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

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Abstract:

This paper focuses on the empirically observed relationship between demographic change and inflation and theoretically explores the nature of this puzzling relationship. It puts the opposing existent empirical findings in the literature into perspective by using an overlapping-generations (OLG) framework combined with a money-in-the-utility (MIU) model. When facing demographic change, individuals' life-cycle decisions affect consumption demand and money holdings and, consequently, price changes. We differentiate demographic change between changes in population size and structure and determine how these separately affect inflation in an aging society. Changes in population size are the main driver of the aging-inflation connection while changes in population structure are of a smaller magnitude. We also explore how the introduction and subsequent implications of a public pay-as-you-go (PAYG) pension system have a negative impact on inflation. In contrast, endogenous labor reactions are found to have a mitigating effect on this negative effect on inflation. A simulation of different stages of demographic change and size of pension systems is carried out for a sample of countries. Findings suggest that aging countries with generous PAYG pension systems face strong deflationary pressures while younger countries face inflationary pressures.

Zusammenfassung:

Dieser Beitrag diskutiert den empirisch beobachteten Zusammenhang zwischen demographischem Wandel und Inflation und untersucht dabei die Art dieser rätselhaften Beziehung mithilfe einer theoretischen Methodik. Die Arbeit setzt die gegensätzlichen empirischen Befunde in der Literatur in Beziehung zueinander, indem sie ein Modell der überlappenden Generationen (OLG) anwendet, das mit einem Money-in-the-Utility-Modell (MIU) kombiniert wird. Während der demografische Wandel voranschreitet, wirken sich individuelle Lebenszyklusentscheidungen auf die Konsumnachfrage und Geldbestände und folglich auf Preisänderungen aus. Wir unterscheiden beim demografischen Wandel zwischen Veränderungen der Bevölkerungsgröße und -struktur und zeigen, wie sich diese Faktoren in einer alternden Gesellschaft einzeln auf die Inflation auswirken. Veränderungen in der Bevölkerungsgröße sind die Hauptursache für den Zusammenhang zwischen Alterung und Inflation, während Veränderungen in der Bevölkerungsstruktur von geringerer Bedeutung sind. Wir untersuchen auch, wie sich die Einführung und die daraus folgenden Implikationen eines öffentlichen, umlagefinanzierten Rentensystems negativ auf die Inflation auswirken. Im Gegensatz dazu haben endogene Arbeitsreaktionen einen abschwächenden Effekt auf diese negative Wirkung auf die Inflation. Für eine Auswahl an Ländern simulieren wir verschiedene Stadien des demografischen Wandels und unterschiedliche Großzügigkeiten der Rentensysteme. Die Ergebnisse deuten darauf hin, dass alternde Länder mit großzügigen PAYG-Rentensystemen einem starken Deflationsdruck ausgesetzt sind, während jüngere Länder einem Inflationsdruck ausgesetzt sind.

Keywords:

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

JEL Classification:

C68, D15, E27, E31, J11

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

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Abstract

This paper focuses on the empirically observed relationship between demographic change and inflation and theoretically explores the nature of this puzzling relationship. It puts the opposing existent empirical findings in the literature into perspective by using an overlapping-generations (OLG) framework combined with a money-in-the-utility (MIU) model. When facing demographic change, individuals' life-cycle decisions affect consumption demand and money holdings and, consequently, price changes. We differentiate demographic change between changes in population size and structure and determine how these separately affect inflation in an aging society. Changes in population size are the main driver of the aging-inflation connection while changes in population structure are of a smaller magnitude. We also explore how the introduction and subsequent implications of a public pay-as-you-go (PAYG) pension system have a negative impact on inflation. In contrast, endogenous labor reactions are found to have a mitigating effect on this negative effect on inflation. A simulation of different stages of demographic change and size of pension systems is carried out for a sample of countries. Findings suggest that aging countries with generous PAYG pension systems face strong deflationary pressures while younger countries face inflationary pressures.

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1. Introduction

The demographic structure of most developed countries has changed in recent decades. As the baby-boom generation ages, we observe that the age dependency ratio has steadily been increasing. At the same time, inflation peaked in the 1970s and since then has steadily been declining. Interestingly, this pattern coincides with the entrance of the baby-boom generation into the labor market and their posterior transition to older ages, while the number of young workers has decreased. Looking at the basic relationship between cumulative inflation and age dependency ratios for different age groups in various countries, 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)[1]. This phenomenon is especially pronounced in Japan, which faces a rapidly aging population and persistent deflation (and stagnation) at the same time. As Juselius and Takáts (2016) put it, there is a puzzling link between inflation and population age structure. We argue that the puzzle can be extended to whether demographic change and inflation are interconnected and to what the nature of this relationship is, illustrated by Figures A.1-A.3 and the example of Japan.

In fact, a growing bulk of mostly empirical literature has focused on trying to disentangle this puzzling relationship and has reached a consensus neither on the relationship itself nor on the roots thereof[2]. 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) contradict this view by demonstrating that population aging exhibits deflationary tendencies, such as in the case of Japan. 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

[1] Note that these figures do not aim to provide an answer to the relationship between demographic change and inflation due to the limitations inherent to the method used. They only provide a motivation for the correlation of various population groups with inflation.
[2] See Figures A.4 and A.5 for contradicting, empirical findings in the literature. For instance, while Yoon, et al. (2014) find that the over 65 age group leads to deflationary pressures Juselius & Takáts (2016) find the opposite for the same age group.

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 simply the general growth or shrinkage of the population size affects prices. Yoon et al. (2014) found 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.

Hence, a general perusal of empirical literature quickly ascertains that there is little concrete consensus in the literature as to the genuine impact of aging on inflation[3]. Given these mixed puzzling empirical findings, the point of departure in this paper is to understand demographic change as a combination of two phenomena: a change in population size and structure. A significant part of the literature concentrates on only one of these phenomena and does not clearly define the differences in the effects of population growth/shrinkage and a changing age distribution. This paper addresses these shortcomings first by clearly distinguishing between both demographic mechanisms and then by identifying the impacts they have on inflation rates using an OLG macro-simulation model. To our knowledge, we are the first to study the effects of aging on inflation, as well as the effects of a PAYG pension system on inflation, by differentiating between the two types of mechanisms in a simulation model, therefore contributing towards the understanding of the aging-inflation puzzle. In order to capture the fundamental channels through which the change in structure and size of population can apply, this paper extends an OLG model à la Auerbach and Kotlikoff (1987) where actual population dynamics are explicitly modelled

[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)and Bullard et al. (2012) show how different structures of a population can influence decisions of policy makers through voting behavior. Katagiri et al. (2014) argue that governments will act differently and plan different targets for inflation depending on how population aging evolves.

using real data. We combine this OLG framework with a money-in-the-utility (MIU) model for households[4].

The first thought when thinking about addressing inflation and monetary issues is to apply the typical New Keynesian framework. However, to address demographic change, during which population size and structure is constantly varying through time, a New Keynesian model framework is less suited to incorporate all the demographic features we introduce in the model and to obtain the type of predictions at which we are aiming[5]. New Keynesian models are by design focused on short-run dynamics of inflation; in contrast, we are interested in studying the long-term effects of demographic change on price development via life-cycle decisions of individuals when facing these demographic changes. Consequently, long-term changes in consumption demand and money holdings as well as savings and investment patterns, and ultimately economic growth will impact aggregate money demand and therefore prices. This OLG-MIU setting presents a more effective way to study the long-run effects of changes that result from structural factors and offers a variety of channels through which both demographic mechanisms, i.e. the size and structure effect, work. We want to stress that our intention is not to forecast exact inflation, but rather have a full picture of the underlying force of demographic change on inflation trends in the long-run, and not in the short-run. Additionally, we discuss channels that may amplify the magnitude of these mechanisms, such as labor decisions and the presence of a pension system. We also take into account the impact of monetary policy in affecting inflation by setting a government who controls money supply and by examining different degrees of government reactions to money demand in our sensitivity analysis. However, despite the importance of the strength of demographic change on monetary policy effectiveness, this effect is not thoroughly addressed in this paper[6]. Throughout the paper, we conduct several experiments under partial and general equilibrium settings which allow us to identify the strength of each demographic mechanism. We calibrate the model carefully through the inclusion of actual and forecasted population data for a selected sample of countries. Due to the country

[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). Since individuals derive utility from money and consumption, it is possible to have, under MIU, demand for money as a positive function of consumption. This allows replicating the empirically observed positive correlation between consumption demand and money demand under a neoclassical model where individuals have perfect foresight and can save for future consumption. Subsequently, under these conditions, our model opens the channel between aggregate demand and inflation through money demand.

[5] Some exceptions that include demographic variables in a New Keynesian framework are Galí (2017) and Fujiwara and Teranishi (2006). Nevertheless, their demographic analyses are restrained to changes in the dependency ratio, which hide several life-cycle mechanisms and a more general long term effect of demographic change (e.g. demographic structure).

[6] On the impact of demographic change on monetary policy effectiveness see, for example, the works of Miles (2002), Fujiwara and Teranishi (2006), Imam (2013), Wong (2014), Juselius and Takáts (2016) and Chen (2016).

heterogeneity in economic and demographic structure, we can compare the expected effects of demographic change on inflationary/deflationary trends between these countries, which give in-depth conclusions for the dual relationship aging-inflation taking into account the economic and structural factors intrinsic to each country.

Our first main conclusion indicates that the part of the inflation rate that can be attributed to demographic change is mainly driven by changes in population size. 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. The intuition is simple, a decrease in aggregate consumption following a decrease in population leads to lower demand for money holdings, which the government accommodates for by adjusting money supply accordingly. This causes a dampening of inflationary pressures, the opposite occurring for positive population growth, which is in accordance with empirical results by Shirakawa (2012) and Yoon, et al. (2014). The latter study finds a positive correlation between population growth and inflation although no channel is identified in the regression analysis.

Our second finding shows that, depending on the life-cycle consumption profile, an aging population structure can have inflationary or deflationary tendencies. The crucial point here is the interaction between the consumption and money holding mechanisms and the age when the consumption profile reaches its peak. If the peak is reached at working ages, an aging population structure will lead to a decline in consumption and money demand. However, if the peak is reached after retirement, an aging population structure produces a rise in consumption along with money holdings. This is in line with Lindh and Malmberg (1998; 2000), and Juselius and Takáts (2016), if the consumption peak occurs around retirement age. Both studies by Lindh and Malmberg advocate for the same channel as in this paper: high consumption and low savings induces higher aggregate demand, fostering inflation. It also holds for empirical findings by Yoon, et al. (2014) and Gajewski (2015) who state that a larger number of very old people poses a downward pressure on prices.

A third result shows how the existence of a PAYG pension system is an important vehicle through which aging affects inflation. 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. According to our findings, the presence of a pension system reduces savings of individuals at working age and has an influence on consumption of both workers and retirees, and, consequently on money demand. The introduction of a pension system then reinforces the effects of changes in population size and structure on inflation by producing deflationary pressures. Furthermore, when facing changes in interest rates and wages, it is within the ability of individuals to adjust the amount of labor supply that mitigates pension systems' deflationary tendencies, accordingly. To our knowledge, this is the first time that such a relationship between pension systems and inflation is examined.

Finally, we perform an illustrative simulation of inflation trends driven by demographic changes in a selected sample of countries. The countries selected represent societies at different stages of demographic change, and, in addition, have differing generosities of pension systems. This delivers interesting examples of the interaction of demographic change and pension systems. Aging countries like Germany, Italy, and Japan are already facing deflationary pressures, while countries like China will experience these same trends during the next decades. The structure effect is found to be especially prominent in Japan starting in the early 1990s, and is explained by early increases of the age dependency ratio. Young countries with fertility rates that are still high such as the US and India, will further go through inflationary pressures stemming from the size effect, while the structure effect will not play a major role. Again, these inflation trends that we explore here give us a perspective of the underlying effect of demographic change on inflationary trends that are in the background of the short-run dynamics of inflation, and not actual forecasts for inflation. The channels affecting inflation are plentiful, and in this paper we only shed light to demographic change, which, as we sustain, is one of the channels behind the long-run behavior of inflation that we observed in Figure 1.

The paper is structured as follows. Section 2 introduces the model and its structure. The methodological approach including calibration is described in Section 3. Section 4 identifies possible channels through which aging affects inflation in a partial equilibrium setting. Section 5 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 6 discusses the results and concludes the paper. A detailed sensitivity analysis is carried out in the appendix.

2. 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 provides money supply. 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 introducing 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.

2.1. 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

$$u(c_{t,j}, m_{t,j}, 1-h_{t,j}) = \frac{1}{1-\theta}\left[\eta c_{t,j}^{\frac{\sigma-1}{\sigma}} + (1-\eta) m_{t,j}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma(1-\theta)}{\sigma-1}} + \Psi \frac{(1-h_{t,j})^{1-\varrho}}{1-\varrho}, \tag{2.1}$$

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 mimicking 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.

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:

$$max \ \sum_{j=1}^{J} \beta^{j-1} \varphi_{t,j} \, u(c_{t,j}, m_{t,j}, l_{t,j}), \tag{2.2}$$

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

$$\boldsymbol{y_{t,j}} = \boldsymbol{h_{t,j} w_{t,j}}(\mathbf{1} - \tau_t) + \boldsymbol{p_t} + \boldsymbol{\sigma_{t,j}}, \tag{2.3}$$

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 (2.17) below).

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

$$\boldsymbol{a_{t,j}} = (\mathbf{1} + \boldsymbol{r_{t-1}})\boldsymbol{a_{t-1,j-1}} + \frac{\boldsymbol{m_{t-1,j-1}}}{\mathbf{1}+\boldsymbol{\pi_t}} - \boldsymbol{m_{t,j}} + \boldsymbol{y_{t-1,j-1}} - \boldsymbol{c_{t-1,j-1}}, \tag{2.4}$$

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:

$$\sum_{j=1}^{J} PDV_j c_j + \sum_{j=2}^{J} PDV_{j-1} \xi_j m_j = \sum_{j=1}^{R} PDV_j h_j w_j (1 - \tau_j) + \sum_{j=R+1}^{J} PDV_j p_j + \sum_{j=2}^{J} PDV_j \sigma_j. \tag{2.5}$$

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 life-time income from labor, pension benefits, and government transfers (right hand side) has to equal the sum of life-time consumption and real costs from holding money.

2.2. Pension system

The pension system in our model economy is a 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 from 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

$$\tau_t = \sum_{j=R+1}^{J} p_t NP_{t,j} \,/\, \sum_{j=1}^{R} w_{t,j} h_{t,j} NW_{t,j}, \tag{2.6}$$

with individual pension benefits, p_t, given by

$$p_t = \rho_t \, w_t (1 - \tau_t). \tag{2.7}$$

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 in several subsections when no PAYG pension system is assumed.

2.3. 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:

$$Y_t = K_t^{\alpha} (A_t L_t)^{1-\alpha}. \tag{2.8}$$

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

$$w_t = A_t (1 - \alpha) k_t^{\alpha}, \tag{2.9}$$

$$r_t = \alpha k_t^{\alpha - 1} - \delta \,, \tag{2.10}$$

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 (2.10) is the return from productive capital since our model abstracts from government bonds.

2.4. 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*:

$$M_t^D = \sum_{g=j-J-1}^{j} m_{g,j+1}. \tag{2.11}$$

Thus, aggregate money demand in the economy will be 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). Since we model the interest rate to be given by the marginal product of capital (see equation (2.10)) and thereby do not model a rate of return for the bond market, 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:

$$M_{t+1}^S = (1 + \mu_t) M_t^S. \tag{2.12}$$

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:

$$M_t^D = \sum_{g=j-J-1}^{j} m_{g,j+1} = \frac{M_{t+1}^S}{P_{t+1}}. \tag{2.13}$$

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 will be 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:

$$\mu_t = \mu_{SS,t} + \rho_\mu(\mu_{t-1} - \mu_{SS,t-1}) + \phi_\mu(\frac{Y_t}{Y_{t-1}} - 1). \tag{2.14}$$

We assume that the government's decision, μ_t, is a function of its exogenously pre-defined steady state value and its realized past deviations from the steady state average $(\mu_{t-1} - \mu_{SS,t-1})$. The growth rate of money shows persistence regarding previous decisions on money supply as we define $\rho_\mu > 0$. $\left(\frac{Y_t}{Y_{t-1}} - 1\right)$ represents growth in output[7]. 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 output gap and money gap are positively correlated with inflation for the years 1980-2001 for Euro area countries[8]. For moderate inflation, however, this effect is not observed. Since inflation rates in our model are caused by demographic change, the resulting moderate inflation rates justify the assumption of a positive correlation of output and inflation and, consequently, of a positive parameter value of ϕ_μ. Following this, we choose a parameter value of $\phi_\mu > 0$, such that output and inflation will be positively correlated.

Furthermore, we assume that money holdings must be positive. To ensure this, the nominal interest rate has to be positive:

$$i_t = (1 + r_t)(1 + \pi_t) - 1 > 0. \tag{2.15}$$

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

$$S_t = \frac{M_{t+1}^S - M_t^S}{P_t} = \sum_{t=j-J}^{j-1} \sigma_{t,j}. \tag{2.16}$$

[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

Furthermore, it is further assumed 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 resources[9]:

$$\sigma_{g,t} = \mu_t m_{g,t}. \tag{2.17}$$

2.5. Computational algorithm

This OLG model has to 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 (2.9) and (2.10), 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.

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

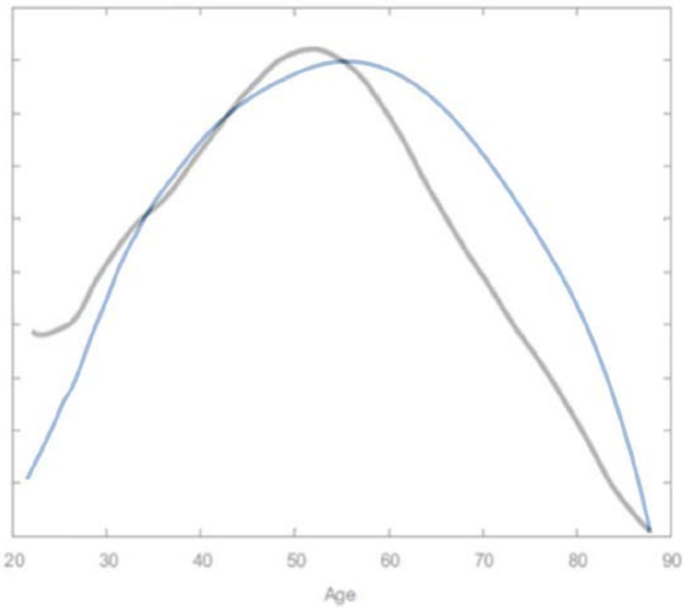
3. Calibration

The life-span of the household is assumed to be 100 years. The household enters the labor market at age 15 and retires at age 65 (mandatory retirement). The structural parameters of the household model are calibrated to match the average of their empirical counterparts for a 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 5.2, 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 (2.2)) 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 this pattern is approximately matched. 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. The structure effect will especially depend on the pattern of the profile since different cohort sizes at a point in time with corresponding divergent levels in consumption expenditures affect aggregate consumption and inflation. Figure 3.1 depicts the empirical (black) and calibrated (blue) consumption profile for a representative cohort in this model entering the labor market in 2017[10].

[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.

Figure 3.1 –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.

To obtain these profiles and to match the other empirical moments, we calibrate the parameters in accordance with the literature. Table (3.1) gives an overview:

Table 3.1 – 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

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 2.4, 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.

Regarding the wage profiles ε_t, we estimate the wage profiles following the procedure of Altig et al. (2001) and Fullerton and Rogers (1993)[11]. The life-cycle wage profile ε_t depicted in Figure A.6 is estimated for the average type individual. For the empirical estimation, we use waves from 1984 until 2013 of the German Socio-Economic-Panel (GSOEP). The wage profile of the average type individual is calculated according to the following formula:

$$\varepsilon_t = e^{\zeta_0+(g+\zeta_1)j+\zeta_2 j^2+\zeta_3 j^3}, \tag{3.1}$$

where j stands for age and g is the constant rate of technological progress. The ζ coefficients are received according to the following procedure (see p. 581 in Altig et al. (2001)). Firstly, hourly wages are regressed on fixed-effect dummies, age-squared, and interactions between age and other demographic variables. Secondly, the coefficients obtained from the previous regression are used to generate the predicted life-cycle wage profile.

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

$$N_{t+1,j+1} = N_{t,j}\varphi_{t,j}, \tag{3.2}$$

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*:

$$N_{c,0} = \sum_{k=0}^{\infty} f_{c,k} N_{c,k}. \tag{3.3}$$

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 4 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 5.2), population data is specific to each country and taken

[11] There is a large discussion in the literature regarding the shape of productivity profiles. Some assume a hump-shaped profile, i.e. individual productivity first increases when young and reaches a peak in middle age and, afterwards, productivity decreases again as a consequence of the aging process, like deteriorating health or declining cognitive skills. Others like Casanova (2013) and Börsch-Supan & Weiss (2016) argue that productivity-age profiles are flat in later ages. This point is also discussed in detail by French (2005). Despite this discussion, we follow the method of Altig et al. (2001) and Fullerton and Rogers (1993) to estimate the average individual productivity profile.

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.

4. The aging-inflation partial model

This section gives an overview of the effects that are essential to understand the interplay between aging, inflation, and pension systems. For this purpose, we simulate a partial equilibrium model by taking the real interest rate and real wages as exogenously given and constant over time. Since our main concern here is to first disentangle the main channels that connect aging and inflation, we choose the simplest model possible. A general equilibrium model calibrated to account for the main macroeconomic indicators will be presented in Section 5.

In this paper 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); Juselius and Takáts (2016)). While studying the impact of demographic change, this channel highlights how aging influences total consumption and savings which will ultimately affect total demand for money and, hence, determine (de-)inflationary pressures. Intuitively, the increase in consumption and demand of goods 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 demographics[12], it is essential to differentiate between changes in population size and shifts in population structure. In times of demographic change, the former reflects the shrinkage of population since mortality rates are higher for older age groups and fertility rates are often low for the younger age groups, while the latter stems from the decrease in the share of young age groups in population and the increase of the share of old age groups in total population. In the case of population shrinkage, aggregate demand decreases leading to a fall in money demand causing deflationary pressures. We label this mechanism "Size Effect". Taking into account that the peak of consumption is reached around ages 55/60 (see Figure 3.1), a change in the structure of population that increases the share of population at old

[12] See Figure A.7 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).

ages and decreases the number of population at the ages close to the peak age of consumption will negatively affect aggregate consumption in the economy. This will be the case in the coming decades when baby-boom cohorts move from the peak of consumption to high ages and will ultimately affect money demand, negatively creating deflationary pressures. We will call this mechanism "Structure Effect". Understanding how these effects work and quantifying them is of utmost importance to detect how future demographic developments of different countries will lead to different patterns of inflation.

In contrast to other models in the literature we allow for endogenous savings decisions. Furthermore, we integrate labor supply decisions and preferences for money which, on the one hand, prevent superneutrality of money[13], and, on the other hand, make the model more sensitive to changes in demographics. Additionally, we study the impact of pension systems on individuals' reactions and, as a consequence, on inflation developments.

In the following section, we first analyze both structure and size effects individually. After the analysis of this basic model, we introduce a PAYG pension system that can affect prices through adjustments in savings behavior since PAYG pensions force households to contribute to the pension system out of their labor income. 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[14] and the macroeconomic effects of both demographic effects in a full model are described.

4.1. Structure and size effects

The size effect is calculated by assuming a moment in time from which we hold the population structure constant (year 1990 in the baseline scenario) but still take into account changes in the size of population. This allows us to exclude the effect that stems from changes in population structure and isolates the pure size effect. The robustness of results regarding the year when population structure becomes constant is presented in the appendix (Table B.5). Second, we then account only for the pure structure effect. This is the share of inflation that results from changes in the share of population groups in the total population which is not explained by the size effect. It is given by the residual difference between our benchmark model scenario (containing both size

[13] See, for example, Drazen (1981), Barro (1995), Gahvari (2007) or Walsh (2010) on (non-) superneutrality of money.

[14] Formally, it is important to note that this connection might also work in the opposite direction: inflation rates can affect labor supply behavior and therefore pension systems. However, we found that this effect is negligibly small in this model framework.

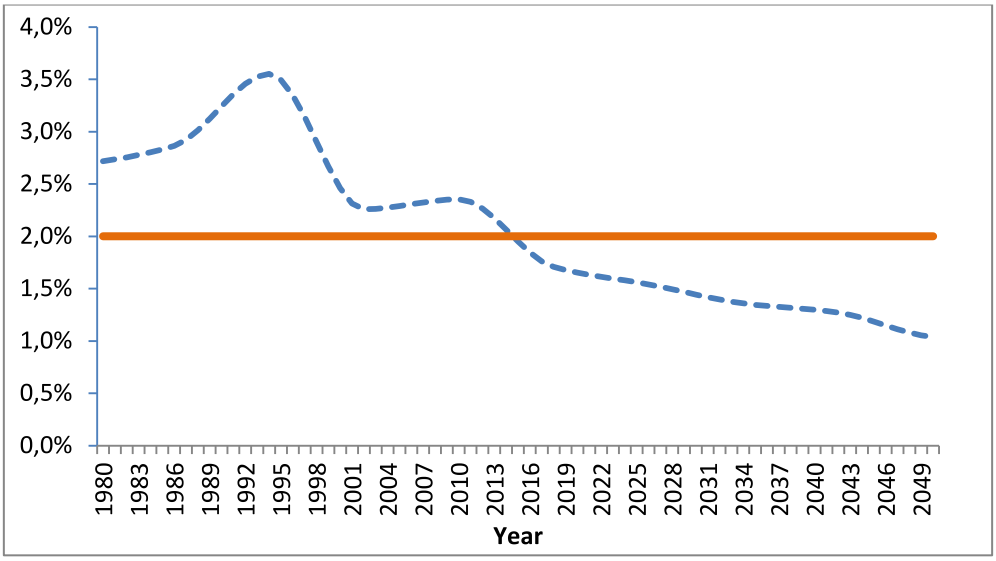
and structure effects) and the scenario that assumes population structure constant (containing only the size effect).

In this subsection we assume a simple partial equilibrium model which does not contain decisions on labor supply but only a consumption/savings decision. Additionally, it does not assume a public PAYG pension system but instead all old-age assets are accumulated through private savings. It further assumes a pro-cyclical government with respect to money creation[15]. The model is calibrated such that consumption profiles fit the empirical moments (see Section 3) so that we can assure that the structural effects are representative of the actual behavior of individuals. This will be our benchmark model for Section 4. The driving force influencing inflation rates will be aging, i.e. enduring shocks in population size and structure in every period.

Figure 4.1 shows the resulting inflation rates for the time period from 1980 to 2050 in our benchmark model. 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 is given by $\mu_t = \mu_{SS,t} =$ 2%. When demographic change 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 as a consequence from demographic change, while inflation rates below this 2% threshold mean a deflationary pressure. As seen in Figure 4.1, inflation rates are above the 2% steady-state threshold (orange line) until the year 2000, which means the presence of inflationary pressures - inflation rates have a value up to 3.3%. As demographic change takes place, inflation levels tend to decrease over time and deflationary pressures gain power when inflation rates become lower than the 2% steady state level.

[15] Table B.3 in the appendix gives an overview and discussion on different types of government actions (different parameterization of ϕ_μ in the money creation equation (2.14)) and its impact on the economy and inflation in particular.

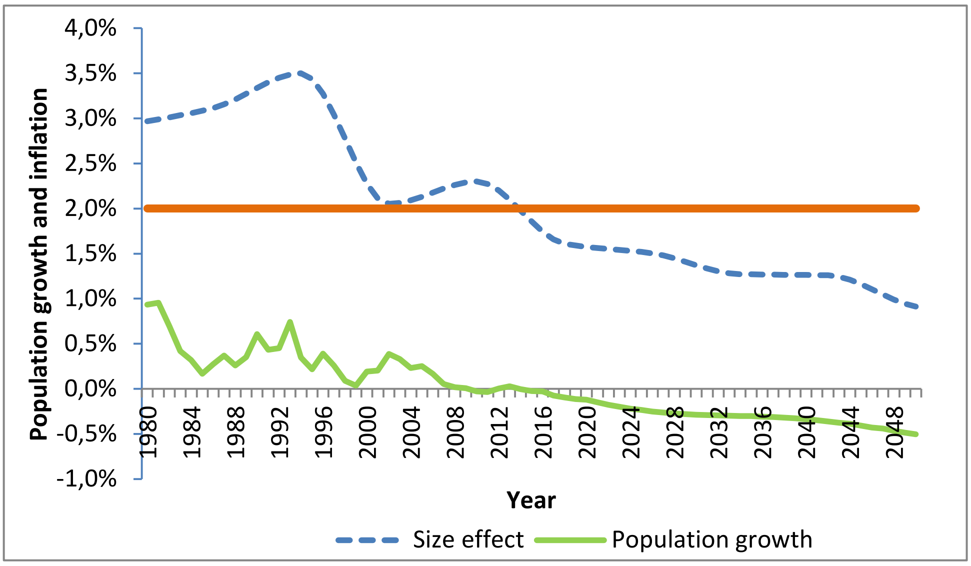
Figure 4.1 –Inflation



Source: own calculations.

In other words, demographic developments would initially lead to inflationary pressures until the year 2000 and would from then on turn deflationary. To understand the source of this pattern, it is essential to differentiate between the size and the structure effect. Figure 4.2 depicts the size effect of demographic developments on inflation as it was explained in the beginning of this chapter, jointly with the growth rate of population. It becomes clear that a major part of inflation can be explained by the size effect. 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.

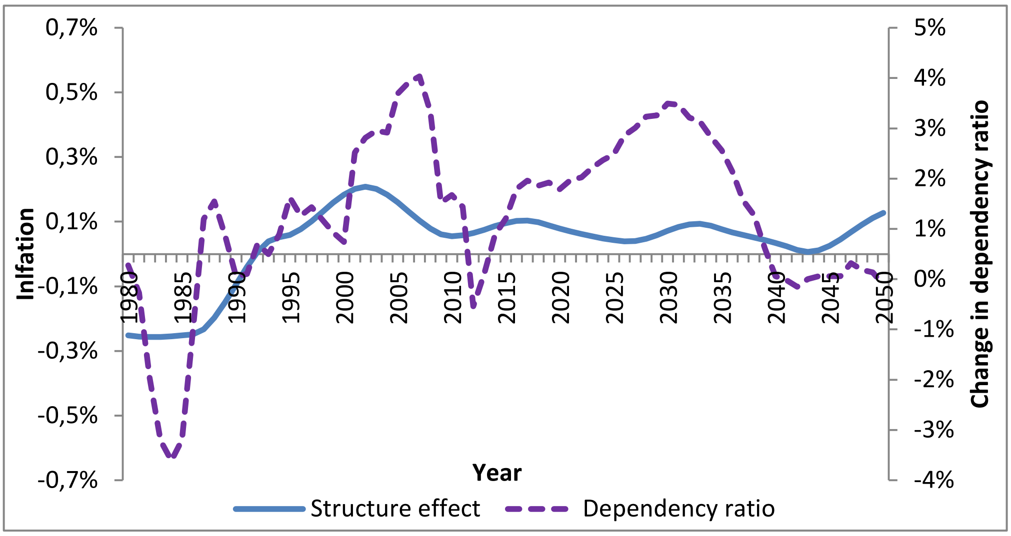
Figure 4.2 – Size effect



Source: own calculations.

For a better understanding of the structure effect, Figure 4.3 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. It is negative until the year 1991 and slightly positive afterwards. Values range from -0.26 p.p. of inflation around 1980, 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 which will be absorbed when we introduce new economic elements to the economy in the following subsections.

Figure 4.3 – Structure effect



Source: own calculations. Percentage change in dependency ratio is shown for Germany.

This relation in the very simple version of the model between dependency ratio growth and the structure effect has its origins in the shape of life-cycle consumption profiles (see Figure 3.1). 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. In contrast to the size effect, demographic change represented by the structure effect is first deflationary and afterwards, when baby boomers reach their retirement age, slightly inflationary.

When applying the same channel as in this model, Lindh and Malmberg (1998; 2000) show that a larger share of young retirees is inflationary which agrees with our results if the consumption peak occurs around retirement age. Along the same line of thought, Juselius and Takáts (2016) find that a larger share of workers is deflationary, which is also predicted by our model for young workers. Last, Yoon, et al. (2014) and Gajewski (2015) state that an increasing number of old people has a downward pressure on prices (without identifying an exact channel), a conclusion that is also reached by our model.

In conclusion, the size effect shows inflationary pressures in early years of the time range studied while it shows deflationary pressures during later years. The structure effect has, in contrast, a deflationary impact in early years and a slight inflationary effect later, although its magnitude is smaller than the size effect.

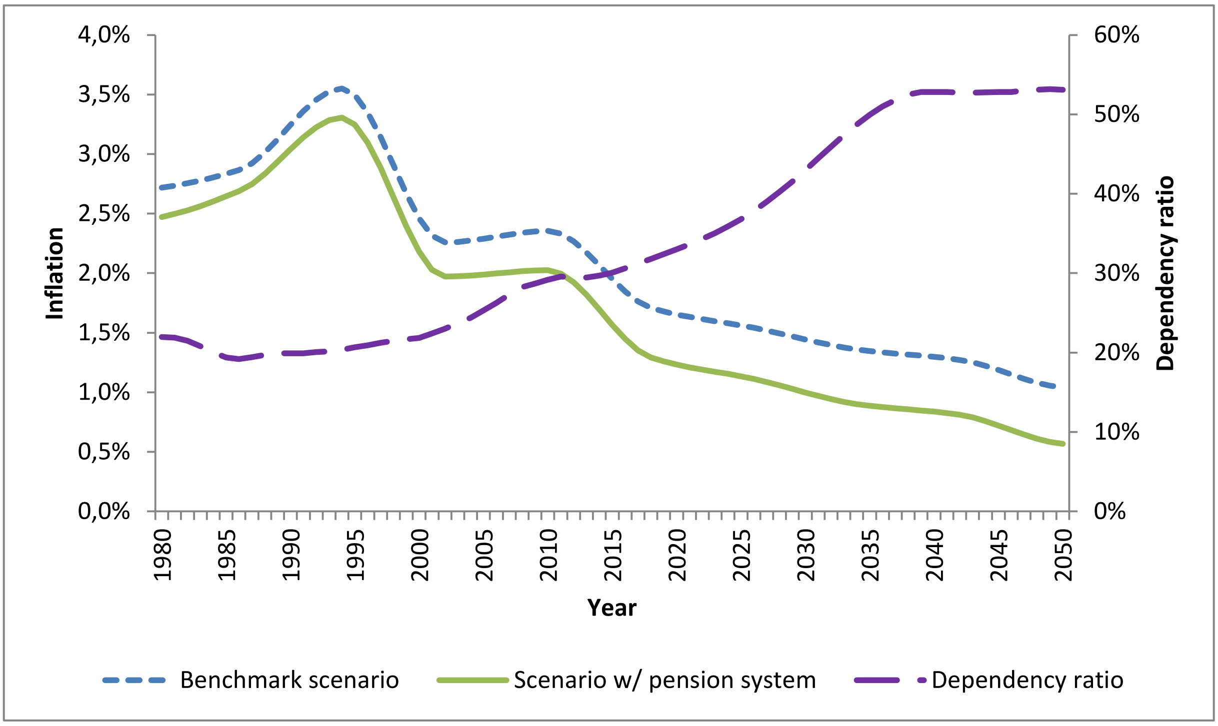
4.2. Pension system’s effects

In addition to the previous discussion, it is also important to look at the effects of the implementation of a pension system on inflation. In this section, we introduce a PAYG pension system with defined benefits as explained in Subsection 2.2. A pension system of this type implies that individuals will have forced contributions during their working life which tend to reduce total consumption of individuals over the life-cycle as long as the internal rate of return of the pension system is lower than the market interest rate (return on productive capital) – which is the case for our calibration and is due to population aging under the typical PAYG pension systems. In these systems, the demographic history (equations (3.2) and (3.3)), the benefit adjustment rule (equation (2.7)) and the individual wage history determine the internal rate of return of the PAYG pension system (Börsch-Supan et al., 2017) and, consequently, consumption possibilities and inflation rates. Particularly, population aging has a direct and negative effect on the internal rate of return of the system through the decline of population growth.

Together with this internal rate of return, another key variable to understand this section's outcome is consumption over the life-cycle. The PAYG system forces households to contribute to the system from their labor income. This potentially decreases consumption because of two reasons. Firstly, available income during working age is diminished and private savings necessarily have to decrease or become negative (in the case of borrowing) if the household wants to keep the same consumption level as in the case without a PAYG system. This implies less income received through the capital market. Secondly, since pension benefits are paid at old age there is less need to privately provide for one's old age during the working phase of life. Since the market interest rate tends to be higher than the internal rate of return of the pension system, which has been true in recent decades due to demographic change, then individuals have a present value of income which is lower than in the case without a pension system. In such a case, we could think of 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 Possen, 2000). For a pension system to be fully funded, the stock of productive capital has to increase by the present value of future pension benefits. This is the case in our model, where we do not assume investments in government bonds but only productive capital such that savings in a fully-funded system receive interest given by the return on productive capital. This will reduce consumption over the life cycle, money demand and, therefore, prices. The result that a decrease in aggregate consumption and therefore demand dampens inflation is in line with theoretical and empirical findings (see Lindh and Malmberg (1998) and Juselius and Takáts (2016)).

In Figure 4.4, we can observe that introducing a pension system reduces inflation in comparison to the benchmark scenario. The difference between inflation rates ads up to roughly 0.3 percentage points in early years. In later years, the difference is half a percentage point. For instance, in year 2017 the difference in inflation rate amounts to 0.4 p.p.. This effect would be even stronger for more generous pension systems. 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.

Figure 4.4 – Inflation with and without a pension system



Source: own calculations. Dependency ratio is shown for Germany.

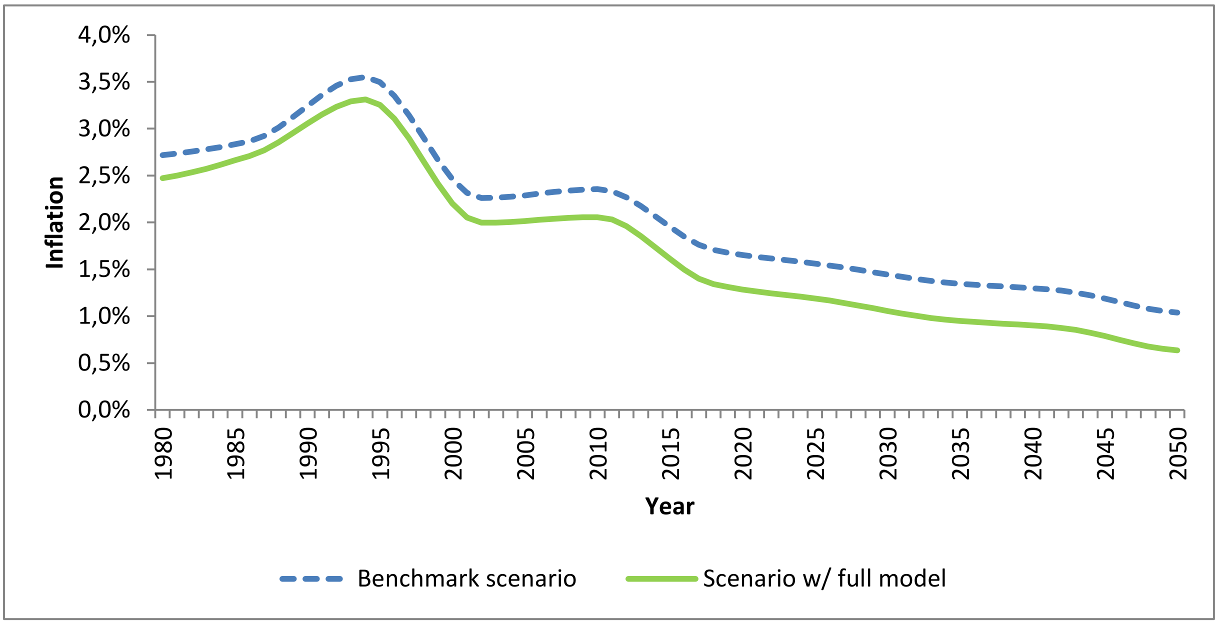
Following the upward trend in the level of the dependency ratio as depicted in Figure 4.4 (right scale), contribution rates also increase over time to compensate for the decreasing number of contributors to the system, pushing available income downwards. Hence, the impact on inflation described above 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 under a pro-cyclical government. The increasing dependency ratio, therefore, ultimately leads to a wider gap between the two scenarios with and without a pension system, see Figure 4.4. As will be seen in the country example in Section 5, the magnitude of this gap will also depend on the size of the PAYG pension system.

4.3. Pension system and labor supply interactions

After describing the main individual paths through which aging can affect inflation, we join all these paths and observe the overall impact of aging on inflation under a partial equilibrium setting. For this purpose, the same simulation from Section 4.1 is carried out but by assuming both endogenous labor decisions and a PAYG pension system. The main impact of the introduction of these elements is a reduction of the inflation rate. Comparing the levels of inflation calculated in

Section 4.1 with the outcome levels in this section (see Figure 4.5), we can clearly observe this pattern.

Figure 4.5 – Inflation rates in the benchmark and full model scenarios

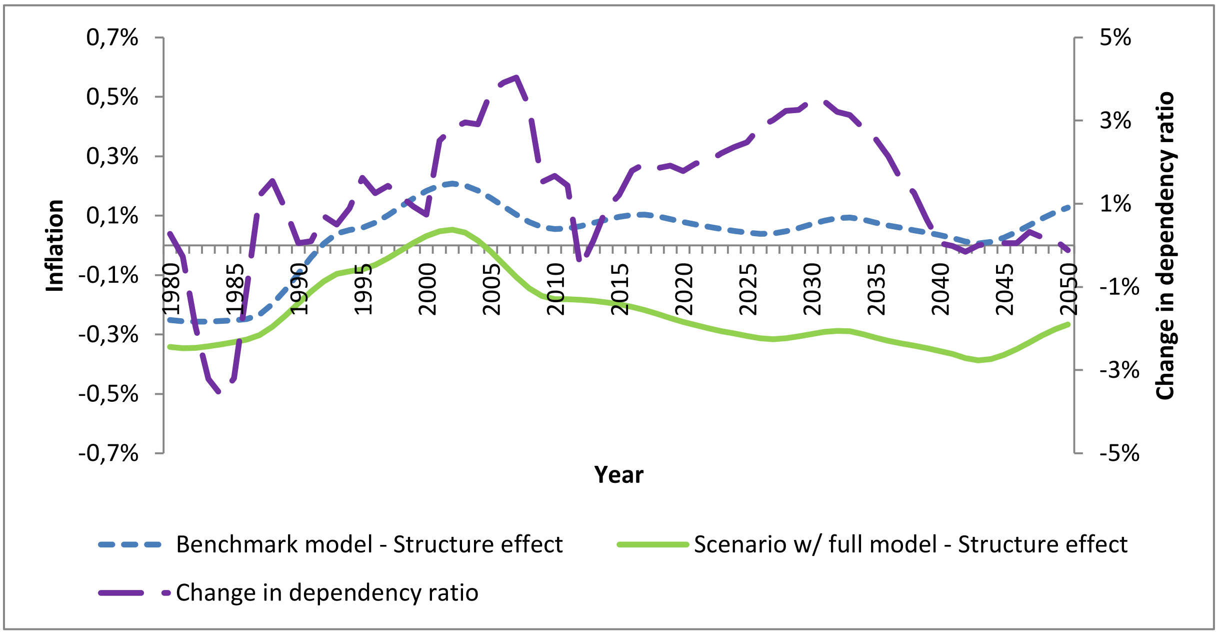


Source: own calculations.

As we highlighted in previous sections, the existence of a pension system affects inflation levels. As expected, the overall negative effect prevails over the entire period of analysis due to a weak effect of labor supply in contrast to the large effect observed when introducing a pension system without an endogenous labor decision. The pattern retains the main features observed previously in Subsection 4.2 in regards to the stronger effect of aging in the pension system's internal rate at later periods.

Comparing the size effect of this scenario to the benchmark scenario, we observe that deflationary pressures are stronger under the former than under the latter. At the same time, the structure effect is negative during the entire period. As is visible in Figure 4.6, in comparison to the benchmark scenario, now the structure effect is 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. 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 population structure stabilizes (the share in population of the baby boomer generation begins to fall after 2040). This increases the share of younger working age groups and reduces the deflationary tendencies on the structure effect.

Figure 4.6 – Structure effect in both scenarios and dependency ratio

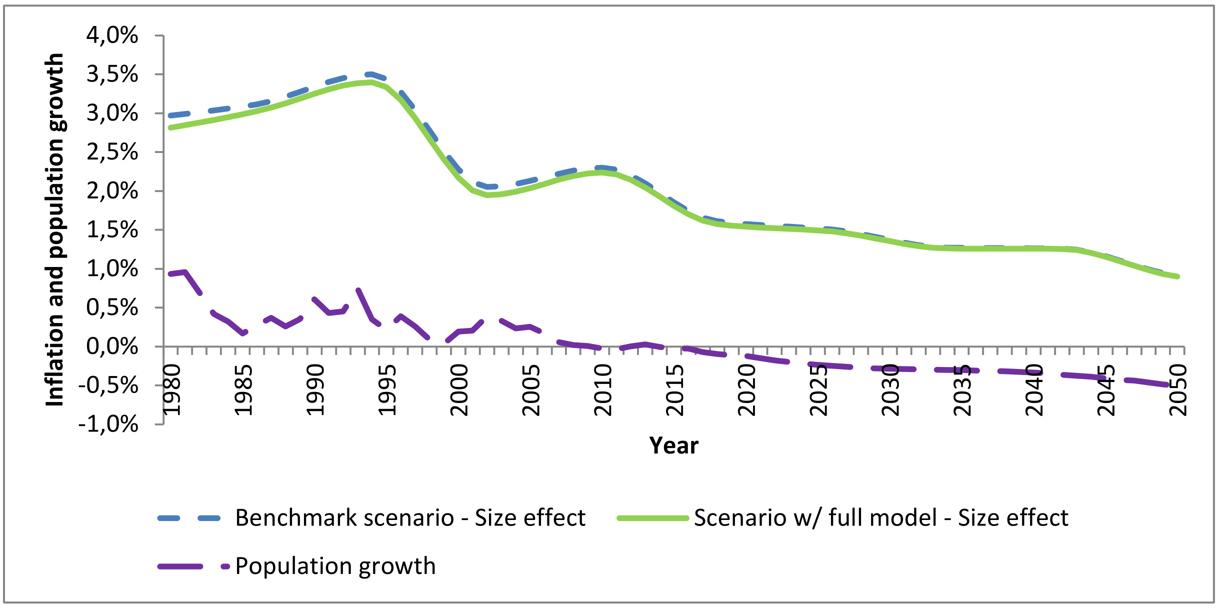


Source: Own computations

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 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.

In addition, Figure 4.7 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. Still, note that the levels are almost identical in both scenarios. This means that lower inflation levels are, in fact, driven by structure effects and not by size effects. Therefore, we should concentrate the analysis on the path of the size effect through time instead of only on a specific point. Still, the overall effect of both structure and size effects leads to a reduction of the inflation rate. This leads to the conclusion that the structure effect is highly affected by the existence of a pension system and this has a large impact on the overall behavior of inflation. This should be noted as the problems that future aging economies may face regarding inflation will also be related with the expansion of their pension systems necessary to cope with a larger amount of pensioners and pension payments. We will come back to this issue in Section 5 when we compare and quantify these impacts on different types of aging economies.

Figure 4.7 – Size effect in both scenarios and population growth



Source: own calculations.

So far, our results emphasized the major impact that a pension system has on the consumption and saving behaviors of individuals. Nevertheless, another feature is implemented in our model, namely, labor decisions. Not surprisingly, in a partial model set-up with exogenously set wages, endogenous labor decisions do not play an important 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, amplifying the impact of labor decisions. These effects work through the fact that labor decisions affect total contributions to the pension system. If endogenous labor decisions lead to a reduction of total hours worked, the pension system will require a higher contribution rate for each individual, which will dampen savings and consumption. This decrease in consumption will then foster deflationary pressures via lower money demand. Still, this effect remains small in comparison with the pension system effect. Figure A.8 shows that differences represent at maximum around 0.1 p.p.. Despite this small value, it is still significant in relative terms when inflation levels are low[16].

In order to have an overall perspective on the impact of aging, pension systems, and labor supply behavior on inflation, Table 4.1 summarizes the main effects of each element depicted in percentage of benchmark inflation.

Table 4.1 – 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 4.1, the size effect exerts a negative effect on inflation – it is lower than steady state inflation level - which increases over time due to population shrinkage (positive correlation). On the other side, an introduction of a pension system and structural changes in the population leads to a stronger structural effect that becomes largely negative in the full scenario. These results give strength to the arguments presented by the strand of literature which argues that population growth has an impact on inflation. As we find here, population growth through the size effect has a negative impact on inflation and a positive correlation with inflation. Interestingly, population structure changes its impact magnitude depending on the economic model we assume. The main difference between models is the presence of the pension system. Indeed, if there is no pension system that absorbs available income and consumption of the working age population, structure changes, which become stronger in the last decades, have a mostly negligible effect (see Table 4.1 and Figure 4.6). In contrast to this pattern, when a pension system is in place, the population structure effect becomes more negative, reflecting diminishing available income and consumption. This results from the decline of the working age population, as well as a decrease of population at the age when consumption reaches its peak and from the increase of population in retirement who already passed their consumption peak and has a decreasing consumption profile.

[16] Since utility is additively separable in leisure, it is not expected that the effects of introducing labor in the model should be large. Most of the effects are mainly indirect through wages, which affect consumption and preference for money, and through savings and, hence, interest rates (in the case of the general equilibrium model in Section 5).

5. The aging – inflation general equilibrium results

Moving from a partial equilibrium setting to a general equilibrium framework introduces a series of new elements - such as equilibrium interest rates (return on productive capital) and wages. While interest rates and wages in Section 4 were assumed to be constant, they now depend on demographic changes and on individual's decisions. Accordingly, interest rates and wages will tend to fluctuate over time due to enduring shocks in population size and structure, which creates positive or negative incentives regarding savings, consumption and hours worked, which are, as we have seen before, the main determinants for inflationary trends. In light of the importance of these interactions, we start by examining the main impacts that a general equilibrium framework has on inflation. Furthermore, we compare how each channel between aging and inflation, which was presented in the last section, changes or is strengthened under this general equilibrium framework.

In the second part of this section, we provide a quantified analysis of how much demographic change can explain inflation in different countries. These countries are in different stages of demographic change and present different types and coverage of public pension systems. This will allow us to observe and quantitatively explain the main arguments and channels presented in this paper and show how aging has a potential effect on inflationary trends.

5.1. Demographic mechanisms in general equilibrium

In times of demographic change, interest rate variations depend on the amount of savings in an economy. Since our model depends on savings accumulation to mount capital, today's changes in population structure where groups of savers (working age population) increase first will force 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 at first sight ambiguous because of these two counteracting effects. Indeed, they work in such a way that inflation, in comparison to the partial model, is significantly lower when population ages (compare Tables 4.1 and 5.1). Therefore, the decreasing interest rate effect overcomes the wage effect in later years of demographic change.

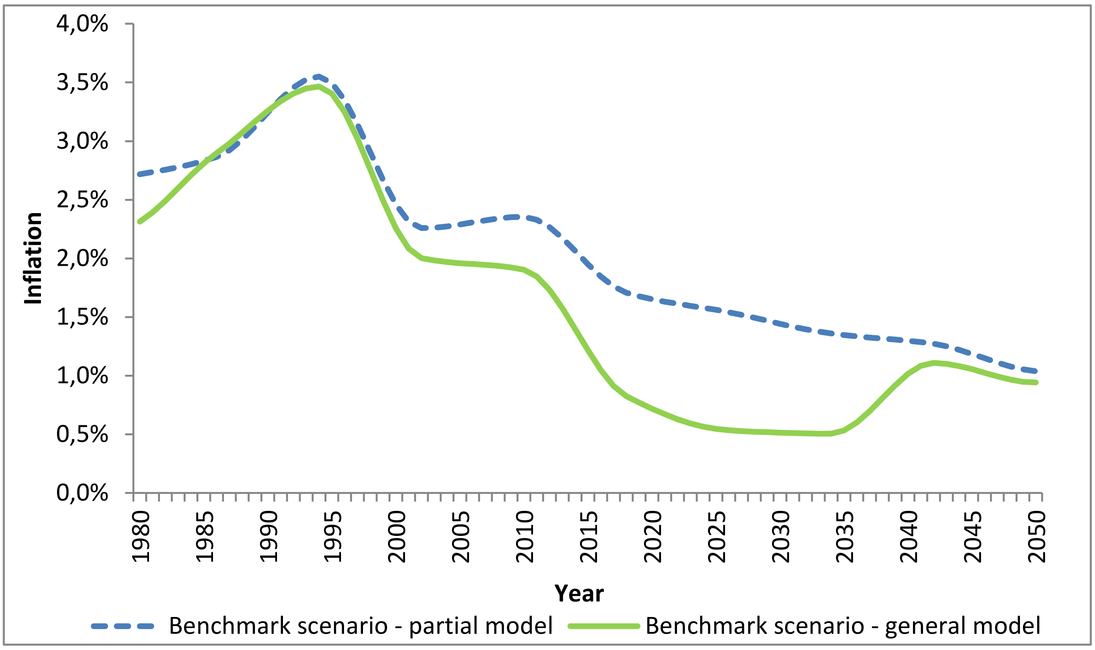
Table 5.1 – Comparison between scenarios (time span: 2015-2025)

	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.

This can also be observed in Figure 5.1, where inflation rates are lower than those in the partial equilibrium setting from 2009 onward, mainly due to the decline in the interest rate. Before 2009, in contrast, the wage effect mostly dominates the interest rate effect. This induces additional consumption and money holdings through higher work income implying higher inflation rates than in the partial model. In total, 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 5.1 –Inflation under partial and general equilibrium



Source: own calculations.

Taking into account the importance of marginal productivities of capital and labor in the general framework, aging will also influence inflation through labor decisions. In an endogenous labor 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, in general equilibrium with increasing wages and decreasing interest rates, the stronger reaction of hours dampens the negative structural effect observed in the benchmark scenario (see Table 5.1). Regarding the structure effect, an increase in wages positively affects hours worked, mostly for cohorts at the ages of higher productivity. This will then lead to a higher positive reaction of consumption demand, and subsequently, money demand in the endogenous labor scenario. Therefore, the deflationary effect of the structure effect will be dampened in this scenario in comparison to the benchmark scenario - 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. The size effect in the scenario with endogenous labor is very similar to the benchmark scenario since the variation in total labor, which depends on both population growth (size) and total hours worked, remains similar in both scenarios.

When introducing a pension system, the negative impact of demographics on inflation is slightly stronger than in the benchmark scenario as was already the case in the partial equilibrium setting. However, this difference is much smaller under a general equilibrium model. A share of savings is now absorbed by the pension system which makes interest rates higher. Moreover, changes in the population structure which increase the amount of retirees will create shocks on contribution rates that will reflect onto consumption and savings and, hence, on inflation. This effect will be amplified by reactions of wages and interest rates that reinforce the negative impact on inflation. This creates deflationary pressures, as we can see from the structure effect of -1.02% in Table 5.1. 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 5.1 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 existence of endogenous labor decisions, 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).

As we have shown, the channels can be hidden either by the general model features explained in this section, or by the several channels involved that may compensate for each other. The importance of these channels will become clear in the next section when we compare different countries with different specificities regarding pension systems and stages of demographic change. The just applied general model will be further used in this paper to quantify and specify the particularities of each country and show how, in reality, aging is partially affecting inflation in each of these countries. The size effect again stays stable among scenarios since the variation in total labor is not affected by a joint effect of both endogenous labor and pension system.

5.2. Country simulations

After evaluating the impact of endogenous interest rates and wages on inflation in Section 5.1 and being aware of the identified channels, we can now simulate the model by making use of real world examples. The aim of this section is 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. The model is simulated using parameters that match the empirical moments of each country and reflecting comparable macroeconomic dynamics where possible. We want to highlight the fact that with these simulations, we are not seeking to obtain exact estimates for inflation[17]. In fact, we are concerned to simulate and illustrate possible impacts of demographic change on inflation.

In accordance with Section 5.1, the general equilibrium model is then employed for a selection of different countries. We have chosen a set of aged countries that have a generous pension system – such as Germany, Italy and Japan. France is also included as a country with a generous pension system but it does not have yet an aged population, showing different dynamic patterns than the ones observed in the previous countries. Finally, a set of young countries composed of US and India represent the countries with a still young population and also with a less generous pension system. China is also included in this group as a country with a less generous pension

[17] As it should be clear, the myriad of channels that drive inflation, as already explained, are too many to be implemented and considered in a sole model. Here we are just concerned in solely detecting the specific impact that demographic change may have on inflation. Therefore, it is expected that the inflation patterns should match the empirical ones but it is not expected that we could calibrate the model such that inflation levels should exactly match the real ones over a large period of time.

system and young population, but which is going to age quickly in the near future. These countries with distinct levels of generosity of pension systems and in different stages of demographic change allow us to have a good overview of the impacts of the different channels on inflation levels.

As a first step, we assume that no public PAYG pension system is existent. Later in this chapter, the respective size of national pension systems will be added in order to identify possible interaction effects and their magnitude for our sample of countries. Note that each country scenario is simulated separately (closed economy setting) since we want to abstract from possible mutual interactions at this point.

We use different calibrations of the model to match key facts of each economy and capture their inflation trends. A series of empirical moments observed in the calibration year 2015 (see Table 5.3) are matched with their corresponding model outcomes. The respective calibrated parameter values for each country are summarized in Table 5.2.

Table 5.2 – Parameter values

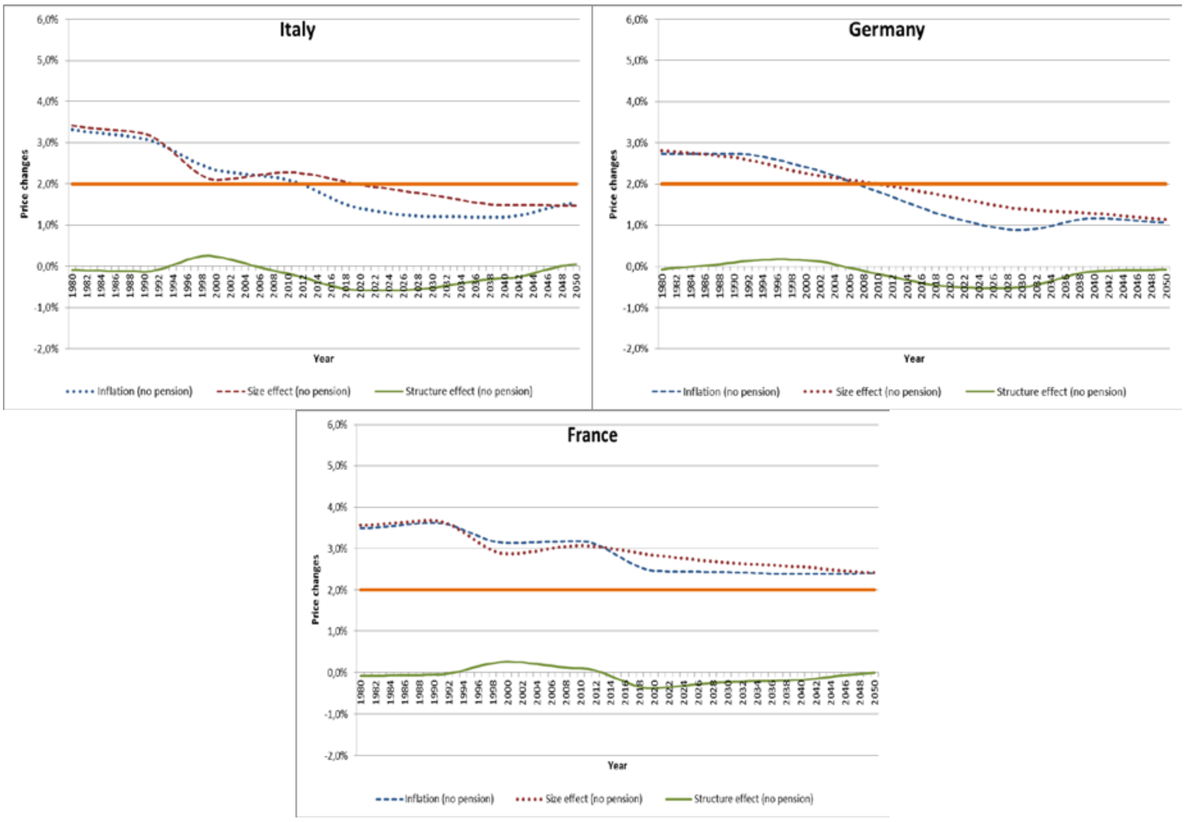
	Discount factor ($\boldsymbol{\beta}$)	Consumption weight ($\boldsymbol{\eta}$)	CES subst. parameter ($\boldsymbol{\sigma}$)	Labor weight ($\boldsymbol{\Psi}$)	Labor parameter ($\boldsymbol{\varrho}$)	Depreciation rate ($\boldsymbol{\delta}$)
France	0.999	0.07	0.4	0.05	2	0.045
Germany	0.999	0.07	0.4	0.12	2	0.055
Italy	0.999	0.2	0.5	0.09	1	0.035
USA	0.965	0.91	0.4	0.22	1	0.05
Japan	0.999	0.01	0.4	0.01	2	0.05
China	0.999	0.008	0.4	0.008	2	0.04
India	0.999	0.82	0.5	0.2	1	0.07

Parameter values are calibrated to match empirical moments displayed in Table 5.3. 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.

5.2.1. Countries' inflation dynamics

Figure 5.2 shows the resulting inflation rates and magnitudes of effect sizes for the three largest EU countries: Germany, France, and Italy. Among these countries, Germany and Italy represent a regime of aging (or already aged) populations, incorporating high survival rates and low fertility rates at the same time. France's population, in contrast, is mostly defined by higher survival rates and longevity but less by low fertility rates and population shrinkage.

Figure 5.2 –Inflation rates and effect sizes for three major EU countries

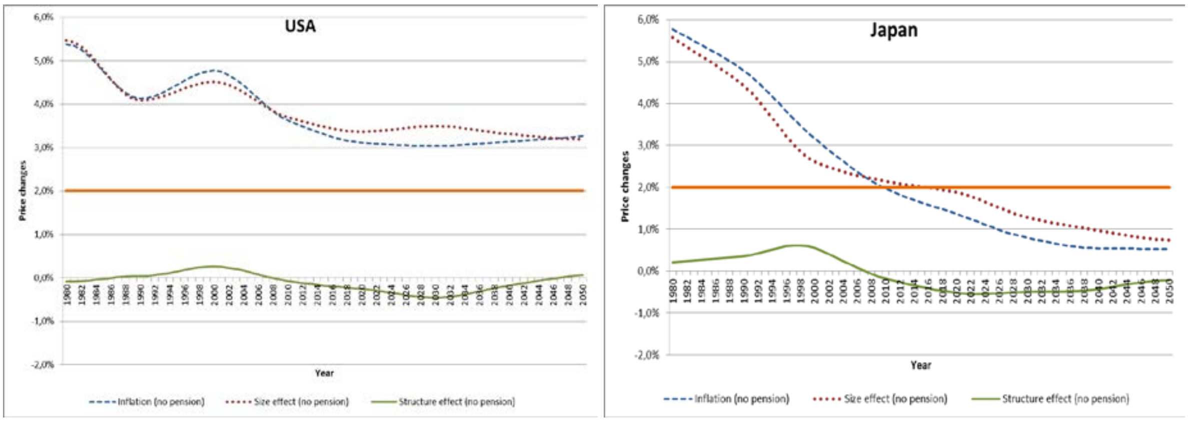


Source: own calculations.

Correspondingly, inflation rates show a clear downward trend for Germany and Italy, which is clearly driven by the size effect. Since fertility rates have been low for decades in these countries, populations shrink when baby boomers become old and these large cohorts reach age groups with high mortality rates. Therefore, the size effect on inflation rates exhibits a deflationary pressure from the year 2021 onward in Italy and a decade earlier in Germany. However, inflation rates drop below the 2% threshold some years earlier. This is due to the negative structure effect, which is also depicted in Figure 5.2. 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 onward in Italy and Germany. France, in contrast, is different: while we still see 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 shrinking.

Leaving the European context, we next compare two major economic powers: the US and Japan. Despite being both 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 shrinkage of population due to low fertility rates. Again, this is perfectly mirrored by inflation outcomes depicted in Figure 5.3.

Figure 5.3 –Inflation rates and effect sizes for USA and Japan

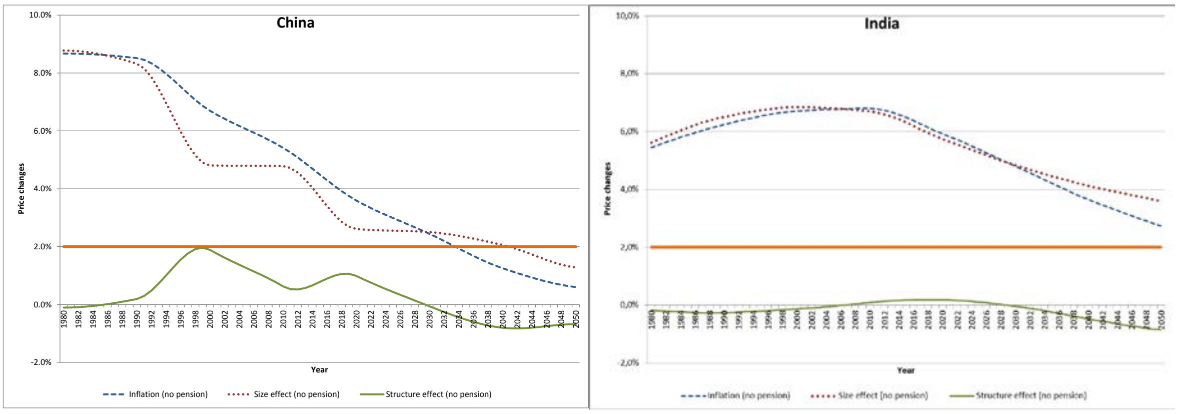


Source: own calculations.

In the USA, 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 shrinking population induces inflation rates to fall strongly below the 2% level because of the size effect. This effect gains substantial importance and becomes larger over time. In 2040, inflation rates stabilize at a very low 0.5% despite a policy target of 2%. However, this is not only due to the size effect but also due to the structure effect, 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 5.4. 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 7 p.p. above the 2% threshold). However, this pattern has quickly changed and China's population will soon shrink (roughly around the year 2035). This will, in turn, lead to a size effect that causes deflationary pressures after the year 2035. In parallel to the aging European countries, where these patterns are already occurring, a strongly negative structure effect will further drive down inflation rates such that they will be close to zero in 2050.

Figure 5.4 –Inflation rates and effect sizes for China and India



Source: own calculations.

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.

The previous analysis was conducted without a PAYG pension system in place. Accordingly, this allowed for comparing countries' inflation rates while abstracting from interactions with the pension system. However, the generosity of public pension systems differs significantly between countries. In our sample of countries, France, Germany, Italy, and Japan possess fairly generous pension systems with replacement rates (as a share of the net wage) ranging from 60% to 70%. China and India, in contrast, have public pension systems with low generosity. For these countries, we simulate our model with replacement rates of 10%. For the US, which constitutes an intermediate candidate in terms of generosity, we take a replacement rate of 30%. As was already discussed in Section 4 and in Section 5.1, the inclusion of a pension system changes some basic dynamics and adds an additional channel through which aging can influence inflation rates. Therefore, we study the same sample of countries but assume realistic sizes of each country's PAYG pension system. Figure A.9 displays the selection of countries, discussed earlier.

Generally, our findings derived in the beginning of this chapter remain valid under pension systems. Inflation rates, however, are now lower than in Figures 5.2 and 5.3 from the 2020s onward if a pension system is in place. This is especially pronounced for Germany and Japan, the countries which are aging the strongest. 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 therefore 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 since lower consumption expenditures cannot be explained by the size effect, i.e. population growth.

As described above, China and India's public pension systems are not very generous and only exhibit replacement rates of roughly 10%. This also holds in part for the US, where we assume a replacement rate of 30%. Since the generosity of these systems is small, a depiction of inflation rates in Figure 5.5 for these three countries does not deliver visible differences. In conclusion, the same qualitative results hold as for the aforementioned countries: the presence of pension systems shifts inflation rates slightly downwards. However, for countries with such small pension systems, the quantitative differences are negligible.

Ultimately, the question arises as to how these international differences in price developments are affecting the real economy, e.g. trade and exchange rates. When evaluating possible consequences, it is essential to differentiate the exchange rate regime in which the respective country is situated: flexible exchange rates towards other countries or fixed exchange rates/currency union. In the former case, deflationary tendencies due to an old population compared to other countries work as follows: deflation (or lower inflation vis-à-vis other countries) makes domestic goods cheaper. In other words, the economy is getting more competitive with respect to prices (abstracting from other mechanisms that might influence competitiveness of an economy). In the aftermath, two effects occur. First, exports increase and second, imports decrease due to the higher price competitiveness of the domestic economy. Increasing exports foster the demand for the country's currency while decreasing imports dampen the supply of this currency. Both effects imply an appreciation of the currency of the aging country vis-à-vis countries with a higher inflation rate. This appreciation, in turn, dampens the increase of the price competitiveness due to deflationary tendencies such that the net effect will be much weaker. In the latter case, when exchange rates are fixed, or when the aging country is located within a currency union, the same mechanisms with respect to exports and imports as just described occur. However, the exchange rate cannot adjust and does not balance demand and supply for currencies. As a result, the aging country with deflationary tendencies contains its price competitiveness while other countries with inflationary tendencies are stuck with a lack of price competitiveness. Therefore, the country with deflationary tendencies will see a decline in its trade deficit while the other countries' trade deficits increase.

5.2.2. Model validity and data comparisons

Comparing the results above to the data reported in the previous subsection, we observe that the main key macroeconomic moments for each country are matched by our model for the year 2015.

Table 5.3 – Calibration targets and model outcomes

	Average annual hours worked	Capital-Output ratio	Consumption-Output ratio	Money-Output ratio
	France			
Empirical moments	0.73	3.09	0.55	4.12
Model outcomes	0.70	2.93	0.60	4.10
	Germany			
Empirical moments	0.66	2.85	0.54	4.12
Model outcomes	0.61	2.80	0.57	4.19
	Italy			
Empirical moments	0.83	3.32	0.61	4.12
Model outcomes	0.81	3.22	0.64	4.10
	USA			
Empirical moments	0.84	2.34	0.68	0.66
Model outcomes	0.84	2.34	0.74	0.65
	Japan			
Empirical moments	0.83	2.85	0.57	9.17
Model outcomes	0.78	2.88	0.51	8.16
	China			
Empirical moments	0.84*	2.85**	0.37	8.38
Model outcomes	0.75	2.45	0.52	7.63
	India			
Empirical moments	0.84*	2.34**	0.59	0.79
Model outcomes	0.85	2.37	0.64	0.79

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.

Matching the empirical moments for each of the countries allows us to make conclusions about the level and inflation trends that can be attributed to the demographic change prevailing in these countries. Table 5.4 summarizes the previous findings of countries and compares them to observed data on inflation. For this purpose, we calculate the difference in the average inflation rates between the periods 1990-2000 and 2006-2016 and divide it by the average inflation rate in the period 1990-2000. 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). Changes in average inflation rates are ranked with respect to the magnitude of the decrease between the two time periods.

Table 5.4 – Change in inflation rates – Empirical data and model outcomes

	% change in average inflation (Data)	**% change in average inflation (Model)**
India	10.22	-2.88
France	34.97	10.98
USA	37.46	19.26
Germany	43.95	32.75
China	60.6	32.64
Italy	61.91	26.79
Japan	73.07	50.27

Source: OECD (2018), World Bank (2018), and own calculations. We calculate the difference in the average inflation rates between the periods 1990-2000 and 2006-2016 and divide it by the average inflation rate in the period 1990-2000. A sensitivity check with respect to differing time periods can be found in the appendix, Tables A.1 – A.3.

From the table above we observe that the predicted value of average inflation is always smaller than the actual average inflation rates. Nevertheless, the negative trend of inflation rates is captured in all of the countries (with the exception of India). As can immediately be observed from Table 5.4 (left column), inflation rates have decreased in the entire sample of countries between the two time periods. Applying the same procedure to model outcomes (right column), one can observe that our model results match the ranking of real world data quite well.

In those countries where we predict the smallest (largest) decrease in inflation rates, we can actually observe the smallest (largest) decrease in real world data. For instance, in the case of India, we predict the smallest change in inflation rates between the two time periods. Model outcomes show that India's inflation has not substantially changed between the two time periods, while the actual data shows a decline of almost 10 p.p.. In the case of Japan, the country for which we predict the largest decrease in inflation due to the rapidly aging population (50.27% decline) is indeed the country with the largest decline in inflation rates observed

(73.07%). The only two countries which switch their ranks are Germany and Italy. However, the general message holds: the set of countries with the strongest aging process have also exhibited the largest decline in inflation rates, which was predicted by the model.

In general, our model can capture average changes in inflation between a range of 27% (France) to 75% (Germany), where the exception is again India with a contrary development of -2%. 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 influence and push inflation trends in the real world through life-cycle behavior of individuals. We can conclude that demographic change in Japan has reinforced disinflationary pressures observed in this country while, on the contrary, India's demographic evolution creates positive pressures on inflation despite the actual negative trend observed. The major short run factors that have a direct effect on inflation dilute the long term effects of demography on inflation.

6. 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. Some attribute an increase in the share of net savers towards the dampening of inflation while also believing that an increase in the share of dis-savers fosters it (e.g. Lindh & Malmberg (1998); (2000)). Others instead argue that population aging and associated changes in demand structure exhibit deflationary tendencies (e.g. Gajewski (2015)). Still another branch focuses on population size where a positive correlation between population growth and inflation is found (e.g. Shirakawa (2012) and Yoon, et al. (2014)). With such a dispersion of theories and results, the aging-inflation puzzle has now received more attention as a time of population aging starts to dominate most of the developed economies in the world.

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 stratified manner as well as the effects of the introduction of a PAYG system on inflation, which has strong implications on the inflation process.

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 the most prominent effect (size effect), the change in population structure also contributes to inflation (structure effect). Population growth is positively correlated with inflationary pressures. As seen in Sections 4 and 5, 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 by the existence of PAYG pension systems that amplify the fall in consumption due to increasing contributions necessary to balance the system. Since demographic change is intimately connected to fluctuations in the main variables of the pension system and they, in turn, affect individuals' decisions, it is unavoidable to study the impact of pension systems on inflation when talking about the aging-inflation puzzle. As exposed in Sections 4 and 5, the introduction of a pension system creates deflationary pressures and exacerbates the size of the structure effect. This is even more visible under the general equilibrium setting where changes in interest rates and wages are highly dependent on the generosity of the 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 that depends on the existent economic institutions, such as the pension system. These effects show how demographic forces jointly with the mechanics of a pension system (without printing money) can conduct to deflationary pressures. These findings are countervailing effects to the literature that focus on the role of printing money to finance the additional social expenditures in pension systems as a channel that creates inflationary pressures, and are important to understanding the different channels in which pension systems affect inflation.

This leads us to think about how inflation in different countries, with different demographic processes and sizes of pension systems, evolves over time. According to our simulations, 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 from the size effect, while the structure effect will not play a major role.

Our findings are as follows: demographic change has an impact on inflation. We do not claim that inflation only depends on demographic change but rather that long-term trends in inflation are dependent on demographic change. This finding has numerous implications for economic growth and monetary policy that must be coordinated with policies that tackle the aging process of economies. The size effect seems to be directly related with population growth and would have to be solved through incentives affecting demography or consumption and expenditures. The structure effect, on the other hand, is much more prone 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. Although our country comparisons do not intend to determine the exact level of inflation of today's economies but only the deviations and trends in comparison to steady state inflation, some of the lessons taken can be seen as recommendations. Some countries, like Japan, would benefit greatly from these policies since it is one of the countries with the most negative structure effect. Tackling this pattern would be a step forward to break with the low inflation trap that persists in the economy.

Despite the urge to always have the most complete possible model, as always, economic models abstract from many aspects of real life. Our model does not explore many of the features of monetary policies used by central banks to address many of the deviations from inflation targets under their mandates. As we referred to previously, this is addressed in many papers of the literature, but in order to concentrate on pure impacts of demographic change, we drop these interactions and address them in the sensitivity analysis.

The only force driving inflation rates in our simulations is demographic change with its accompanying effects on population size and structure. Hereby, we abstract from any policy reforms such as increasing statutory eligibility ages for retirement and other parametric pension reforms (see, e.g. Börsch-Supan, et al. (2017)). Indeed, such reforms might potentially have interesting and unforeseen consequences on prices, which are worth studying. Since the idea of this paper is to put light on the size and structure effect mechanisms through which aging affects inflation, this task will be left to future research.

Another issue is financial markets. Of course, in the course of life, private investment decisions change over time which will be reflected in the way central banks can influence savings decisions and transmit their monetary policy to individuals and the economy. In this paper, financial markets are taken to be as simple as possible without any kind of choice between types of financial assets or uncertainty. This aspect will be tackled in future research but not in this paper.

Finally, our model is mute on business cycles or any type of New Keynesian mechanisms. We apply a MIU model that is more suitable to connect the OLG setting to demographic transitions and mechanisms that we explain in this paper in a more elegant way. This, of course, has the trade-off of not including some of the New Keynesian modelling elements but, again, regarding the goal of the paper, does not harm the main conclusions and findings.

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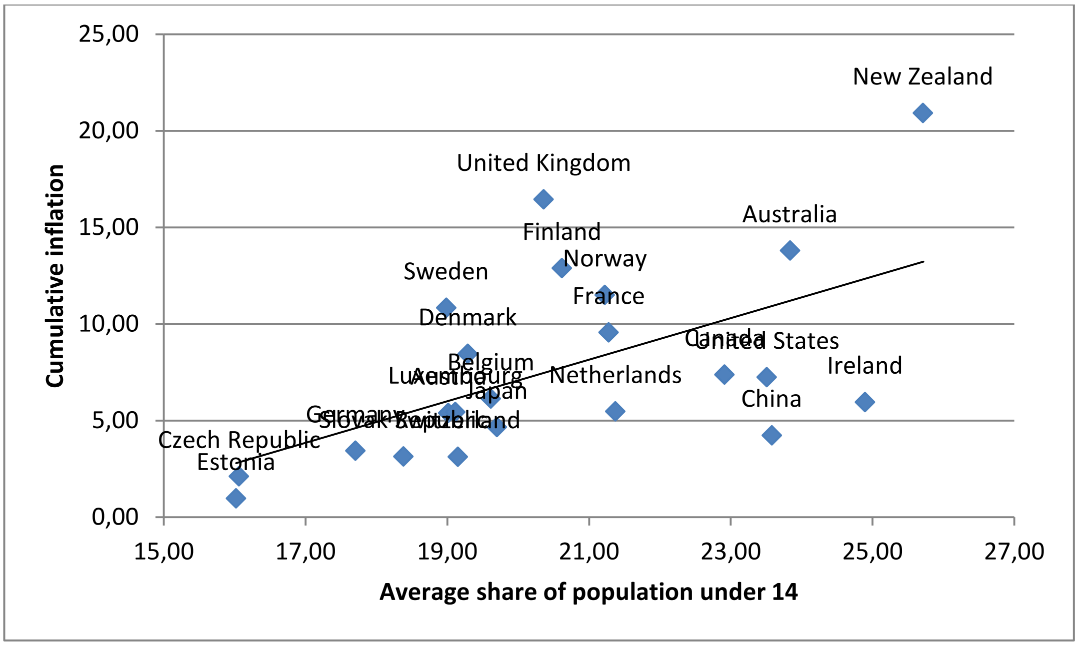
Appendix

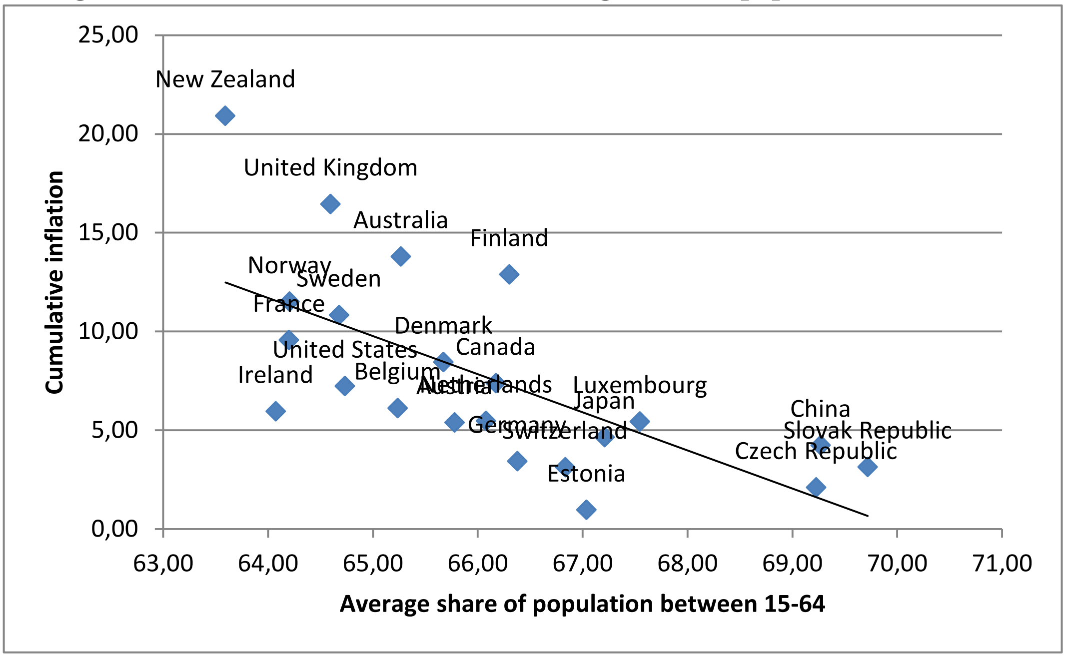
A. Figures and Tables

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



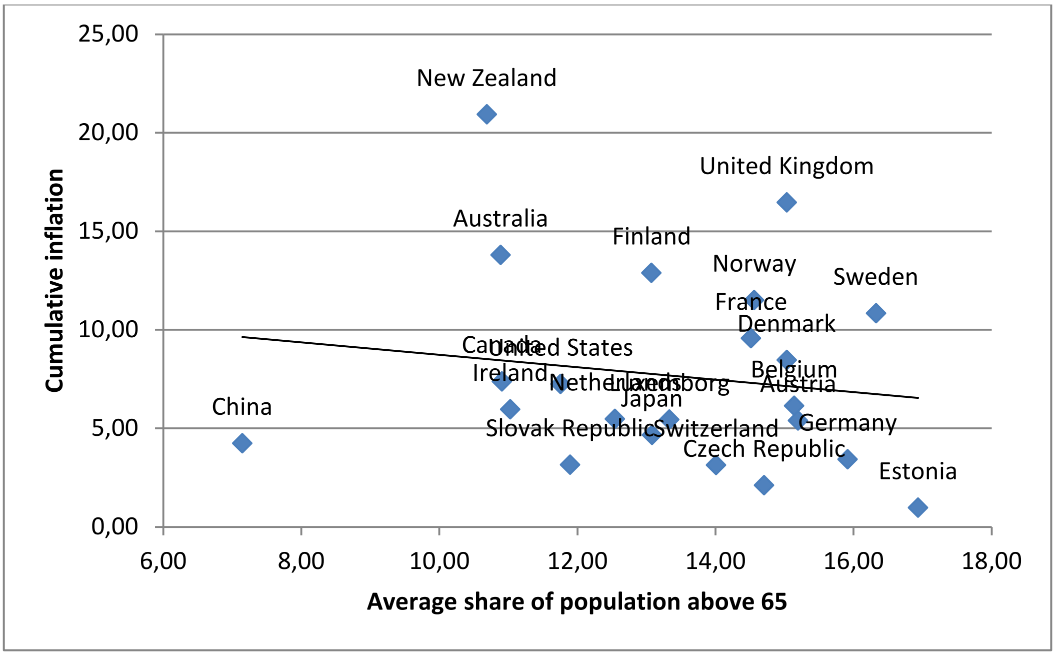
Source: OECD (2018) and World Bank (2018). The vertical axis shows the cumulative inflation rates over the time period 1960-2016, while the horizontal axis shows the average share of population which is under 14 years old during this time period. Note that we do not take any additional explanatory variables 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 – Empirical findings I

	OECD					Japan				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Population Growth	0.339	0.524		0.549	0.317	6.689	6.363		6.708	6.725
	[0.715]	[0.577]		[0.570]	[0.764]	[0.005]***	[0.003]***		[0.001]***	[0.001]***
Share of 65 and over		-0.176	-0.125	-0.137	-0.416		-0.101	-0.321	-0.300	-0.242
		[0.009]***	[0.013]**	[0.006]***	[0.008]***		[0.394]	[0.082]*	[0.060]*	[0.227]
Share of 15-64			-0.101	-0.103	-0.330			-0.476	-0.544	-0.499
			[0.226]	[0.233]	[0.037]**			[0.030]**	[0.008]***	[0.026]**
Life Expectancy					0.304					-0.092
					[0.043]**					[0.748]
TOT change	-0.145	-0.144	-0.145	-0.144	-0.143	-0.169	-0.174	-0.178	-0.148	-0.147
	[0.005]***	[0.005]***	[0.005]***	[0.005]***	[0.005]***	[0.016]**	[0.014]**	[0.013]**	[0.016]**	[0.016]**
GDP growth	-0.750	-0.795	-0.799	-0.802	-0.784	-0.246	-0.319	-0.517	-0.431	-0.452
	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.015]**	[0.033]**	[0.008]***	[0.008]***	[0.022]**
M2 growth	0.192	0.183	0.180	0.180	0.176	0.059	0.034	0.007	-0.009	-0.015
	[0.000]***	[0.000]***	[0.001]***	[0.001]***	[0.000]***	[0.118]	[0.379]	[0.869]	[0.826]	[0.751]
Budget Balance Chg.	0.129	0.153	0.153	0.158	0.150	-0.105	-0.086	0.006	0.040	0.059
	[0.051]*	[0.022]**	[0.033]**	[0.018]**	[0.022]**	[0.540]	[0.563]	[0.971]	[0.776]	[0.690]
Constant	-0.053	2.418	8.443	8.739	4.132	0.074	1.870	37.962	42.051	45.446
	[0.910]	[0.060]*	[0.149]	[0.151]	[0.255]	[0.821]	[0.399]	[0.031]**	[0.010]**	[0.038]**
Observations	1167	1167	1167	1167	1167	53	53	53	53	53
Number of ifscode	30	30	30	30	30					
R-squared	0.212	0.216	0.217	0.217	0.222	0.530	0.545	0.462	0.602	0.603
RMSE	5.235	5.227	5.223	5.223	5.209	2.077	2.066	2.246	1.954	1.973

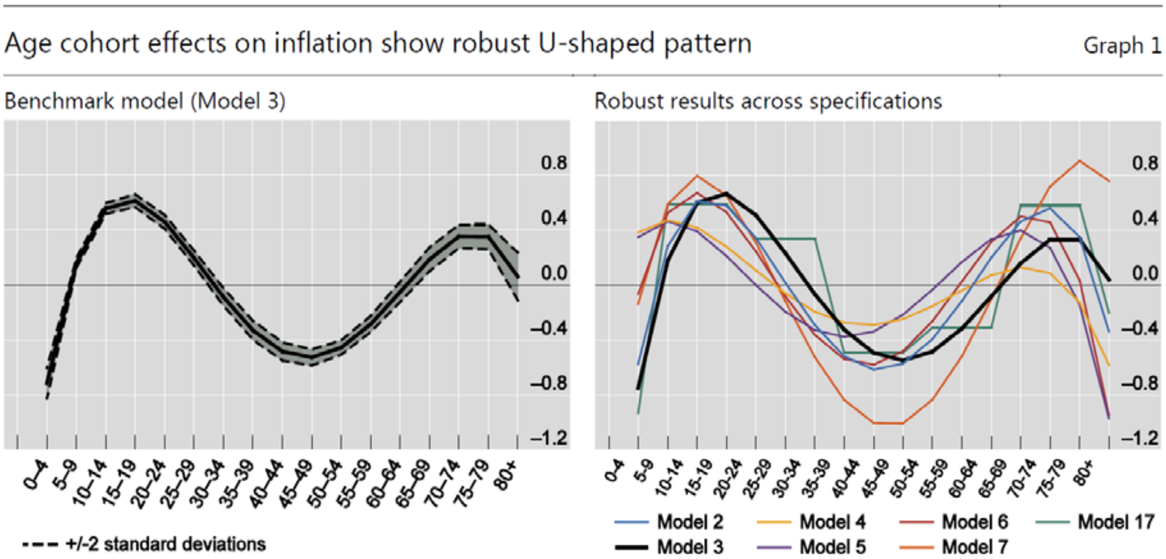
1/ Inflation and population growth are detrended using quadratic filter.

2/ Fixed-effect estimation for OECD and OLS for individual country regressions using annual data.

3/ P-values based on robust t-statistics in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

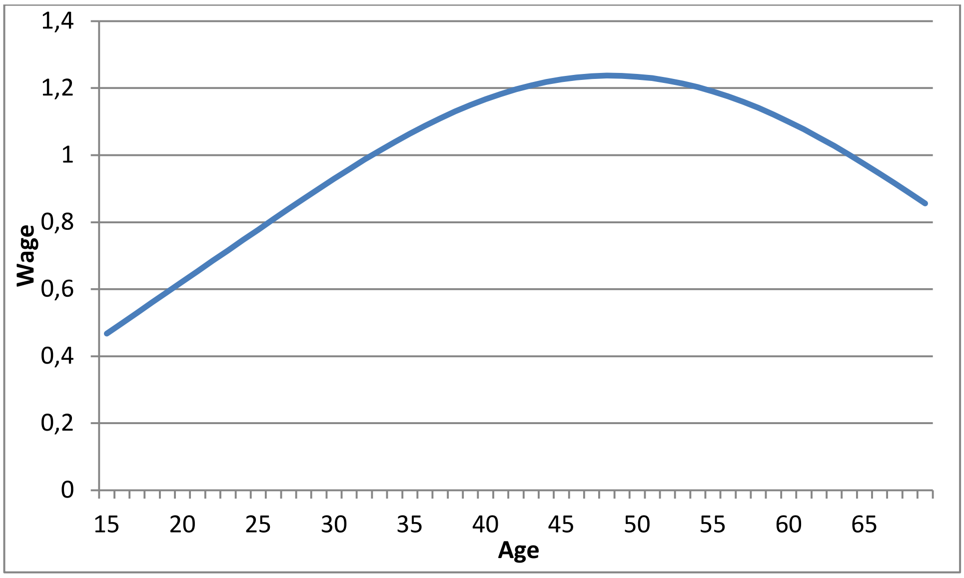
Source: (Yoon, et al., 2014).

Figure A.5 – Empirical findings II



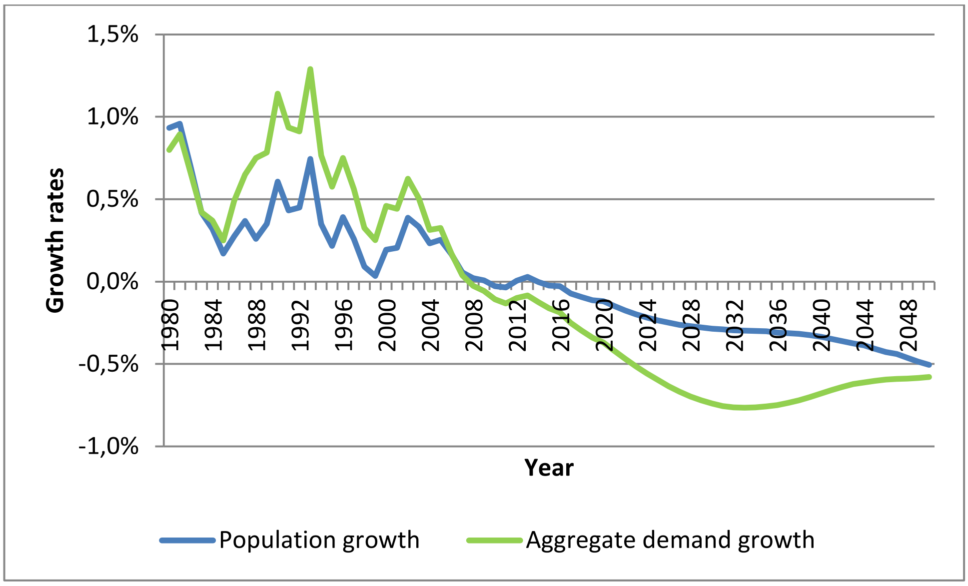
Source: (Juselius & Takáts, 2016).

Figure A.6 –Wage Profiles



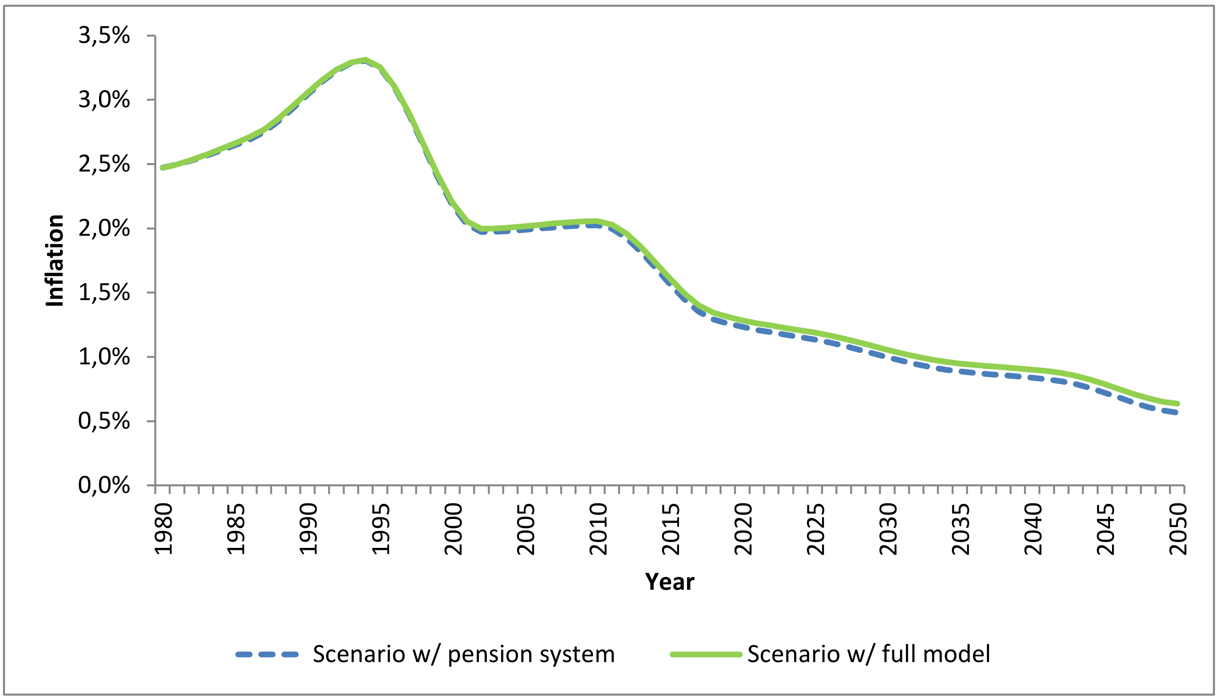
Source: own calculations.

Figure A.7 –Comparison between population and aggregate demand growth rates



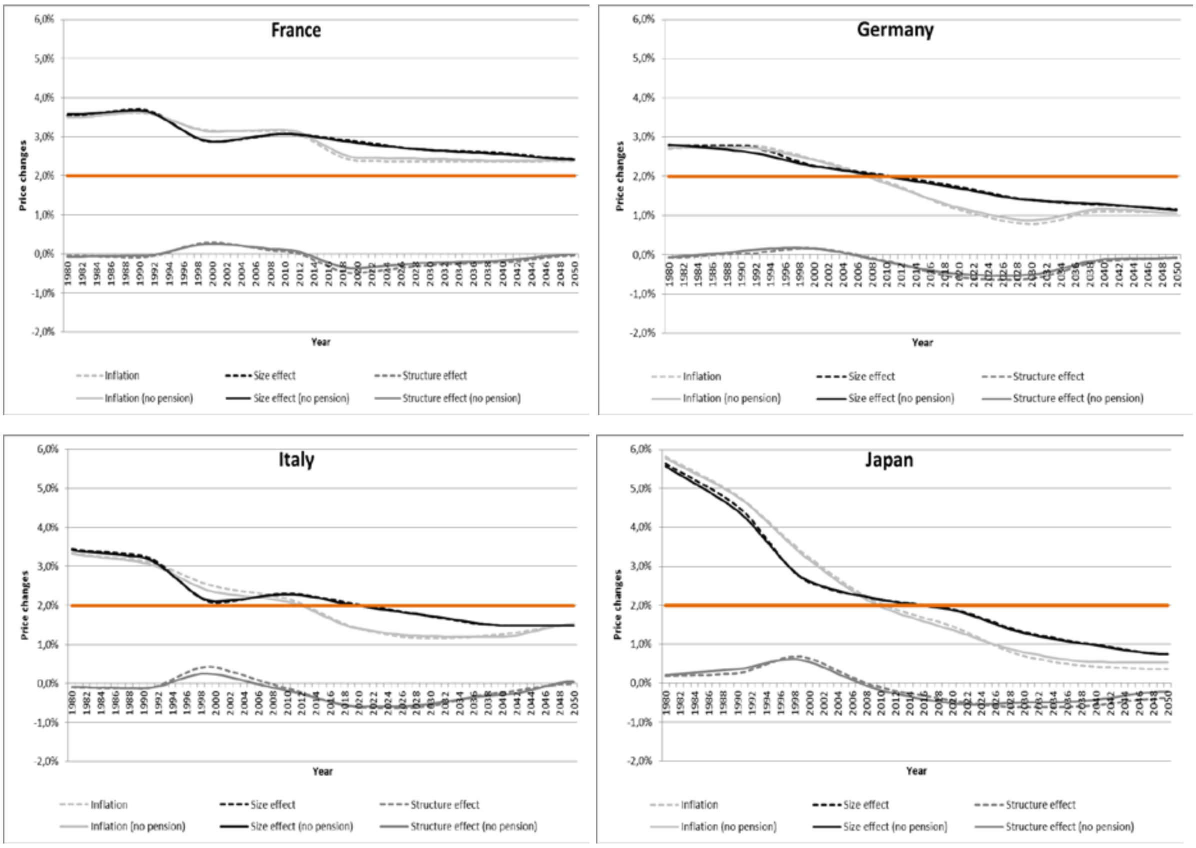
Source: own calculations.

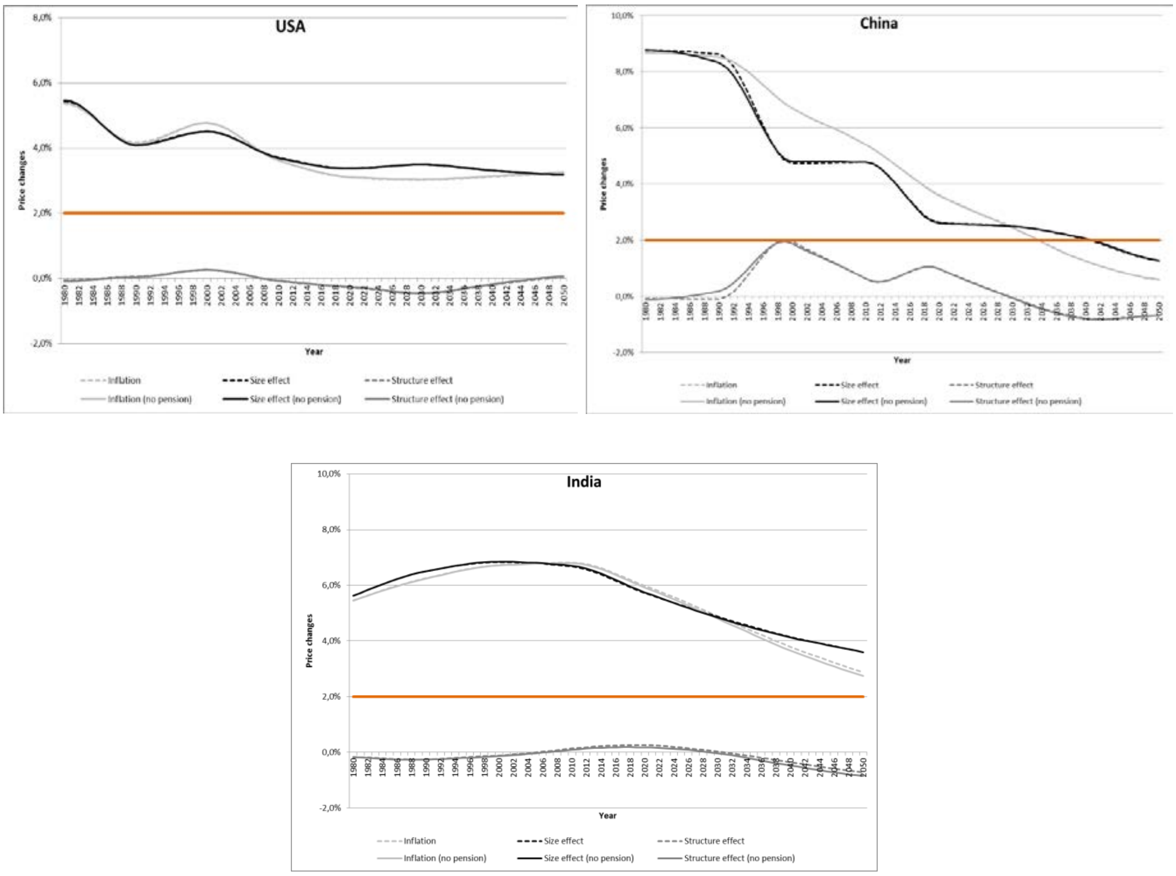
Figure A.8 –Comparison between models with and without labor



Source: own calculations.

Figure A.9 –Inflation rates with and without a PAYG pension system





Source: own calculations.

Table A.1 – Change in inflation rates: Periods (1986-1996 / 2006-2016)

	% change in average inflation (Data)	% change in average inflation (Model)
India	11.20	-6.44
France	53.23	14.59
USA	45.62	16.96
Germany	42.46	35.16
China	75.88	37.39
Italy	70.93	32.26
Japan	77.55	56.65

Source: own calculations.

Table A.2 – Change in inflation rates:
Periods (1990-1995 / 2011-2016)

	% change in average inflation (Data)	% change in average inflation (Model)
India	25.81	-3.58
France	60.51	17.50
USA	53.09	20.84
Germany	65.11	41.51
China	76.74	41.74
Italy	77.34	36.14
Japan	65.04	59.07

Source: own calculations.

Table A.3 – Change in inflation rates:
Periods (1995-2000 / 2011-2016)

	% change in average inflation (Data)	% change in average inflation (Model)
India	5.59	0.24
France	27.90	10.6
USA	36.19	26.98
Germany	10.20	37.11
China	39.39	33.58
Italy	58.56	27.59
Japan	-147.16	49.81

Source: own calculations.

B. Sensitivity Analysis

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 degrees of monetary accommodation are shown in Table B.3. Higher positive values imply a more pro-cyclical reaction of governmental money supply to changes in output and therefore also on money demand. Negative parameter values imply a counter-cyclical reaction. Inflation rates and the size effect are larger for lower parameter values since the government accommodates less to changes in money demand. The structure effect is consequently decreasing as parameter values increase. Accordingly, 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 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 untility 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.