printing money is one of the main channels that produce inflation, the goal of this paper is not to focus on this specific channel. Instead, we concentrate on alternative channels, where the share of working age or dependent groups in the economy and, subsequently, the share of net savers and net consumers has an impact on inflation.

pension systems reduce inflation dynamics via changes in population structure. Labor supply decisions have, nevertheless, a dampening effect on the negative population structure effect due to general equilibrium implications. When considered together, this dampening effect of endogenous labor supply mitigates the negative effects of pension systems on inflation dynamics leading to a global less negative structure effect.

Finally, we perform an illustrative simulation for a selected sample of countries at different stages of demographic change, and, in addition, with different generosity of pension systems. We quantify and compare the predictions and dynamics of inflation, in this simple CGE model, to the actual dynamics in inflation for each of these countries separately. Following the previous results, the higher the generosity of the pension systems, the more negative effects on the inflation dynamics. However, the differences are relatively small given the balancing effects of having endogenous labor supply decisions. We conclude that, aging countries like Germany, Italy, and Japan are already facing deflationary pressures mostly due to strong deflationary population structure effects, while countries like China will experience these same trends during the next decades. The structure effect is especially prominent in Japan starting in the early 1990s, and is explained by early increases of the age dependency ratio. Young countries such as the US and India will further go through inflationary pressures because of a strong positive population growth. Population structure effects will dampen the inflationary pressures of the size effect but this is not enough to conduct global deflationary pressures.

These predictions give us a perspective of the underlying effect of demographic change on inflation dynamics that are in the background of the short-run dynamics usually presented in the literature. Our contribution gives way to understanding how serious the ongoing effects of secular stagnation may be and aims to call the attention of policy makers about the underlying forces contributing to these macroeconomic patterns. Of course, the forces affecting inflation are plentiful, and, in this paper, we do not intend to forecast actual inflation rates but, instead, we shed light on one of these channels and the underlying trends that this channel implies for inflation. This is achieved namely by showing how demographic patterns lead to underlying deflationary pressures for the next decades in most developed countries, halting economic growth and reducing, for example, the effectiveness of key economic tools such as monetary policy to an even greater extent in a world of low real interest rates.

The paper proceeds as follows. Section 2 overviews some of the related literature with our paper. Section 3 introduces the model and its structure. The methodological approach including calibration is presented in Section 4. Section 5 identifies possible channels through which aging affects inflation in a partial equilibrium setting. Section 6 contains a general equilibrium model and simulates this model to illustrate the effects of different demographic stages and channels on

inflation in a sample of countries. Section 7 discusses the results and concludes the paper. We also carry out a detailed sensitivity analysis in the appendix.

2. Related literature

A growing bulk of mostly empirical literature has focused on trying to disentangle the puzzling relationship between aging and inflation. It has reached a consensus neither on the relationship itself nor on the roots thereof⁶. Lindh and Malmberg (1998; 2000) look at age structure and inflation and find a robust correlation indicating that an increase in the share of net savers (workers) dampens inflation while an increase in the share of dis-savers (young retirees) fosters inflation. Accordingly, this increase in the savings rate dampens inflation by reducing aggregate demand and, consequently, exerts a deflationary pressure on the price level in the economy. Juselius and Takáts (2016) obtain similar results by observing a stable and significant negative correlation between the share of workers and inflation. Anderson et al. (2014) and Bobeica et al. (2017) contradict this view by demonstrating that population aging exhibits deflationary tendencies. The former authors study the case of Japan while the latter investigate the case of the euro area. These deflationary tendencies stem from a decline in growth, falling land prices, and dis-savings by the elderly, which puts a downward pressure on asset prices. Katagiri (2012) investigates the impact of changes in demand structure due to aging in Japan and concludes that these shocks cause deflationary pressures. Similarly, Gajewski (2015) and Yoon et al. (2014) find a negative relationship between the share of older people and inflation for varying samples of OECD countries. Nevertheless, Nishimura and Takáts (2012) find opposite outcomes and state that a larger base of working age people has a positive impact on inflation. Another branch of literature defends the idea that it is simply the general growth or shrinkage of the population size that affects prices. Yoon et al. (2014) find that population growth has a positive impact on inflation for Japan. The same positive correlation between population growth and inflation is also found for OECD countries in the 2000s by Shirakawa (2012). Contrasting these findings, McMillan and Baesel (1990) find a negative relation between total population growth and inflation, indicating that shrinkage in population due to aging would lead to inflationary tendencies.

By supplying a theoretical analysis which identifies possible channels through which demographic change affects inflation and by providing an illustrative quantification of these effects in a simple and intuitive way, we distance ourselves from this empirical literature and contribute to a theoretical framework to understand some of the outcomes found in these papers. In contrast to other papers that offer some formalization of these mechanisms in the literature such as Lindh and Malmberg (1998; 2000), Fujiwara and Teranishi (2006) and Galí (2017), we provide a model that examines

⁶ See, for instance, Yoon, et al. (2014) and Juselius & Takáts (2016) for contradicting, empirical findings in the literature.

several life-cycle mechanisms and a more general long-term perspective of the impact of demographic change on inflation. Moreover, many demographic analyses are mostly restrained to stylized definitions of demographic change – as the dependency ratio –, which hide the different mechanisms at work under the different phenomena that make up demographic change, namely population growth and population structure, leading to considerable diverse outcomes regarding inflation dynamics. Moreover, and given this, our model also differs from some approaches using OLG models to formalize some of the trends of secular stagnation (Aksoy, et al., 2016; Eggertsson, et al., 2019). Furthermore, we integrate labor supply decisions and preferences for money in a full CGE model containing actual population dynamics. On the one hand, this prevents superneutrality of money (e.g. Drazen (1981), Barro (1995), Gahvari (2007) or Walsh (2010)) and, on the other hand, makes the model more sensitive to changes in demographics. Moreover, the feedback effects expected between population dynamics and individuals' adaptation to these demographic shocks via aggregate demand decisions are of paramount importance to aggregate savings, labor supply and, hence, output, given all of the general equilibrium effects at work. The relevance of these population dynamics works against some of the literature that has emphasized that one can apply the typical New Keynesian framework when addressing inflation and monetary issues under a demographic change perspective (Galí, 2017). Indeed, the New Keynesian models are by design focused on short-run dynamics of inflation, which make them less suited to incorporating these demographic dynamics.

As already mentioned, it is not the aim of this paper to determine the exact level of inflation using such a simple model; rather we want to extract the underlying inflation dynamics associated with demographic change. However, the challenges that demographic change imposes on monetary policy are very visible in the conclusions and outcomes observed through the paper. Several studies have been conducted that show the impact of demographic change on monetary policy effectiveness (Miles, 2002; Fujiwara & Teranishi, 2006; Imam, 2013; Wong, 2014; Chen, 2016). Even though we take into account the impact of monetary policy in affecting inflation by setting a government which controls money supply as in Hamann (1992), Shimasawa and Sadahiro (2009) and thereby check for different degrees of government reactions, this topic is not thoroughly investigated in this paper.

3. OLG-Inflation model

The applied OLG model consists of a household sector, a PAYG pension system and a representative firm in the general equilibrium framework developed by Auerbach and Kotlikoff (1987). We extend the household's decision problem by adding real money holdings (MIU framework, see Sidrauski (1967)) and a simple government sector that supplies money. We follow Hamann (1992), Shimasawa and Sadahiro (2009) and Walsh (2010) when describing the money

market and the government's money supply rule. The MIU framework allows for the introduction of a monetary economy into a neoclassical framework and incorporates individuals whose utility depends directly on their consumption of goods and money holdings in the basic neoclassical model.

3.1. Household problem

Households choose between consumption, leisure, and real money holdings. Holding money directly delivers utility to the households (MIU framework). This can be interpreted as stemming from lower transaction costs when consuming goods (see Walsh (2010)). Households of age j at time t receive utility from consumption, $c_{t,j}$, money, $m_{t,j}$ and leisure, $1 - h_{t,j}$ according to the instantaneous utility function given by

$$u(c_{t,j}, m_{t,j}, 1 - h_{t,j}) = \frac{1}{1-\theta} \left[\eta c_{t,j}^{\frac{\sigma-1}{\sigma}} + (1-\eta) m_{t,j}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma(1-\theta)}{\sigma-1}} + \Psi \frac{(1-h_{t,j})^{1-\varrho}}{1-\varrho}, \quad (3.1)$$

where η denotes the utility weight of consumption. Parameters θ and ϱ are measures for risk aversion. σ is a measure for the elasticity of substitution between money and consumption. Under a CES utility function, demand for money is a positive function of consumption which allows for replicating the empirically observed positive correlation between consumption and money demand. Therefore, even though we are under a neoclassical model where individuals have perfect foresight and can save for future consumption, individuals still want to hold money in proportion to consumption in order to increase their utility, creating the channel between aggregate demand and inflation. Under these conditions, our model opens this channel between aggregate demand and inflation through money demand. Finally, the parameter Ψ describes the relative weight of leisure in the utility. Utility is additively separable in leisure, as observed in the literature on business cycles (Walsh, 2010).

Households are neoclassical life-cyclers with perfect foresight. They solve an expected utility maximization problem over the entire life-cycle which lasts for a maximum of J years. The life-time maximization problem of a cohort is therefore given by:

$$\max \sum_{j=1}^J \beta^{j-1} \varphi_{t,j} u(c_{t,j}, m_{t,j}, l_{t,j}), \quad (3.2)$$

where β is the pure time discount factor. In addition to pure discounting, households discount future utility with their unconditional survival probability, $\varphi_{t,j}$, expressing the uncertainty about the time of death. We do not include intended bequests in our model and assume that accidental bequests

resulting from premature death are taxed away by the government at a confiscatory rate and used for otherwise neutral government consumption.

The household's disposable non-asset income $y_{t,j}$ is

$$y_{t,j} = h_{t,j}w_{t,j}(1 - \tau_t) + p_t + \sigma_{t,j}, \quad (3.3)$$

which has three components. The first term of the right-hand side reflects labor income (hours worked, $h_{t,j} = 1 - l_{t,j}$, multiplied by the net wage, $w_{t,j}(1 - \tau_t)$). Wages depend on age productivity such that they may rise to a peak well before retirement and then decline with age. In a neo-classical world, hourly wages then evolve as $w_{t,j} = w_t \varepsilon_j$, where ε_j generates age and type specific wage profiles. The second term is pension income. Thirdly, $\sigma_{t,j}$ denotes government transfers to the households which originate in the redistribution of seigniorage in proportion to real money holdings (see also equation (3.17) below).

Denoting total assets by $a_{t,j}$, maximization of the household's intertemporal utility is subject to a dynamic budget constraint given by:

$$a_{t,j} = (1 + r_{t-1})a_{t-1,j-1} + \frac{m_{t-1,j-1}}{1+\pi_t} - m_{t,j} + y_{t-1,j-1} - c_{t-1,j-1}, \quad (3.4)$$

where π_t is the inflation rate and r_t the real interest rate (return on productive capital). Retirement is assumed to be exogenously determined by a mandatory retirement age, R , at which individuals must stop working and will begin receiving pension benefits. This implies that $p_t = 0$ for $j \leq R$ and $h_{t,j} = 0$ for $j > R$.

Over a household's lifetime, the following intertemporal budget constraint in real terms is given by:

$$\sum_{j=1}^J PDV_j c_j + \sum_{j=2}^J PDV_{j-1} \xi_j m_j = \sum_{j=1}^R PDV_j h_j w_j (1 - \tau_j) + \sum_{j=R+1}^J PDV_j p_j + \sum_{j=2}^J PDV_j \sigma_j. \quad (3.5)$$

PDV_j is the factor of the present discounted value, ξ_t is the marginal cost of holding real money and is defined as $\xi_t = i_t / (1 + i_t)$. Accordingly, the sum of lifetime income from labor, pension benefits, and government transfers (right hand side) has to equal the sum of lifetime consumption and real costs from holding money.

3.2. Pension system

The pension system in our model economy is a simple defined benefit PAYG system where a cohort of retirees is promised a pension benefit which is typically defined by a replacement rate, ρ_t , which is independent of the demographic and macroeconomic environment. Contributions are due until

age R ; pension benefits are paid from the claiming age, R , onwards. In this way, the young generation pays the revenues of the system, and the older generation receives the expenditures.

The contribution rate to the system, τ_t , is computed to balance the PAYG system in every period t . Revenues are the product of the contribution rate, τ_t , and the wage bill, $\sum_{j=1}^R w_{t,j} h_{t,j} NW_{t,j}$, where the number of workers of age j is denoted by $NW_{t,j}$. Expenditures are the sum of the products of pension benefits p_t and number of pensioners $NP_{t,j}$. The budget-balancing contribution rate is thus given by

$$\tau_t = \sum_{j=R+1}^J p_t NP_{t,j} / \sum_{j=1}^R w_{t,j} h_{t,j} NW_{t,j}, \quad (3.6)$$

with individual pension benefits, p_t , given by

$$p_t = \rho_t w_t (1 - \tau_t). \quad (3.7)$$

Alternatively, we could assume a fully-funded pension system. In this system, in contrast, a generation pays into a fund during its working life and receives interest on the accumulated capital, which is then used to finance the consumption of the same generation during retirement. At this level of abstraction, a funded system is equivalent to voluntary private saving, which is the case in several subsections when we assume no PAYG pension system.

3.3. Production

The production sector consists of a representative firm. Production is given by a Cobb-Douglas production function using capital stock, K_t , and aggregate effective labor, L_t as inputs:

$$Y_t = K_t^\alpha (A_t L_t)^{1-\alpha}. \quad (3.8)$$

A_t is technology (growing at rate g_t). α is the capital share in the economy. Since factors earn their marginal product, real wages and real interest rates are given by

$$w_t = A_t (1 - \alpha) k_t^\alpha, \quad (3.9)$$

$$r_t = \alpha k_t^{\alpha-1} - \delta, \quad (3.10)$$

where k_t denotes the capital stock per efficient unit of labor ($K_t/(A_t L_t)$) and δ is the depreciation rate of capital. Note that the interest rate given in equation (3.10) is the return from productive capital since our model abstracts from government bonds.

3.4. Money market

Real aggregate money demand in the economy, M_t^D , at time t is the sum of all real money holdings by households alive at time t :

$$M_t^D = \sum_{g=j-J-1}^j m_{g,j+1}. \quad (3.11)$$

Thus, aggregate money demand in the economy is positively correlated with aggregate output/income since consumption and real money holdings are complements for households (see discussion of the household parameter σ in the appendix, Table B.2). We model the real interest rate to be given by the marginal product of capital (see equation (3.10)) and thereby do not model a rate of return for the bond market. Therefore, aggregate money demand depends only on aggregate output/income and not additionally on the bond market interest rate, as is often the case in classical LM theory (Hicks, 1937).

As for the supply side, the government creates nominal money supply at an exogenous rate (μ_t). We model money supply creation following Hamann (1992) and Walsh (2010) such that:

$$M_{t+1}^S = (1 + \mu_t)M_t^S. \quad (3.12)$$

In the money market, real money supply and money demand have to be equal. In the absence of a bond interest rate, which would equate aggregate money demand and supply, the price level has to adjust to reach the equality of money demand and supply in the economy:

$$M_t^D = \sum_{g=j-J-1}^j m_{g,j+1} = \frac{M_{t+1}^S}{P_{t+1}}. \quad (3.13)$$

As a consequence, growing output with an accompanying increase in money demand by households would lead to a falling price level. The empirical literature finds no such negative relationship; the only exception is McCandless and Weber (1995) who find a slightly positive correlation for OECD countries. In order to have a growth of prices driven by an excess of money demand, the supply of money has to accompany the demand for money, which is accomplished by introducing a rule on the money growth rate. This money growth rate, μ_t , is a function which is governed according to the following rule:

$$\mu_t = \mu_{SS,t} + \rho_\mu(\mu_{t-1} - \mu_{SS,t-1}) + \phi_\mu\left(\frac{Y_t}{Y_{t-1}} - 1\right). \quad (3.14)$$

We assume that the money growth rate, μ_t , is a function of its exogenously pre-defined steady state value and its realized past deviations from the steady state average ($\mu_{t-1} - \mu_{SS,t-1}$). Since empirically money growth displays a positive serial correlation, e.g. in the United States (see Walsh (2010)), the growth rate of money in our model also shows persistence regarding previous money growth rates defined by $\rho_\mu > 0$. A negative parameter value, in contrast, would mean a negative serial correlation of money growth leading to unrealistic patterns.

The third term of equation (3.14), $\left(\frac{Y_t}{Y_{t-1}} - 1\right)$ represents growth in output⁷. We assume that there is an elastic money supply by the government that accommodates money demand that arises when households consume. As Walsh (2010) summarizes, for positive parameters ($\phi_\mu > 0$), output (and aggregate demand) growth and inflation will be positively correlated. This pattern is found by McCandless and Weber (1995) for the case of OECD countries, and Gerlach and Svensson (2003) also show that both the output gap and money gap are positively correlated with inflation for the years 1980-2001 for Euro area countries. This is true for moderate inflation scenarios, justifying, then, the assumption of a positive correlation of output and inflation ($\phi_\mu > 0$)⁸. Intuitively, a positive value of ϕ_μ can also be seen as a mechanism that translates booms and busts in money circulation, which is independent of a central bank's policy: while the economy is booming, private banks lend more money in the economy, which increases the money multiplier of a central bank's base money. During a recession, in contrast, the money multiplier contracts since banks are lending less extensively. For example, this is done by Fedotenkov (2018), who explicitly models commercial banks as providers of money supply, which makes inflation dependent on total credits. Since we do not implement a commercial banking sector, the described mechanism is mirrored through a positive value of ϕ_μ , which accelerates money growth in times of a growing economy and vice versa. Furthermore, we assume that money holdings must be positive. To ensure this, the nominal interest rate has to be positive:

$$i_t = (1 + r_t)(1 + \pi_t) - 1 > 0. \quad (3.15)$$

For positive values of money growth, seigniorage is collected by the government and paid as a transfer to households constituting a part of their income.

$$S_t = \frac{M_{t+1}^S - M_t^S}{P_t} = \sum_{j=t-J}^{t-1} \sigma_{t,j}. \quad (3.16)$$

We further assume that the seigniorage is distributed in proportion to real money holdings at the beginning of the period in order to prevent an intergenerational redistribution of resources⁹:

$$\sigma_{g,t} = \mu_t m_{g,t}. \quad (3.17)$$

⁷ Note that output, among other variables, is de-trended in our model. As a result, in the initial and final steady states (see Section 2.5 on the computational algorithm) no change in (de-trended) output takes place due to a constant population. Therefore, the growth rate of money creation will be equal to $\mu_{SS,t}$ in the long run.

⁸ There is also empirical literature (see, e.g. Barro, (2013); Fischer, (1993)) that suggests that the relationship between inflation and economic growth might be negative. However, Gosh and Phillips (1998) and Mallik and Chowdhury (2001) argue that this takes place only for periods of high inflation.

⁹ The proceeds from seigniorage are transferred back to households in the same proportional way as they were paid before, avoiding any intergenerational transfer.

3.5. Computational algorithm

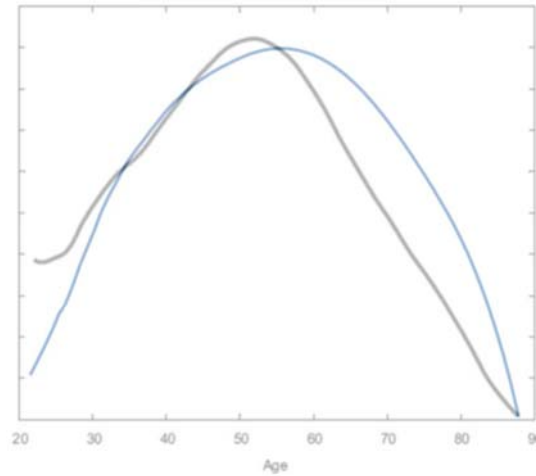
This OLG model must be solved numerically. The algorithm searches for equilibrium paths of consumption, hours worked, money holdings, and capital to output ratios and, in the case that there are social security systems, pension contribution rates. We determine the equilibrium path of the OLG model by using the modified Gauss-Seidel iteration as described in Ludwig (2007). The solution of the life-cycle optimization is solved recursively by taking initial guesses for consumption at last age. Then, the model is solved backwards using recursive methods by applying first order conditions and appropriately handling the constraints. This procedure delivers first guesses for the vectors of consumption, hours worked and money holdings. We then calculate savings and assets, applying the budget constraint. The consumption profile, including consumption at last age, is then updated. This procedure is repeated until consumption, the hours profile and money holdings converge. After the convergence of these inner loops, all cohorts' asset holdings and hours worked at a given year t are aggregated to receive the capital stock, K_t , and labor supply, L_t . By using equations (3.9) and (3.10), the wage and interest rate can be updated. Then, real money holdings by households are aggregated for every period t to receive aggregate money demand. Using the money market clearing condition (Hamman (1992); Shimasawa and Sadahiro (2009)), we compute the aggregate price levels, which will be used for the next iteration until convergence is reached. Our time line has four periods: a phase-in period, a calibration period, a projection period, and a phase-out period. First, we start calculations with the assumption of an “artificial” initial steady state in 1850. The time period around 2015-2017 is then used as the calibration period to determine the structural parameters of the model. Our projections run from 2015 until 2050. For technical reasons, the model then continues to run during a transition to a steady-state population in 2150 and an additional 100-year period until the model reaches its final steady state in 2250.

4. Calibration

The life-span of the household is 100 years. The household enters the labor market at age 15 and retires at age 65 (mandatory retirement). In a first step, for section 5 and subsection 6.1, the structural parameters of the household model are calibrated to match the average of their empirical counterparts for a synthetic group of developed countries. We target the capital-output ratio of 2.6 (based on estimates of the stock of fixed assets to output), a consumption-output ratio of 0.75 (based on Forrester (2017)), average hours worked during working time of individuals, and a consumption profile that matches estimates obtained from Yang (2006), Fernández-Villaverde and Krueger (2007) and Park and Feigenbaum (2018). In our country simulations in Subsection 6.2, the parameters are calibrated to target these moments for each specific country.

The latter empirical moment is important since the shape of the consumption profile will have a strong influence on the structure effect: depending on the age at which the consumption profile peaks, the change in population structure will have a different impact on inflation (structure effect) through time. Therefore, we calibrate the model such that the consumption profile of individuals approximately resembles the ones observed empirically. Note that due to the presence of survival rates (φ_j , see equation (3.2)) in the utility maximization problem, the shape of the life-cycle consumption profile of our model is defined by cohort-specific survival rates in addition to the time preference and interest rate. In the data, we observe that consumption expenditures reach its peak when individuals reach ages between 55 and 60 years. We calibrate the model such that the life cycles obtained match this pattern as closely as possible. In this way, we capture a more realistic relationship when analyzing the impact of changes in the population structure on total consumption and consequently inflation. By keeping this calibration, our results are a bit too high for the consumption dynamics of older generations (see Figure 4.1 below), which only means that our deflationary dynamics calculated later in the paper are even underestimated and we should actually expect stronger ones. Figure 4.1 depicts the empirical (black) and calibrated (blue) consumption profile for a representative cohort in this model entering the labor market in 2017¹⁰.

Figure 4.1 –Empirical and calibrated consumption profiles



Source: own calculations and Fernández-Villaverde and Krueger (2007). Note that the empirical estimates (black) show adult equivalent consumption expenditures for non-durables. Applied data is US consumer expenditure survey data from 1980-2001. The authors control for time, cohort, and household composition effects. The profile is estimated using a pseudo-panel dataset assuming 10 cohorts with a length of five years. Empirical estimates are in black, calibrated model output in a general equilibrium framework is in blue. The life-cycle consumption profile for the model outcome is for a representative cohort entering the labor market in 2017.

¹⁰ Note that the peak in the consumption profile happens at slightly too high ages despite a careful calibration. This is a general problem that Park and Feigenbaum (2018) discuss in their paper proposing a time-inconsistent modelling of the household problem to receive an even more realistic consumption life-cycle profile. This, however, is beyond the scope of this paper and will be a point of future research.

To obtain these profiles and to match the other empirical moments, we calibrate the parameters in accordance with the literature. To achieve these targets, the discount factor, β , is set to 0.975 (see overview by Frederick et al. (2002)). The risk preference parameter, θ , is assumed to be 2, which makes the household slightly risk averse and lies in the middle of estimates in the literature (see overview by Bansal and Yaron (2004) and Browning et al. (1999)). The same value is assumed for ϱ . The capital share, α , in the economy is assumed to be 0.35 and annual productivity growth is 1.5%. The depreciation rate of capital is calibrated to 6% per year, given our calibration target of a capital output ratio of 2.85. As already referred to in Subsection 3.4, the steady state growth rate of money creation is set to 2%, while the lag persistence parameter (ρ_μ) and the output growth coefficient (ϕ_μ) are set to 0.85 and 0.7, respectively. In the appendix (Tables B.1-B.4), we present a sensitivity analysis of the results with respect to the parameters η , σ , ϕ_μ , and Ψ . Table (4.1) gives an overview:

Table 4.1 – Parameter calibration

Parameter	Values	Sources
Discount factor (β)	0.975	Frederick et al. (2002)
Risk preference (θ)	2	Bansal and Yaron (2004) and Browning et al. (1999)
Leisure weight in utility function (Ψ)	0.3	Assumption
Leisure parameter (ϱ)	2	Bansal and Yaron (2004) and Browning et al. (1999)
CES substitutability parameter (σ)	0.4	Walsh (2010)
Consumption weight in utility function (η)	0.97	Walsh (2010)
Capital share in production (α)	0.35	Cooley and Prescott (1995)
Growth rate of labor productivity (g)	0.015	Assumption
Depreciation rate of capital (δ)	0.08	Assumption
Steady state growth rate of money creation (μ_{SS})	0.02	Inflation target of most Central Banks
Lag persistence coefficient of money creation (ρ_μ)	0.75	Walsh (2010)
Output growth coefficient in money creation (ϕ_μ)	0.7	Assumption
Retirement age (R)	65	Legal age in most developed countries

Regarding the wage profiles ε_t , we estimate the wage profiles following the procedure of Altig et al. (2001) and Fullerton and Rogers (1993). The life-cycle wage profile ε_t depicted in Figure A.4 is estimated for the average type individual – see in more detail the estimation procedures and

discussion on the shape of wage profile in Börsch-Supan et al. (2018). Demography is described by the size of each cohort, the survival of that cohort, and additions through net migration. We treat all three demographic forces as exogenous. The size of the population aged j in period t is given recursively by

$$N_{t+1,j+1} = N_{t,j}\varphi_{t,j}, \quad (4.1)$$

where $\varphi_{t,j}$ denotes the age-specific conditional survival rate. The original cohort size for cohort c depends on the fertility of women aged k at time $c=t-j$:

$$N_{c,0} = \sum_{k=0}^{\infty} f_{c,k} N_{c,k}. \quad (4.2)$$

Population aging has three demographic components: past and future increases in longevity, expressed by $\varphi_{t,j}$; the historical transition from baby-boom to baby-bust expressed by past changes of $f_{c,k}$; and fertility below replacement in many countries expressed by current and future low levels of $f_{c,k}$. Population data, age distributions, and assumptions on projections for fertility, mortality, and migration rates in Section 5 are taken from the Human Mortality Database (2016). In this section, we use population data representative of an aging European country (e.g. Germany) in the illustrative partial equilibrium and general equilibrium models. Afterwards, in the country simulations (Subsection 6.2), population data is specific to each country and taken from both Human Mortality Database and UN Population data. Variations in fertility and survival rates over time will lead to changes in population size and structure, known as demographic change. These ongoing, yearly shocks in population will influence labor supply and money holdings through the dynamics of the economy households' consumption, leading to inflationary and deflationary pressures over the years.

5. The aging-inflation channels

To disentangle the effects of demographic change on inflation, we first have to understand how both changes in population size and population structure individually work. Hence, we isolate both components of demographic change and observe what the effects on inflation dynamics would be relative to the steady state of each of these phenomena. Furthermore, we strip down the model of all perturbation elements and start with a partial equilibrium model where individuals only face demographic shocks and can decide on the binomial consumption/savings - all old-age assets are accumulated through private savings -, and where both real interest rate and real wage are exogenously given and constant over time. After going through this simple model, we separately introduce and go through step by step new mechanisms in the model, such as a PAYG pension

system, labor supply decisions and, then, all these new mechanisms together. Due to the negligible individual effects of labor supply in partial equilibrium, only the combination of labor supply behavior with the dynamics of a PAYG pension system is shown and the macroeconomic effects of both demographic effects in a full model are described. A general equilibrium model calibrated to account for the main macroeconomic indicators will be presented in Section 5.

To define the mechanisms connecting demographic change and inflation dynamics, we follow the strand of literature, which identifies savings and consumption patterns as the main channels for age effects on inflation, e.g. Lindh and Malmberg (2000). Intuitively, and supposing an increase in consumption and demand of goods, this intensifies the demand for money as a means to pay for transactions. As the demand for money increases, the government accommodates this need by issuing more money which also increases money supply, resulting in inflationary pressures in the economy. Since aggregate demand in an economy depends on demographics¹¹, not only through the growth of population but also its structure, it becomes clear why we disentangle both in our model and look at them separately. In the case of population growth, changes in total aggregate demand due to a higher (lower) number of population leads to an increase (decrease) in money demand causing inflationary (deflationary) pressures - we label this mechanism as “Size effect”. Regarding the second mechanism that we from now on call “Structure effect”, it takes into account the impacts of the life-cycle consumption profile of individuals and the peak of consumption (reached around ages 55/60 - see Figure 3.1) and the adjustment of the share of age groups during demographic change on aggregate demand. A change in population structure that increases (decreases) the share of population at old ages and decreases (increases) the number of population at the ages close to the peak age of consumption will negatively (positively) affect aggregate consumption in the economy and will ultimately affect money demand the same way, thus creating deflationary (inflationary) pressures.

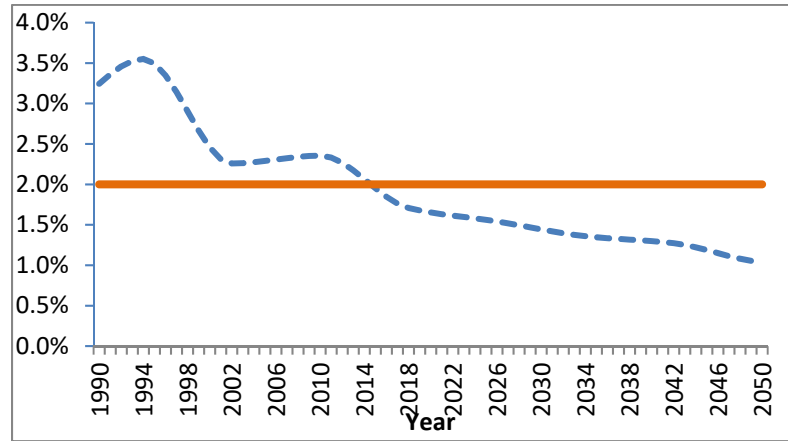
5.1. Population structure and size effects decomposition

We start this section by analyzing the main dynamics of the model under the partial equilibrium model and then, separately, both the population size and structure effects. Right now, in such a simple model, the only driving force influencing inflation rates will be aging, i.e. enduring shocks in population size and structure in every period, which is exactly what we need to understand each of the population size and structure effects. Since steady-state inflation rates are determined by money supply under the absence of any demographic shock, this means that from equations (2.12) and (2.14), money supply growth under no population change and no other shock in the economy

¹¹ See Figure A.5 in the appendix for the claim that population growth affects aggregate demand in our model framework. Since our simplified production sector is perfectly competitive (equation (2.8) to (2.10)), goods markets clear in all t , i.e. produced output always equals aggregate demand (abstracting from capital depreciation and government consumption).

is given by $\mu_t = \mu_{SS,t} = 2\%$. When demographic shocks takes place, both size and structure effects will affect inflation via changes in both consumption aggregate demand and accommodating money supply such that $\mu_t \lesseqgtr 2\%$. Under this framework, values of inflation above 2% represent inflationary pressures, while inflation rates below this 2% threshold mean a deflationary pressure as a consequence of demographic change. Figure 5.1 shows the resulting inflation rates for the time period from 1990 to 2050 in our benchmark model. As seen in Figure 5.1, inflation rates have a value up to 3.3%, above the 2% steady-state threshold (orange line) until the year 2000, which indicates that there is the presence of inflationary pressures. As demographic change takes place, inflation levels tend to be lower than the 2% steady state level, meaning that deflationary pressures become pervasive over time.

Figure 5.1 –Inflation

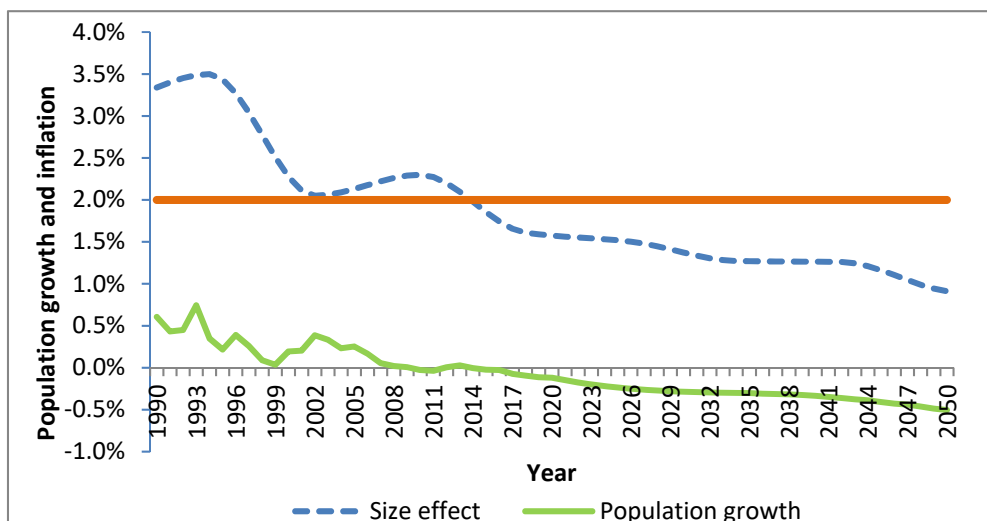


Source: own calculations. Steady state inflation under no demographic change is 2%. A value of inflation above 2% represents inflationary pressures, whereas a value of inflation below 2% represents deflationary pressures.

In other words, demographic developments would initially lead to inflationary pressures until the 2000s and would from then on turn deflationary. To understand the causes for this pattern, we decompose demographic changes between the size and the structure effects. Starting with the size effect, it is determined by holding the population structure constant and only accounting for population growth - each age group will increase proportionally to the population growth rate, keeping the population structure fixed over time. We assume this for the years after 1990 and we show in the appendix (Table B.5) that results are robust if we would have chosen other baseline years for holding population structure fixed. This method allows us to exclude the effect that stems from changes in population structure and isolates the pure size effect. Figure 5.2 depicts the size effect jointly with the growth rate of population. The size effect and population growth rates have a parallel development. Positive population growth rates induce higher total consumption in the economy, leading to upward pressures on prices, whereas a shrinking population leads to the opposite effect. Indeed, exactly at the point in time (2017) when population growth turns negative,

the size effect on inflation rates is below the 2% threshold. These results are in accordance with the empirical findings by Shirakawa (2012) and Yoon, et al. (2014) explained in the literature review.

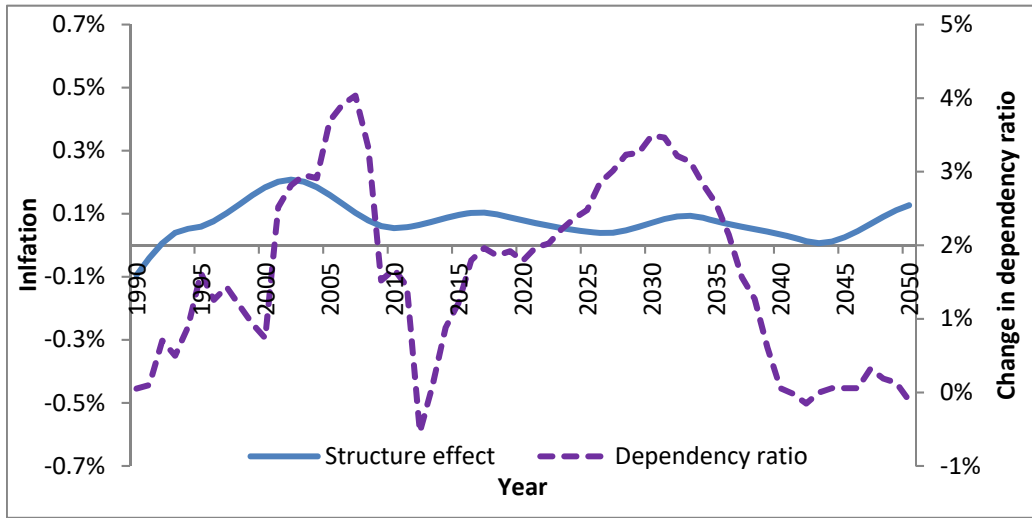
Figure 5.2 – Size effect



Source: own calculations. The size effect is depicted here with the growth rate of population. Positive population growth leads to higher total consumption and an upward pressure on prices, whereas negative growth rates lead to opposite effects. When population growth turns negative, the size effect leads to deflationary pressures.

It also becomes clear that in the current scenario, by comparing both Figures 5.1 and 5.2, the major level of inflation is explained by the size effect. Indeed, when we account only for the pure structure effect its relative weight on total inflation is much smaller than the one from the size effect. The population structure effect is given by the residual difference between our benchmark model scenario (containing both size and structure effects) and the scenario that assumes population structure constant (containing only the size effect). For a better understanding, Figure 5.3 also depicts the growth rate of the dependency ratio since it gives a good measure for a changing population structure during times of aging. As the vertical axis on the left indicates, the structure effect is smaller than the size effect. Values range from -0.1 p.p. of inflation around 1990, to 0.2 p.p. in 2002, and remain around 0.1 p.p. afterwards. When comparing the structure effect and growth rates of the dependency ratio, we detect an apparent, slight positive correlation between the two measures over time. This correlation will be absorbed when we introduce new economic elements to the economy in the following subsections.

Figure 5.3 – Structure effect



Source: own calculations. Percentage change in dependency ratio is shown for Germany as representative of developed countries. The left axis shows that the structure effect is much smaller than the size effect. Values range from -0.1 p.p. of inflation around 1990, to 0.2 p.p. in 2002, and remain around 0.1 p.p. afterwards.

This relation between dependency ratio growth and the structure effect has its origins in the shape of life-cycle consumption profiles (see Figure 4.1). These consumption profiles usually peak around the retirement age. As a consequence, when the share of people aged around 65 increases due to an aging population (i.e. a rising age dependency ratio), aggregate consumption in the economy rises as well and the consumption life-cycle profile induces inflationary pressures. Accordingly, the correlation between the structure effect and the growth of the dependency ratio is positive, although slightly lagged, through time. Given that we currently have a very simple and partial equilibrium model, a first glimpse at the results shows that the size effect presents inflationary pressures when population is increasing and when demographic change takes place while when population growth is negative, it shows deflationary pressures. The structure effect has, in contrast, a deflationary impact in early years and a slight inflationary effect later with a magnitude that is smaller than the one from the size effect.

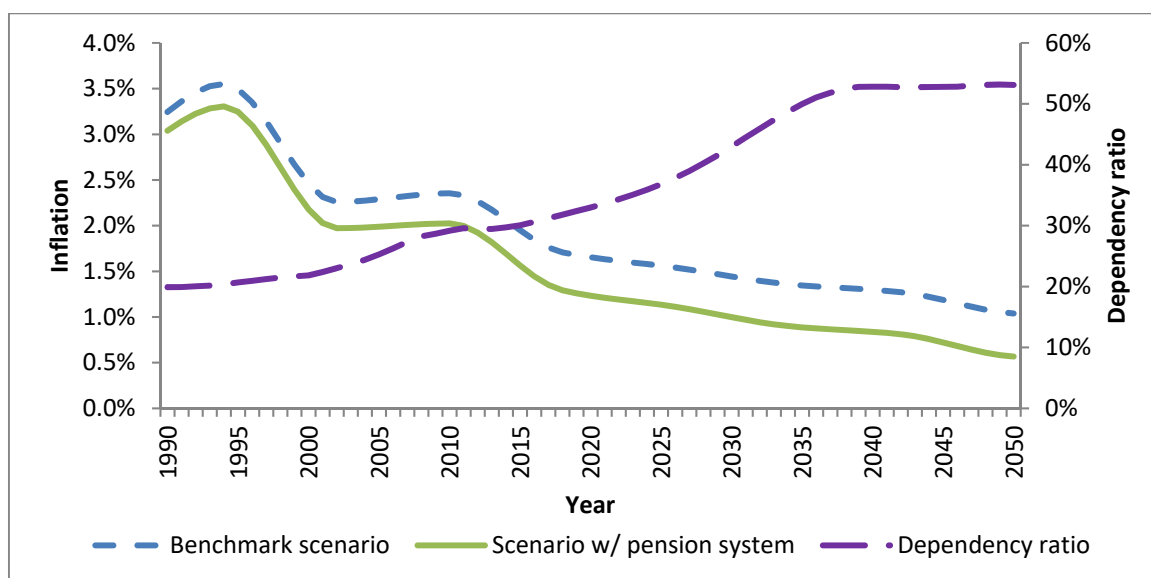
5.2. Pension system's effects

Given these first results, we look now to the effects of the scenario where we introduce a PAYG pension system with defined benefits as explained in Subsection 3.2. A pension system brings new features to the dynamics of the model and on individuals' decisions. It implies that individuals will have forced contributions during their working life. The demographic history (equations (4.2) and (4.3)), the benefit adjustment rule (equation (3.7)) and the individual wage history determine the internal rate of return of the PAYG pension system (Börsch-Supan et al., 2017), which increases, or decreases, total consumption of individuals over the life-cycle depending on the relative value to

the real market interest rate (return on productive capital). In this partial equilibrium model we assume a fixed real market interest rate that is higher than the internal rate of return of the pension system in the period of analysis (1990-2050), which replicates the observed pattern in recent decades mostly because of the decline of population growth due to demographic change. Given this, individuals have a present value of income which is lower than in the scenario without a pension system, reducing aggregate demand¹². Additionally to this, a PAYG system also forces households to contribute to the system from their labor income. This decreases the available income during working age and private savings necessarily have to decrease, or individuals have to borrow in case they want to keep the same consumption level as in the scenario without a PAYG system. This implies less income received through the capital market and, again, lower demand. As an overall outcome, both effects of the PAYG system in a scenario of population aging tend to reduce consumption over the life cycle, which also implies a reduction on money demand and, therefore, prices. In Figure 5.4, we can observe this pattern where the introduction of a pension system creates stronger deflationary pressures in comparison to the benchmark scenario. The difference between inflation rates adds up to roughly 0.3 percentage points in early years. In later years, the difference reaches half a percentage point. For instance, in the year 2017 the difference in inflation rate amounts to 0.4 p.p.. This effect would be stronger or weaker depending on the generosity of the pension system. Although the impact is not always similar over the years, there is a clear reduction of inflation due to the pension system. The reason for this behavior stems from the decreasing internal rate of return of the pension system that occurs due to the increasing share of old age individuals that receive pension payments in comparison to the reduction of the working age population paying for the system.

¹² Please note that, we could think of our model without a pension system as a voluntary fully-funded pension system. The internal rate of return of such a fully-funded pension system is the interest rate on the capital market. Importantly, it matters whether the contributions to a funded pension system are invested in productive capital (e.g., via the stock market) or in debt (e.g., via government bonds). If contributions are invested in government bonds, they do not constitute funding in a macroeconomic sense since the government debt will have to be repaid by future taxes, thus using the same mechanism as a PAYG system in which pension promises have to be paid by future contributions (Diamond, 1965; Pestieau and Posse, 2000).

Figure 5.4 – Inflation with and without a pension system



Source: own calculations. Dependency ratio is shown for Germany as representative of developed countries. The introduction of a pension system creates even stronger deflationary pressures compared to the benchmark scenario. The strength of this effect depends on the generosity of the pension system. The higher the dependency ratio, the higher the gap between inflation levels in the benchmark scenario and the scenario with a pension system.

Following the upward trend in the level of the dependency ratio as depicted in Figure 5.4 (right scale), contribution rates also increase over time to compensate for the decreasing number of contributors to the system, igniting the second effect mentioned above and pushing available income downwards. Hence, the impact on inflation described above will be reinforced and create deflationary pressures: lower savings imply lower capital income which reduces consumption possibilities and therefore money demand, which, in turn, implies lower inflation rates.

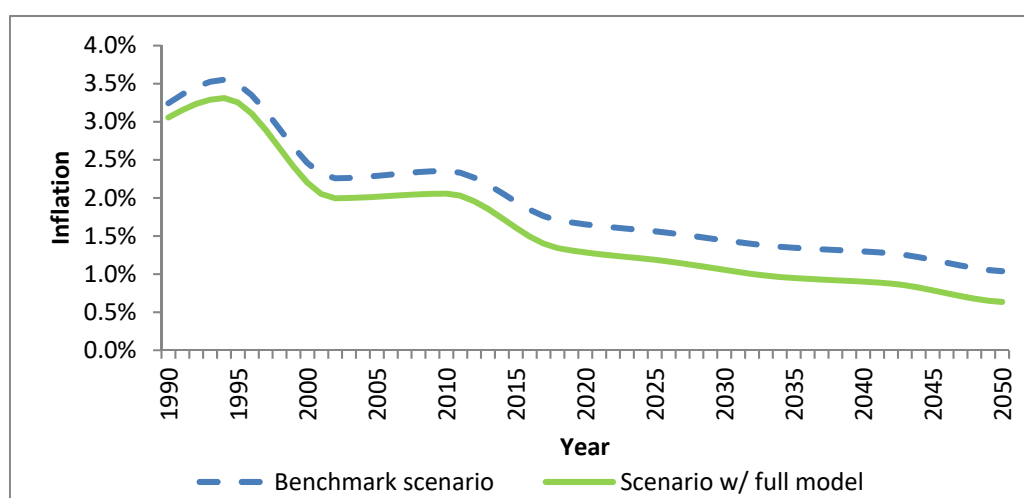
5.3. Overall impact of pension system and labor supply interactions

As previously mentioned, the effects of labor supply decisions in a partial model are relatively small in comparison to the benchmark scenario. Not surprisingly, in a partial model framework with exogenous real wages and real interest rates, endogenous labor decisions do not play a determinant role as a vehicle to affect inflation. However, when integrated in a model with a pension system, interaction effects between these two channels take place. These effects take place when individuals adapt their hours worked in response to increasing contributions to the pension system. If endogenous labor decisions lead to an increase of total hours worked, the pension system will require a lower contribution rate for each individual, which will boost savings and consumption relative to a scenario with only a pension system. This increase in consumption will then dampen deflationary pressures (we will see this clearly below in Table 5.1). As Figure A.6 shows, the effect of labor supply decisions alone is small in comparison to the pension system effect (inflation

differences to the baseline scenario mount to a maximum of 0.1 p.p.). Despite this small value, it is still significant in relative terms when inflation levels are low¹³.

Due to the low individual impact of labor supply decisions we decide to concentrate the analysis on the overall impact of both channels. For this purpose, the same simulation from Section 5.1 is carried out but by assuming both endogenous labor supply decisions and a PAYG pension system. As expected, the main pattern observed is the increase of deflationary pressures over time, leading to a reduction of the inflation rate. Comparing the levels of inflation calculated in Section 5.1 with the outcome levels in this section (see Figure 5.5), we can clearly observe this pattern.

Figure 5.5 – Inflation rates in the benchmark and full model scenarios



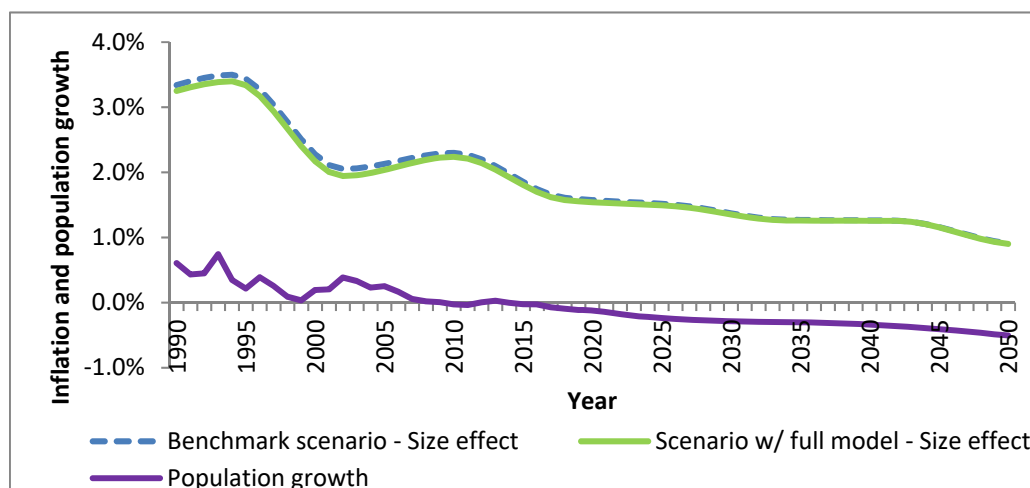
Source: own calculations. Deflationary pressures cause a reduction in the inflation rate. The main features of Subsection 5.2 are retained due to a weak effect of labor supply compared to the large impact of the pension system.

The pattern of Figure 5.5 retains the main features already observed in Subsection 5.2 due to a weak effect of labor supply in contrast to the large impact observed when introducing a pension system mostly due to the stronger effect of aging in the pension system's internal rate of return. Comparing the size effect of this full model scenario to the benchmark scenario (see Figure 5.6), we observe that deflationary pressures are only slightly stronger under the former than under the latter. In addition, Figure 5.6 shows that the size effect presents the same decreasing pattern as was observed in the benchmark scenario as a consequence of a shrinking population. The same channels regarding population levels and aggregate money demand apply here, too. This means that a negative population growth plays a significant role because it leads to a constant downward trend on inflation dynamics, in the long run and for all scenarios. But given that total inflation levels are much lower in this scenario than in the baseline one, this clearly indicates that the structure effect plays a major

¹³ Since utility is additively separable in leisure, most of the expected effects are mainly indirect via wages, which affect consumption, demand for money, and savings. We will see these effects later in the case of the general equilibrium scenarios in Section 6.

role in pushing inflation down - it is negative during the entire period of analysis. A significant part of inflation dynamics are driven by structure effects and not by size effects.

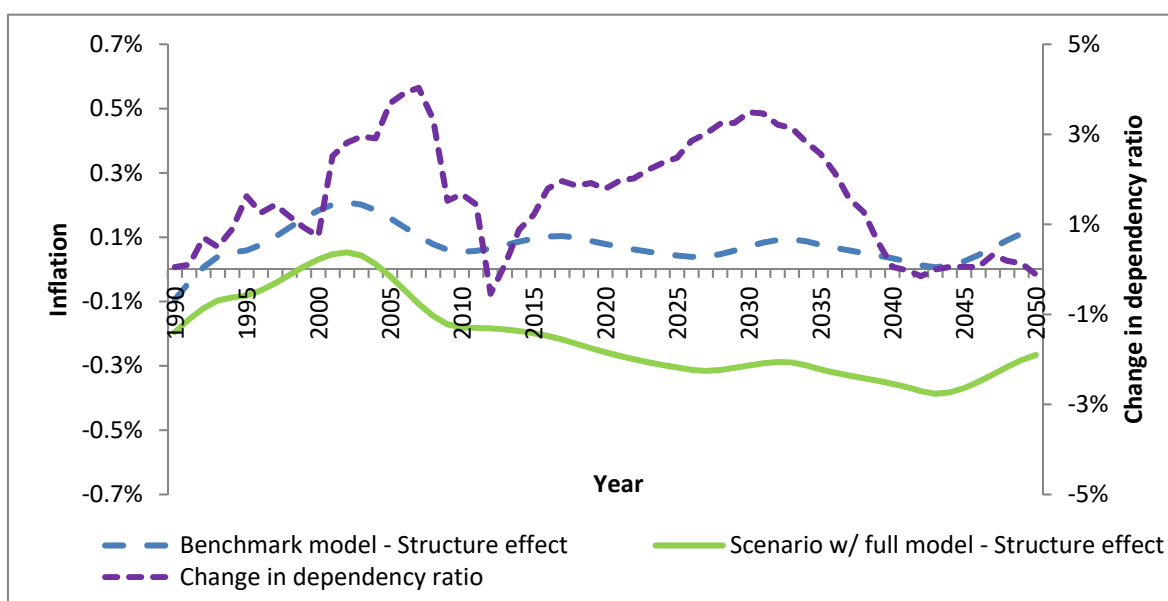
Figure 5.6 – Size effect in both scenarios and population growth



Source: own calculations. The size effect of the full model scenario compared to the benchmark scenario. Deflationary pressures are only slightly stronger under the full model scenario than the benchmark scenario. The size effect presents the same decreasing pattern as under the benchmark scenario, due to a declining population.

As is visible in Figure 5.7, in comparison to the benchmark scenario, the structure effect is now more negative and does not react to changes in the dependency ratio growth as before. This is mainly driven by pension system dynamics that amplify the deflationary tendencies of the age structure mechanism. The existence of a pension system for a given age structure of population leads to larger losses of disposable income and affects consumption over the life-cycle, producing deflationary pressures. This is reinforced by the interdependence between population structure and the pension system through the internal rate of return of the system, as discussed before. We can, nevertheless, observe that the structure effect becomes less negative the moment the growth rate of the dependency ratio slows down, which means that the population structure stabilizes (the share in population of the baby boomer generation begins to fall after 2040). This increases the relative share of younger working age groups and reduces the deflationary tendencies on the structure effect.

Figure 5.7 – Structure effect in both scenarios and dependency ratio



Source: Own computations. The structure effect is more negative in comparison to the benchmark scenario and it is no longer directly correlated with changes in the dependency ratio. This is largely due to pension system dynamics amplifying deflationary tendencies of the age structure mechanism.

We can infer that without a pension system a structural change in the population has small effects on inflation, and, if there is an effect, it is first negative and then positive due to working age population consumption not being hindered by large payments of contributions and the increasing share of retirees not being sufficiently large to have a negative impact on money demand and, hence, on inflation. But, if there is a pension system, the impact on inflation is stronger. The reason is twofold. The first reason is the larger amount of retirees which have a decreasing consumption profile. This is also true in an economy without a pension system. The second and distinguishing reason is the decreasing consumption of the working age population, which reaches its consumption peak around retirement and becomes sufficiently strong to create a downward trend in money demand and, consequently, in inflation. It is the combination of a smaller working population at the age of peak consumption and a decrease in consumption due to the pension system that conducts to a strong negative structure effect. This is mostly visible after the 1990s because of the constant increase in the dependency ratio. This should be regarded as a sign for the problems that future aging economies may face concerning inflation, related to the expansion of their pension systems necessary to cope with a larger amount of pensioners and pension payments - we come back to this issue in Section 6. In order to have an overall perspective on the impact of aging, pension systems, and labor supply behavior on inflation, Table 5.1 summarizes the main effects of each element depicted in percentage of benchmark inflation.

Table 5.1 – Comparison between scenarios (time span: 2015-2025)

	Inflation level	Size Effect	Structural Effect	Ratio (scenario/benchmark)
Benchmark scenario	1.69%	1.61%	0.08%	100%
Scenario w/ only endogenous labor	1.67%	1.58%	0.09%	98.9%
Scenario w/ only pension system	1.27%	1.61%	-0.34%	75.4%
Scenario w/ full model	1.32%	1.58%	-0.25%	78.4%

Source: own calculations.

As described in Table 5.1, the size effect exerts a negative effect on inflation – it is lower than steady state inflation level (2%) – and becomes stronger over time due to a decline in population. It is interesting to observe that this size effect is quite stable across scenarios (1.58%-1.61%). Nevertheless, inflation levels are much lower as we add new elements to our model. Namely, the introduction of a pension system leads to a stronger fall in inflation levels (less 0.4 percentage points). This fall is mainly driven by a negative outcome on the structure effect with a negative impact on inflation of -0.34 p.p.. This is, however, dampened when individuals can decide how much labor they want to supply (-0.34% vs -0.25%), which indicates that the fall of available income due to contributions to the pension system leads to an increase of total hours worked. This will boost savings and consumption and hinder the deflationary pressures observed in the scenario with only a pension system. As an overall effect, just by adding several typical elements affecting life-cycle decisions, we observe an already impressive reduction of inflation levels of around 25%. These results give strength to the arguments presented by the strand of literature which argues that population growth is positively correlated on inflation. In such a simple partial equilibrium model, demographic change through the size effect has a negative impact on inflation. This is supported by evidence from Yoon, et al. (2014), Gajewski (2015) and Bobeica et al. (2017), who argue exactly that an increasing number of old age population has a downward pressure on prices. As for population structure, it changes its impact magnitude depending on the economic model we assume. The main difference between models is the presence of the pension system. If there is no pension system that absorbs available income and consumption of the working age population, population structure changes have a mostly negligible effect (see Table 5.1, first line, and Figure 5.3). This would be along the same line of thought of Lindh and Malmberg (1998; 2000) and Juselius and Takáts (2016) who find that old age population produces inflationary tendencies. However, when a pension system is in place, the population structure effect becomes more negative, reflecting diminishing available income and consumption, which rejects the previous findings. Nevertheless, one must remember that we are still in a very simple framework, in the next section we will debate the implications of a general equilibrium model and see whether all of these results still hold.

6. Aging – inflation dynamics

As mentioned in the previous section, a partial equilibrium is not enough to study the complex dynamics of life-cycle decisions and its macroeconomic feedback effects. Therefore, in the first part of this section, we start by examining the main impacts that a general equilibrium framework has and compare how each channel between aging and inflation, presented in the last section, changes or is strengthened. Real interest rates and wages are no longer fixed and depend on the equilibrium of the production sector which is determined among other things by aggregate individual decisions on labor supply and capital (obtained from savings). Accordingly, interest rates and wages will tend to fluctuate over time due to enduring shocks in the size and structure of population, which creates positive, or negative, incentives regarding savings, consumption and hours worked.

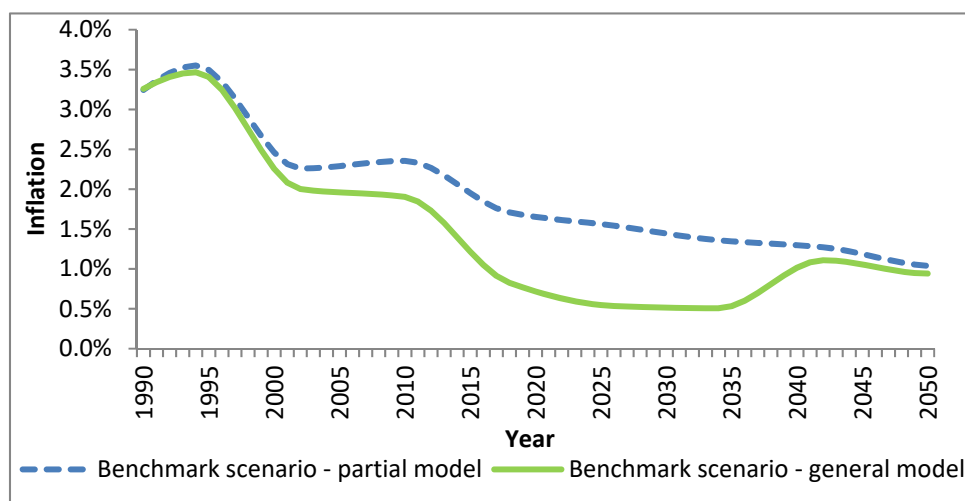
These dynamics will be important to understand the outcomes in the second part of this section. Here, we provide a quantified analysis of how much demographic change can explain inflation dynamics in different countries. Since these countries are in different stages of demographic change and have different types of public pension systems, this allow us to quantitatively explain the main arguments and channels presented in this paper and project the potential impact of demographic change on inflation patterns.

6.1. Demographic mechanisms in general equilibrium

In times of demographic change, real interest rate variations depend on the amount of savings in an economy. Since our model depends on savings accumulation to increase capital, today's changes in population structure where groups of savers (working age population) increase first forces interest rates to decline, and at the same time, wages to increase. As a consequence, on the one hand, consumption and money demand tend to increase due to higher wages but, on the other hand, declining interest rates make savings less rewarding, which leads to lower consumption growth. The overall effect is a priori ambiguous because of these two counteracting effects. Nevertheless, the overall effect becomes clear as the decreasing interest rate effect overcomes the wage effect in later years of demographic change. As a consequence, in comparison to the partial model, inflation levels are significantly lower as demographic change takes place. Figure 6.1 shows, for both benchmark scenarios, how inflation rates are lower in a general equilibrium framework than in partial equilibrium when demographic change is slowly taking place. This is most observable when demographic change takes place and leads to a wide gap between both scenarios. This shows mainly the structure effect at work, since an aging population leads to a decline on the real interest rate and, hence, to lower consumption and lower money demand. The counteracting wage effect is not sufficiently strong to avoid the deflationary effects resulting from demographic change. On the

whole, the general equilibrium setting with its varying factor prices reinforces demographic effects on inflation because the partial model with its constant factor prices closes an additional channel through which demography can work.

Figure 6.1 –Inflation under partial and general equilibrium



Source: own calculations. For both benchmark scenarios, the inflation rates are lower in a general equilibrium than in a partial equilibrium when demographic change takes place. The general equilibrium setting reinforces demographic effects on inflation due to its varying factor prices, whereas constant factor prices in the partial equilibrium model close a channel in which demography can work.

In the current framework where general equilibrium effects are at play, the possibility that individuals decide on their labor supply significantly influences inflation dynamics. In such a scenario, variations in wages and interest rates will affect hours dedicated to work and, hence, consumption and savings choices. By inspecting the results for the endogenous labor scenario (see Table 6.1), under demographic change and, hence, increasing wages and decreasing interest rates, the positive reaction of hours worked dampens the deflationary pressures observed in the benchmark scenario. The size effect, as already observed in the section before, remains quite stable across scenarios since the relation between population growth (size) and total hours worked remains similar in both scenarios. The main cause for this pattern is the structure effect. Given a change in population structure, an increase in wages positively affects hours worked, which was not possible when hours were exogenous, boosting the wage mechanism and hampering the negative impact of the interest rate mechanism, mostly for cohorts at the ages of higher productivity. This leads to a higher positive reaction of consumption demand, and subsequently, money demand and, therefore, the deflationary effect of the structure effect reduces by 0.2 p.p. - the deviation from the 2% steady-state inflation level is larger in the benchmark scenario. This is a substantial difference to the partial equilibrium setting which showed almost no difference between the benchmark scenario and the scenario with endogenous labor.

Table 6.1 – Comparison between scenarios (time span: 2015-2025)

	Inflation level	Size Effect	Structural Effect	Ratio (scenario/benchmark)
Benchmark scenario	0.77%	1.80%	-1.03%	100%
Scenario w/ only endogenous labor	0.93%	1.78%	-0.85%	120.2%
Scenario w/ only pension system	0.78%	1.80%	-1.02%	100.6%
Scenario w/ full model	0.97%	1.77%	-0.81%	125.0%

Source: own calculations.

When introducing a pension system, the negative impact of demographics on inflation is now similar to the benchmark scenario in contrast to the partial equilibrium setting. Countervailing effects lead to this outcome. A share of savings is now absorbed by the pension system which reduces private savings of individuals and, hence, pushes interest rates up, which increases the budget possibilities of households. In contrast to this positive effect, changes in the population structure, which increase the amount of retirees, make inevitable the increase of contribution rates and, again, the fall on the internal rate of return of the pension system together with the reduction on net wage. This has the same kind of negative impacts on consumption and savings as the ones verified in the partial equilibrium model. This effect will be amplified by negative reactions of hours worked that reinforce this negative cycle. Altogether, it produces deflationary pressures, as we can see from the structure effect of -1.02% in Table 6.1. However, in comparison to the benchmark, the impact of the pension system is minimal. As the ratio scenario/benchmark depicts, under a general equilibrium framework, the reduction of inflation is smaller than under a partial equilibrium setting (100.6% instead of 75.4%) due to the feedback effects produced by wages and interest rates.

As soon as all channels are incorporated together in a single full model, we observe that the small deflationary effect of a pension system is dominated by the stronger positive effect of endogenous labor. As Table 6.1 shows, the inflation level is on average similar in both the scenario with endogenous labor and the full model scenario (120.2% and 125.0% of benchmark scenario levels, respectively). This shows how endogenous labor more than compensates the negative impact of pension systems through a stronger reaction to changes in wages and interest rates through the structure effect. The existence of a pension system and the increasing contribution rates lead to negative reactions in consumption and, subsequently, in money demand, as already explained above. The fact that individuals can decide endogenously on their labor supply, however, more than erodes this effect. The effect of increasing wages on hours worked more than compensates for the contribution rates effect on hours, leading to a dampening of the structure effect (less negative than in the scenario only with a pension system).

These results show strong evidence that the channels linking aging and inflation have a major impact through general equilibrium mechanisms and are either hidden by these same general model

features, or by the other channels involved that may compensate for each other. Nevertheless, by decomposing the several channels as we did before and now integrating them sequentially allows us to know the exact strength of each one and its direction. These more robust results continue to support the literature which argues that population growth is positively correlated with inflation. As for population structure, the magnitude of the negative impact on inflation clearly favors the views of those that advocate that demographic change, and more properly speaking, population aging, will lead towards deflationary pressures and not inflationary ones. Therefore, given the decomposition of channels and of mechanisms behind the binomial aging-inflation, it is now possible to elaborate on conjectures for different economies of how different policies affect, for example, pension systems and labor force participation and may work towards deflationary or inflationary tendencies. This is an important tool for policy makers to anticipate the possible inflation dynamics in different economic and social contexts. The importance of this knowledge will become clear in the next section when we compare different countries with different specificities regarding pension systems and stages of demographic change.

6.2. Aging-inflation dynamics by country

After evaluating the individual impact of the identified channels, we can now simulate the model to illustrate the channels and mechanisms described above and at the same time portray the main inflation dynamics of countries with different macroeconomic and demographic specificities. For that, we apply the general model from above. It is simulated using parameters that match several empirical moments of each country in order to quantify the dynamics between demographic change and inflation. We want to again highlight the fact that, with these simulations, we are not seeking to obtain exact estimates for inflation but only replicate the last decades' patterns and understand how much of demographic change could explain the decline in inflation observed¹⁴. Our only concern is to simulate and illustrate the underlying impacts of demographic change on inflation.

In order to have a better understanding of the different paradigms which connect demographics and inflation, we choose contrasting countries at different demographic stages and with different social concepts of social security structures. We select a set of aged countries that have a generous pension system – such as Germany, Italy, France and Japan. France is a special case since it is aging at the top of the pyramid (increasing life expectancy) but still has a very high fertility rate. Finally, a set of young countries composed of the US and India represent the countries with a still young

¹⁴ As it should be clear, there are too many channels that drive inflation (specifically financial ones, not explicitly assumed in our model) to be implemented in a single model. In this paper, we are just concerned with detecting the specific impact that demographic change may have on inflation. Therefore, it should only be expected that inflation trends match the empirical ones and not all fluctuations originated from momentaneous changes in monetary policy or specific macroeconomic shocks.

population and also with a less generous pension system. China is also included in this group as a country with a less generous pension system and young population, but which is aging quickly. From the lessons of Section 6.1, we know that part of the effects of a pension system are absorbed by countervailing effects from other mechanisms in the model although different levels of generosity affect the strength of the dynamics. Therefore, we will show here the main results taking into account a PAYG pension system. In our sample, some countries possess fairly generous pension systems with replacement rates (as a share of the net wage) ranging from 60% (France, Germany, and Japan) to 70% (Italy). China and India, in contrast, have public pension systems with low generosity (10%). For the US, which constitutes an intermediate country in terms of generosity, the replacement rate is 30%. Note that we abstract from open economy scenarios in this paper (each country scenario is simulated in a closed economy), since we want to have the cleanest understanding of how individual inflation dynamics are influenced by its own demographic change patterns. We calibrate the model by country to match key empirical moments of each economy. We also guarantee that the parameters are in the intervals defined in our assumptions and the ones found in the literature. For instance, ϕ_μ must have reasonably high values given the empirical evidence discussed in Section 3 – for European countries we assume the same value of ϕ_μ since they all belong to the euro area. The values assumed for China and India are slightly lower as it is expected that credit and financial markets are still developing and cannot produce as high a multiplier as, for instance, in the US. The parameter values are summarized in Table 6.2 and all the others remain as given in Table 4.1.

Table 6.2 – Parameter values

	Discount factor (β)	Consumption weight (η)	Depreciation rate (δ)	Labor weight (Ψ)	Coefficient in money creation (ϕ_μ)
France	0.999	0.76	0.06	0.16	0.95
Germany	0.999	0.80	0.065	0.30	0.95
Italy	0.999	0.81	0.05	0.05	0.95
USA	0.98	0.90	0.07	0.045	0.95
Japan	0.999	0.3	0.07	0.03	0.99
China	0.995	0.3	0.04	0.02	0.7
India	0.995	0.75	0.065	0.035	0.8

Parameter values are calibrated to match empirical moments displayed in Table 6.3. The main goal in this Section is to match each country's empirical moments with our model outcomes, even if parameter values might seem extreme for some countries. Hereby, the discount factor and the depreciation rate are used to target the empirical capital-output ratio. The consumption weight parameter is used to target the consumption-output ratio and the money-output ratio. Finally, the two labor parameters are used to mainly target average annual hours worked.

A series of empirical moments observed in the calibration year 2015 (see Table 6.3) are matched with their corresponding model outcomes. In order to avoid problems in calibration related with fluctuations in inflation, we calibrate the model such that the relative change in average inflation between the years 1990 and 2010 in the data is matched in the model. We achieve a good match for all moments in all countries. Regarding inflation dynamics, a good percentage of the change in the average inflation can be replicated, even taking into account the quite volatile nature of inflation.

Table 6.3 – Calibration targets and model outcomes

	Average annual hours worked	Capital-Output ratio	Consumption-Output ratio	Money-Output ratio	Relative change in inflation
France					
Empirical moments	0.73	3.09	0.55	1.03	-0.52
Model outcomes	0.72	2.94	0.66	1.06	-0.22
Germany					
Empirical moments	0.66	2.85	0.54	1.03	-0.59
Model outcomes	0.66	2.86	0.65	1.05	-0.54
Italy					
Empirical moments	0.83	3.32	0.61	1.03	-0.76
Model outcomes	0.82	3.14	0.69	1.04	-0.38
USA					
Empirical moments	0.84	2.34	0.68	0.67	-0.70
Model outcomes	0.83	2.38	0.70	0.66	-0.26
Japan					
Empirical moments	0.83	2.85	0.57	2.36	-1.23
Model outcomes	0.83	2.86	0.65	2.42	-0.72
China					
Empirical moments	0.84*	2.85**	0.37	2.02	0.06
Model outcomes	0.83	2.89	0.65	2.00	-0.30
India					
Empirical moments	0.84*	2.34**	0.59	0.85	0.34
Model outcomes	0.84	2.32	0.66	0.86	0.05

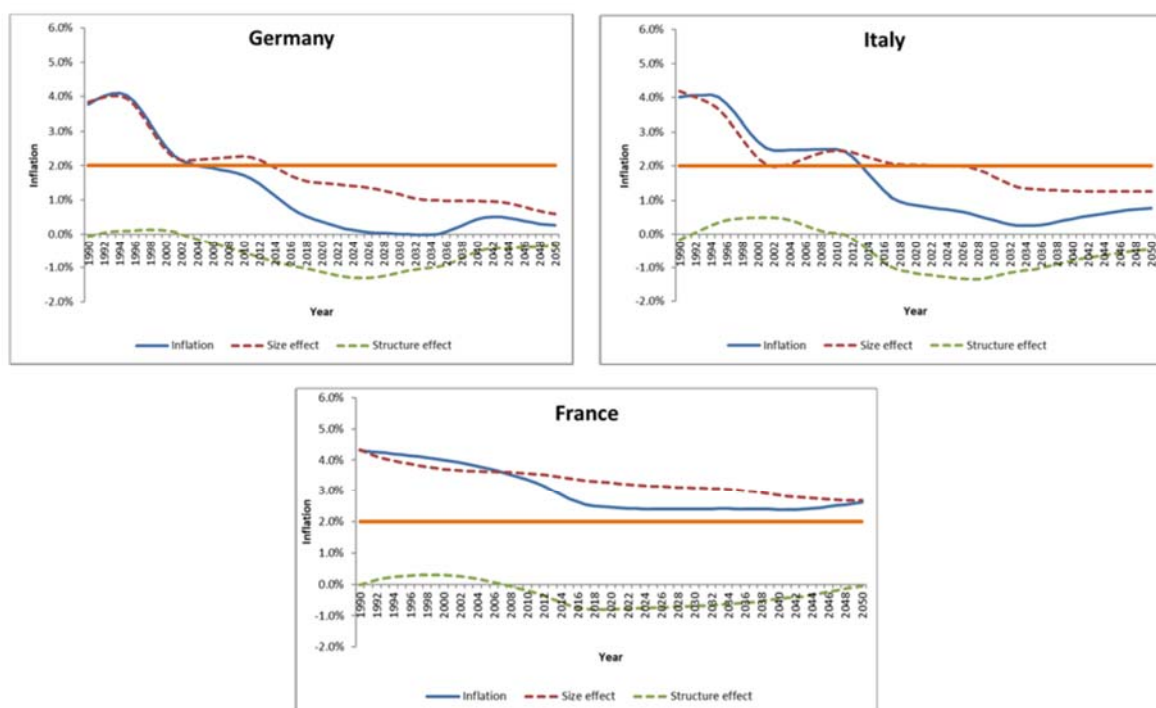
Source: European Commission (2018), FRED (2018), The World Bank (2018). Calibration year is 2015. Average annual hours worked are displayed as the fraction of assumed maximum hours worked of 40 hours/week * 52 weeks/year = 2080 hours/year. *Data for annual hours worked for China and India is not available. However, it seems to be very high. Therefore, it is assumed to be the highest in our sample together with the USA. **Data for capital output ratios for China and India is not available. FRED (2018) data, which defines capital in a much wider sense than other sources, suggests that the Chinese capital-output ratio is comparable to the ratio in Japan. The same relationship holds between India and the USA. Relative change in inflation is calculated for the differences between the years 1990 and 2010 (year before the quantitative easing measures in Europe).

After matching all the empirical moments above, we can examine the predictive behavior of inflation dynamics for the different countries and how they depend on demography. For a summary of the results, Table A.1 shows the main inflation dynamics for each country. From Table A.1 and Figure 6.2 the resulting inflation rates and magnitudes of both population structure and size effects for the three largest EU countries are shown. As already mentioned, Germany and Italy represent a regime of aging populations, both due to high life expectancies and low fertility rates, while France is aging due to higher longevity but still maintains higher fertility rates.

Inflation shows a clear downward trend for Germany and Italy. This trend is initially driven by the population size effect until the 2000s, but then the structure effect is responsible for a larger part of the variation in inflation. This shows evidence of the powerful effect of changes in population structure and the approach of baby-boomers to retirement age, passing their peak of consumption. Since fertility rates have been low for decades in these countries, population is declining and aging faster as baby boomers age and these large cohorts reach age groups with high mortality rates. Therefore, the size effect on inflation rates exhibits a deflationary pressure only from the year 2014 onward in Germany and shows the same trend a decade later in Italy. However, inflation rates drop below the 2% threshold almost a decade earlier for both countries. As already mentioned, this is due to the negative structure effect. When large cohorts reach the stage in their life-cycle at which

consumption decreases, there is deflationary pressure on inflation rates. This happens from 2006 in Germany and from 2012 onwards in Italy. This is especially pronounced for these countries if we take into account them having some of the more generous pension systems among all the countries examined here. The explanation was already given earlier: due to population aging, the internal rates of return of PAYG pension systems in these countries are lower than the market interest rates. Therefore, life-time income and consumption are lower in these aging countries, inducing a lower demand for money and, consequently, lower inflation rates. Subsequently, the structure effect is shifted towards (more) negative values. France, in contrast, shows a quite different profile. While we still observe a small deflationary structure effect due to aging baby boomers, the size effect on inflation always shows strong inflationary tendencies. This causes inflation rates to be consistently above the 2% threshold. As mentioned above, this effect stems from relatively high fertility rates in France during the last decades that have prevented aggregate population from declining.

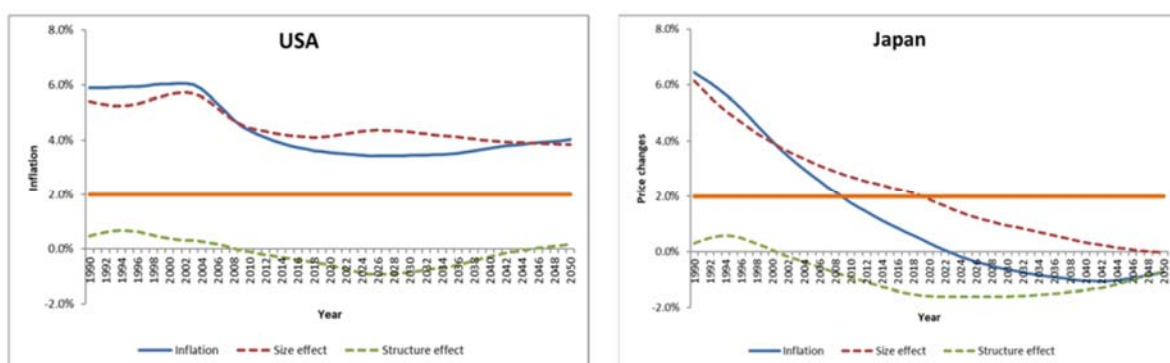
Figure 6.2 –Inflation rates and effect sizes for three major EU countries



Source: own calculations. Germany and Italy show clear downward trends in inflation due to their aging populations. This shows evidence of the strong effect of changes in population structure. France, which does not suffer from an aging population, shows inflation rates consistently above the 2% threshold.

Leaving the European context, we next compare two major economic powers: the US and Japan. Despite both being among the most developed countries, their demographic structure differs substantially: while the US still enjoys relatively high fertility rates and a growing population, Japan is closer to the aging European countries and suffers from a substantial decline of population due to low fertility rates. Additionally, Japan has a much more generous pension system which, as we have seen before, creates stronger deflationary pressures. This is particularly visible by the huge strength of the effect of changes in population structure that reaches almost -2%, meaning inflation levels are decreased by the same proportion. That is why we observe for years until 2020 very low inflation levels due to demographic change and afterwards Japan even enters into deflation. This provides evidence of a cause for the low inflation trap that Japan currently suffers from and has not been able to escape from. This is perfectly observed by inflation outcomes depicted in Figure 6.3.

Figure 6.3 –Inflation rates and effect sizes for USA and Japan

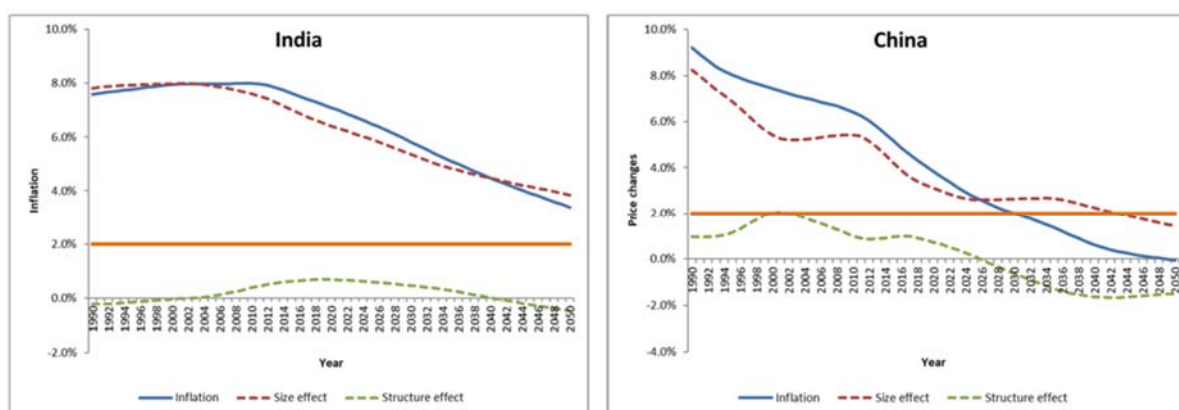


Source: own calculations. The US does not suffer from an aging population as does Japan, but Japan has a much more generous pension system, creating deflationary pressure. The effect of changes in population structure is quite large—inflation falls to -2%. In the US, the size effect is massive, so the structure effect does not play a major role.

In the US, the size effect on inflation causes inflationary tendencies due to permanent positive population growth. The structure effect is similar to the ones in the European countries due to aging baby-boomers and their life-cycle consumption profiles. However, since the size effect is massive, the structure effect does not play a major role. In Japan, though, the situation is very different. Comparable to European countries, an increasing population pushes inflation rates above the 2% threshold until the late 2000s. Afterwards, a strong population structure effect induces inflation rates to fall strongly below the 2% level. This effect gains substantial importance and enlarges over time. It is important to note that the size effect is inflationary until today and becomes deflationary around the 2020s. In 2040, inflation rates stabilize at a very low 0.5% despite a policy target of 2%. This shows a double interaction between the structure and size effects from which Japan extraordinarily suffers, driving inflation rates even further down.

Finally, the two largest Asian countries in terms of population, China and India, are examined in Figure 6.4. China's one child policy as a reaction to population growth pressures is well-known as a major driver of its current demographic development. Large population growth rates during the past decades induced the size effect to have an inflationary pressure on inflation rates until recently (up to 8 p.p. above the 2% threshold). Jointly, the entrance in the labor market of many young workers increased the structure effect to extremely higher values, as is clear from Figure 6.4 below – this has already been happening from the 1990s until today and then turns negative after the 2020s. In parallel to the aging European countries, this negative structure effect will further drive down inflation dynamics such that they will be close to zero in 2050. Moreover, since China's population will soon decline (roughly around the year 2035) the size effect will also promote deflationary pressures after the year 2035.

Figure 6.4 –Inflation rates and effect sizes for China and India



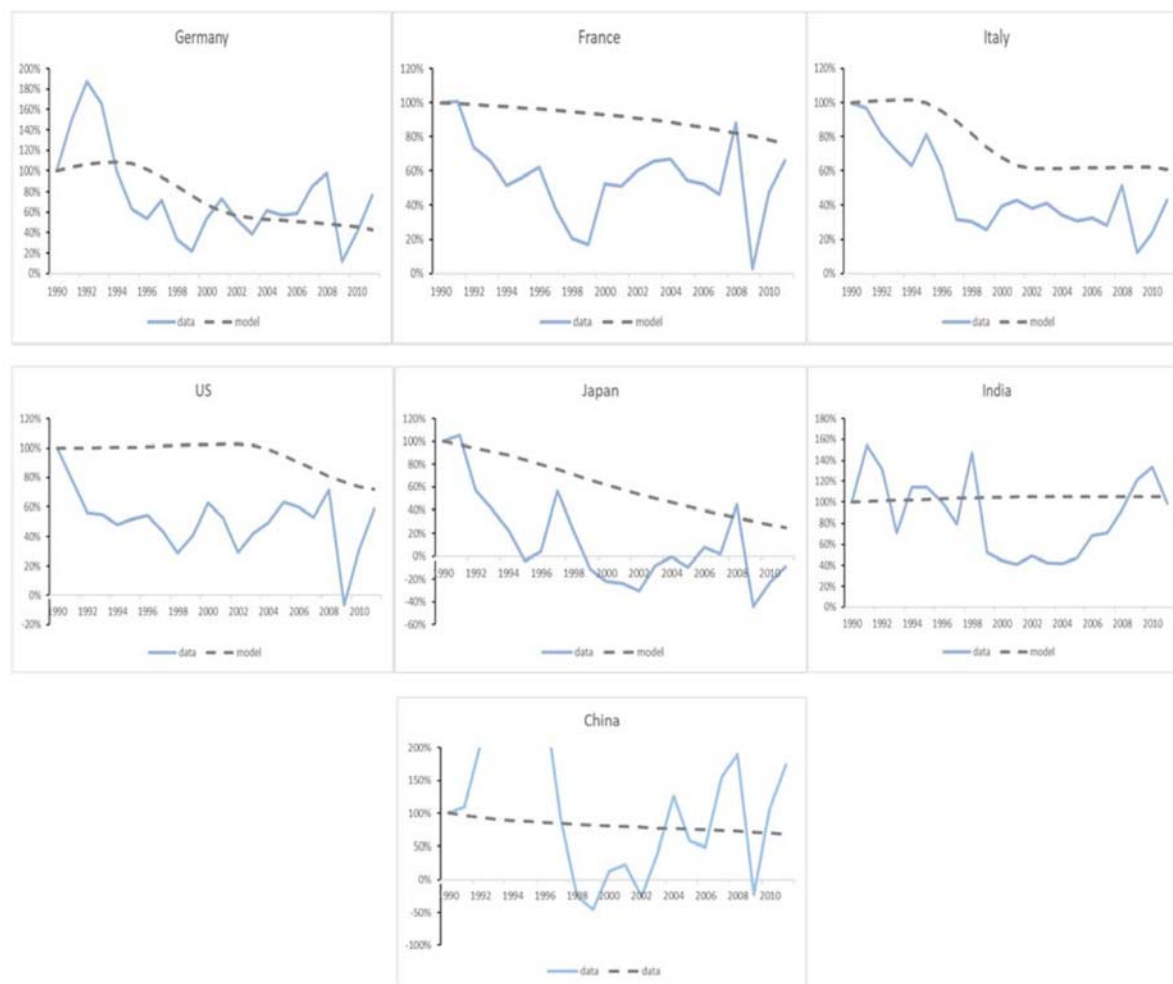
Source: own calculations. Large population growth rates in China induced the size effect to have inflationary pressures. But, China's population will soon shrink, and the size effect will cause deflationary pressures. In India, the population will continue to grow in the next decades, so the size effect keeps inflation above the 2% threshold.

In India, the picture looks completely different. India's population is still growing around 2% per year and will continue to grow during the next decades at rates around 1%. Therefore, the size effect elevates inflation rates consistently above the 2% steady state inflation. The structure effect, in contrast, is small compared to other countries and does not add much to the enormous size effect. This is due to the slow growth of the dependency ratio in India. In sum, inflation rates are up to 5 p.p. above the 2% threshold for a prolonged period of time.

In general, our findings and the secular trends presented in this section remain valid under a scenario without a PAYG pension system, which turns our results robust. The only difference is a slightly higher level of inflation in comparison to the simulations with a pension system. Of course this is of high importance because it shows how accounting for the dynamics of a pension system that significantly influences life-cycle decisions of individuals mostly in times of demographic change is of mount importance for policy and for macroeconomic dynamics in this era of secular stagnation.

This becomes clear in Figure 6.5. This figure reports how well our simple model replicates the patterns of inflation in the last 2-3 decades. Given only the impact of demographic change, we can replicate with substantial accuracy the patterns of inflation which show that the part of inflation variation attributed to demographic change can be quite significant.

Figure 6.5 – Inflation levels: data vs model



Source: own calculations. The graphs above compare the results of our model to the patterns of inflation of the last 2-3 decades. Using only the impact of demographic change, we can replicate inflation patterns quite significantly. Further, the part of inflation variation explained by demographic change is quite substantial.

Table 6.5 summarizes the previous findings of countries and compares them to observed data on inflation. We also calculate the percentage change in average inflation rates for different time periods. This procedure is executed for both the time series of model output and real world data obtained from OECD (2018) and the World Bank (2018).

Table 6.5 – Percentage change in average inflation rates: data vs model

	1988-1992/2008-2012		1988-1992/2012-2016		1990-1995/2005-2010		1990-2000/2006-2016	
	Data	Model	Data	Model	Data	Model	Data	Model
India	4.47	4.99	-22.33	1.87	-21.89	1.09	-10.22	1.18
France	-43.24	-22.06	-76.31	-33.02	-34.81	-30.48	-34.97	-22.9
USA	-52.01	-25.49	-69.69	-33.59	-30.59	-32.92	-37.46	-27.01
Germany	-48.73	-55.17	-67.60	-70.12	-54.21	-69.74	-43.95	-58.96
China	-66.80	-30.57	-78.67	-40.68	-75.87	-25.06	-60.6	-20.26
Italy	-60.85	-39.33	-84.82	-55.65	-63.77	-53.27	-61.91	-41.46
Japan	-109.17	-72.22	-66.22	-82.23	-106.73	-79.51	-73.07	-69.12

Source: OECD (2018), World Bank (2018), and own calculations. We calculate the difference in the average inflation rates between the different periods and divide it by the average inflation rate in the earliest period.

Both Table 6.5 and Figure 6.5 confirm that the negative trend of inflation rates is captured in all of the countries (with the exception of India for some time periods). As previously explicitly referred, the main objective of the model is not to capture all of the inflation dynamics and predict inflation. It is instead showing that demography plays a role on determining inflation. Therefore, from the tables and figures above, we should keep in mind that we match the patterns and show that we are able to capture the demographic effect on inflation. From Table 6.5 (left columns - data), inflation rates have decreased in the entire sample of countries between the several pairs of time periods. Applying the same procedure to model outcomes (right columns - model), one can observe that our model results match around a third to a half of the actual trend of inflation. For some time periods, we can even show that the smallest (largest) decrease in inflation rates observed in the real data can actually be captured by our model. For instance, in the case of India, we capture the smallest change in inflation rates between time periods. Model outcomes show that India's inflationary patterns due to demographic change have not substantially changed between the pairs of time periods, while the actual data shows a decline of almost all of them. In the case of Japan, the country for which we predict the largest decrease in inflation (a 69% to 79% decline) is also the country with the largest decline in inflation rates observed (65% to 78%). The special case of Germany is the only exception. Our model overestimates the trends, meaning that are other factors besides demographic change overcompensating the inflation effect. For some countries our model captures a weaker negative effect of aging on inflation than others, but we observe in the data that these countries have a stronger decline. However, the general message holds: the set of countries with the strongest aging process also tend to exhibit the largest decline in inflation rates, as predicted by the model.

Since the model does not account for several determinants of inflation such as aggressive monetary policies (as quantitative easing in Europe and Japan), financial disturbances, technology shocks and other events, it should be expected that predictions of inflation in this model will not explain the levels of inflation observed in the data. In fact, the effects of demography on inflation are long ranging and are an underlying force hidden by short run events that have a more immediate impact

on inflation. Nevertheless, we can retain from these simulations how demographic change influences and pushes inflation trends in the real world through life-cycle behavior of individuals.

7. Conclusions

Since the 1970's inflation has decreased while age dependency ratios have increased. This pattern has posed the puzzle in the literature of whether demographic change and inflation are interconnected. Although many argue that either population structure or population growth can pose positive or negative pressures on inflation, no consensus has been reached until now. With such a dispersion of theories and results, the puzzle about the aging-inflation link has now received more attention as a time of population aging starts to dominate most of the developed economies.

This paper contributes to the literature by applying a theoretical OLG model that provides a partition of demographic change as a combination of a change in population size and structure. While in the literature usually only one of the mechanisms is examined, both of them are analyzed jointly in this paper. To our knowledge, we are the first ones to study the effects of aging on inflation in this decomposed manner, bringing new insights to the inflation dynamics involved.

Our findings indicate that a part of the actual inflation rate can be attributed to demographic processes. While changes in population size seem to have a prominent effect, the change in population structure contributes most decisively to the dynamics of inflation. We show that population growth is positively correlated with inflationary pressures. As seen in Sections 5 and 6, the size effect follows the trend in population growth, which stems from the decrease in aggregate consumption that reduces money demand and, hence, pressures on inflation. Since the structure effect depends on the change of shares of each age group, the decline in the (relative) size of those groups which are situated at the peak of life cycle consumption leads to a decline in consumption and money demand, negatively affecting inflation. These impacts are strengthened under a general equilibrium setting where changes in interest rates and wages interact with labor supply decisions and the existence and the generosity of a PAYG pension system. It is indeed under this framework that we clearly observe how the size effect is quite stable over different scenarios, reinforcing the role of the structure effect. As exposed in Sections 5 and 6, the introduction of such mechanisms creates deflationary pressures and exacerbates the structure effect.

We show how demographic change works through these mechanisms in different countries, with different demographic processes and sizes of pension systems, and their effects on inflation dynamics. According to our results, aging countries like Germany, Italy, and Japan already face deflationary pressures while China will experience a similar trend in the next decades. The structure effect is found to be especially prominent in Japan starting in the early 1990s, which is explained by early increases of the age dependency ratio. Young countries with high fertility rates like the US

and India, will further go through inflationary pressures stemming mostly from the size effect but also from the structure effect.

We do not claim that inflation dynamics only depends on demographic change, but we show that demographic change does indeed have a long-run impact on them. Although our country comparisons do not intend to determine the exact level of inflation of today's economies, some of the lessons taken can be seen as recommendations. The findings have numerous implications for economic growth and monetary policy that must be coordinated with policies that tackle the aging process of economies. The size effect is directly related with population growth and must be solved through incentives affecting either higher fertility/migration or higher consumption and expenditures. The structure effect, on the other hand, is much more open to being tackled by policies that prolong working age that will move consumption peaks to later in life, as well as policies that increase consumption possibilities for older age groups. Some countries, like Japan and Germany, would benefit from these policies since they have the most negative structure effects today.

As already mentioned, we concentrate on pure impacts of demographic change. The only force driving inflation rates in our simulations is demographic change with its accompanying effects on population size and structure. Thus, our model does not explore some of the features of monetary policies used by central banks to address inflation targets, although we replicate some of the main mechanisms involved, as explained in Section 3 and explored in the sensitivity analysis. Our model is mute on business cycles or any type of New Keynesian mechanisms, too. This was an option taken, since we believe that for the purpose of the paper these fluctuations should be left out and that our MIU model is a more suitable tool to connect the OLG setting to demographic transitions and mechanisms that we explain in this paper. We also do not explore the potential effects of having open economies. Ultimately, the question arises as to how these international differences in price developments are affecting the real economy, e.g. trade and exchange rates. As a possible consequence, in a flexible exchange rate regime, deflationary tendencies due to an old population makes domestic goods cheaper and leads to higher a competitiveness of such an economy (abstracting from other mechanisms that might influence competitiveness of an economy). This brings a new world of interactions worth investigating, which is left to future research.

Despite these elements not included in this paper, we are able to contribute to the field by providing a model that was missing in the literature which uncovers even more of the main mechanisms of demographic change that affect inflation dynamics, and we show that a part of these dynamics can be explained by this demographic process.

References

- Altig, D. et al., 2001. Simulating Fundamental Tax Reform in the United States. *American Economic Review*, Volume 3, pp. 574-595.
- Anderson, D., Botmann, D. & Hunt, B., 2014. Is Japan's Population Aging Deflationary?. *IMF Working Paper 14/139*.
- Auerbach, A. J. & Kotlikoff, L. J., 1987. *Dynamic Fiscal Policy*. New York, USA: Cambridge University Press.
- Bansal, R. & Yaron, A., 2004. Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles. *The Journal of Finance*, Volume 4, pp. 1481-1509.
- Barro, R., 2013. Inflation and Economic Growth. *Annals of Economics and Finance*, Volume 1, pp. 85-109.
- Barro, R. J., 1995. *Inflation and Economic Growth*, s.l.: NBER Working Paper Series .
- Börsch-Supan, A., Härtl, K., Ludwig, A. & Leite, D., 2017. Endogenous Retirement Behavior of Heterogeneous Households Under Pension Reforms. *MEA Discussion Paper*.
- Börsch-Supan, A. & Weiss, M., 2016. Productivity and age: Evidence from work teams at the assembly line. *The Journal of the Economics of Ageing*, pp. 30-42.
- Browning, M., Hansen, L. & Heckman, J. J., 1999. Micro Data and General Equilibrium Models. In: J. Taylor & M. Woodford, eds. *Handbook of Macroeconomics*. s.l.:Elsevier Science B.V., pp. 543-633.
- Bullard, J., Garriage, C. & Waller, C. J., 2012. *Demographics, Redistribution, and Optimal Inflation*, St. Louis : Federal Reserve Bank of St. Louis.
- Casanova, M., 2013. Revisiting the Hump-Shaped Wage Profile: Implications for Structural Labor Supply Estimation. *University of California, Los Angeles*.
- Chen, W.-Y., 2016. Demographic structure and monetary policy effectiveness: evidence from Taiwan. *Quality & Quantity*, 51(6), pp. 2521-2544.
- Cooley, T. & Prescott C., 1995. Economic Growth and Business Cycles. In: T. Cooley, ed. *Frontiers of Business Cycle Research*. Princeton: Princeton University Press, pp. 1-38.
- Doepke, M. & Schneider, M., 2006. Inflation and the Redistribution of Nominal Wealth. *Journal of Political Economy*, pp. 1069-1097.
- Drazen, A., 1981. Inflation and Capital Accumulation Under A Finite Horizon. *Journal of Monetary Economics* , pp. 247-260.
- European Commission, 2018. *Economic and Financial Affairs - AMECO*. [Online]
Available at: http://ec.europa.eu/economy_finance/ameco/user/serie/SelectSerie.cfm

- Fernández-Villaverde, J. & Krueger, D., 2007. Consumption over the Life Cycle: Facts from Consumer Expenditure Survey Data. *The Review of Economics and Statistics*, pp. 552-565.
- Fischer, S., 1993. The role of macroeconomic factors in growth. *Journal of Monetary Economics*, pp. 485-512.
- Forrester, K., 2017. Home to market: implications for the consumption to output ratio. *Macroeconomic Dynamics*, pp. 1-31.
- FRED, 2018. *Federal Reserve Bank of St. Louis - Economic Data*. [Online]
Available at: <https://fred.stlouisfed.org/>
- Frederick, S., Loewenstein, G. & O'Donoghue, T., 2002. Time Discounting and Time Preference: A Critical Review. *Journal of Economic Literature*, 40(2), pp. 351-401.
- Fujiwara, I. & Teranishi, Y., 2006. A dynamic new Keynesian life-cycle model: Societal aging, demographics, and monetary policy. *Journal of Economics Dynamics & Control*.
- Fullerton, D. & Rogers, D., 1993. *Who bears the lifetime tax burden?*. Washington D.C.: Brookings Institution Press.
- Gahvari, F., 2007. The Friedman rule: Old and new. *Journal of Monetary Economics*, pp. 581-589.
- Gajewski, P., 2015. Is ageing inflationary? Some evidence from OECD countries. *Applied Economics Letters*, 22(11), pp. 916-919.
- Galí, J., 2017. Monetary Policy and Bubbles in a New Keynesian Model with Overlapping Generations. *Working Papers 959, Barcelona Graduate School of Economics*.
- Gerlach, S. & Svensson, L., 2003. Money and inflation in the euro area: A case for monetary indicators?. *Journal of Monetary Economics*, Volume 50 (8).
- Gosh, A. & Phillips, S., 1998. Warning: Inflation may be harmful to your growth. *IMF Working Papers Vol. 45, No. 4*.
- Hamann, A. J., 1992. The Optimal Rate of Money Creation in an Overlapping Generations Model: Numerical Simulations for the U.S. Economy. *IMF Working Paper 92/37*.
- Hicks, J., 1937. Mr. Keynes and the "Classics". A Suggested Interpretation. *Econometrica*, pp. 147-159.
- Huggett, M., Ventura, G. & Yaron, A., 2011. Sources of Lifetime Inequality. *American Economic Review*, 101(7), pp. 2923-2954.
- Human Mortality Database, 2016. *University of California, Berkeley (USA) and Max Planck Institute for Demographic Research (Germany)*. [Online]
Available at: www.humanmortality.de
- Imam, P., 2013. Shock from Graying: Is the Demographic Shift Weakening Monetary Policy Effectiveness. *IMF Working Paper 13/191*.
- Juselius, M. & Takáts, E., 2016. The age-structure-inflation puzzle. *Bank of Finland Research Discussion Paper No. 4/2016*.

Katagiri, M., 2012. Economic Consequences of Population Aging in Japan: Effects through Changes in Demand Structure. *IMES Discussion Paper No. 2012-E-3*.

Katagiri, M., Konishi, H. & Ueda, K., 2014. Aging and Deflation from a Fiscal Perspective. *Federal Reserve Bank of Dallas, Globalization and Monetary Policy Institute, Working Paper No. 218*.

Lindh, T. & Malmberg, B., 1998. Age structure and inflation - a Wicksellian interpretation of the OECD data. *Journal of Economic Behavior & Organization*, Volume 36, pp. 19-37.

Lindh, T. & Malmberg, B., 2000. Can Age Structure Forecast Inflation Trends?. *Journal of Economics and Business*, Volume 52, pp. 31-49.

Ludwig, A., 2007. The Gauss-Seidel-quasi-Newton method: A hybrid algorithm for solving dynamic economic models. *Journal of Economic Dynamics & Control*, 31(5), pp. 1610-1632.

Mallik, G. & Chowdhury, A., 2001. Inflation and economic growth: Evidence from South Asian Countries. *Asian Pacific Development Journal*, Volume 1.

McCandless, G. & Weber, W., 1995. Some Monetary Facts. *Quarterly Review*, Volume 3, pp. 1-11.

McMillan, H. M. & Baesel, J. B., 1990. The Macroeconomic Impact of the Baby Boom Generation. *Journal of Macroeconomics*, Volume 12 (2), pp. 167-195.

Miles, D., 2002. Should Monetary Policy be Different in a Greyer World?. In: *Ageing, Financial Markets and Monetary Policy*. s.l.:Springer, Berlin, Heidelberg, pp. 243-276.

Nishimura, K. & Takát, E., 2012. Ageing, property prices and money demand. *BIS Working Paper No. 385*.

OECD, 2018. *OECD Inflation (CPI)*. [Online]
Available at: <https://data.oecd.org/price/inflation-cpi.htm>

Park, H. & Feigenbaum, J., 2018. Bounded rationality, lifecycle consumption, and social security. *Journal of Economic Behavior and Organization*, Volume 146, pp. 65-105.

Shimasawa, M. & Sadahiro, A., 2009. Policy reform and optimal rate for Japan in computable OLG economy. *Economic Modelling*, Volume 26, pp. 379-384.

Shirakawa, M., 2012. Demographic Changes and Macroeconomic Performance: Japanese Experiences. *Opening Remark at 2012 BOJ-IMES Conference*.

Sidrauski, M., 1967. Rational choice and patterns of growth in a monetary economy. *American Economic Review*, 57(2), pp. 534-544.

Walsh, C. E., 2010. *Monetary Theory and Policy*. Cambridge, MA: MIT Press.

Wong, A., 2014. Population Aging and the Aggregate Effects of Monetary Policy. *MPRA working Paper*.

World Bank, 2018. *World Development Indicators*. [Online]
Available at: <https://data.worldbank.org/indicator/NE.CON.PETC.ZS>

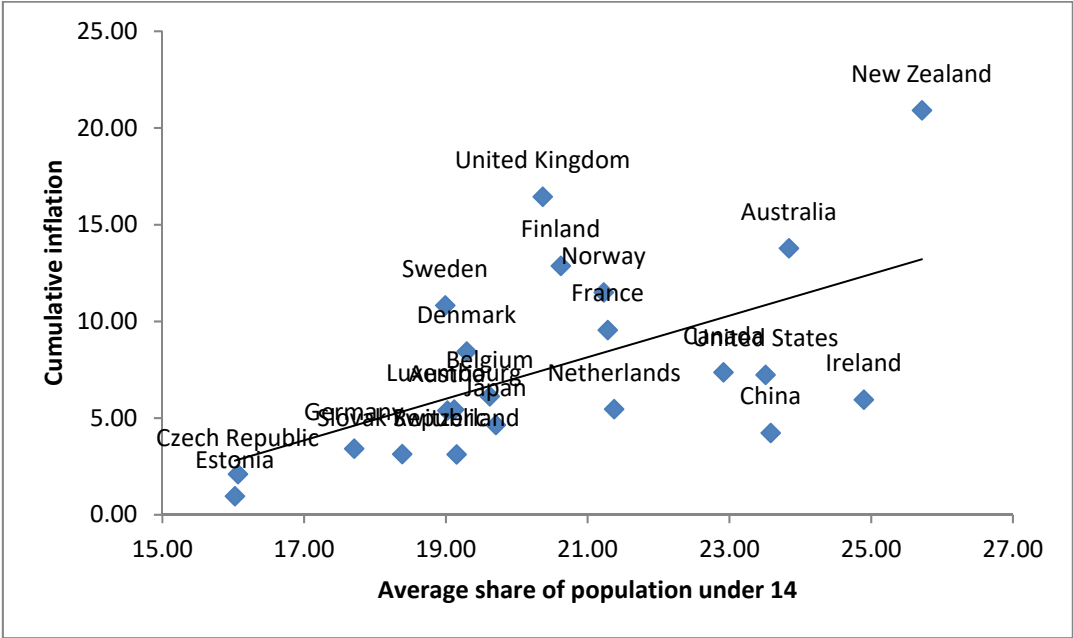
Yang, F., 2006. Consumption over the life cycle: how different is housing?. *Federal Reserve Bank of Minneapolis Working Paper*.

Yoon, J.-W., Kim, J. & Lee, J., 2014. Impact of Demographic Changes on Inflation and the Macroeconomy. *IMF Working Paper 14-210*.

Appendix

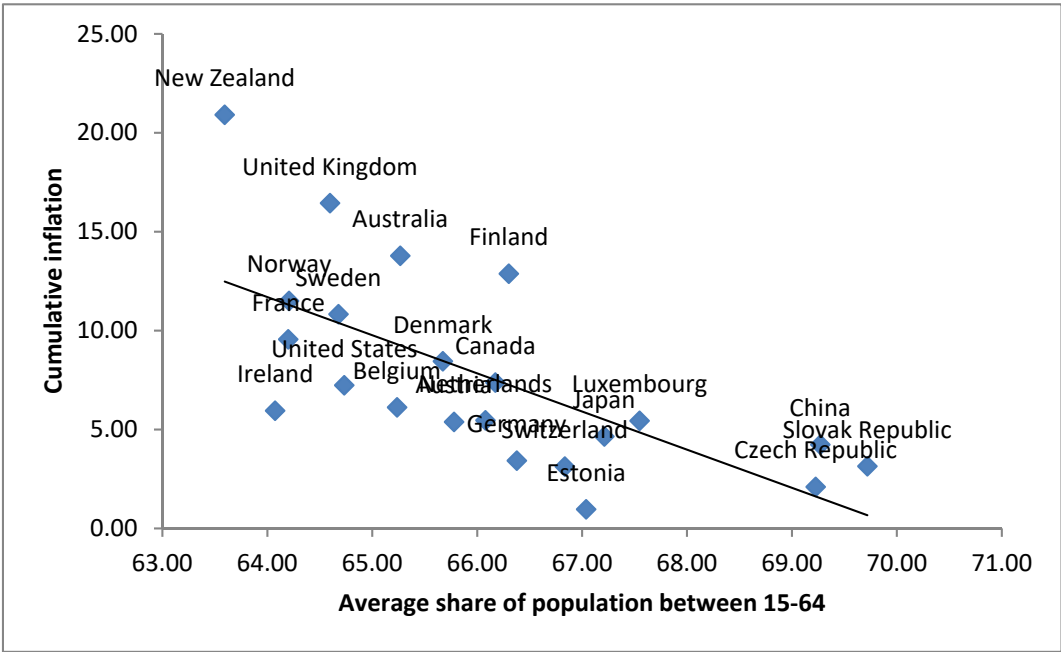
A. Figures and Tables

Figure A.1 – Cumulative Inflation vs. Average share of population under 14



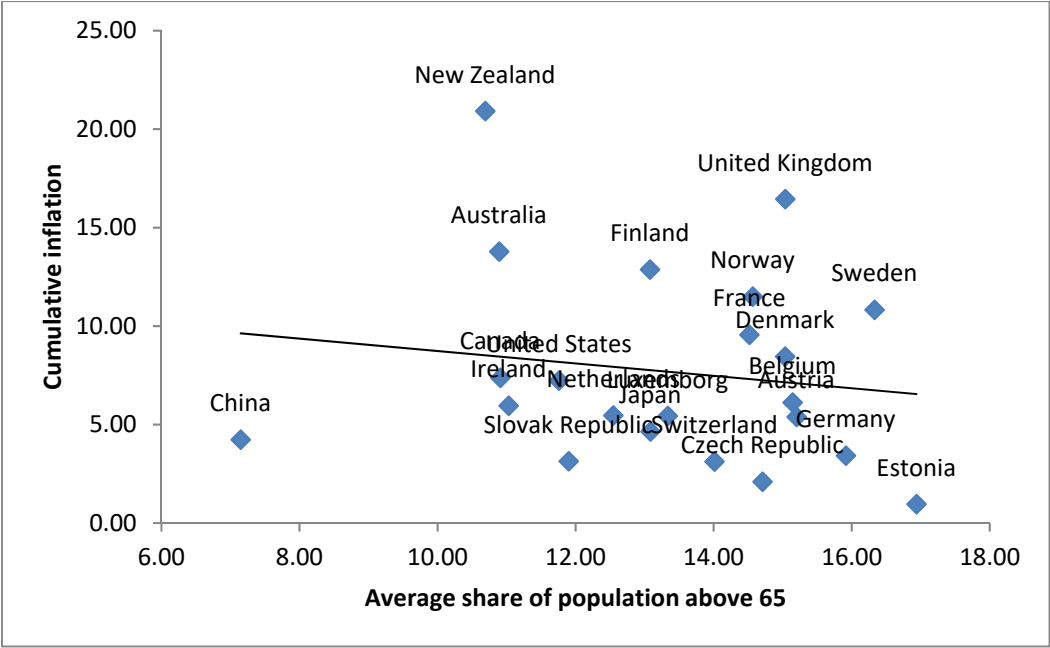
Source: OECD (2018) and World Bank (2018). The vertical axis shows the cumulative inflation rates over the time period 1960-2016, while the horizontal axis shows the average share of population which is under 14 years old during this time period. Note that we do not take any additional explanatory variables into account since this correlation is only for motivational reasons. As can be derived, there is a positive correlation between the variables for the countries examined. However, this does not imply that there is causality. See Figures A.4 and A.5 for a more in-depth empirical evaluation.

Figure A.2 – Cumulative Inflation vs. Average share of population between 15-64



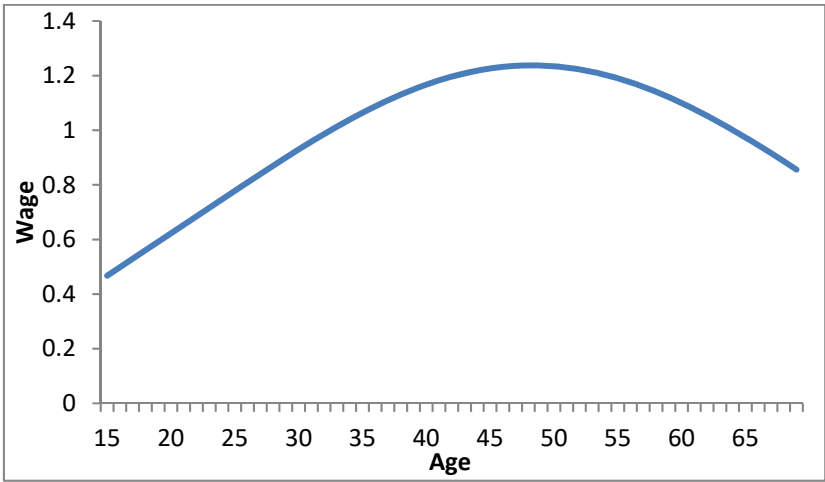
Source: OECD (2018) and World Bank (2018). The vertical axis shows the cumulative inflation rates over the time period 1960-2016, while the horizontal axis shows the average share of population which is between 15 and 64 years old during this time period. Note that we do not take any additional explanatory variables into account since this correlation is only for motivational reasons. As can be derived, there is a negative correlation between the variables for the countries examined. However, this does not imply that there is causality. See Figures A.4 and A.5 for a more in-depth empirical evaluation.

Figure A.3 – Cumulative Inflation vs. Average share of population above 65



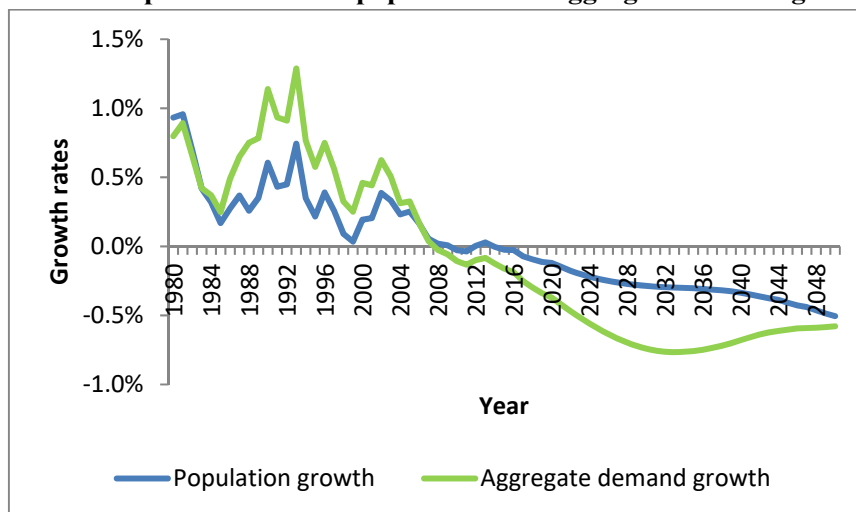
Source: OECD (2018) and World Bank (2018). The vertical axis shows the cumulative inflation rates over the time period 1960-2016, while the horizontal axis shows the average share of population which is more than 65 years old during this time period. Note that we do not take any additional explanatory variables into account since this correlation is only for motivational reasons. As can be derived, there is a slight negative correlation between the variables for the countries examined. However, this does not imply that there is causality. See Figures A.4 and A.5 for a more in-depth empirical evaluation.

Figure A.4 –Wage Profiles



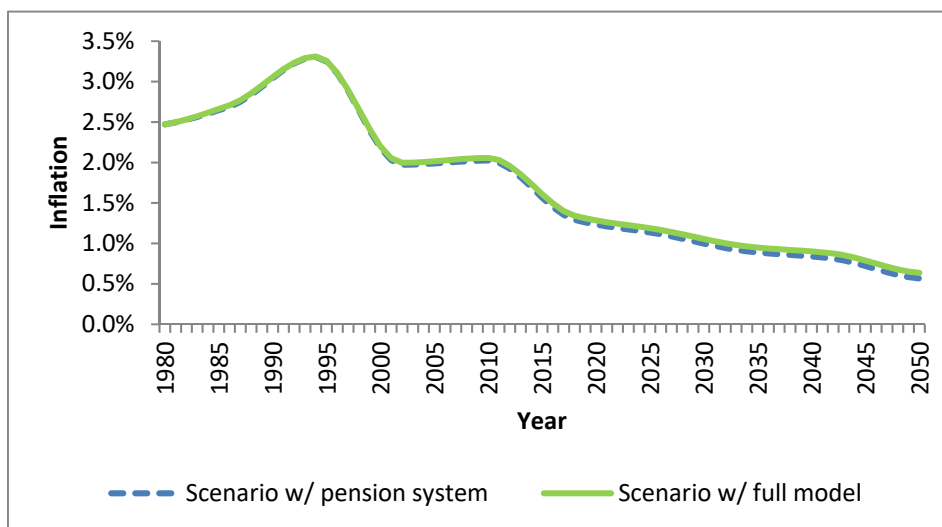
Source: own calculations.

Figure A.5 –Comparison between population and aggregate demand growth rates



Source: own calculations.

Figure A.6 –Comparison between models with and without labor



Source: own calculations.

Table A.1 – Inflation dynamics per country (with PAYG)

	Inflation level	Size Effect	Structural Effect
Germany	0.41%	1.53%	-1.12%
France	2.5%	3.27%	-0.77%
Italy	0.94%	2.05%	-1.10%
United States	3.59%	4.21%	-0.62%
Japan	0.33%	1.87%	-1.54%
China	3.88%	3.21%	0.67%
India	7.08%	6.43%	0.65%

Source: own calculations.

B. Sensitivity Analysis

This section applies the general model presented in Section 6.1. Deviating from the standard calibration parameters from Table 4.1, we vary several core parameters in this section to show the robustness of our findings. To make the comparison between different scenarios easier, we calculate the mean of inflation rates, the size effect, and the structural effect for the time period between 2015 and 2025, to abstract from possible short peaks in inflation rates.

Table B.1 – Comparison w.r.t. different consumption weights

	Inflation level	Size Effect	Structural Effect
$\eta = 0.97$ Baseline	0.93%	1.77%	-0.85%
$\eta = 0.9$	0.97%	1.77%	-0.81%
$\eta = 0.8$	1.00%	1.76%	-0.76%

Source: own calculations.

An alternative set of consumption weights is displayed in Table B.1. Accordingly, higher inflation rates and smaller size effects are observed for lower parameter values. Consequently, the structure effect is less negative for lower values. In general, lower values mean that for utility purposes consumption is valued less and money holdings more. In steady-state this will not have an effect on inflation, but in transition the effects of demographic shocks on individuals' decisions will have an impact on inflation rates. On one side, changes in consumption due to the consumption life-cycle profile induce smaller changes in money holdings. As a consequence, the structure effect has a lower impact on the overall demographic effect on inflation. Therefore, its negative effect on inflation is hindered and since the size effect is almost stable, inflation levels are not as low as before. On the other side, a lower preference for consumption reduces the impact of macroeconomic changes on consumption which leads to lower

money demand and suppress inflation. Overall, the former effect is stronger than the latter, as we may observe in Table B.1.

Table B.2 – Comparison w.r.t. different CES substitutability

	Inflation level	Size Effect	Structural Effect
$\sigma = 0.5$	0.85%	1.77%	-0.92%
$\sigma = 0.4$ Baseline	0.97%	1.77%	-0.81%
$\sigma = 0.3$	2.30%	1.69%	0.61%

Source: own calculations.

Table B.2 displays various outcomes for different CES substitutability parameters. According to this, higher inflation rates and higher size effects can be observed for lower parameter values. Consequently, the structure effect is less negative for lower parameter values. In theory, lower parameter values mean money and consumption are more complementary goods, i.e. changes in consumption go along with larger changes in money holdings and therefore inflation rates. Since consumption p.c. (C/N not C/AN) grows, households hold more money which increases inflation.

Table B.3 – Comparison w.r.t. different output growth coefficient

	Inflation level	Size Effect	Structural Effect
$\phi_\mu = 1.0$	0.30%	1.57%	-1.27%
$\phi_\mu = 0.7$ Baseline	0.97%	1.77%	-0.81%
$\phi_\mu = 0.3$	1.81%	1.95%	-0.14%
$\phi_\mu = 0.0$	2.36%	2.07%	0.28%
$\phi_\mu = -0.3$	2.95%	2.20%	0.75%

Source: own calculations.

Different parameterizations of the money creation rule are shown in Table B.3. Higher positive values imply a more pro-cyclical reaction of money supply to changes in output and therefore also on money demand. As described above, a positive value of ϕ_μ translates the economy's output growth in money circulation: while the economy is growing, private banks lend more money, which increases the money multiplier (see Fedotenkov (2018)). During a recession, in contrast, the money multiplier is substantially smaller. This mechanism is mirrored through a positive value of ϕ_μ , which accelerates money growth in times of a growing economy and vice versa. Negative parameter values, in contrast, imply a counter-cyclical reaction of the money growth rates.

Inflation rates and the size effect are larger for lower parameter values since the government accommodates less to changes in money demand. For negative values of ϕ_μ , the size effect is even higher than the 2% threshold. The structure effect, however, is decreasing as parameter values increase. In detail, the structure effect even turns positive for negative values of ϕ_μ . In contrast, more extreme values such as $\phi_\mu = 1$, lead to a lower size effect and a more negative structure effect. We nevertheless assume $\phi_\mu = 0.7$ in Section 5 and Subsection 6.1 in order to have a large accommodative effect but still not a one to one impact of output growth on government's decisions. Our choice of a more conservative value works, in any case, in the favor of our results since it underestimates the impact of demographic change.

Table B.4 – Comparison w.r.t. different labor weight

	Inflation level	Size Effect	Structural Effect
$\Psi = 0.5$	0.98%	1.78%	-0.80%
$\Psi = 0.3$ Baseline	0.97%	1.77%	-0.81%
$\Psi = 0.1$	0.94%	1.77%	-0.82%

Source: own calculations.

Table B.4 displays outcomes for different values of Ψ , the labor weight in the utility function. One can observe lower inflation rates for lower values of the parameter. At the same time, the size effect is slightly smaller and the structure effect more negative for lower parameter values. In general, lower values mean a lower weight on leisure, i.e. more weight on money holdings and consumption and labor. Therefore, consumption (in levels) is higher, which does not impact inflation (level effect) in general. However, changes in these (high) consumption levels due to the life-cycle consumption profile are larger. Therefore, money holdings change more strongly. This causes a larger reaction in the structure effect. With a size effect being almost constant, this reduces inflation.

Table B.5 – Comparison w.r.t. years at which aging is held constant

	Inflation level	Size Effect	Structural Effect
1980	0.97%	1.85%	-0.88%
1990 Baseline	0.97%	1.77%	-0.81%
2000	0.97%	1.70%	0.24%

Source: own calculations.

In Table B.5, we display different years at which we hold the population constant. The resulting inflation rates of these model versions are displayed as the size effect; accordingly, the difference to the baseline model is the structural effect. It is found that the earlier we hold aging constant, the higher the size effect

and the more negative the structure effect. Differences however are not very large and direction of the effect stays the same. The explanation is, the earlier we hold population constant, the less demographic change has affected population yet. Therefore, inflation is closer to the 2% steady state for early years. Consequently, the negative structure effect must be more negative, since it is the difference between baseline inflation and inflation when holding population constant.