Demographic Trends and Government Debt Dynamics in the United States and Europe *

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Abstract

This paper quantifies the impact of demographic change on government debt dynamics in the United States and five major European economies. We develop a multi-country model that embeds demographic projections into the intertemporal government budget constraint. Population aging affects debt sustainability through slower potential growth, weaker primary balances, and a narrowing gap between output growth and interest rates. Simulations show that demographic trends alone can generate persistent debt accumulation, especially in Italy, Spain, France, and the United States. In contrast, Germany and the Netherlands remain more resilient. Counterfactual experiments indicate that sustained migration inflows can substantially mitigate these demographic pressures and are more effective than delayed retirement.

Keywords: Demographics, Debt Sustainability, Fiscal Policy, Migration, Europe, United States

JEL Classification: H63, E62, J11, F15

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1 Introduction

Advanced economies have experienced a sustained long-term increase in government debt-to-GDP ratios. Figure 1 illustrates this trend for the United States and five major European countries, using annual data from 1960 to 2024.

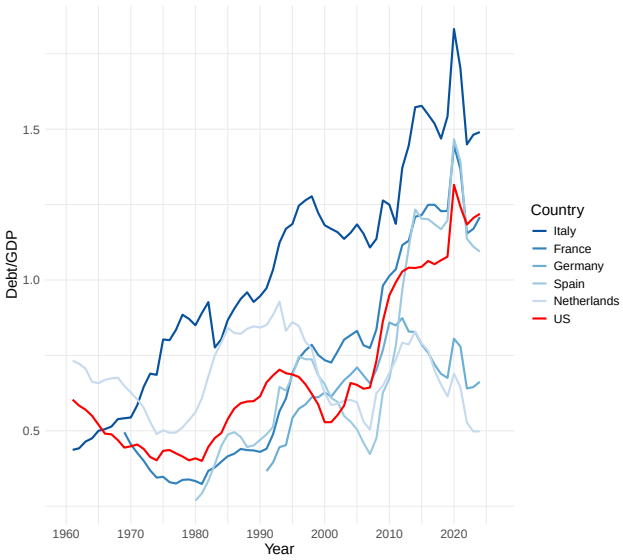


Figure 1: Debt Ratio, 1960–2024

Interestingly, these fiscal dynamics coincide with marked demographic shifts. Figure 2 presents the evolution of the old-age dependency ratio—defined as the ratio of the population above working age to the working-age population—over the same period.

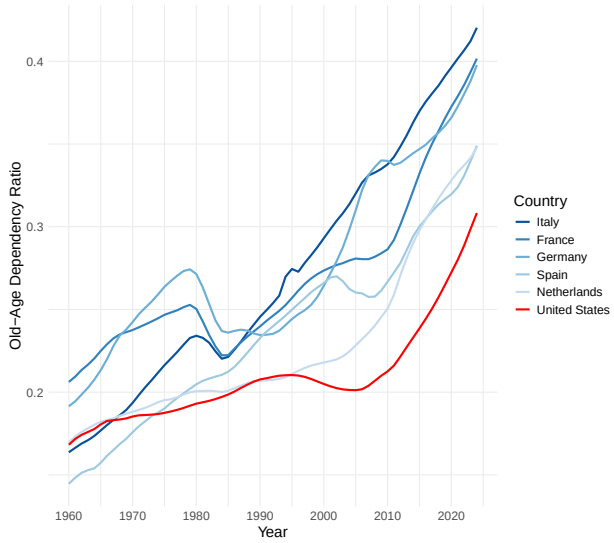


Figure 2: Old-Age Dependency Ratio, 1960–2024

This evidence raises a central question: to what extent do common demographic and fiscal trends reflect a causal relationship?

A recent and influential study by Yared (2019) surveys normative macroeconomic theories in which government debt plays three key roles: facilitating tax smoothing, providing a safe asset, and promoting dynamic efficiency. Yared concludes that the persistent rise in public debt across advanced economies is inconsistent with these frameworks. In particular, theories of tax smoothing would predict debt consolidation—not accumulation—in response to foreseeable long-term fiscal pressures from demographic change, such as declining fertility and increasing longevity.

Instead, Yared draws on political economy models to argue that population aging, rising political polarization, and increasing electoral uncertainty provide more plausible explanations for the observed debt trajectory. As he states:

> "Current governments want to be fiscally irresponsible, while simultaneously hoping that future governments will be fiscally responsible."

Assessing the quantitative implications of demographic trends for debt dynamics remains essential—indeed, especially so if governments behave myopically rather than forward-looking. Such an exercise provides a benchmark for the counterfactual scenario in which fiscal policy internalizes future demographic pressures. Comparing observed debt trajectories with those implied solely by demographic fundamentals allows for a quantitative evaluation of the fiscal cost of government myopia. Moreover, this comparison sheds light on the magnitude of the policy adjustments that will eventually be required to restore debt sustainability as demographic headwinds intensify.

Quantitative analysis is also crucial for evaluating the potential effects of alternative policy reforms that have been proposed in the literature and debated among policymakers (Pinkus and Kirkegaard, 2025).

This paper aims to provide a quantitative assessment of the impact of demographic trends on public debt dynamics, with a particular focus on identifying a potential causal link between demographic change and government debt accumulation.

While the generational accounting literature (Auerbach et al., 1994, 2007) offers important insights and motivates our approach, our methodology differs in a fundamental respect. Generational accounting evaluates the intertemporal fiscal burden across cohorts by incorporating both explicit and implicit liabilities, including unfunded social security commitments. In contrast, we focus narrowly on government debt as defined in the national accounts. We consider social security spending only to the extent that it contributes to primary expenditure, excluding unfunded liabilities or the concept of social security debt from our simulations.

This narrower scope reflects our specific interest in the sustainability of market debt—that is, debt held by private investors in financial markets. Unlike social security obligations, which may be adjusted through legislative reform, market debt constitutes binding contractual claims. As such, understanding how demographic trends influence the trajectory of market debt is critical for assessing fiscal risk and policy options. Our focus is on the impact of demographics trends on fiscal trends rather than on the effect of demographic trends on the effectiveness of fiscal policy (Cho and Rhee, 2024).

To address this, we build a dynamic model that jointly simulates demographic evolution and the intertemporal government budget constraint. In our framework, the key components of the debt-to-GDP ratio—namely, the average cost of debt financing, output growth, and the primary surplus—are modeled as functions of demographic indicators, potential output growth, and long-term inflation expectations.

Our approach departs from typical institutional analyses of aging and debt, which tend to focus primarily on the effect of aging on the primary surplus, without fully accounting for the influence of demographic shifts on long-run output growth and the cost of debt financing.[1] While such studies offer detailed insights into age-related expenditure, particularly within specific pension and social security systems, an important branch of the macroeconomic literature (Blanchard, 2023) emphasizes that the relative dynamics of output growth and debt financing costs are crucial for debt sustainability.

Despite the simplifications in our treatment of age-related spending, we argue that accounting for the feedback effects of demographic change on both growth and interest rates is essential for understanding the long-term implications of ageing for public debt dynamics.

We propose an integrated model of demographic and fiscal evolution in the six countries of interest, in which demographic variables directly influence the key drivers of debt dynamics.

Following model specification and estimation, we proceed in two steps. First, we conduct a within-sample counterfactual analysis to quantify the contribution of demographic trends to the observed increase in the debt-to-GDP ratio. Second, we perform out-of-sample simulations using United Nations projections of mortality, fertility, and migration to forecast the trajectory of government debt under a baseline demographic scenario. Finally, we evaluate our baseline projections against alternative scenarios characterised either by different demographic assumptions, namely migration rates, or by a reform of the social security system, namely a postponement of the retirement age.

[1] See, for example, Directorate General for Economic and Financial Affairs (2021), Directorate Economic and Financial Analysis and Research, Department of the Treasury (2023), Bodnár and Nerlich (2022).

2 Modeling Strategy

The analysis of the research questions outlined in the previous section is based on the specification, estimation, and simulation of a multi-country, integrated demographic–macroeconomic model of government debt dynamics using annual data.

Our model explicitly incorporates demographic dynamics for each of the i countries in the sample: the United States and the five largest Euro area economies—Germany, France, the Netherlands, Italy, and Spain.[2].

The economic block of the model is structured around the intertemporal government budget constraint, where all relevant fiscal variables are expressed as ratios to GDP. This is not a mere normalization but a theoretically meaningful choice. Unlike individuals, governments are infinitely lived institutions and are not required to repay debt in levels as long as they can refinance it. What matters for fiscal sustainability is therefore the evolution of debt relative to the economy's productive capacity, which GDP captures. Financial markets also assess solvency in relative terms, focusing on the debt-to-GDP ratio rather than on nominal debt levels. The distinction is important: the conditions for bubbles or explosive dynamics in the debt-to-GDP ratio differ from those for the nominal level of debt, and debt sustainability depends not only on the trend of public debt itself but on its trajectory relative to that of GDP.[3]

The model focuses on the (stochastic) trend components of public debt determinants, treating cyclical components as residuals.

Demographic dynamics are modeled as exogenous with respect to the evolution of the debt-to-GDP ratio. However, population growth and the age structure of the population are key determinants of macroeconomic variables that directly affect debt dynamics—namely, the average cost of financing government debt, GDP growth, and the primary surplus-to-GDP ratio.

To capture the influence of population growth and age structure on these macroeconomic variables, we classify the total population in each country into four economically meaningful life-cycle age groups: (i) young non-workers (ages 0–19), (ii) young workers (ages 20–45), (iii) middle-aged workers (ages 45–65), and (iv) retirees (ages 65 and older).

Population dynamics are driven by three stochastic processes: annual mortality, natality, and net migration rates. These processes are treated as exogenous and are calibrated using UN projections in our baseline out-of-sample simulations. This allows us to trace the implied

[2]The full model specification is provided in Appendix 1.

[3]Interestingly, most papers discussing the fiscal theory of the price level formulate the intertemporal government budget constraint in levels rather than as ratios to GDP. There are, however, notable exceptions—see, for example, Canzoneri et al. (2001).

long-run trajectory of the debt-to-GDP ratio under projected demographic trends.

The debt-to-GDP dynamics for each country are derived from the intertemporal government budget constraint, which decomposes changes in the debt ratio into three components: (i) the snowball effect—that is, the automatic impact of the relationship between the average interest rate on government debt, GDP growth, and the existing debt stock; (ii) the primary surplus-to-GDP ratio; and (iii) stock-flow adjustments. For simulation purposes, the latter is kept equal to its observed values for within-sample periods and set to zero in out-of-sample projections. Both the average cost of debt financing and GDP growth are modeled explicitly, allowing for demographic influences, particularly through age structure.

We begin by modeling the average cost of financing government debt.

Focusing on long-run behavior, we isolate the persistent component of the average interest rate, treating its transitory fluctuations as residuals. For the United States, where long demographic and financial time series are available, we model the long-run forecast of the average cost of financing government debt as the sum of the long-run inflation forecast and the long-run real interest rate forecast.

In our modeling framework, long-run inflation expectations converge to the credible central bank's inflation target. Empirically, we adopt a specification in which U.S. inflation converges to the Federal Reserve's long-run target and shares a common stochastic trend with inflation in the five European countries in our sample. This specification captures well the within-sample inflation trend and is maintained in the out-of-sample simulations.

In the terminology of Canzoneri et al. (2001), we focus on a money-dominant (MD) regime rather than a fiscal-dominant (FD) regime, where in the latter the price level is determined by the gap between the current real value of government debt and the present discounted value of future primary surpluses (Cochrane, 2023).

This modeling choice is justified on several grounds. First, our main objective is to simulate policies aimed at stabilizing the projected debt-to-GDP ratio in the presence of demographic pressures. Second, in line with the empirical evidence reported by Bohn (1998), we allow for a stabilization feedback from the debt-to-GDP ratio in fiscal rules for the primary surplus. Third, five of the six countries in our sample belong to the Euro area, where monetary policy is conducted by the European Central Bank rather than by national authorities.

The long-run forecast of real interest rates corresponds to the so-called natural rate of interest. In a standard Ramsey framework, Laubach and Williams (2003) show that intertemporal optimization yields a relationship between the natural rate of interest r, the

output growth rate g, and household preferences θ:

$$r = \frac{1}{\sigma} g + \theta. \tag{1}$$

However, Jordà and Taylor (2019) and Mian et al. (2021) show that fluctuations in per capita output growth cannot fully explain the observed drift in the natural rate. This motivates the inclusion of time-varying preference factors. Following Krueger and Ludwig (2007), Favero et al. (2016), Lunsford and West (2019), and Favero et al. (2022), we posit that demographic composition—specifically, the ratio of middle-aged to young workers—affects agents' time preferences.

This mechanism is well-grounded in overlapping generations (OLG) models such as Geanakoplos et al. (2004), where agents live for three periods (young, middle-aged, old) and save only during middle age. According to Bakshi and Chen (1994), life-cycle portfolio behavior implies that equilibrium interest rates adjust in response to the relative size of these age cohorts. When the middle-aged-to-young ratio is high, there is an excess supply of savings, which puts downward pressure on real interest rates and supports higher asset prices.

In sum, our model for the trend component of the U.S. average debt financing cost links it to (i) long-term productivity as proxied by potential output growth, (ii) demographic structure—particularly the age composition of the working-age population—and (iii) long-run inflation expectations, captured by survey-based measures used in the Fed's FRB/US model.[4]

The average cost of financing the safest European government debt—namely, German debt—is assumed to share the same stochastic trend as that of the United States. The average debt cost for the other European countries depends on the spread relative to Germany's, which is modeled as a function of fiscal fundamentals—specifically, the difference between each country's debt-to-GDP ratio and that of Germany.

Nominal GDP growth is decomposed into real growth and inflation. Inflation is projected using long-run expectations: within-sample we use survey-based measures, and out-of-sample we assume convergence to central bank targets. Real GDP converges to potential output with an adjustment term that depends on the dependency ratio, defined as the ratio of the non-working to the working population. Both population growth and age structure influence the trend in potential output growth.

Lastly, the primary surplus is modeled as a function of the output gap, a debt feedback term, a debt-stabilizing fiscal component, and demographic structure—particularly the ratio

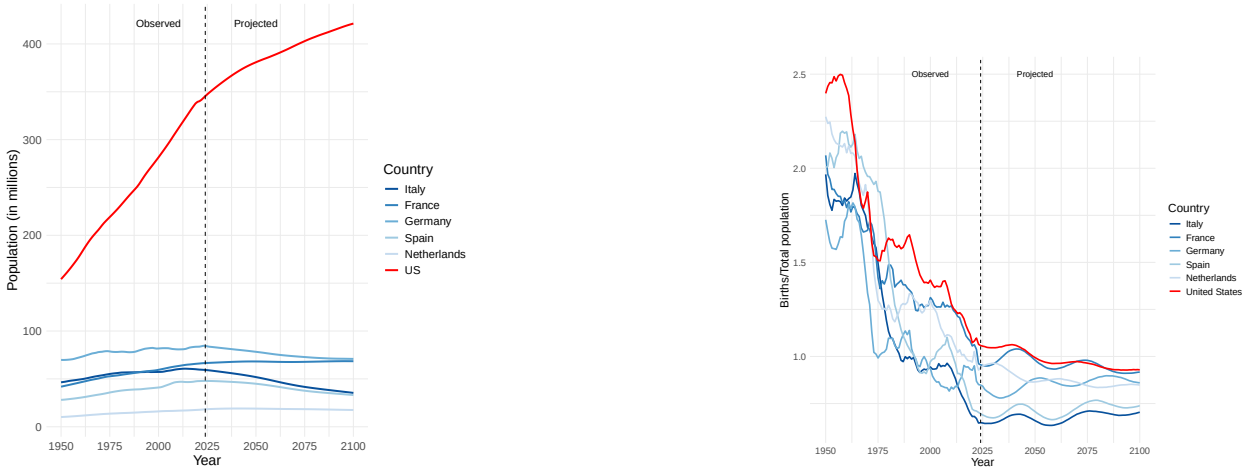
[4] Available at https://www.federalreserve.gov/econres/us-models-package.htm.

of retirees to workers.

3 Modelling Demographic Dynamics

We treat demographic dynamics as exogenous[5] for the estimation of the parameters of interest in the model of government intertemporal budget constraints. We use annual demographic data from the United Nations database[6] and adopt the UN projections, currently available up to 2100, to construct the baseline scenario for our out-of-sample simulations.

In each country in our sample, demographic dynamics are driven by three key variables: natality rates, mortality rates, and net migration rates. These three indicators are reported in Figure 3 and Figure 4, along with trends in total population.



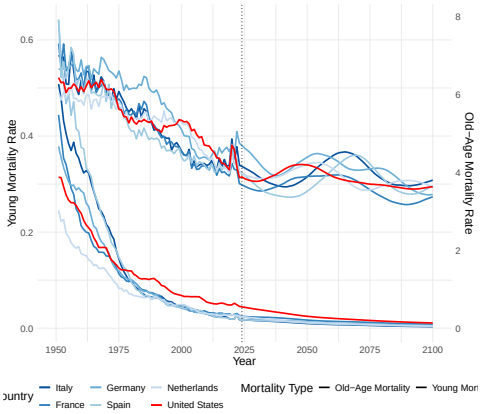
(a) Total Population, 1950–2100

(b) Annual Natality Rates (in %), 1950–2100

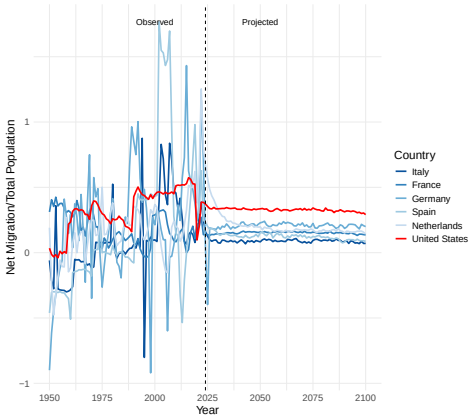
Figure 3: Population and Natality Trends

[5]In fact, as super-exogenous in the classification of Engle et al. (1983)

[6]See the Data Appendix for a detailed description of the data.



(a) Annual Mortality Rates (in %), 1950–2100

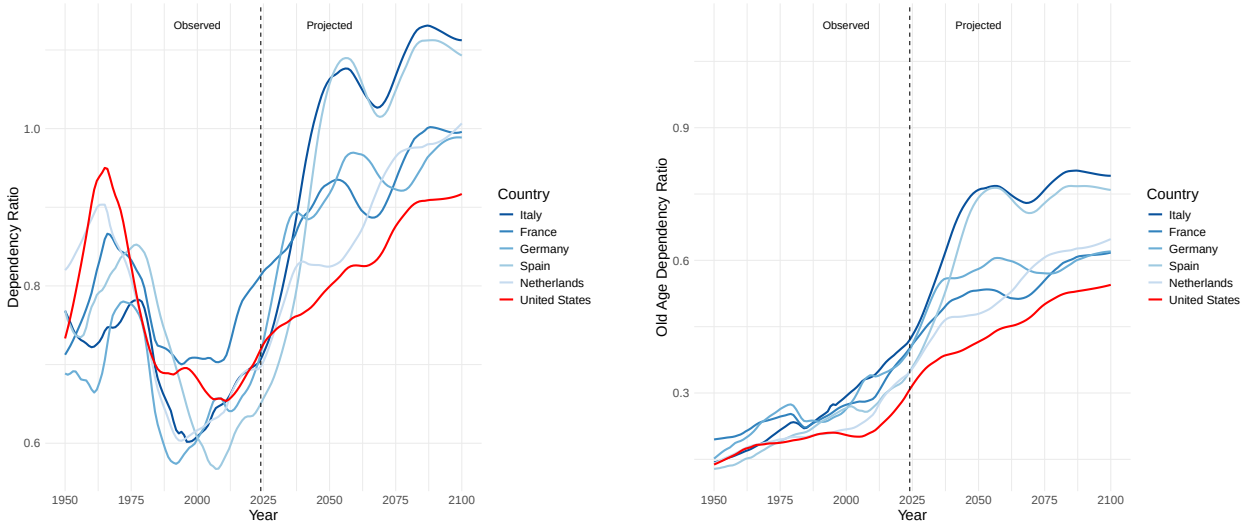


(b) Net Migration Rate (in %), 1950–2100

Figure 4: Mortality and Migration Trends

Natality rates have collapsed from an average of 2 per cent of total population in the 50s' to an average below 1 per cent in 2025. Young-age mortality has also collapsed and old-age mortality has substantially declined. A measure of longevity, residual life expectancy at age 65, has increased by approximately one year every six years over the past four decades. The pattern of net migration has been more volatile with weaker evidence for trends. The evolving patterns in natality and mortality have resulted in a hump-shaped trajectory for total population—one that has already peaked in some countries and is projected to do so in others, eventually giving way to a declining trend. These demographic shifts have also significantly altered the age structure of the population, one of the most important demographic determinants of macroeconomic outcomes (Bloom et al., 2003).

Figure 5 reports the old-age dependency ratio, which measures the share of the elderly (retired) population relative to the working-age population, for all countries in our sample.



(a) Total Dependency Ratio, 1950–2100

(b) Old-Age Dependency Ratio, 1950–2100

Figure 5: Dependency Ratios: Total and by Age Group

The graphical evidence reveals substantial shifts in demographic trends across all countries in the sample. These shifts are not synchronized: they begin relatively homogeneously but diverge over time, particularly in the projected paths of population aging and dependency ratios.

3.1 Model Specification and Calibration

We model population dynamics via a compartmental approach that divides total population in four age groups: $N^1_{i,t}$, 0-19, $N^2_{i,t}$,20-45, $N^3_{i,t}$, 45-65, and $N^4_{i,t}$, over 65. The dynamics for each group and total population are then specified as follows:

$$\begin{aligned}
N^1_{i,t} &= N^1_{i,t-1} + \nu_{i,t} N_{i,t-1} - p^1_{i,t} N^1_{i,t-1} - \phi^1_{i,t} N^1_{i,t-1} \\
N^2_{i,t} &= N^2_{i,t-1} + p^1_{i,t} N^1_{i,t-1} + \mu_{i,t} N_{i,t-1} - p^{2,i}_{t} N^{2,i}_{t-1} - \phi^2_{i,t} N^2_{i,t-1} \\
N^3_{i,t} &= N^3_{i,t-1} + p^2_{i,t} N^2_{i,t-1} - p^3_{t} N^3_{i,t-1} - \phi^3_{i,t} N^3_{i,t-1} \\
N^4_{i,t} &= N^4_{i,t-1} + p^3_{i,t} N^3_{i,t-1} - \phi^4_{t} N^4_{i,t-1} + u_{i,t} \\
N_{i,t} &= N^1_{i,t} + N^2_{i,t} + N^3_{i,t} + N^4_{i,t}
\end{aligned}$$

$\nu_{i,t}$ is the birth rate, $\mu_{i,t}$ is net migration rate, defined as the ratio of total net migration in year t to total population at the end of period t-1, $\phi^j_{i,t}$ are the rates of fatality in age group j and country i, $p^j_{i,t}$ is the percentage of individuals in country i included in compartment j in year $t-1$ who move to compartment $j+1$ in year t. $\nu_{i,t}$, $\mu_{i,t}$, $\phi^j_{i,t}$ are obtained from the UN database, $p^1_{i,t}, p^2_{i,t}, p^3_{i,t}$ are then obtained by solving the first three equations of our system in

each period. Only the equation for $N^4_{i,t}$ contains a measurement error, $u_{i,t}$. Table 1 reports the definition of all demographics variables included in our model.

Table 1: Definitions of Demographic Variables

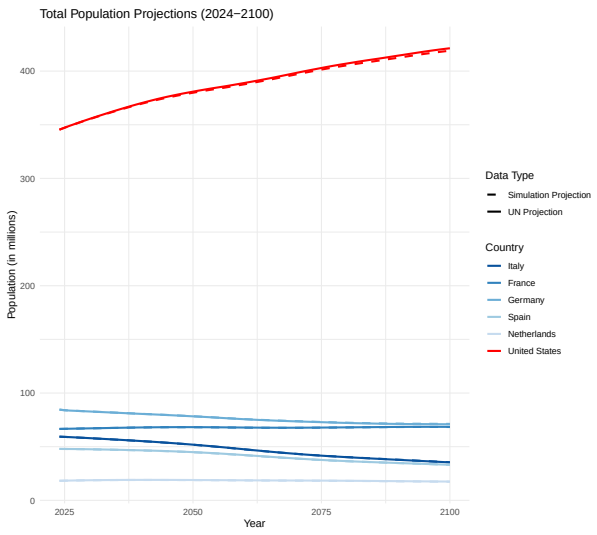
Symbol	Definition	Source	Notes / Transformation
$N^1_{i,t}$	Population aged 0–19 in country i at time t	UN Data	Constructed from age-specific population sizes
$N^2_{i,t}$	Population aged 20–45	UN Data	Constructed from age-specific population sizes
$N^3_{i,t}$	Population aged 45–retirement age[7]	UN Data	Constructed from age-specific population sizes
$N^4_{i,t}$	Population above retirement age	UN Data	Constructed from age-specific population sizes
$N_{i,t}$	Total population ($N^1_{i,t}+N^2_{i,t}+N^3_{i,t}+N^4_{i,t}$)	UN Data	Sum of age groups
$\Delta n_{i,t}$	Population growth rate	UN Data	$\frac{N_{i,t}-N_{i,t-1}}{N_{i,t-1}}$
$\frac{N^3_{i,t}}{N^2_{i,t}}$	Middle-aged to young ratio	–	Used as proxy for age structure in rate equations
$\frac{N^4_{i,t}}{N^2_{i,t}+N^3_{i,t}}$	Old-age dependency ratio	–	Captures retirees relative to working-age population
$\frac{N^1_{i,t}+N^4_{i,t}}{N^2_{i,t}+N^3_{i,t}}$	Total dependency ratio	–	Includes both young and elderly dependents
$\nu_{i,t}$	Birth rate (births per total population)	UN Data	Direct use
$\mu_{i,t}$	Net migration rate (net migration per total population)	UN Data	Direct use
$\phi^j_{i,t}$	Mortality rate in age group j	UN Mortality Tables	Direct use
$p^j_{i,t}$	Transition probability from age group j to $j+1$	Calibrated	Solved via system of cohort equations
$u_{i,t}$	Measurement error term	Not observed	Residual in $N^4_{i,t}$ equation

3.2 Model Evaluation

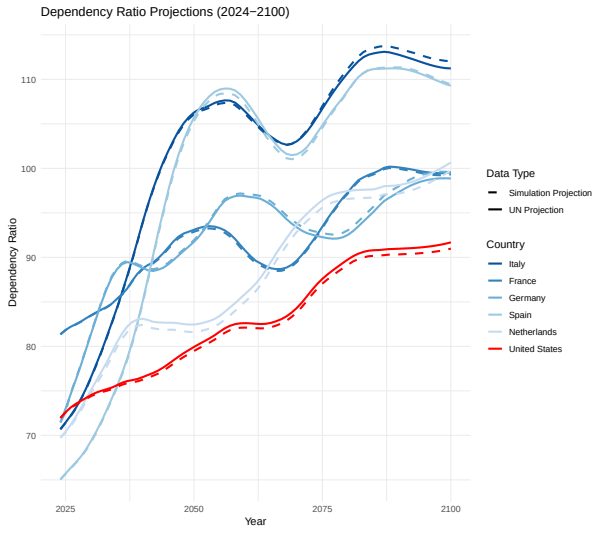
We evaluate the importance of the approximation errors introduced by our specification by comparing the out-of-sample UN projections for demographic variables with the projections obtained by dynamic simulation of our model. The evidence is supportive of the chosen

[7]Baseline retirement age = 65. Alternative ages only used in reform scenarios.

specification as illustrated by Figure 6 reporting total population, and old-age dependency ratios.



(a) UN and Simulation Projected Population, 2024–2100



(b) UN and Simulation Projected Dependency Ratio , 2024–2100

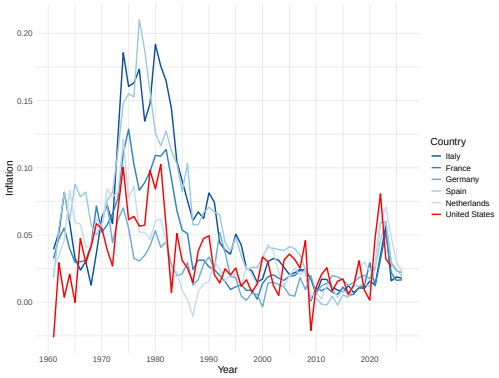
Figure 6: Demographics model evaluation

4 Modelling the Debt Dynamics

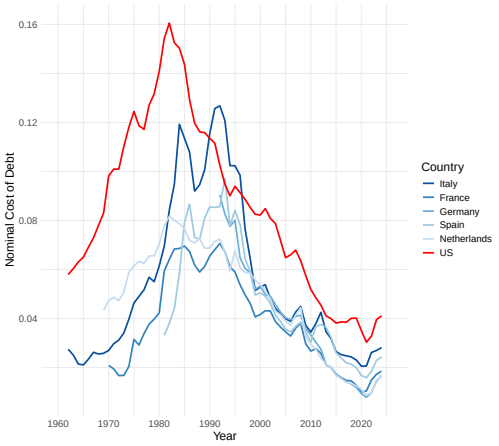
Our strategy for modelling the debt dynamics is very simple: we start from the intertemporal government budget constraint (IGBC) and we model the trend in its drivers by taking explicitly into account the impact of demographic trends. Our strategy focuses exclusively on the trend components and on the importance of demographics in determining economic trends. Considering the debt to GDP ratio, $b_{i,t}$, the IGBC for each country i is :

$$b_{i,t} = b_{i,t-1} + \frac{R^{av}_{i,t} - g_{i,t}}{1 + g_{i,t}} b_{i,t-1} - s_{i,t} + sfa_{i,t} \tag{2}$$

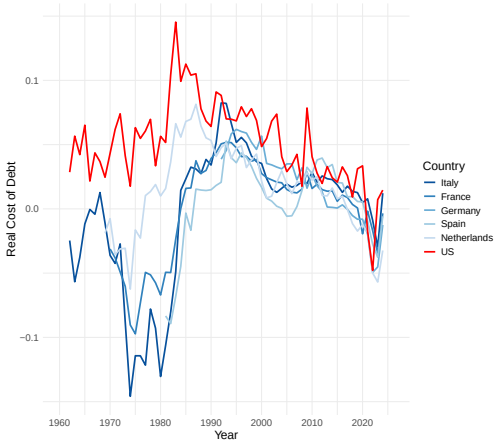
so our strategy requires modelling the average cost of financing the debt, $R^{i,av}_t$, growth, g^i_t, and the primary surplus to GDP ratio s^i_t. Figure 7 reports the time-series of all these variables by decomposing the cost of financing the debt and output growth into their real component and inflation. All variables are very persistent and very slowly mean reverting showing the presence of stochastic trends.



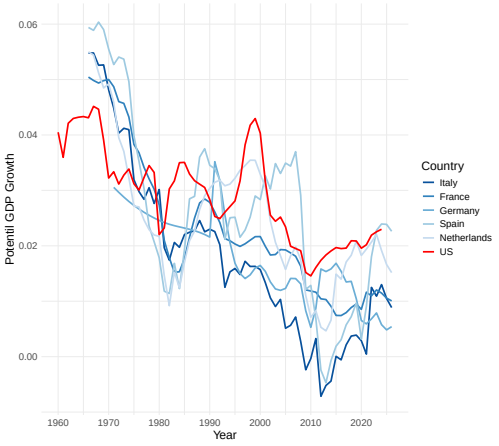
(a) Annual Inflation, 1960–2024



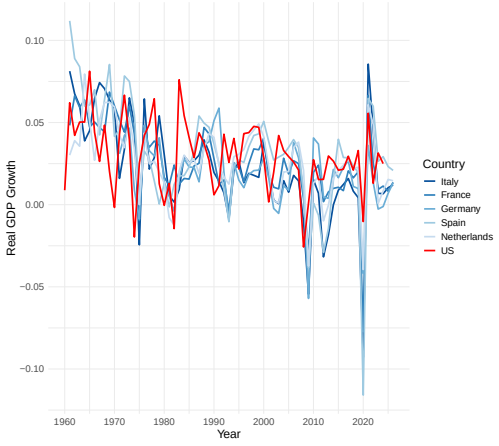
(b) Nominal Average Cost of Financing Debt, 1960–2024



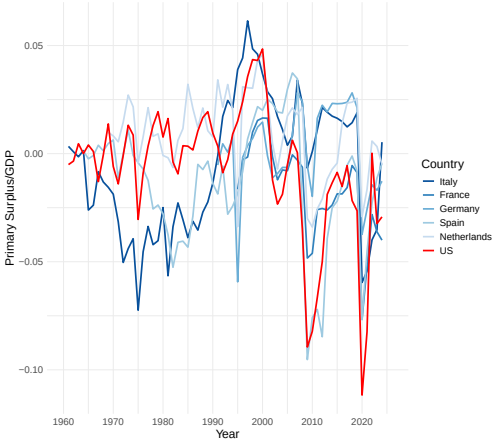
(c) Real Cost of Financing Debt, 1960–2024



(d) Real Potential Output Growth, 1960–2024



(e) Real Output Growth, 1960–2024



(f) Primary Surplus/GDP, 1960–2024

Figure 7: Macro-fiscal trends

4.1 Model Specification and Estimation

We adopt a modelling strategy in which the stochastic trends in the debt drivers are related to demographic trends. In the following subsections we shall illustrate specification and estimation of the system of the equations we employ to simulate the debt to GDP dynamics. The definition of all variables is reported in Table 2

Table 2: Definitions of Economic and Fiscal Variables

Symbol	Definition	Source	Notes / Transformation
$g_{i,t}$	Nominal GDP growth	FRED, AMECO	$g_{i,t} = \Delta y_{i,t} + \pi_{i,t}$
$\Delta y_{i,t}$	Real GDP growth	FRED, AMECO	-
$\Delta y_{i,t}^{pot}$	Potential real GDP growth	FRED, AMECO	For Germany(pre-1990) constructed using HP-filter
$y_{i,t}^{gap}$	Output gap	Constructed	$y_{i,t} - y_{i,t}^{pot}$
$\pi_{i,t}$	Inflation rate	FRED, AMECO	Constructed from GDP deflators
$\pi_{US,t}^{LR}$	Long-run U.S. inflation expectations	Fed FRB/US model	Survey-based measure of long-run inflation target
$B_{i,t}$	Total government debt (nominal)	OECD	Gross Public Debt
$b_{i,t}$	Debt-to-GDP ratio	Constructed	$b_{i,t} = \frac{B_{i,t}}{Y_{i,t}}$
$S_{i,t}$	Primary surplus (nominal)	OECD	Total Revenue − (Total Expenditure − Interest Payments)
$s_{i,t}$	Primary surplus-to-GDP ratio	Constructed	$s_{i,t} = \frac{S_{i,t}}{Y_{i,t}}$
$R_{i,t}^{av}$	Average nominal cost of financing debt	National accounts	$\frac{\text{Interest Expenditure}}{B_{i,t-1}}$
$sfa_{i,t}$	Stock-flow adjustment	OECD	Residual change in $b_{i,t}$ not explained by flows
$\frac{R_{i,t}^{av} - g_{i,t}}{1+g_{i,t}} b_{i,t-1}$	Snowball effect	Constructed	Contribution of interest-growth differential to change in debt ratio

4.1.1 Modelling the Average Costs of Financing the Debt

Our starting point is to model the trend in the US average cost of financing the debt using long-term productivity, measured by potential output growth, long-run inflation expectations $\pi_{US,t}^{LR}$, measured by the survey-based measure of long-run inflation expectations, the age structure of the population as proxied by the middle-aged to young ratio, $\frac{N_{US,t}^3}{N_{US,t}^2}$. This variable

has been successfully used to model the common trend in real US rates and we exploit the availability of a relatively larger sample for the US data (1957-2024) to pin down the relevant parameters determining the trend. Next, we consider the average cost of financing the safer European debt, i.e. the German debt, which is modelled as sharing a common trend with the US cost of financing the debt. Finally, the long-term trend in the spread of the average cost of financing the debt of all other European countries on the German average cost of financing the debt is modelled as a function of fiscal fundamentals, and in particular of the relative debt to GDP ratio. To sum up we specify the following system:

$$\begin{aligned} R^{av}_{US,t} &= \beta_1 \Delta y^{pot}_{US,t} + \beta_2 \pi^{LR}_{US,t} + \beta_3 \frac{N^3_{US,t}}{N^2_{US,t}} + \epsilon^{US}_{1,t} \\ R^{av}_{DE,t} &= \beta_0 + \beta_1 R^{av}_{DE,t-1} + \beta_2 R^{av}_{US,t} + \epsilon^{DE}_{1,t} \\ R^{av}_{j,t} &= R^{av}_{DE,t} + \beta_{0,j} + \beta_{1,j}(b_{j,t-1} - b_{DE,t-1}) + \epsilon^{j}_{1,t} \end{aligned} \tag{3}$$

where $j = NED, FR, SP, IT$

The estimation results, reported in Table 3, confirms the significance of thew age structure of US population in determining the trend in real rates with sign and magnitude of estimated coefficients on this variable, on the proxy for productivity, growth of real potential output, and on the long-run inflation expectations in line with those available in the literature[8]. The German average cost of financing the debt converges in the long run to the US cost with a negative spread. The spread of of European cost of financing the debt is successfully related to the fundamentals and the cross-equation restrictions that the effect of the debt difference on the spread is homogeneous across countries cannot be rejected. The estimated value of ρ parameter in the regression of the residuals on their lags and the value of the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1981) statistics speak overall in favor of the success of the adopted specification in modelling the trend in the average cost of financing the debt.

[8]See for example Favero et al. (2022)

	$R^{av}_{US,t}$	$R^{av}_{DE,t}$	$R^{av}_{NED,t} - R^{av}_{DE,t}$	$R^{av}_{FR,t} - R^{av}_{DE,t}$	$R^{av}_{SP,t} - R^{av}_{DE,t}$	$R^{av}_{IT,t} - R^{av}_{DE,t}$
(Intercept)	0.081***	-0.009***	0.001	-0.007***	0.002**	-0.001
	(0.020)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
$\Delta y^{pot}_{US,t}$	0.879***					
	(0.230)					
$\pi^{LR}_{US,t}$	1.467***					
	(0.124)					
$\frac{N^3_{US,t}}{N^2_{US,t}}$	-0.107***					
	(0.021)					
$R^{av}_{US,t}$		0.307***				
		(0.080)				
$R^{av}_{DE,t-1}$		0.693***				
		(0.080)				
$(b_{i,t-1} - b_{DE,t-1})$			0.013***	0.013***	0.013***	0.013***
			(0.002)	(0.002)	(0.002)	(0.002)
$SMPL$	1968-2024	1993-2024	2000-2024	2000-2024	2000-2024	2000-2024
R^2	0.936	0.984	0.379	0.629	0.515	0.126
σ	0.0096	0.0030	0.0021	0.0026	0.0046	0.0057
ρ	0.847	0.058	0.315	0.461	0.741	0.770
ADF	-2.007	-5.092	-3.370	-4.034	-2.032	-1.943

Table 3: Modeling the Average Cost of Financing the Debt $R^{i,av}_t$

4.1.2 Modelling Growth

We model nominal growth in each country by decomposing it into its two components, real GDP growth and GDP inflation:

$$g^i_t = \Delta y^i_t + \pi^i_t$$

The trend in real output growth in each country is modelled as a function of potential output and the age-structure of the population, as reflected in the dependency ratio. In turn, demographics play a role in the determination of real potential output growth via both population growth and the age-structure of the population, proxied by the young to middle-age ratio and the old-age dependency ratio.[9] The following specification is therefore adopted:

$$\Delta y^{pot}_{i,t} = \gamma_{1,i}\Delta n_{i,t} + \gamma_{2,i}\frac{N^2_{i,t}}{N^3_{i,t}} + \gamma_{3,i}\frac{N^4_{i,t}}{N^2_{i,t} + N^3_{i,t}} + \epsilon^3_{i,t} \quad (4)$$

$$\Delta y_{i,t} = \gamma_{0,i} + \gamma_{1,i}\Delta y^{pot}_{i,t} + \gamma_{2,i}(y_{i,t-1} - y^{pot}_{i,t-1}) + \gamma_{3,i}\frac{N^1_{i,t} + N^4_{i,t}}{N^2_{i,t} + N^3_{i,t}} + \epsilon^4_{i,t} \quad (5)$$

Table 4 reports the results of the estimation of our Error Correction specification where

[9]This is consistent with the approach adopted by (Brunnschweiler et al., 2021), who build a model of endogenous interactions between fertility and innovation-led productivity growth.

the trend in output is determined by the trend in potential output with a correction determined by the dependency ratio, which has a negative impact on growth very homogeneous across different countries. The estimates of ρ and the ADF statistics offer strong evidence against non-stationarity of the residuals of all equations.

The evidence in Table 5 shows the significance and the importance of both population growth and the age structure of population in determining the trends in productivity. These effects are very homogeneous across countries and the restriction that the effect of population growth is exactly the same across countries cannot be rejected and it is imposed in the estimated system.

Inflation trends are modeled based on the understanding that central banks exert substantial control over inflation and that inflation has become increasingly influenced by global factors. Accordingly, we adopt a simple specification for U.S. inflation in which it exhibits persistence but gradually converges to long-run inflation expectations. These expectations have declined over time, aligning with the Federal Reserve's 2 percent inflation target since the early 2000s.

We proxy long-run inflation expectations using the survey-based measure π_t^{LR}, which is also employed in the Federal Reserve's FRB/US model[10]. This measure has exhibited a downward trend over time, converging toward the Federal Reserve's 2 percent target. The credibility of the central bank implies that long-run expectations should remain closely anchored to the target.

Given that both the Federal Reserve and the European Central Bank (ECB) share the same long-run inflation target, and considering that inflation has increasingly become a global phenomenon, we model inflation in Euro area countries as an autoregressive process that, in the long run, converges to U.S. inflation. The following specification is therefore adopted:

$$\begin{aligned} \pi_{US,t} &= \phi_{1,US}\pi_{US,t-1} + (1-\phi_{1,US})\pi_{LR}^{US,t} + \epsilon_{2,t}^{US} && (6) \\ \pi_{k,t} &= \phi_{1,k}\pi_{k,t-1} + (1-\phi_{1,k})\pi_{US,t} + \epsilon_{2,t}^{k} && (7) \\ k &= DE, NED, FR, SP, IT \end{aligned}$$

This is admittedly a highly simplified model of inflation; however, it is effective in capturing the observed trends across the countries in our sample. The success of this specification in modeling inflation trends—despite not explicitly linking them to public debt dynamics—should not be interpreted as evidence against the fiscal theory of the price level (Cochrane, 2023). According to this theory, it is not the level of debt per se that causes

[10] Available at https://www.federalreserve.gov/econres/us-models-package.htm.

inflation, but rather the gap between the current debt level and the present discounted value of future primary surpluses. Thus, the current success of central banks in keeping long-term inflation anchored at their target may be the result of market expectations of future surpluses that stabilize the debt. Such expectations could deteriorate if debt levels become unsustainable.

Since the primary focus of our model is the effect of demographic trends on public debt dynamics, we maintain in our out-of-sample simulations the assumption that the inflation trends observed over the past 50 years will continue unchanged.

The estimation results are reported in Table 6. All coefficients are significantly different from zero, and the restrictions that U.S. inflation converges to long-run expected inflation, and that inflation in European countries converges to the shared long-run target of the Fed and the ECB, are validly imposed. The estimated value of the ρ parameter in the regression of the residuals on their lags, together with the Augmented Dickey-Fuller (ADF) statistic (Dickey and Fuller, 1981), confirm the stationarity of the residuals and validate the success of the adopted specification in capturing inflation trends.

	$\Delta y_{US,t}$	$\Delta y_{DE,t}$	$\Delta y_{NED,t}$	$\Delta y_{FR,t}$	$\Delta y_{SP,t}$	$\Delta y_{IT,t}$
$\Delta y_{i,t}^{pot}$	1.433***	1.433***	1.433***	1.433***	1.433***	1.433***
	(0.086)	(0.086)	(0.086)	(0.086)	(0.086)	(0.086)
$(y_{i,t-1} - y_{i,t-1}^{pot})$	-0.448***	-0.467***	-0.518***	-0.590***	-0.339***	-0.538***
	(0.102)	(0.118)	(0.127)	(0.130)	(0.068)	(0.097)
$\frac{N_{i,t}^1+N_{i,t}^4}{N_{i,t}^2+N_{i,t}^3}$	-0.019***	-0.014***	-0.016***	-0.015***	-0.020***	-0.016***
	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)
$SMPL$	1960-2024	1971-2026	1966-2026	1966-2026	1966-2026	1966-2026
R^2	0.372	0.345	0.552	0.559	0.525	0.566
σ	0.0173	0.0169	0.0144	0.0152	0.0213	0.0199
ρ	0.126	0.184	0.203	0.086	0.179	0.030
ADF	-7.194	-6.080	-6.522	-7.059	-6.404	-7.558

Table 4: Modeling Real Growth $\Delta y_{i,t}$

	$\Delta y^{pot}_{US,t}$	$\Delta y^{pot}_{DE,t}$	$\Delta y^{pot}_{NED,t}$	$\Delta y^{pot}_{FR,t}$	$\Delta y^{pot}_{SP,t}$	$\Delta y^{pot}_{IT,t}$
$\Delta n_{i,t}$	1.294***	1.294***	1.294***	1.294***	1.294***	1.294***
	(0.154)	(0.154)	(0.154)	(0.154)	(0.154)	(0.154)
$\frac{N^2_{i,t}}{N^3_{i,t}}$	0.011***	0.020***	0.014***	0.020***	0.020***	0.024***
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)
$\frac{N^4_{i,t}}{N^2_{i,t}+N^3_{i,t}}$	-0.013	-0.035***	-0.023*	-0.050***	-0.049***	-0.058***
	(0.020)	(0.012)	(0.012)	(0.013)	(0.014)	(0.010)
$SMPL$	1960-2024	1971-2026	1966-2026	1966-2026	1966-2026	1966-2026
R^2	0.400	0.578	0.501	0.536	0.459	0.548
σ	0.0067	0.0052	0.0087	0.0089	0.0124	0.0108
ρ	0.869	0.681	0.894	0.939	0.933	0.937
ADF	-2.080	-3.212	-2.423	-2.326	-1.299	-1.326

Table 5: Modeling Real Potential Growth $\Delta y^{pot}_{i,t}$

	$\pi_{US,t}$	$\pi_{DE,t}$	$\pi_{NED,t}$	$\pi_{FR,t}$	$\pi_{SP,t}$	$\pi_{IT,t}$
$\pi_{US,t-1}$	0.367***					
	(0.132)					
$\pi^{LR}_{US,t}$	0.633***					
	(0.132)					
$\pi_{k,t-1}$		0.769***	0.667***	0.772***	0.900***	0.858***
		(0.078)	(0.072)	(0.067)	(0.040)	(0.036)
$\pi_{US,t}$		0.231***	0.333***	0.228***	0.100**	0.142***
		(0.078)	(0.072)	(0.067)	(0.040)	(0.036)
$SMPL$	1968-2024	1972-2024	1971-2024	1971-2024	1971-2024	1971-2024
R^2	0.793	0.605	0.792	0.913	0.902	0.894
σ	0.0198	0.0109	0.0123	0.0107	0.0164	0.0184
ρ	0.119	-0.084	0.065	0.056	0.139	0.152
ADF	-6.632	-7.643	-7.303	-6.524	-6.192	-5.977

Table 6: Modeling Inflation π^i_t

4.1.3 Modelling Primary Surplus to GDP ratios

Our specification for the primary surplus to GDP ratio extends the standard approach (see, for example, Bohn (1998)) modelling a debt stabilization motive, as captured by the debt to GDP ratio, together with an output stabilization motive, as captured by the output gap, to include the old-age dependency ratio to capture the impact of the trends in social

security and health expenditure determined by the age structure of population. The following specification is then adopted:

$$s_{i,t} = \beta_0 + \beta_1 y_{i,t}^{gap} + \beta_2 b_{i,t-1} + \beta_{3,i} \frac{N_{i,t}^4}{N_{i,t}^2 + N_{i,t}^3} + \epsilon_{i,t}^5 \tag{8}$$

The estimation results are reported in Table 7. Surpluses feature procyclicality in all countries, with coefficients on output gaps all significantly positive and somewhat heterogeneous. As far as the debt stabilization motive is concerned countries can be grouped in those with a significant stabilizing debt feedback (DE, NED and SP) and those for which the debt feedback can be restricted to zero (US, FR, and IT). The effect of the old age dependency ratio is always negative but again countries can be grouped in those with surplus sensitivity to the age-structure (US, SP, and IT) and those with a lower surplus sensitivity to the age-structure (DE, NED, FR). Also in this case the overall evidence is for residuals' stationarity, with the only exception of France.

	$s_{US,t}$	$s_{DE,t}$	$s_{NED,t}$	$s_{FR,t}$	$s_{SP,t}$	$s_{IT,t}$
(Intercept)	0.093***	0.004	0.004	0.018	0.082***	0.162***
	(0.013)	(0.015)	(0.013)	(0.014)	(0.015)	(0.019)
$y_{i,t}^{gap}$	1.293***	0.639***	0.889***	0.703***	0.734***	0.080
	(0.187)	(0.218)	(0.190)	(0.186)	(0.084)	(0.131)
$b_{i,t-1}$	0.000	0.048***	0.048***	0.000	0.048***	0.000
	(0.000)	(0.011)	(0.011)	(0.000)	(0.011)	(0.000)
$\frac{N_{i,t}^4}{N_{i,t}^2+N_{i,t}^3}$	-0.447***	-0.103**	-0.103**	-0.103**	-0.447***	-0.447***
	(0.057)	(0.043)	(0.043)	(0.043)	(0.057)	(0.057)
$SMPL$	1991-2024	1992-2024	1991-2024	1995-2024	1991-2024	1991-2024
R^2	0.530	0.370	0.602	0.617	0.691	0.368
σ	0.0272	0.0170	0.0153	0.0139	0.0206	0.0222
ρ	0.502	0.286	0.269	0.840	0.579	0.569
ADF	-3.413	-4.174	-4.296	-1.459	-3.072	-3.286

Table 7: Modeling Primary Surplus to GDP Ratios $s_{i,t}$

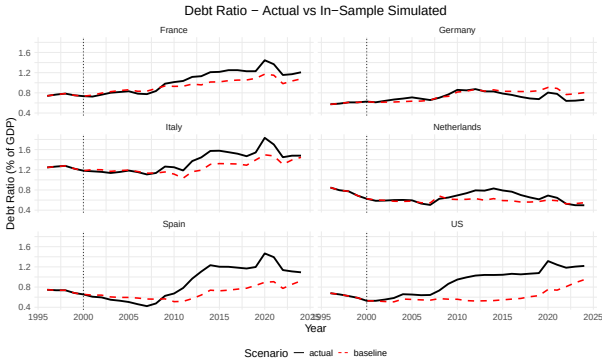
4.2 Model Evaluation

Since the goal of our specification is to assess the extent to which demographic trends can explain debt dynamics, a natural way to evaluate the model is to compare actual data with the simulated outcomes generated by our full model within the sample period. Figure 8 presents the results of these simulations, in which both demographic and economic variables

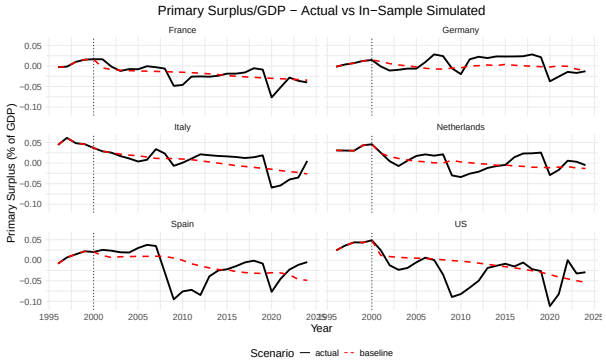
are endogenously determined by solving the complete model.

The key finding is the model's ability to replicate the trend in the debt-to-GDP ratio. The sample period includes three major shocks—the U.S. financial crisis, the European sovereign debt crisis, and the COVID-19 pandemic—which the model does not explicitly account for, leading to temporary deviations from the demographic-driven trend. However, toward the end of the sample, as the effects of these shocks dissipate, the observed data realign with the demographic-based trajectory.

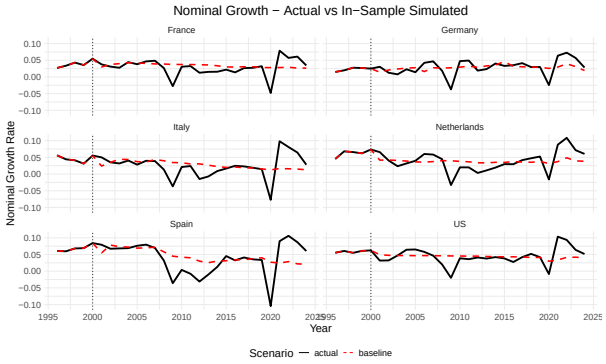
As expected, the simulated series for output growth, the primary surplus, and the average cost of debt financing are smoother than their empirical counterparts. Nonetheless, the model successfully captures the underlying trends in all these variables. This evidence supports the conclusion that demographic factors play a central role in determining the long-run trends in the key drivers of debt dynamics and the debt-to-GDP ratio.



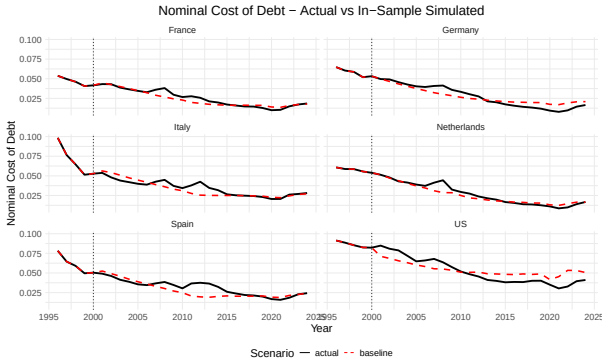
(a) Debt/GDP



(b) Primary Surplus/GDP



(c) Nominal Growth



(d) Nominal Cost of Debt

Figure 8: Within sample Projections (2000-2024)

5 Where Do We Go From Here? Model Simulation

Having validated the model within the estimation sample, we now turn to the question of the debt dynamics implied by our framework under different demographic trends and alternative scenarios for the social security system.

We first consider a baseline scenario in which demographic variables evolve according to the projections of the United Nations, without any policy intervention. We then turn to policy interventions that alter the dynamics of the variables in the model, while keeping the estimated parameters fixed. This ensures that simulations remain consistent with the parameters identified in the estimation sample. In particular, we analyze changes in migration policy and, subsequently, reforms to the statutory retirement age.[11]

5.1 Baseline Scenario

We start from a baseline scenario where we project the demographic variables over the sample 2025-2040 using the baseline scenario for the demographic variables provided by the UN database. The debt-GDP dynamics obtained in this baseline scenario are reported in Figure 9, where the debt to GDP ratios are reported with their associated ninety per cent confidence interval as a stochastic solution for the model has been implemented by bootstrapping the residuals from the estimation.[12]

[11] Reforms to the retirement age have in fact already been implemented in Italy, most notably under Minister Fornero during the Monti Government (Law 214/2011 implements Article 24 of D.L. 6 December 2011, No. 201, known as the "Save-Italy" decree, converted into law on 22 December 2011, and commonly referred to as the "Fornero Reform"). The effects of such reforms on economic dynamics unfold only gradually. For readers interested in simulating alternative reform scenarios with different timings and magnitudes, we have made our model available for simulation via an R Shiny application at Demographic Reform and Public Debt Dynamics Simulator.

[12] The bootstrap method implemented allows for simultaneous correlations across residuals by putting all of them in a matrix and drawing with replacements from the row of this matrix.

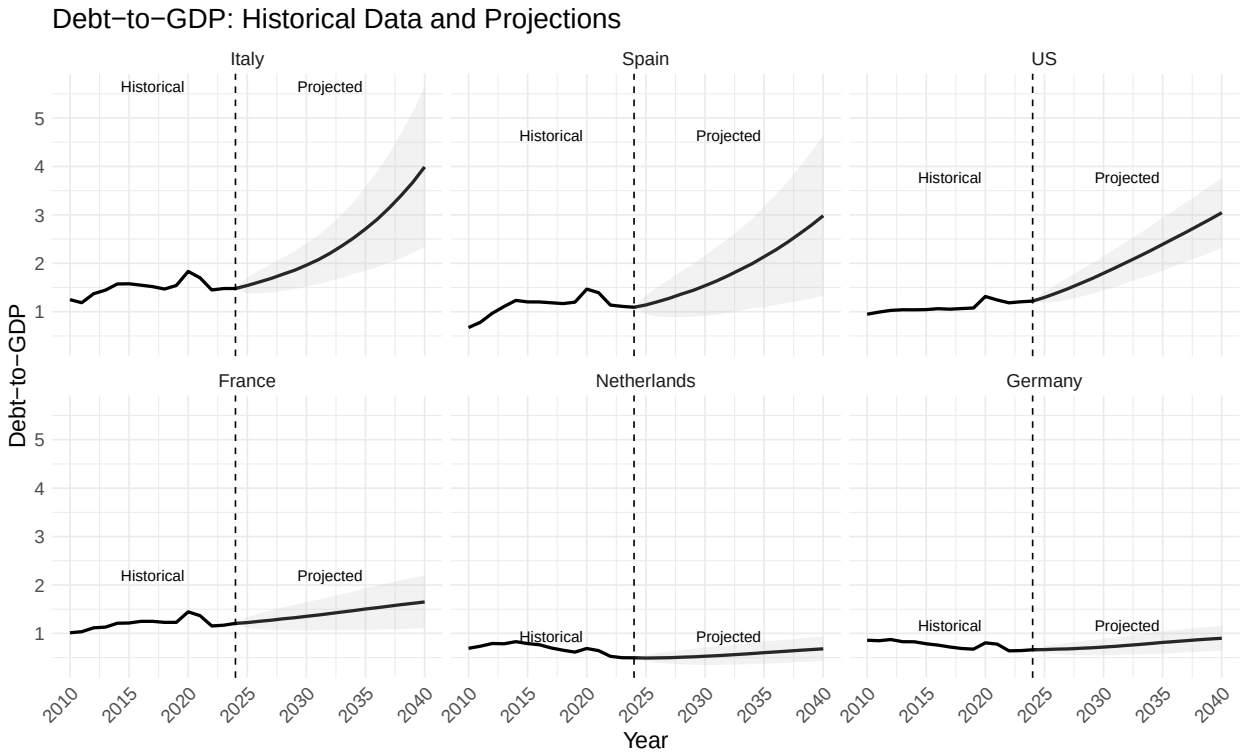


Figure 9: Debt/GDP

The evidence indicates that demographic trends lead to a sustainable debt trajectory only in two countries: Germany and the Netherlands. In France, debt appears to be on a potentially unsustainable path, while in Italy, Spain, and the United States, the debt-to-GDP ratio is clearly on an explosive trajectory.

This cross-country heterogeneity reflects differences in three key channels: (i) the sensitivity of the primary surplus to demographic dynamics; (ii) the strength of the debt-stabilizing properties of the estimated fiscal rules governing primary surpluses; and (iii) the impact of demographic trends on the differential between output growth and the average cost of debt financing (Blanchard, 2023; Mehrotra and Sergeyev, 2021). Moreover, heterogeneity across European countries increases when the debt dynamics of peripheral nations diverge from those of Germany, as this divergence significantly affects the spread between their average debt financing costs and Germany's.[13]

5.2 Alternative Scenario with Different Migration Rates.

To evaluate the potential effect of demographics policy on debt sustainability we consider the cases of Spain and Italy, the two European countries featuring unsustainable debt in the

[13]The dynamics of primary surpluses to GDP ratios, nominal output growth rates and the average costs of financing debts are reported in Figures in the Appendix

baseline scenario, and evaluate the impact of alternate scenarios based on the specification of different migration rates. In particular, as shown in Figure 10, we consider together with the baseline scenario where migration at the rate projected by the UN, two alternate scenarios in which the migration rate is increased, for these two countries only, first at ten per thousand (a level consistent with the maximum rate observed within sample in Italy) and then at fifteen per thousand (a level consistent with the maximum rate observed within sample for the two countries). The simulation, reported in Figure 11, shows that migration reduces the risk of debt becoming unsustainable and can even lead to debt stabilization. This result is driven by a decline in the old-age dependency ratio caused by migration, which in turn lowers the primary deficit-to-GDP ratio. Interestingly, stabilization occurs even without generating a primary surplus, as the shift in the population's age structure raises the output growth rate above the average cost of debt financing. As illustrated in Figure 11, a negative "snowball effect" makes the primary deficts sustainable.

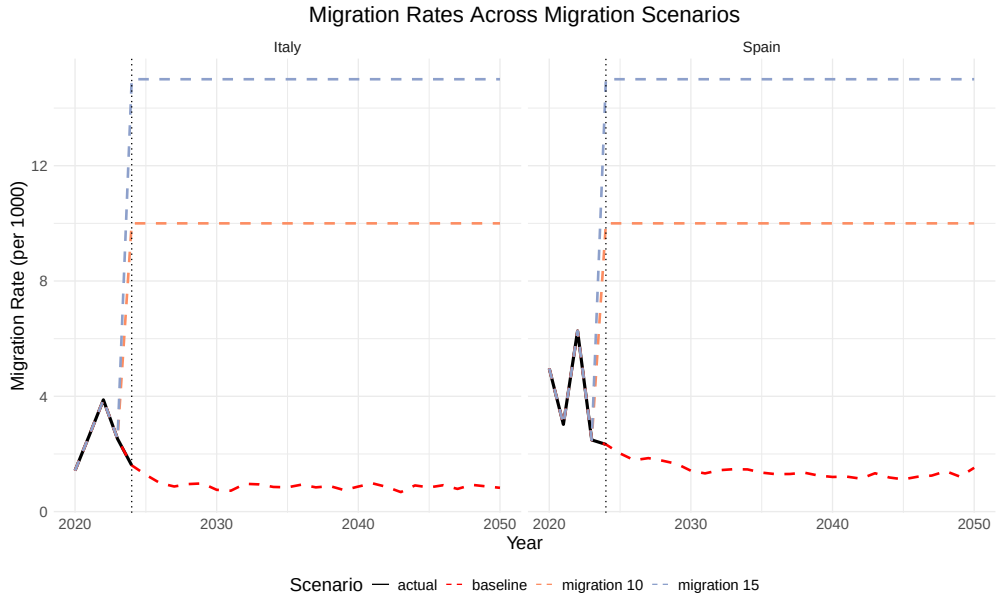
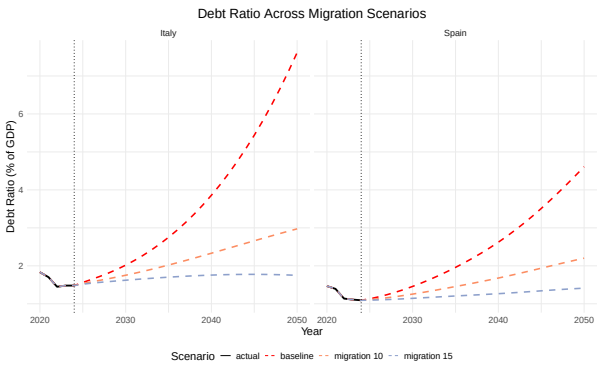
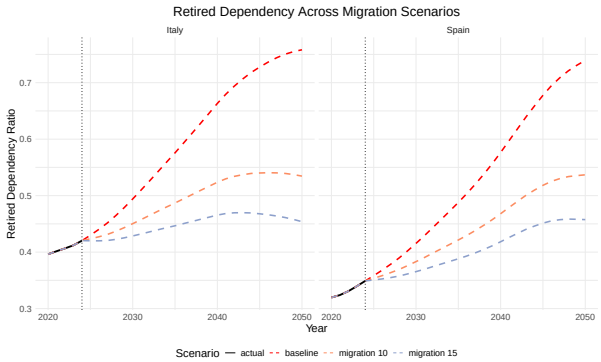


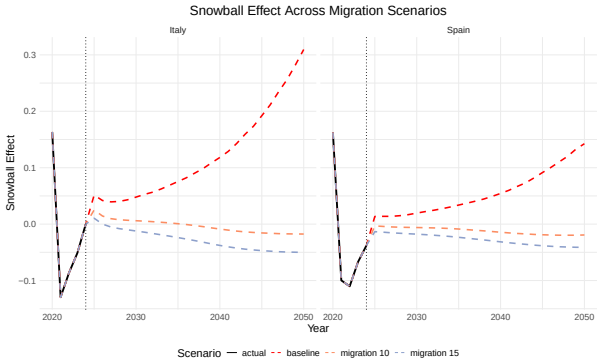
Figure 10: Factual and Counterfactual Migration Rates



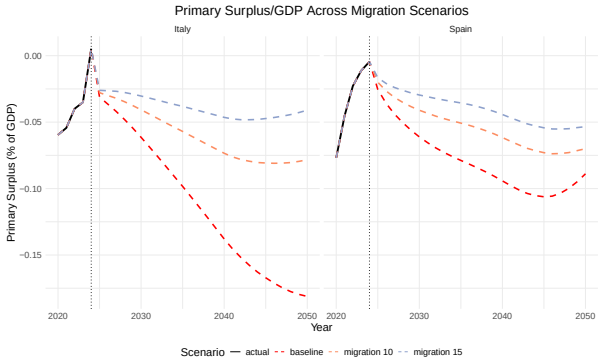
(a) Debt/GDP



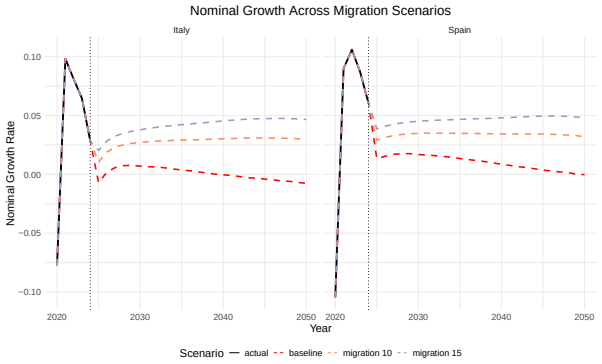
(b) Old-Age Dependency $\left(\frac{N^4_{i,t}}{N^2_{i,t}+N^3_{i,t}}\right)$



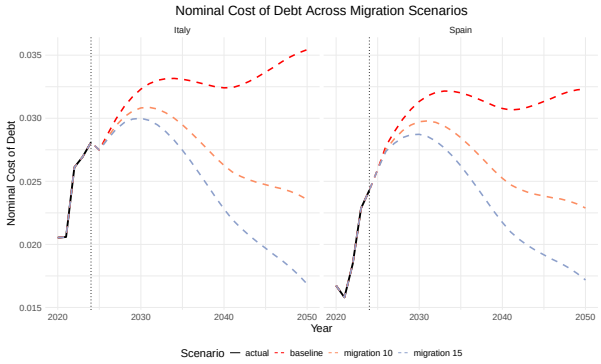
(c) Snowball Effect $\left(\frac{R^{av}_{i,t} - g_{i,t}}{1+g_{i,t}} b_{i,t-1}\right)$



(d) Primary Surplus/GDP



(e) Nominal GDP Growth



(f) Average Cost of Debt Financing

Figure 11: Migration Scenario Projections (2025-2050)

5.3 Alternative Scenario with Reform of the Retirement Age

To evaluate the potential effects of fiscal policy, and in particular social security policy, on debt sustainability, we assess the impact of counterfactual scenarios based on different implementations of a reform that postpones the statutory retirement age, always in the cases of Spain and Italy.

As shown in Figure 12, we compare the baseline scenario—in which the retirement age is kept constant at 65 years—with two counterfactual scenarios. In the first one, the retirement age is immediately raised to 67 years in the first period of the simulation and then kept constant thereafter. In the second scenario, the retirement age is also set initially at 67 years, but is then increased gradually to reach a steady state of 70 years by 2030.[14]

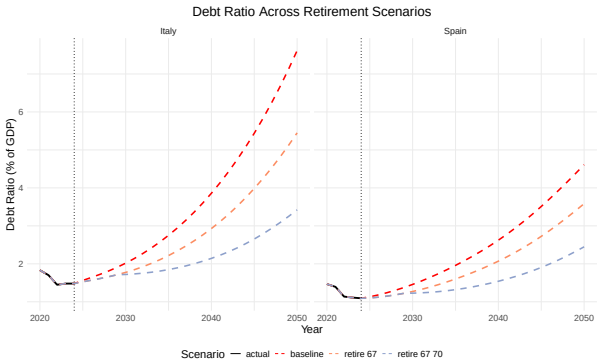
The simulation of the alternative scenarios is constructed using the UN projections for the population across different age brackets, but with a different characterization of two life-cycle groups: middle-aged workers and retirees. In the baseline scenario, the upper bound of the middle-aged group and the lower bound of the retirees are both fixed at 65 years. In the two alternative scenarios, these bounds vary according to the time profile of the retirement age.

Estimated parameters in the econometric models are kept constant, however the different definitions of $N^3_{i,t}$ and $N^4_{i,t}$ generate distinct outcomes in the baseline and counterfactual scenarios. Figure 13 present the results of the simulations showing that—similar to the migration scenario—postponing the retirement age exerts a moderating effect on debt dynamics. This result is driven by improvements in the primary surplus and a more favorable trajectory for the average cost of debt financing. However, the effect of raising the retirement age on the old-age dependency ratio is much smaller than that of migration. As a result, the alternative migration scenario produces a more stable debt-to-GDP path than the scenarios based on retirement-age postponement.

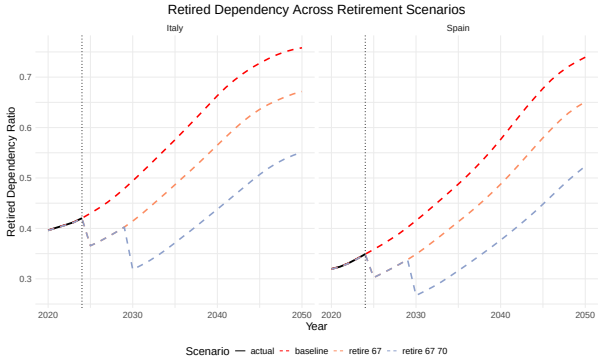
[14]The specification of the alternative scenario is designed to mimic the pattern of retirement-age postponement introduced in Italy with the Fornero reform of the pension system. The reform was introduced in December 2011 (law decree "Salva Italia," converted into Law 214/2011) under the Monti government and promoted by Minister of Labour and Welfare Elsa Fornero. It came into effect on January 1, 2012. The reform featured an initial increase in statutory retirement ages, followed by further automatic adjustments linked to life expectancy.



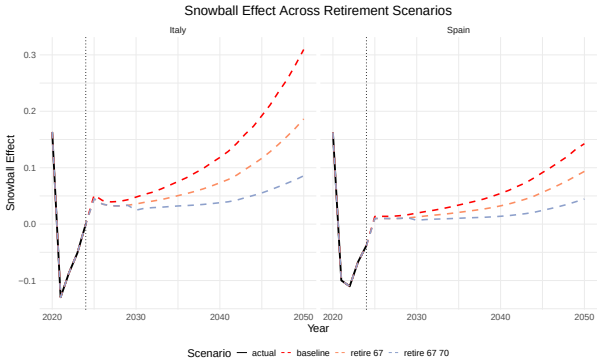
Figure 12: Factual and Counterfactual Retirement Ages



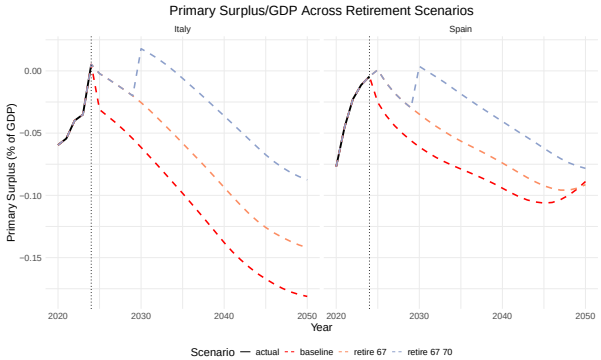
(a) Debt/GDP



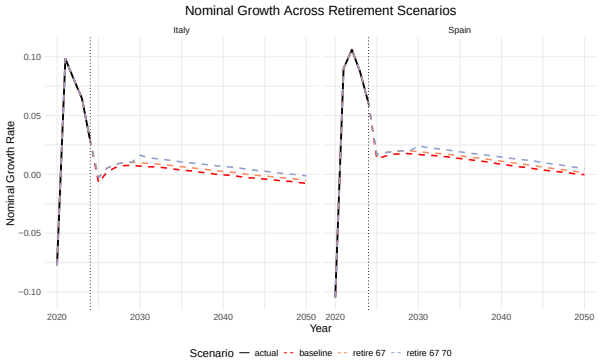
(b) Old-Age Dependency $\left(\frac{N^4_{i,t}}{N^2_{i,t}+N^3_{i,t}}\right)$



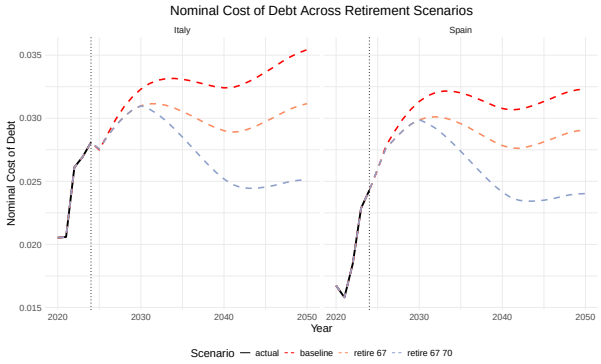
(c) Snowball Effect $\left(\frac{R^{av}_{i,t}-g_{i,t}}{1+g_{i,t}}b_{i,t-1}\right)$



(d) Primary Surplus/GDP



(e) Nominal GDP Growth



(f) Average Cost of Debt Financing

Figure 13: Retirement Reforms Projections (2025-2050)

6 Conclusion

This paper has developed a framework that integrates demographic dynamics into the analysis of public debt sustainability for six advanced economies: the United States and five major European countries. By modeling the debt-to-GDP ratio through its key determinants—output growth, the average cost of debt financing, and the primary surplus—as functions of demographic variables, we have show that demographic trends play a fundamental role in shaping fiscal trajectories.

Our simulations demonstrate that the rising old-age dependency ratio has placed and will place persistent upward pressure on public debt levels through its negative effects on both economic growth and primary fiscal balances. While countries like Germany and the Netherlands benefit from demographic trends and fiscal policies that support debt sustainability, others—notably Italy, Spain, France, and the United States—face growing fiscal vulnerabilities and very high risk of the debt to GDP ratio getting on explosive paths under baseline projections for the population dynamics.

A key policy insight from our counterfactual analysis is that migration can serve as a powerful lever to improve debt dynamics and it does so better than postponement of retirement age. In particular, higher net migration reduces the old-age dependency ratio, thereby easing pressure on the primary deficit and raising output growth. In Italy and Spain, we find that sufficiently high migration rates can stabilize debt ratios even without achieving primary surpluses, thanks to favorable shifts in the growth-interest rate differential.

The findings of this paper carry several important policy implications. First, fiscal frameworks and sustainability assessments should explicitly account for demographic dynamics, particularly shifts in the population age structure and dependency ratios. Second, migration policy should be considered a core component of long-term fiscal strategy, not merely a response to labor market needs. Third, given the heterogeneity in demographic profiles and fiscal responses across countries, a one-size-fits-all approach to debt consolidation is unlikely to be effective. Countries facing adverse demographic trends will require more proactive measures, such as targeted migration, labor force participation policies and pension reform. Finally, for euro area countries, the divergence in debt dynamics between core and peripheral members risks widening sovereign spreads and increasing financial fragmentation. Coordinated European policy efforts that address demographic imbalances could therefore help preserve fiscal cohesion and financial stability in the monetary union.

In conclusion, our evidence on demographics and public finance dynamics stresses the importance of incorporating debt sustainability analysis in the simulation of policies for the long-run, already highlighted by in-depth analysis of sovereign debt sustainability in the face

of climate change impacts (Calcaterra et al., 2025).

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Appendix 1: Model Specification

$$
\begin{aligned}
N^1_{i,t} &= N^1_{i,t-1} + \nu_{i,t} N_{i,t-1} - p^1_{i,t} N^1_{i,t-1} - \phi^1_{i,t} N^1_{i,t-1} \\
N^2_{i,t} &= N^2_{i,t-1} + p^1_{i,t} N^1_{i,t-1} + \mu_{i,t} N_{i,t-1} - p^{2,i}_t N^{2,i}_{t-1} - \phi^2_{i,t} N^2_{i,t-1} \\
N^3_{i,t} &= N^3_{i,t-1} + p^2_{i,t} N^2_{i,t-1} - p^3_t N^3_{i,t-1} - \phi^3_{i,t} N^3_{i,t-1} \\
N^4_{i,t} &= N^4_{i,t-1} + p^3_{i,t} N^3_{i,t-1} - \phi^4_t N^4_{i,t-1} + u_{i,t} \\
N_{i,t} &= N^1_{i,t} + N^2_{i,t} + N^3_{i,t} + N^4_{i,t} \\
b_{i,t} &= b_{i,t-1} + \frac{R^{av}_{i,t} - g_{i,t}}{1 + g_{i,t}} b_{i,t-1} - s_{i,t} + sfa_{i,t} \\
R^{av}_{US,t} &= \beta_{0,US} + \beta_{1,US} \frac{N^3_{US,t}}{N^2_{US,t}} + \beta_{2,US} \Delta y^{pot}_{US,t} + \beta_{3,US} \pi^{LR}_{US,t} + \epsilon^1_{US,t} \\
R^{av}_{DE,t} &= \beta_{0,DE} + \beta_{1,DE} R^{av}_{DE,t-1} + \beta_{2,DE} R^{av}_{US,t} + \epsilon^1_{DE,t} \\
R^{av}_{j,t} &= R^{av}_{DE,t} + \beta_{0,j} + \beta_{1,j} (b_{j,t-1} - b_{DE,t-1}) + \epsilon^1_{j,t} \\
j &= NED, FR, SP, IT \\
g_{i,t} &= \Delta y_{i,t} + \pi_{i,t} \\
\pi_{US,t} &= \phi_{1,US} \pi_{US,t-1} + (1 - \phi_{1,US}) \pi^{LR}_{US,t} + \epsilon^2_{US,t} \\
\pi_{k,t} &= \phi_{1,k} \pi_{i,t-1} + (1 - \phi_{1,k}) \pi^{US,t} + \epsilon^2_{k,t} \\
k &= DE, NED, FR, SP, IT \\
\Delta y^{pot}_{i,t} &= \gamma_{1,i} \Delta n_{i,t} + \gamma_{2,i} \frac{N^2_{i,t}}{N^3_{i,t}} + \gamma_{3,i} \frac{N^4_{i,t}}{N^2_{i,t} + N^3_{i,t}} + \epsilon^3_{i,t} \\
\Delta y_{i,t} &= \gamma_{0,i} + \gamma_{1,i} \Delta y^{pot}_{i,t} + \gamma_{2,i} (y_{i,t-1} - y^{pot}_{i,t-1}) + \gamma_{3,i} \frac{N^1_{i,t} + N^4_{i,t}}{N^2_{i,t} + N^3_{i,t}} + \epsilon^4_{i,t} \\
s_{i,t} &= \delta_0 + \delta_1 (y_{i,t} - y^{pot}_{i,t}) + \delta_2 b_{i,t-1} + \delta_3 \frac{N^1_{i,t}}{N^2_{i,t} + N^3_{i,t}} + \delta_4 \frac{N^4_{i,t}}{N^2_{i,t} + N^3_{i,t}} + \epsilon^4_{i,t}
\end{aligned}
$$

The demographics dynamics is described in a system of five equations, where the total population for each country i is classified in four age groups: $N^1_{i,t}$:0-19, $N^2_{i,t}$:20-45, $N^3_{i,t}$: 45-65 and $N^4_{i,t}$: over 65. $\nu_{i,t}$ is the birth rate,$\mu_{i,t}$ is net migration rate, defined as the ratio of total net migration in year t to total population at the end of period t-1, $\phi^j_{i,t}$ are the rates of fatality in age group j and country i, $p^j_{i,t}$ is the percentage of individuals in country i included in compartment j in year $t-1$ who move to compartment $j+1$ in year t. $\nu_{i,t}$, $\mu_{i,t}$, $\phi^j_{i,t}$ are obtained from the UN database. After the calibration of these time-varying rates, $p^1_{i,t}, p^2_{i,t}, p^3_{i,t}$ are obtained by solving the first three equations of our system in each period. Only the equation for $N^4_{i,t}$ contains a measurement error, $u_{i,t}$.

The debt to GDP dynamics for each country is defined by the government intertemporal budget constraint that decomposes the change in the debt to gdp ratio into three components: the snow-ball effect, $\frac{R^{av}_{i,t}-g_{i,t}}{1+g_{i,t}}b_{i,t-1}$, the primary surplus to gdp ratio, $d_{i,t}$ and the stock-flow adjustment, $sfa_{i,t}$. The simulation of the debt dynamics under different scenarios requires the specification and estimation of equations for $g_{i,t}, R^{av}_{i,t}, d_{i,t}$, as we keep $sfa_{i,t}$ equal to its observed values for within sample simulations and we set it to zero for out-of-sample simulations.

Our model for the trend for the average cost of finacing the debt in the US links it to long-term productivity, as captured by potential output growth, the age structure of population, $\frac{N^3_{US,t}}{N^2_{US,t}}$, and long-run inflation expectations $\pi^{LR}_{US,t}$, as captured by the survey-based measure of long-run inflation expectations, used in the Fed's FRB/US model.[15]

The average cost of financing the safest European Government Debt, i.e. the German, shares the same (stochastic) trend with the average cost of financing the US debt, while the average cost of financing the debt for the other European countries depends on the spread of their average cost of financing the debt on the average cost of financing the German debt. These spreads are driven by fiscal fundamentals, i.e. the difference between each country's debt/GDP ratio and the German debt/GDP ratio.

Nominal growth depends on real growth and inflation. Inflation is projected within sample using the long-run expected inflation and out-of-sample with the long-run expected inflation at the central banks target. The specification for real growth implies that output converges to potential output with an adjustment that depends on the age structure of the population and in particular on the dependency ratio. Population growth and the age structure of population are in turn drivers of the trend in potential output growth.

Finally, the primary surplus is projected as a function of a cyclical term, of a debt stabilizing part and of the age structure of population with different coefficients for the "young" dependency ratio ,$\frac{N^1_{i,t}}{N^2_{i,t}+N^3_{i,t}}$ and the "old" dependency ratio,$\frac{N^4_{i,t}}{N^2_{i,t}+N^3_{i,t}}$.

[15] Available at https://www.federalreserve.gov/econres/us-models-package.htm.

Appendix 2: The out-of-sample Dynamics of Macroeconomic Variables

The following figures report the dynamics of primary surpluses, nominal output growth rate and the average cost of financing the debt in our baseline simulation.

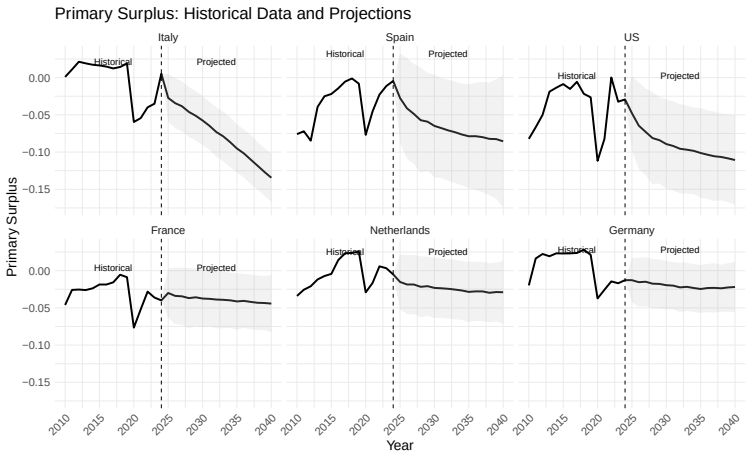


Figure 14: Primary Surplus/GDP

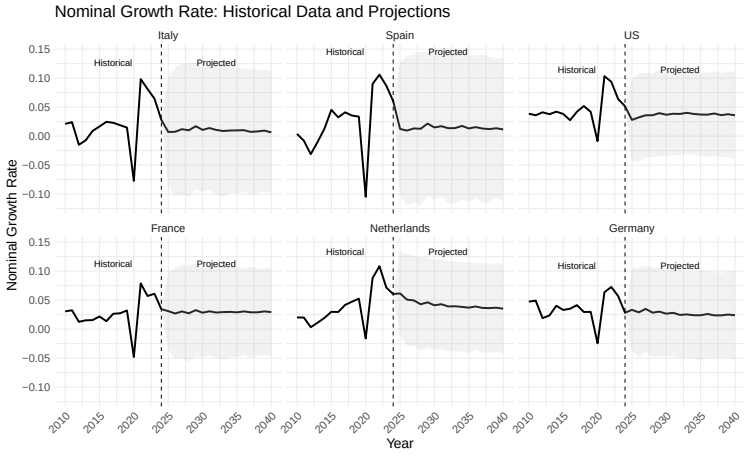


Figure 15: Nominal Growth

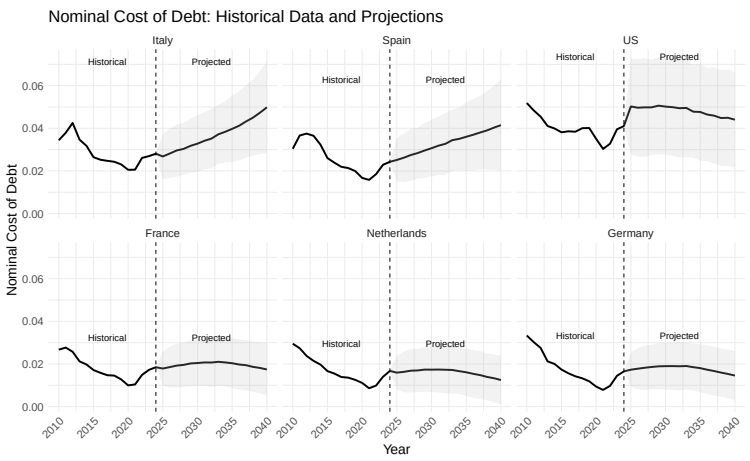


Figure 16: Nominal Cost of Debt

Appendix 3: Data

Appendix 3.1 Demographics

Demographic variables are sourced from the United Nations World Population database, available at https://population.un.org/wpp/downloads?folder=Standard%20Projections. We use single-year, age-specific population and mortality estimates to construct aggregated series for four broad age groups, covering both historical estimates and future projections. Additional demographic indicators include the Crude Birth Rate (CBR), Crude Death Rate (CDR), Net Migration, Crude Net Migration Rate (CNMR), and Total Fertility Rate (TFR), all obtained from the "Demographic Indicators" section of the same dataset.

Appendix 3.2 Macro-Fiscal Variables

For the United States, macroeconomic data are obtained from the Federal Reserve Economic Data (FRED) database. Specifically, we use nominal GDP (GDPA), real GDP (GDPC1), and potential GDP (GDPPOT). The GDP deflator is constructed as the ratio of nominal to real GDP.

For the five Euro Area (EA) countries in our sample, macroeconomic data are taken from the AMECO database. We use nominal GDP (UVGD), real GDP (OVGD), and potential GDP (OVGDP). For Germany, we extend the GDP series back to 1970 using FRED data (nominal GDP: GDPNADSMEI; deflator: GDPDEFAISMEI). Potential GDP for this pre-1990 extension is estimated using a Hodrick–Prescott filter.

The Federal Reserve's perceived target rate (PTR) for inflation is a survey-based measure of long-run inflation expectations; PTR is used in the Fed's FRB/US model and available at https://www.federalreserve.gov/econres/us-models-package.htm

Fiscal variables for both the United States and the five EA countries are sourced from theOECD Economic Outlook database. Key variables include:

- **YRGT**: General government total revenue,
- **YPGT**: General government total expenditure,
- **GGINTP**: General government interest payments,
- **GGFL**: General government financial liabilities (gross public debt).

From these fiscal aggregates, we construct derived variables including the nominal cost of debt, primary surplus, and the stock-flow adjustment.

We rely on the GGFL data series because it provides long historical coverage across countries, with data extending back to 1960. GGFL, constructed under the SNA 2008 standards, may include instruments valued at market prices. For robustness, we complement this with debt measures computed at nominal value. Since the model estimations for the nominal cost of debt and primary surplus exclude observations prior to 1990 for European countries, we instead use the AMECO Gross Public Debt series (UDGG), available from 1995 onwards. For the United States, we draw on the FRED series "Total Public Debt" (GFDEBTN), which is reported at nominal value. The model estimations and simulations remain qualitatively unchanged; results are presented in Appendix 4: Robustness Check below.

Appendix 4: Robustness Check

Model Estimations

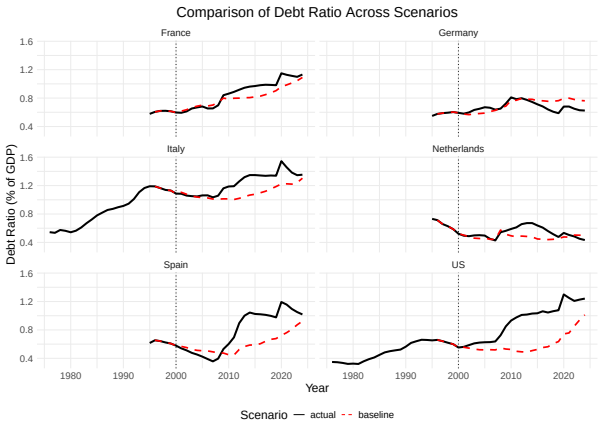
	US	DE	Netherlands	France	Spain	Italy
(Intercept)	0.015	-0.007***	0.005***	-0.001	0.006***	0.002*
	(0.025)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
dypot-US	1.527***					
	(0.285)					
PTR-US	2.448***					
	(0.154)					
MY-US	-0.062**					
	(0.026)					
IR-US		0.264***				
		(0.075)				
lag-IR-Germany		0.736***				
		(0.075)				
b-diff-lag-i			0.010***	0.010***	0.010***	0.010***
			(0.002)	(0.002)	(0.002)	(0.002)
$SMPL$	1968-2024	1997-2024	2000-2024	2000-2024	2000-2024	2000-2024
R^2	0.946	0.993	-0.053	0.416	0.491	0.196
σ	0.0119	0.0019	0.0033	0.0019	0.0039	0.0055
ρ	0.808	0.359	0.446	0.149	0.781	0.825
ADF	-2.298	-3.535	-3.074	-4.094	-1.671	-1.573

Table 8: Nominal Cost of Debt

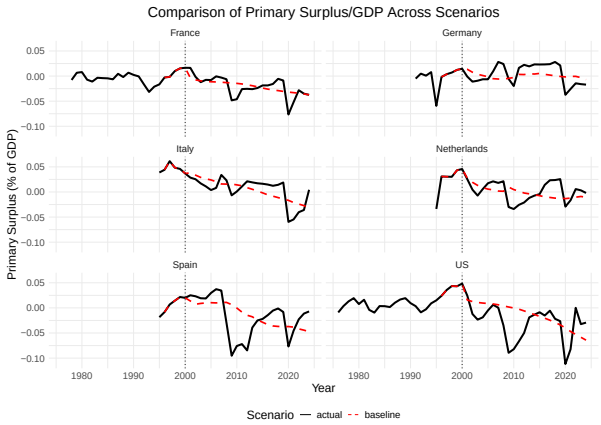
	US	Germany	Netherlands	France	Spain	Italy
(Intercept)	0.123***	0.005	0.009	0.029**	0.110***	0.210***
	(0.015)	(0.017)	(0.014)	(0.014)	(0.017)	(0.021)
ygap-i	1.349***	0.643***	0.916***	0.695***	0.764***	0.044
	(0.177)	(0.218)	(0.190)	(0.179)	(0.082)	(0.124)
b-lag-i	-0.000	0.068***	0.068***	0.000	0.068***	0.000
	(0.000)	(0.014)	(0.014)	(0.000)	(0.014)	(0.000)
D-R-i	-0.576***	-0.137***	-0.137***	-0.137***	-0.576***	-0.576***
	(0.062)	(0.045)	(0.045)	(0.045)	(0.062)	(0.062)
$SMPL$	1991-2024	1996-2024	1996-2024	1996-2024	1996-2024	1995-2024
R^2	0.556	0.488	0.679	0.642	0.756	0.538
σ	0.0264	0.0139	0.0135	0.0136	0.0200	0.0202
ρ	0.465	0.587	0.668	0.794	0.579	0.529
ADF	-3.579	-2.657	-2.314	-2.051	-2.704	-2.718

Table 9: Primary Surplus/GDP

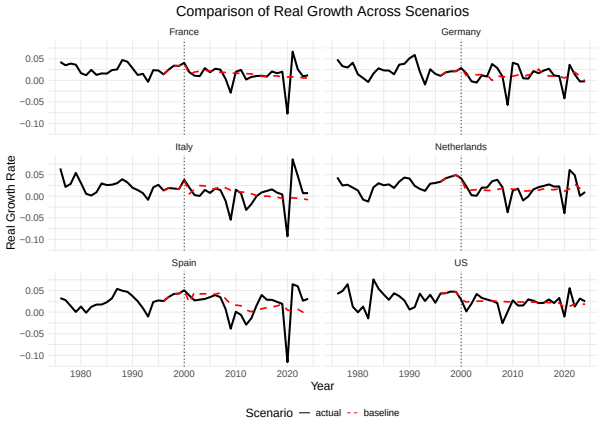
Model Evaluation



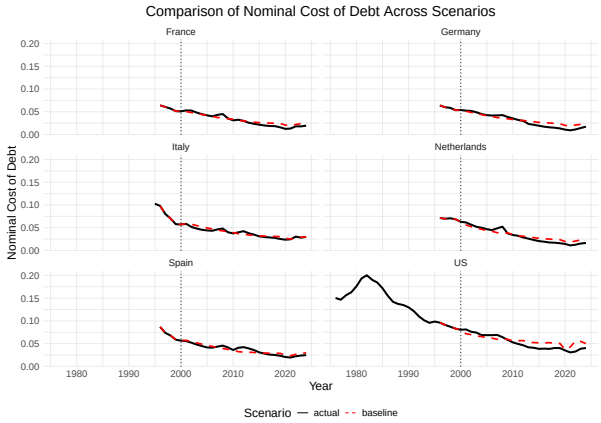
(a) Debt/GDP



(b) Primary Surplus/GDP



(c) Real Growth



(d) Nominal Cost of Debt

Figure 17: Within sample Projections (2000-2024)

Stochastic Simulations

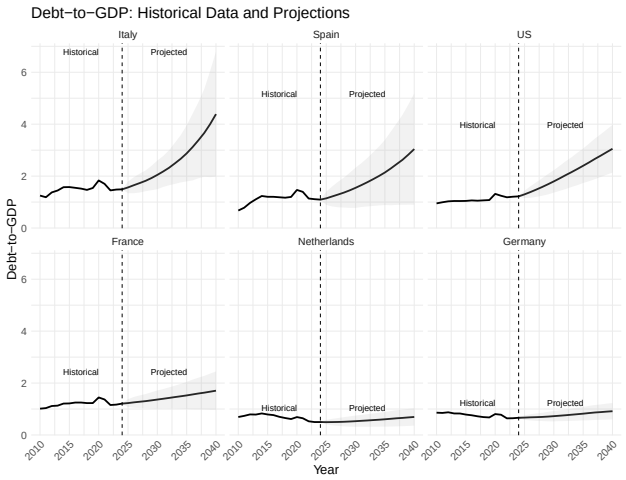
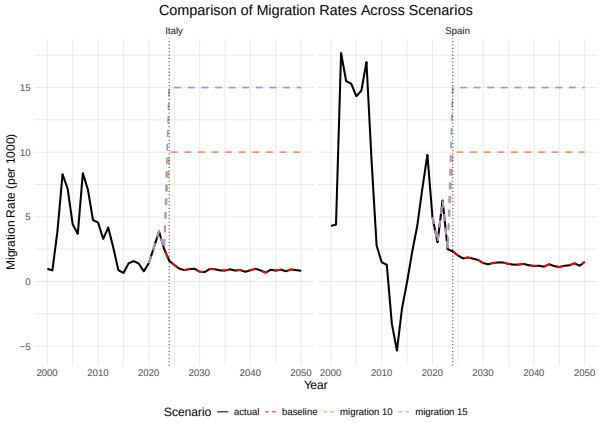
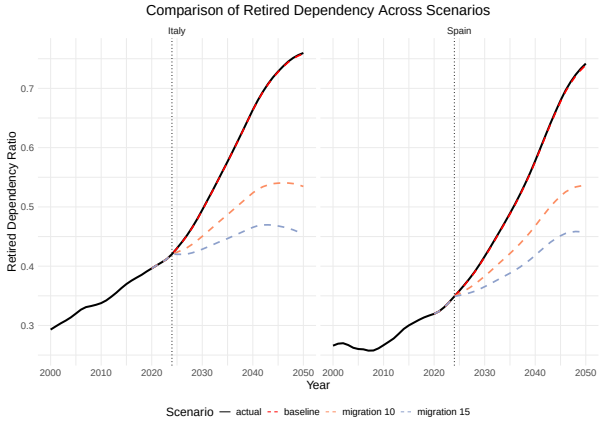


Figure 18: Debt/GDP

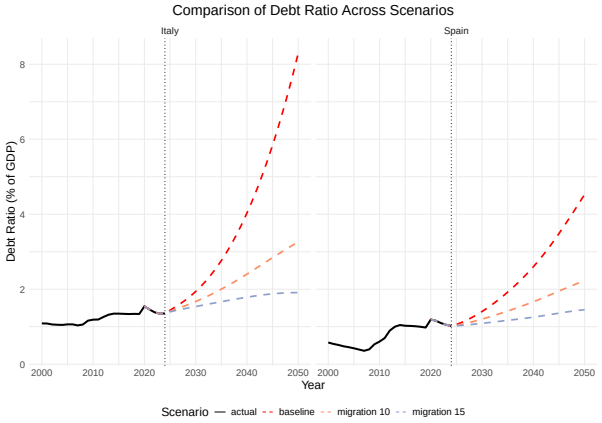
Migration Scenarios



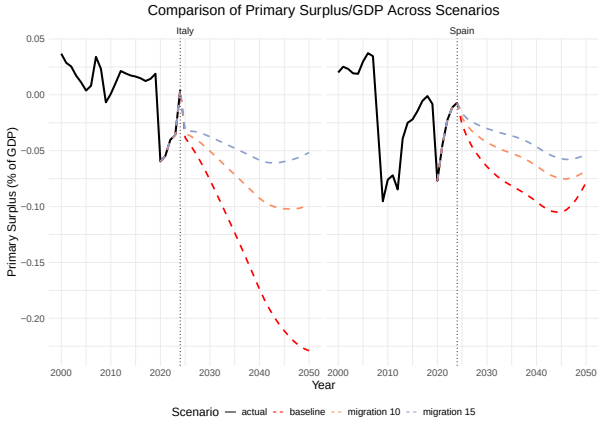
(a) Migration Rate



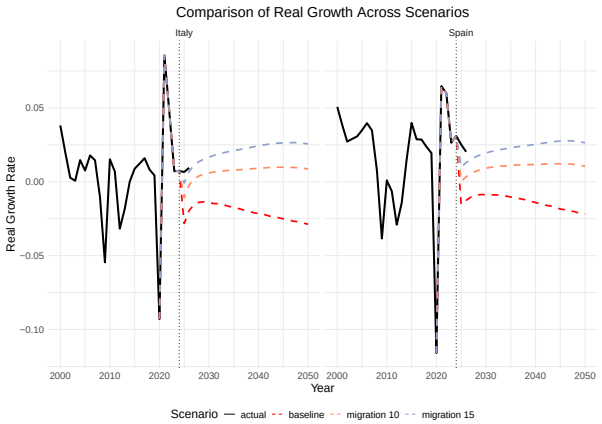
(b) Old-Age Dependency



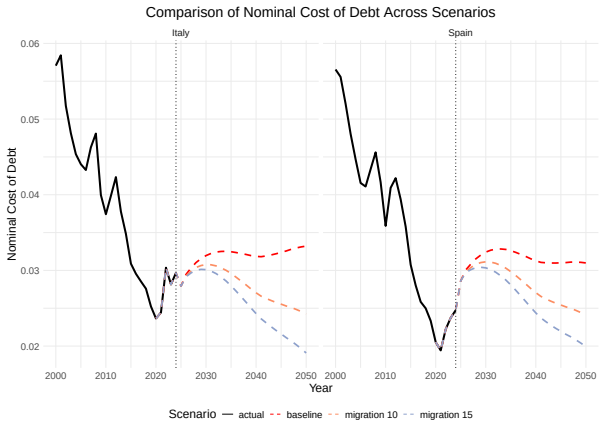
(c) Debt/GDP



(d) Primary Surplus/GDP



(e) Real Growth



(f) Nominal Cost of Debt

Figure 19: Migration Scenario Projections (2025-2100

Appendix 5: OECD Data on Average Labor Market Exit Age

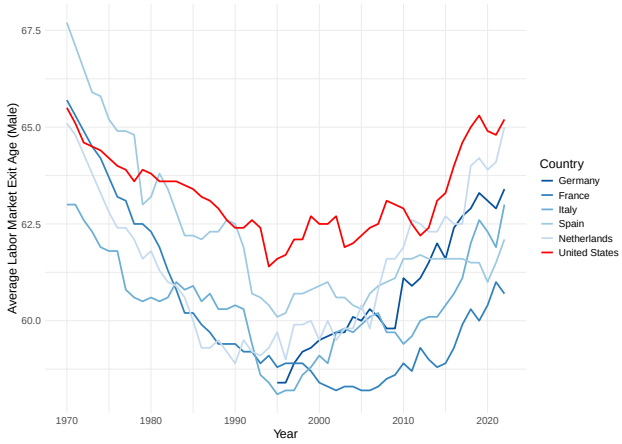


Figure 20

Appendix 6: Replication Package

All code and data necessary to reproduce the results presented in this paper are available in the following public GitHub repository:

https://github.com/devpra1999/Demographic-Trends-and-Government-Debt-Dynamics

The repository includes:

- Raw and processed data files used in the analysis,
- R scripts for data processing, model estimation, and plotting,
- Output figures ,
- Instructions for replicating results.