Research Article

Population Aging and Macroeconomic Dynamics: A Calibrated OLG–PAYG Analysis

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Abstract: This study examines the effects of population aging on macroeconomic equilibria within the framework of an Overlapping Generations (OLG)–Pay-As-You-Go (PAYG) model calibrated with Turkish data. The analysis focuses on how the demographic transformation, accelerated by declining fertility rates and increasing life expectancy, affects the social security system, capital accumulation, output, real interest rates, and intergenerational welfare. The model incorporates representative individuals with a two-period life cycle, a Cobb–Douglas production structure, and a PAYG mechanism linked to the old-age dependency ratio. Following the calibration based on demographic and macroeconomic indicators for the Turkish economy during the 2011–2021 period, three different scenarios are simulated: the baseline equilibrium, a population aging shock, and a reform scenario. The findings indicate that an increase in the old-age dependency ratio raises the contribution rate in the PAYG system, weakens the net income and saving capacity of the working generations, and consequently exerts downward pressure on capital intensity and output levels. Moreover, the aging process is found to adversely affect the welfare of younger generations, particularly during the transition period. The reform scenario partially mitigates the pressure on contribution rates and the associated loss in output. Overall, the results demonstrate that population aging generates significant structural implications for social security sustainability and macroeconomic stability in Türkiye.

Keywords: Population Aging, OLG Model, PAYG Pension System, Intergenerational Welfare, Macroeconomic Dynamics
Jel Codes: E17, H55, J11, J18, O41

Nüfusun Yaşlanması ve Makroekonomik Dinamikler: Kalibre Edilmiş OLG–PAYG Analizi

Öz: Bu çalışma, nüfus yaşlanmasının makroekonomik dengeler üzerindeki etkilerini, Türkiye verileriyle kalibre edilmiş bir Overlapping Generations (OLG)–Pay-As-You-Go (PAYG) modeli çerçevesinde incelemektedir. Çalışmada doğurganlık oranlarının düşmesi ve yaşam beklentisinin artmasıyla hızlanan demografik dönüşümün; sosyal güvenlik sistemi, sermaye birikimi, üretim, reel faiz ve kuşaklararası refah üzerindeki etkileri analiz edilmektedir. Model, iki dönemli yaşam döngüsüne sahip temsilî bireyler, Cobb–Douglas üretim yapısı ve yaşlı bağımlılık oranına bağlı bir PAYG mekanizması içermektedir. Türkiye ekonomisine ait 2011–2021 dönemi demografik ve makroekonomik göstergeleri kullanılarak gerçekleştirilen kalibrasyon sonrasında üç farklı senaryo simüle edilmiştir: temel denge, nüfus yaşlanması şoku ve reform senaryosu. Bulgular, yaşlı bağımlılık oranındaki artışın PAYG sisteminde prim oranını yükselttiğini, çalışan kuşakların net gelirini ve tasarruf kapasitesini zayıflattığını, bunun da sermaye yoğunluğu ile çıktı düzeyi üzerinde aşağı yönlü baskı yarattığını göstermektedir. Ayrıca yaşlanma sürecinin özellikle geçiş dönemindeki genç kuşakların refahını olumsuz etkilediği görülmektedir. Reform senaryosu ise prim baskısını ve üretim kaybını kısmen hafifletmektedir. Sonuç olarak çalışma, nüfus yaşlanmasının Türkiye'de sosyal güvenlik sürdürülebilirliği ve makroekonomik istikrar açısından önemli yapısal sonuçlar doğurduğunu ortaya koymaktadır.

Anahtar Kelimeler: Nüfus Yaşlanması, OLG Modeli, PAYG Emeklilik Sistemi, Kuşaklararası Refah, Makroekonomik Dinamikler
Jel Kodları: E17, H55, J11, J18, O41

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1. Introduction

The global decline in fertility rates and the increase in life expectancy have accelerated population aging in many countries, and this demographic transformation generates significant effects not only on social security systems and health policies but also on the fundamental components of macroeconomic equilibrium (Bloom, Canning, & Fink, 2010; Lee & Mason, 2011; United Nations, 2023). Population aging constitutes a structural process that directly influences variables such as labor supply, the savings–investment balance, capital accumulation, real interest rates, public expenditures, and long-term economic growth performance. In particular, the increase in the old-age dependency ratio reduces the relative weight of the working-age population, thereby transforming both productive capacity and the financing base of social security systems. For this reason, examining the macroeconomic consequences of demographic aging through both theoretical and quantitative approaches is of particular importance for economies experiencing increasing pressure on their social security systems (Goodhart & Pradhan, 2020; Lee & Mason, 2011).

In analyzing these relationships, the Overlapping Generations (OLG) model provides a powerful theoretical framework. Developed by Samuelson (1958) and Diamond (1965), the OLG approach enables the examination of intergenerational interactions, saving behavior, capital accumulation, and welfare distribution within a micro-founded structure. The principal advantage of the OLG model lies in its ability to address changes in demographic structure, intergenerational transfer mechanisms, and individual life-cycle decisions simultaneously within a unified general equilibrium framework (Blanchard & Fischer, 1989; Romer, 2019). In this respect, the model is particularly well-suited for analyzing the interaction between population structure and the sustainability of Pay-As-You-Go (PAYG) pension systems. An increase in the old-age dependency ratio may directly affect contribution rates, pension transfers, public finances, and the balance of intergenerational welfare within PAYG systems (Barr & Diamond, 2008; Feldstein, 1974).

In recent years, the impact of population aging on the natural rate of interest (r*) and its relationship with the debate on "secular stagnation" has received increasing attention in the literature (Summers, 2014; Rachel & Smith, 2015; Eggertsson, Mehrotra, & Robbins, 2019; Rachel & Summers, 2019). In aging economies, longer life expectancy, stronger precautionary saving motives, and weaker investment demand may exert downward pressure on real interest rates (Carvalho, Ferrero, & Nechio, 2016; Gagnon, Johannsen, & Lopez-Salido, 2016). However, the interest variable used in this study does not correspond empirically to the natural rate of interest (r*), but rather to the real return on capital (r) derived from the marginal product of capital within the model. Therefore, the interest rate path generated here should not be expected to correspond one-to-one with empirical estimates of r*. The objective of this study is not to estimate the natural rate of interest empirically; rather, it is to trace the general equilibrium effects of population aging and the PAYG mechanism within a structural OLG framework.

Although the international literature on the macroeconomic effects of population aging is extensive, calibrated OLG applications that integrate the old-age dependency ratio and the social security burden within a simple yet tractable general equilibrium mechanism remain relatively limited for developing economies such as Türkiye, where demographic transition is accelerating. Existing studies largely focus on advanced economies or address demographic change within broader discussions of growth and interest rate dynamics (Bloom et al., 2010; Lee & Mason, 2011; Eggertsson et al., 2019). In the case of Türkiye, however, it is particularly important to analyze the effects of demographic transition on the social security structure, labor market dynamics, and growth prospects within a theoretically consistent framework capable of generating scenario-based analysis. This study aims to address this gap by employing an OLG–PAYG model scaled to Turkish data.

In this context, the study examines the macroeconomic effects of population aging within an OLG–PAYG framework through both a theoretical perspective and a structural simulation approach. The model incorporates household optimization under a two-period OLG structure, a Cobb–Douglas production technology, and a general PAYG mechanism. The PAYG balance is defined through the old-age dependency ratio, and the contribution rate is linked to the replacement rate parameter representing the pension-to-wage ratio. In this way, the effects of demographic pressure on the social security burden and macroeconomic equilibrium can be jointly traced within a single model (Samuelson, 1958; Diamond, 1965; Barr & Diamond, 2008).

The model is calibrated for the period 2011–2021 using Turkish data. The selection of this period is motivated by the availability of consistent data and its relative separation from the high-inflation and negative real interest rate regime that became more pronounced after 2022. In the calibration process, demographic structure, growth indicators, and interest rate variables are taken as benchmarks; rather than estimating parameters econometrically, the objective is to ensure that the magnitudes generated by the model are scale-consistent with observed values in the Turkish economy (Heer & Maussner, 2024; Romer, 2019). This approach allows demographic shocks to be evaluated in terms of their direction and relative magnitude within a structural framework, consistent with the objectives of the study.

The contribution of this study to the literature can be summarized in four points. First, the OLG–PAYG mechanism is calibrated using Turkish data, and the effects of an increase in the old-age dependency ratio on the contribution rate, capital accumulation, and the model-implied real return are quantitatively demonstrated. Second, transition dynamics over ten periods are simulated under three scenarios: the baseline equilibrium, an aging shock, and a reform scenario. Third, a sensitivity analysis conducted for the replacement rate parameter evaluates the responsiveness of the results to the design of the pension system. Fourth, by comparing transitional generational welfare outcomes, the intergenerational distributional effects of aging are revealed. Rather than presenting an empirical analysis based on econometric estimation, this study investigates the macroeconomic consequences of demographic aging through a calibrated OLG–PAYG structural simulation scaled to Turkish data.

The findings indicate that an increase in the old-age dependency ratio raises the contribution rate within the PAYG system, weakens capital accumulation through its effects on net wages and saving behavior, and adversely affects the welfare of younger generations during the transition period. The reform scenario, by contrast, partially mitigates production and welfare losses by limiting the pressure on contribution rates. In addition, the model-implied interest rate variable, determined by the marginal product of capital under the demographic shock, may diverge from the trajectories discussed in the natural rate of interest literature. This observation highlights the importance of conceptual distinctions between different interest rate measures in demography-based macroeconomic analysis.

The remainder of the article is organized as follows. Section 2 discusses the theoretical foundations of the OLG model. Section 3 examines the macroeconomic effects of population aging from an OLG perspective. Section 4 presents the model structure and calibration strategy. Sections 5 and 6 report the scenario design and simulation results. Section 7 discusses the findings in relation to the literature, while Section 8 evaluates policy implications. The final section provides the overall assessment and concluding remarks.

2. Theoretical Background: Foundations of The OLG Model

This section examines the theoretical foundations of the Overlapping Generations (OLG) model. The OLG approach analyzes an economic structure in which multiple generations coexist simultaneously, thereby providing a framework for examining the effects of intergenerational interactions on savings, capital accumulation, and welfare. In

this context, the section is structured under three subsections. First, the role of intergenerational interactions in macroeconomic equilibrium is discussed through Samuelson's (1958) pioneering model. Second, the contributions of the Diamond (1965) model to the analysis of production, capital accumulation, and public debt are examined. Finally, the fundamental assumptions of the OLG model are presented.

2.1. The Samuelson (1958) Model: Basic Logic

Paul A. Samuelson's study entitled "An Exact Consumption-Loan Model of Interest with or without the Social Contrivance of Money" (Samuelson, 1958) established the foundational framework of the Overlapping Generations (OLG) approach and provided the theoretical basis for the analysis of intergenerational interactions in modern macroeconomics. The Samuelson model demonstrates that, within an economic structure in which multiple generations coexist, individuals' saving and consumption decisions may influence not only their own life cycles but also the welfare of future generations. In this respect, the model offers the first formal framework that enables the analysis of the consequences of economic decisions for the distribution of welfare across generations.

In the model, individuals live for two periods: youth and old age. During their working years, young individuals earn income and accumulate savings, while in old age they consume their accumulated wealth. This life-cycle structure creates an equilibrium mechanism in which the economic decisions of different generations are interdependent. Consequently, individuals' saving decisions affect not only their own welfare but also the intergenerational allocation of resources within the economy.

However, the Samuelson model is built upon a pure exchange economy that does not incorporate production or capital accumulation. For this reason, the model remains limited in explaining the production structure and capital accumulation dynamics of real-world economies. The extension of the OLG framework to include production, capital accumulation, and public policy was developed by Diamond (1965), and it subsequently became a central reference framework in modern macroeconomic growth analysis. In the present study, the analytical structure is likewise constructed on a Diamond-type OLG framework that incorporates production and capital accumulation.

2.2. The Diamond (1965) Model: Capital Accumulation and Welfare

Diamond's study entitled "National Debt in a Neoclassical Growth Model" (Diamond, 1965) made an important contribution to modern macroeconomic growth analysis by extending the Samuelson model to incorporate production, capital accumulation, and technology. By combining the OLG framework with neoclassical production theory, the Diamond model examines the relationship between saving decisions and capital accumulation within a general equilibrium setting.

In the model, each generation lives for two periods. During youth, individuals earn income, consume part of that income, and save the remainder. These savings determine the future capital stock of the economy. The aggregate savings of new generations are transformed into the capital stock of the next period:

$$K_{t+1} = s_t L_t$$

Here K_{t+1} denotes the capital stock of the next period, s_t represents the level of individual savings, and L_t denotes the working population.

The production process is defined by a Cobb–Douglas production function under the assumption of constant returns to scale (Barro & Sala-i-Martin, 2004; Acemoglu, 2009):

$$Y_t = F(K_t A_t L_t) = K_t^{\alpha} (A_t L_t)^{1-\alpha}$$

Here A_t denotes the level of technology (labor productivity), L_t represents the quantity of labor, and α indicates the share of capital in production (Barro & Sala-i-Martin, 2004; Acemoglu, 2009).

Technology and population grow according to the following processes:

$$A_{t+1} = (1 + g)A_t$$

$$L_{t+1} = (1 + n)L_t$$

The analysis is generally conducted in terms of effective labor. Accordingly, the capital variable is defined as follows:

$$k_t = \frac{K_t}{A_t L_t}$$

Under perfect competition, factor prices are equal to their marginal products. Accordingly, the real interest rate and the real wage are expressed as follows:

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

$$w_t = (1 - \alpha)k_t^{\alpha}$$

Here r_t denotes the real return on capital, w_t represents the real wage, and δ indicates the depreciation rate of capital.

One of the most important theoretical implications of the Diamond model is the condition for the Golden Rule level of capital. This condition defines the capital stock that maximizes consumption per unit of effective labor:

$$f'(k^*) = \delta + n + g$$

Here k^* denotes the optimal level of capital. If the realized capital level in the economy satisfies $k>k^*$, the economy is dynamically inefficient; that is, society is saving above the optimal level. In such a case, policy instruments such as public debt may increase welfare by reducing the capital stock (Diamond, 1965; Blanchard & Fischer, 1989).

The Diamond model has also been used to analyze the effects of public debt on intergenerational welfare. An increase in public debt may raise the welfare of the current generation while imposing costs on future generations. However, if the economy is in a dynamically inefficient state, public debt may become an instrument for increasing welfare (Weil, 1987; Romer, 2019). For this reason, the Diamond model is widely regarded as a fundamental theoretical reference framework in analyses of both public finance and demographic change.

2.3. Fundamental Assumptions of the Model

OLG models are constructed under certain assumptions in order to provide analytical clarity. While these assumptions allow the model to be solved mathematically, they may not fully capture the complex behavioral processes observed in real economies.

Agents and time horizon: Individuals live for two periods (young–old) and possess rational expectations. During the youth period, they earn wage income, consume part of it, and save the remainder. In old age, they consume their accumulated savings.

Demography and technology: Population and technology grow deterministically:

$$L_{t+1} = (1 + n)L_t$$

$$A_{t+1} = (1 + g)A_t$$

The analysis is conducted in terms of effective labor, and variables are expressed in lowercase letters:

$$k_t = \frac{K_t}{A_t L_t}$$

Production and market structure: Total output is defined by a production function with constant returns to scale:

$$Y_t = K_t^{\alpha} \, (A_t L_t)^{(1-\alpha)}$$

Under perfect competition, factor prices are equal to their marginal products.

Budget constraints and closure: The basic model operates under the assumption of a closed economy. Savings are transformed into domestic investment, and there is no external balance.

Public sector: In the basic model, the public sector is either absent or assumed to be neutral at a scale that does not distort economic equilibrium. Pension systems and public policies may be incorporated into the model in later sections.

Financial markets and uncertainty: The basic framework is deterministic, and physical capital is the only savings instrument.

3. Macroeconomic Effects of Population Aging: The OLG Perspective

Population aging is one of the most important demographic transformations shaping the long-term macroeconomic dynamics of contemporary economies. Increases in life expectancy and declines in fertility rates permanently alter both the structure of the labor force and the savings–investment balance (Bloom, Canning, & Fink, 2010; Lee & Mason, 2011). This change in demographic structure affects not only the composition of the population but also key macroeconomic variables such as economic growth, interest rates, capital accumulation, and public finance.

The OLG (Overlapping Generations) model is regarded as one of the most suitable theoretical frameworks for analyzing the effects of such demographic transformations on economic equilibrium. This is because the OLG approach can jointly address saving decisions, production dynamics, and intergenerational transfer mechanisms within a structure in which different generations coexist simultaneously in the economy (Blanchard & Fischer, 1989; Romer, 2019). For this reason, when the macroeconomic effects of population aging are examined from an OLG perspective, they can be analyzed systematically through specific transmission channels.

In the literature, the economic effects of demographic aging are generally explained through three main macroeconomic channels. The first is the savings and capital accumulation channel, through which life-cycle saving behavior affects capital accumulation. The second is the equilibrium interest rate and secular stagnation channel, which relates to the determination of real interest rates through the balance between savings and investment. The third is the labor and growth channel, which encompasses the effects of demographic structure on labor supply, productivity, and economic growth. In addition, the effects of an aging population on social security systems and intergenerational transfer mechanisms constitute an important field of analysis in the OLG literature.

This section examines these mechanisms under four subsections. First, the effects of aging on saving behavior and capital accumulation are addressed; next, the long-term effects of demographic change on interest rates are discussed. The third subsection examines the effects of aging on labor supply and growth dynamics, and finally, pension systems and intergenerational transfer mechanisms are evaluated from an OLG perspective.

3.1. The Savings and Capital Accumulation Channel

In OLG models, individuals' consumption and saving decisions over the life cycle play a central role in determining macroeconomic equilibrium. Similar to Modigliani's life-cycle hypothesis (1954), individuals within the OLG framework earn income and save during their working years, while they consume their accumulated wealth during retirement. Consequently, changes in demographic structure have direct implications for the aggregate saving rate and capital accumulation of the economy.

As the population ages, the share of elderly individuals in the economy increases, and this development may influence aggregate saving behavior in two different directions. On the one hand, longer life expectancy encourages individuals to prepare for a longer retirement period, which may increase the propensity to save during working years (Bloom, Canning, & Fink, 2010; Börsch-Supan & Lusardi, 2003). On the other hand,

the increasing share of retirees within the total population may accelerate the dissaving process, thereby reducing aggregate saving rates at the macroeconomic level (Carvalho, Ferrero, & Nechio, 2016). These two opposing mechanisms indicate that the net effect of population aging on capital accumulation depends on several factors, including demographic structure, public transfers, and life-cycle saving behavior (Heer & Maussner, 2024).

Within the OLG framework, the effect of aging on capital accumulation primarily emerges through cohort size. When the relative size of the working-age population declines, the number of young cohorts who save also decreases. This reduction may lower the overall volume of savings, slow the growth rate of the capital stock, and reduce the equilibrium capital–labor ratio. Empirical and quantitative studies conducted by Weil (1987) and Lee, Mason & Miller (2000) confirm these effects of demographic change on saving rates and capital accumulation.

Another important factor affecting saving behavior is the size of public pension systems. In Pay-As-You-Go (PAYG) pension systems, contributions paid by the working population are directly transferred to retirees. In such systems, it has been argued that as the magnitude of public transfers increases, individuals' private savings for retirement may decline (Feldstein, 1974; Nishiyama & Smetters, 2007). Therefore, the growing pressure on social security systems resulting from population aging may affect not only public finances but also the overall capital accumulation potential of the economy.

In conclusion, within the OLG framework, the effect of population aging on capital accumulation is determined by the interaction between individual life-cycle saving behavior and public transfer mechanisms. These effects of demographic change on the savings–investment balance also play a crucial role in shaping the equilibrium interest rate and growth dynamics of the economy. For this reason, the impact of aging on savings and capital accumulation is closely related to the dynamics of interest rates discussed in the following section.

3.2. The Natural Rate of Interest r* and Demographic Dynamics

In recent years, the persistent long-term decline in real interest rates in advanced economies has revived the debate on "secular stagnation" in the macroeconomic literature (Summers, 2014; Rachel & Smith, 2015; Rachel & Summers, 2019). Within this literature, population aging is regarded as one of the key structural factors exerting downward pressure on the natural rate of interest (r*) by influencing the global savings–investment balance. While increases in life expectancy tend to strengthen individuals' propensity to save, slower labor force growth may constrain investment demand, thereby contributing to a decline in the equilibrium interest rate (Carvalho, Ferrero, & Nechio, 2016).

However, the interest rate variable analyzed in this study does not correspond to the natural rate of interest (r*) discussed in the empirical literature; rather, it refers to the model-implied real return on capital (r) derived from the marginal product of capital within the OLG framework. Accordingly, the interest rate path obtained here does not represent the returns on safe financial assets observed in financial markets, but instead reflects the equilibrium return on capital generated by the production structure. For this reason, the empirical effects of demographic aging on r* should not be expected to correspond one-to-one with the dynamics of r obtained within the model.

This distinction highlights the importance of carefully differentiating conceptual variables when interpreting the macroeconomic consequences of demographic change.

3.3. Labor Supply, Productivity, and Growth Dynamics

One of the macroeconomic effects of population aging arises through changes in labor supply and economic growth. The aging of demographic structure may directly affect the productive capacity of the economy and its potential growth rate by reducing the share of the working-age population in total population (Lee & Mason, 2011). Although labor supply is often assumed to be fixed in classical OLG models, demographic

transformations in real economies substantially alter both the size of the labor force and the structure of production.

A decline in the share of the working-age population may constrain productive capacity by reducing aggregate labor supply in the economy. This effect becomes particularly pronounced in economies where low fertility rates persist over a long period. Bloom, Canning & Fink (2010) show that population aging not only reduces labor supply, but may also affect growth dynamics through saving behavior, consumption patterns, and the composition of public expenditures.

At the same time, the effects of an aging labor force on productivity are not unidirectional. An increase in the share of experienced workers may support productivity in the short run through accumulated knowledge and experience. However, over the long run, a decline in the relative share of young and highly skilled workers may slow innovation capacity and the renewal of human capital (Feyrer, 2007). For this reason, the effect of demographic transformation on total factor productivity is closely linked to changes in labor force composition.

The literature also emphasizes that aging economies may develop certain adjustment mechanisms in response to demographic pressures. For example, some studies indicate that the contraction in labor supply may induce firms to adopt more capital-intensive technologies and automation investments, and that such technological adaptation may partially offset the adverse effects on output (Acemoglu & Restrepo, 2017). Nevertheless, the net effect of these mechanisms on growth may vary depending on labor market structure and the pace of technological transformation.

Accordingly, the effects of population aging on growth exhibit a multidimensional structure. On the one hand, a decline in the working-age population exerts downward pressure on the potential growth rate; on the other hand, technological adaptation and a more capital-intensive production structure may offset this effect to some extent. Within this framework, demographic aging emerges in the OLG perspective not only as a factor affecting savings and interest rate dynamics, but also as an important structural determinant of labor supply, productivity, and the long-run growth path. These mechanisms provide the basis for the quantitative analysis of the effects of demographic change on macroeconomic equilibrium within the model framework developed in the following section.

3.4. Pension Systems and Intergenerational Transfer Mechanisms

Population aging affects not only individual saving and consumption decisions, but also the fiscal sustainability of social security systems and the intergenerational allocation of resources. The OLG model is one of the theoretical frameworks most commonly used to analyze these interactions, because it allows life-cycle saving decisions and intergenerational transfer mechanisms to be examined within the same general equilibrium structure (Blanchard & Fischer, 1989; De Nardi, 2015). In this context, the macroeconomic effects of pension systems constitute an important field of analysis in the OLG literature.

In OLG models, pension systems are generally analyzed through two main mechanisms. The first is the Pay-As-You-Go (PAYG) system. In this system, contributions paid by the working population are transferred directly to current retirees, and pension payments are financed through an intergenerational transfer mechanism. The second mechanism is the fully funded system. Under this structure, individuals save during their working years to build retirement funds, and retirement income depends largely on returns earned in financial markets.

In PAYG systems, fiscal balance depends to a large extent on demographic structure. In particular, the old-age dependency ratio, which expresses the ratio of the elderly population to the working-age population, is one of the key determinants of the system's sustainability. When this ratio deteriorates due to declining fertility rates and increasing life expectancy, the financing burden on working generations may increase (Feldstein,

1974). According to the theoretical framework developed by Samuelson (1958), the internal rate of return of a PAYG system depends approximately on the growth rate of the wage bill, that is, on the sum of population growth (n) and labor productivity growth (g) (Barr & Diamond, 2008). Therefore, under conditions of low fertility and low productivity growth, the return provided by the PAYG system may fall below the return available in capital markets, while the contribution burden on working generations may rise (Diamond, 1965).

In fully funded pension systems, by contrast, individuals earn income on the basis of their own accumulated savings, and pension payments depend on returns on financial assets. In theory, such systems may support economic growth by encouraging capital accumulation. However, the transition from a PAYG system to a fully funded system may generate substantial costs, because during the transition period working generations may have to finance both the benefits of current retirees and their own retirement savings. In the literature, this situation is referred to as the "double burden" (Kotlikoff, 2002). For this reason, many studies suggest that mixed pension systems combining PAYG and funded components may provide a more sustainable structure (Börsch-Supan, 2005; Holzmann & Hinz, 2005).

In conclusion, from an OLG perspective, pension system design is closely related to demographic structure. Variables such as the population growth rate (n), productivity growth (g), and the return on capital (r) play a decisive role in the sustainability of social security systems. As demographic aging intensifies the pressure on social security systems, retirement policies become increasingly important for macroeconomic equilibrium. For this reason, the macroeconomic consequences of changes in demographic structure are analyzed quantitatively within the model framework developed in the following section.

4. Model and Methodology: The OLG–PAYG Framework and Calibration

This section presents the model structure and calibration methodology used to analyze the macroeconomic effects of population aging. The study is based on the standard Overlapping Generations (OLG) model developed by Samuelson (1958) and Diamond (1965), augmented with a Pay-As-You-Go (PAYG) pension mechanism. This framework allows the joint analysis of individuals' life-cycle saving decisions and intergenerational transfer mechanisms within a general equilibrium setting (Blanchard & Fischer, 1989; Romer, 2019).

The model is discrete-time and represents an economic structure in which a new generation enters the economy in each period. The economy consists of individuals who live for two periods: youth and old age. During youth, individuals work, earn wage income, and save; during old age, they consume through the return on their accumulated savings and pension transfers. The model is constructed under the assumption of a closed economy, where savings are directly transformed into capital accumulation.

Production technology in the economy is represented by a neoclassical production function, and firms operate under conditions of perfect competition. Population and technology evolve deterministically, with the population growth rate denoted by n and the rate of labor productivity growth denoted by g. These assumptions allow the analysis of the effects of demographic change on capital accumulation and interest rates.

4.1. Structure of the Model: Households

In the model, the economy consists of representative individuals who live for two periods. Each individual works and earns wage income during youth and saves part of that income; during old age, consumption is financed through the return on accumulated savings and pension transfers. This structure follows the standard OLG framework developed by Samuelson (1958) and Diamond (1965).

The utility function of the representative individual is defined as follows:

$$U = lnc_{1,t} + \beta lnc_{2,t+1}$$

Here:

$c_{1,t}$: consumption during the youth period

$c_{2,t+1}$: consumption during the old-age period

B ∈ (0,1): the discount factor representing individuals' time preference.

The logarithmic utility function represents a standard preference specification widely used in the OLG literature (Diamond, 1965; Blanchard & Fischer, 1989).

Individuals' budget constraints are defined separately for the two periods of the life cycle.

During youth, the individual earns wage income, consumes part of that income, and saves the remainder. At the same time, contributions are paid from wages within the PAYG pension system. The budget constraint of the young individual is expressed as follows:

$$c_{1,t} + s_t = (1 - \tau_t)w_t$$

Here:

s_t: savings

τ_t: the contribution rate paid into the PAYG system

w_t: the real wage level

During old age, the individual has withdrawn from working life and finances consumption through the return on savings accumulated in the previous period and pension transfers. The budget constraint for the old-age period is written as follows:

$$c_{2,t+1} = (1 + r_{t+1})s_t + b_{t+1}$$

Here:

r_{t+1}: the real return on capital

b_{t+1}: the pension transfer received from the PAYG system.

This structure explicitly captures within the model the interaction between individuals' life-cycle saving decisions and the social security system.

4.2. The PAYG Mechanism

In the model, the pension system is defined as a Pay-As-You-Go (PAYG) type social security mechanism. In a PAYG system, contributions paid by the working generation are transferred directly to the currently retired generation, and the system operates through an intergenerational redistribution mechanism. This structure is widely used in the OLG literature to analyze the macroeconomic effects of pension systems (Samuelson, 1958; Barr & Diamond, 2008).

In the PAYG system, working individuals pay a certain proportion of their wage income as contributions. These contributions are transferred to individuals who retire in the same period. The system's budget balance can be expressed as follows:

$$\tau_t w_t L_t = b_t N_t^{old}$$

Here:

τ_t: the contribution rate collected from workers

w_t: the real wage level

L_t: the working population

b_t: the per capita pension transfer

N_t^{old}: the retired (elderly) population

This equation represents the basic budget identity of the PAYG system. The total contribution revenue collected from workers is equal to the total transfer payments made to retirees in the same period.

Demographic structure is one of the key factors determining the sustainability of the PAYG system. In this context, the old-age dependency ratio in the model is defined as follows:

$$D_t = \frac{N_t^{old}}{L_t}$$

This ratio represents the proportion of the retired population relative to the working population in the economy and constitutes one of the key indicators measuring the pressure of demographic aging on the social security system.

The replacement rate parameter, denoted by ρ, represents the ratio of pension transfers to the wage level. In this case, the per capita pension payment can be defined as follows:

$$b_t = \rho w_t$$

This specification represents a wage-indexed pension structure within the PAYG system. When this relationship is evaluated together with the PAYG budget identity, the following relationship between the contribution rate and the demographic structure is obtained:

$$\tau_t = \rho D_t$$

This equation is regarded in the literature as the basic accounting identity of PAYG systems (Blanchard & Fischer, 1989; Barr & Diamond, 2008). Accordingly, an increase in the old-age dependency ratio leads to a rise in the contribution rate that must be collected from workers under a fixed replacement rate.

Therefore, population aging places direct pressure on the fiscal balance of the PAYG system. A relative decline in the working-age population may make it more difficult to finance pension transfers, thereby increasing contribution rates and intensifying the financing pressure on the social security system. This mechanism plays a central role in the OLG model for understanding the effects of demographic transformation on intergenerational income distribution and saving behavior.

4.3. Firms and Production

In the economy, production is carried out by representative firms operating within the framework of neoclassical production theory. Firms operate under conditions of perfect competition and rent production factors at prices equal to their marginal products. Within this framework, production technology is represented by a Cobb–Douglas production function with constant returns to scale (Diamond, 1965; Barro & Sala-i-Martin, 2004):

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

Here:
Y_t: total output
K_t: capital stock
L_t: the quantity of labor
A_t: the level of technology representing labor productivity
$\alpha \in (0,1)$: the share of capital in production

The level of technology is assumed to grow exogenously over time. This process is expressed as follows:

$$A_{t+1} = (1+g)A_t$$

Here, g represents the growth rate of labor productivity.

Under the assumption of perfect competition, firms rent production factors at prices equal to their marginal products. In this case, the real return on capital and the real wage are obtained as follows:

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

$$w_t = (1-\alpha)k_t^{\alpha}$$

Here:
r_t: the real return on capital
w_t: the real wage
δ: the depreciation rate of capital
k_t: the level of capital per unit of effective labor.
The capital variable per unit of effective labor is defined as follows:

$$k_t = \frac{K_t}{A_t L_t}$$

Through this transformation, the model variables are expressed in terms of effective labor, allowing the balanced growth path of the economy to be analyzed. In this way, the dynamics of capital accumulation and interest rates can be examined within a general equilibrium framework together with demographic structure and saving behavior.

This production structure follows the standard production and factor pricing mechanism of the Diamond (1965) model and determines within the model the relationship between household saving decisions and capital accumulation.

4.4. Capital Accumulation and Dynamic Updating

Within the OLG framework, capital accumulation is determined by the saving decisions of the young generation. Under the closed economy assumption in the model, individuals' savings are directly transformed into investment and constitute the capital stock of the next period. For this reason, the total volume of savings represents the primary determinant of capital accumulation in the economy.

The total savings generated by the young generation determine the capital stock of the following period. This relationship can be expressed as follows:

$$K_{t+1} = s_t L_t$$

Here:
K_{t+1}: the total capital stock in the next period
s_t: the savings of the young individual
L_t: the working population
This expression indicates that the capital stock is updated through the direct transformation of aggregate savings into investment.

The analysis is generally conducted in terms of variables per unit of effective labor. Accordingly, the capital variable per unit of effective labor is defined as follows:

$$k_t = \frac{K_t}{A_t L_t}$$

Here A_t denotes the level of technology representing labor productivity. Population and technology processes grow deterministically:

$$L_{t+1} = (1+n)L_t$$

$$A_{t+1} = (1+g)A_t$$

Using these definitions, the capital accumulation equation can be written in terms of effective labor as follows:

$$k_{t+1} = \frac{s_t}{(1+n)(1+g)}$$

Under the assumption that growth rates are small, this expression is commonly approximated as follows:

$$k_{t+1} \approx \frac{s_t}{(1+n+g)}$$

This dynamic transition equation represents the standard capital accumulation mechanism of the Diamond (1965) model. Accordingly, the long-run equilibrium level of

the economy is determined by individuals' saving behavior together with demographic growth and technological progress.

Therefore, the population growth rate n and the productivity growth parameter g are the key variables determining the balanced growth path of the economy. As a result of population aging, a decline in the rate n may alter the dynamics of capital per unit of effective labor and thereby directly affect the economy's long-run growth path and interest rate trajectory.

This framework makes it possible to analyze quantitatively the effects of demographic change on capital accumulation and macroeconomic equilibrium. In the following section, the model parameters are calibrated using data for the Turkish economy, and the model outcomes are evaluated through simulation analysis.

4.5. Data and Calibration

The model is calibrated using demographic and macroeconomic data for the Turkish economy. The calibration approach refers to determining model parameters in a manner consistent with observed macroeconomic magnitudes rather than estimating them directly through econometric methods. This method is widely employed, particularly in structural OLG models, to examine the long-run macroeconomic effects of demographic change (Romer, 2019; Heer & Maussner, 2024).

In the study, the period 2011–2021 is selected as the main calibration window. There are two primary reasons for choosing this period. First, the selected interval provides a relatively stable and comparable dataset in terms of key macroeconomic and demographic indicators. Second, the years after 2022 are excluded from the calibration window because the high inflation and negative real interest rate regime that became pronounced in the Turkish economy during this period constitutes an exceptional environment that may distort the model's long-run structural parameters. Thus, the objective is to ground the model in a more stable macroeconomic framework.

The main parameters used in the model are presented in Table 1.

Table 1. Main Parameters Used in the Calibration

Parameter	Value	Source/Rationale
α	0.33	Standard capital share (Barro & Sala-i-Martin, 2004)
δ	0.06	Commonly used depreciation rate in the literature
β	0.96	Annual discount factor
ρ	0.50	Replacement rate assumption for the baseline scenario
D	TÜİK (65+/15–64)	Old-age dependency ratio

The parameter α in the production function represents the capital share commonly used in the neoclassical growth literature. Although the baseline calibration adopts the conventional value of α=0.33 to maintain comparability with standard OLG and neoclassical growth models, alternative estimates for Türkiye generally suggest higher capital-share values. Therefore, the implications of using Türkiye-specific capital-share estimates are briefly discussed in Footnote 1.

The depreciation rate δ and the discount factor β are based on standard values frequently employed in OLG and dynamic general equilibrium models. Although the baseline

[1] The baseline calibration uses α=0.33 in line with the standard neoclassical growth and OLG literature. However, Türkiye-specific studies report alternative capital-share estimates. The DPTMAKRO-ARZ model developed for the Ninth Development Plan reports sectoral capital coefficients of 0.597893 for industry and 0.245103 for services (Devlet Planlama Teşkilatı, 2006). Saygılı & Cihan (2008) use α=0.505 for Türkiye, while Senhadji (2000) estimates a capital coefficient of approximately 0.63 for Türkiye. Using a higher Türkiye-specific value of α would affect the levels of output and the model-implied return on capital, but it would not alter the qualitative ranking of the scenarios: population aging still reduces capital intensity relative to the baseline, whereas the reform scenario partially limits this decline.

calibration uses δ=0.06, alternative Türkiye-specific studies commonly employ a lower annual depreciation rate of approximately 4%; this issue is briefly discussed in Footnote 2 .The replacement rate parameter ρ associated with the pension system reflects a calibration choice in the baseline scenario, assuming that a certain proportion of wages is paid as pension transfers. The old-age dependency ratio D is defined using data from the Turkish Statistical Institute (TÜİK) as the ratio of the population aged 65 and over to the population aged 15–64.

During the calibration process, key macroeconomic indicators of the Turkish economy are utilized. The old-age dependency ratio is constructed using population data from the Turkish Statistical Institute, defined as the ratio of the population aged 65 and over to the population aged 15–64 (Turkish Statistical Institute (TURKSTAT, n.d.). The real interest rate is represented by the annual average difference between long-term government bond yields and CPI inflation. For the real growth rate, growth data based on the chain-linked volume index are used. In order to represent saving behavior, the savings-to-GDP ratio and related macroeconomic indicators are employed. These macroeconomic data are obtained from the Turkish Statistical Institute and the World Bank World Development Indicators database (TURKSTAT, n.d.; World Bank, n.d.). The observed real interest rate indicator used here is not intended to empirically match the model-implied interest rate variable directly, but rather to provide a macroeconomic reference for calibration magnitudes. The interest rate variable generated by the model does not represent the return on safe assets observed in financial markets; instead, it corresponds to the model-implied real return derived from the marginal product of capital.

These data are used not to estimate the model parameters directly, but to ensure that calibration magnitudes are scale-consistent with the levels observed in the Turkish economy. Accordingly, the study should be interpreted not as an empirical analysis based on econometric estimation, but as a calibrated structural OLG–PAYG simulation scaled to Turkish data. The objective is not to estimate parameters statistically, but rather to make the macroeconomic effects of demographic change visible within a theoretically consistent general equilibrium framework.

5. Scenarios and Simulation Design

The scenarios developed in this section should not be interpreted as direct econometric forecasts, but rather as counterfactual calibration assumptions designed to analyze the effects of demographic aging on macroeconomic equilibrium. Accordingly, the values used for the old-age dependency ratio and growth components in the scenarios are selected in a manner consistent with the observed demographic trends of the Turkish economy and are intended to reveal the direction and relative magnitude of specific mechanisms. The objective is not to generate point forecasts for the future, but to comparatively examine the potential effects of demographic change on macroeconomic equilibrium within the OLG–PAYG framework.

In this study, the macroeconomic effects of population aging are analyzed using a dynamic simulation method based on a calibrated OLG–PAYG model. The dynamic simulation approach is widely employed in structural macroeconomic models to examine the long-run effects of policy changes and demographic shocks (Romer, 2019; Heer & Maussner, 2024). Within this framework, the model generates transition paths for the

[2] The baseline calibration uses δ=0.06 in line with values commonly employed in OLG and dynamic general equilibrium models. However, Türkiye-specific studies suggest that an annual depreciation rate of approximately 4% may also be considered. Yaşar (2008) uses an annual depreciation rate of 4% in an application for Türkiye. Similarly, Saygılı & Cihan (2008) report that the average service life of the capital stock excluding housing is approximately 26 years, which corresponds to a depreciation rate close to 4%. Using δ=0.04 instead of δ=0.06 would affect the level of the model-implied return on capital and the steady-state capital-output relationship, since depreciation directly enters the return equation. Nevertheless, the qualitative ranking of the scenarios would remain unchanged: the aging scenario would still exert downward pressure on capital intensity, while the reform scenario would partially mitigate this effect. Therefore, δ=0.06 is retained in the baseline calibration for comparability with the standard OLG literature, while the Türkiye-specific 4% depreciation rate is acknowledged as an alternative robustness consideration.

economy under different demographic and institutional assumptions, starting from an initially calibrated equilibrium state.

All scenarios begin from the same initial equilibrium and differ only in the relevant demographic and institutional parameters. This approach allows the effects of changes in the old-age dependency ratio and alternative configurations of pension system parameters to be examined comparatively in terms of the PAYG contribution rate, capital accumulation, the interest rate, and the level of output. The simulations generate ten-period transition dynamics for each scenario and illustrate how the economy evolves toward a new equilibrium path.

Three main scenarios are defined in the study. The first scenario is the baseline scenario, representing the initial equilibrium of the economy under the existing demographic structure. The second scenario is the population aging shock (aging scenario), in which demographic pressure intensifies through an increase in the old-age dependency ratio and a weakening of growth dynamics. The third scenario is the reform scenario, in which this pressure is partially mitigated through pension system and labor market policies. In addition, a separate sensitivity analysis is conducted in order to evaluate the responsiveness of the model outcomes to the replacement rate parameter.

In this section, D denotes the old-age dependency ratio. For ease of presentation, D is reported in percentage form in the text, although it is used as a ratio in the model calculations. Accordingly, for example, the expression D=12.45% is treated as D=0.1245 in the model computations.

5.1. Scenario 0: Baseline Equilibrium

The first scenario represents the initial equilibrium state of the economy under the existing demographic structure. In this scenario, the old-age dependency ratio is set at D=12.45% on the basis of the demographic indicators obtained within the calibration window. This value represents the demographic structure of the Turkish economy under the baseline scenario and serves as the reference point for evaluating the changes observed in the other scenarios.

In the model, under the PAYG system, the contribution rate is defined as the product of the replacement rate and the old-age dependency ratio:

$$\tau = \rho D$$

When the replacement rate parameter is assumed to be ρ=0.50 in the baseline scenario, the initial contribution rate is calculated as follows:

$$\tau = 0.50 \; x \; 0.1245 = 0.0623$$

Accordingly, in the baseline equilibrium scenario, the PAYG contribution rate is approximately

$$\tau = 6.23\%$$

In this scenario, all other parameters are held at their baseline values determined in the calibration section. Accordingly, Scenario 0 represents the initial equilibrium structure of the model economy and serves as the primary reference framework for comparing the transition dynamics that emerge under the population aging and reform scenarios.

5.2. Scenario 1: Population Aging Shock (Aging Scenario)

The second scenario is designed as a counterfactual aging shock scenario representing the pressure exerted by demographic aging on macroeconomic equilibrium. In this scenario, it is assumed that as the old-age dependency ratio increases, the burden on the social security system rises, while labor force growth and production dynamics weaken. The objective is to examine comparatively the effects of population aging on capital accumulation, the contribution rate, the interest rate, and output relative to the baseline equilibrium scenario.

Within this framework, the old-age dependency ratio is assumed to increase to

$$D = 15.50\%$$

This value is not used as a point forecast for a specific date; rather, it serves as a scenario calibration representing the pressure of demographic aging on the social security system. Since the contribution rate in the PAYG system is determined by the relationship

$$\tau = \rho D$$

and the replacement rate parameter is maintained at ρ=0.50, as in the baseline scenario, the contribution rate in this scenario is calculated as follows:

$$\tau = 0.50\ x\ 0.1550 = 0.0775$$

Accordingly, in the aging shock scenario, the PAYG contribution rate rises to approximately

$$\tau = 7.75\%$$

It is widely emphasized in the literature that demographic aging may exert downward pressure not only on the social security system but also on labor force growth and economic growth (Bloom, Canning, & Fink, 2010; Lee & Mason, 2011). For this reason, in the aging scenario the aggregate growth component $(n + g)$ is assumed to decline by 0.5 percentage points. This adjustment should not be interpreted as an econometric estimate; rather, it is treated as a calibration choice representing the adverse effects of aging on labor supply and productivity dynamics.

Under this scenario, the deterioration in demographic structure operates through two main channels. First, the increase in the old-age dependency ratio requires a higher contribution rate within the PAYG system, thereby increasing the burden on the working generation. Second, the decline in the $(n + g)$ component weakens the dynamics of capital accumulation and the output trajectory. In this respect, Scenario 1 serves as the main comparative scenario for examining the effects of population aging on macroeconomic equilibrium.

The increase in the old-age dependency ratio is treated as a counterfactual assumption representing the aging trend indicated by long-term demographic projections for Türkiye. Accordingly, the values used do not represent the direct outcome of a population projection; rather, they are representative magnitudes selected to analyze the macroeconomic effects of demographic pressure.

5.3. Scenario 2: Reform Scenario

The third scenario is designed as a representative reform scenario in which the macroeconomic effects of demographic aging are partially mitigated through appropriate policy interventions. Rather than constituting a direct estimate of a specific policy package, this scenario represents a counterfactual framework in which demographic pressure is moderated through measures such as increasing the retirement age, raising labor force participation rates, and the supportive effects of migration policies. The objective is to examine the extent to which the adverse macroeconomic effects observed under the aging shock can be alleviated.

In this scenario, the old-age dependency ratio is assumed to reach

$$D = 14.00\%$$

This value represents a structure in which demographic pressure does not disappear entirely, but remains more limited compared to the aging scenario due to policy interventions. Since the contribution rate in the PAYG system is again determined by the relationship

$$\tau = \rho D$$

and the replacement rate parameter is maintained at ρ=0.50, as in the baseline scenario, the contribution rate in this scenario is calculated as follows:

$$\tau = 0.50\ x\ 0.1400 = 0.0700$$

Accordingly, in the reform scenario, the PAYG contribution rate rises to approximately

$$\tau = 7.00\%$$

In the reform scenario, it is assumed that not only the demographic burden but also the pressure on growth dynamics is partially alleviated. Accordingly, the decline in the aggregate growth component $(n + g)$ is assumed to be limited to 0.2 percentage points. This value should not be interpreted as a direct econometric estimate; rather, it is treated as a scenario calibration representing the possibility that labor market and social security reforms may partially offset the adverse effects of aging on growth.

Under this scenario, reforms are assumed to operate through two main channels. First, limiting the increase in the old-age dependency ratio reduces the financing burden of the PAYG system and partially restrains the rise in the contribution rate. Second, due to the improvement in labor force participation and growth dynamics, the deterioration in capital accumulation and the output trajectory remains more limited than in the aging scenario. In this respect, Scenario 2 provides a comparative framework for evaluating the macroeconomic consequences of policy interventions in response to demographic aging.

The reform scenario is a counterfactual policy scenario constructed to examine the extent to which institutional arrangements that may be implemented in the social security system can offset demographic pressure. Therefore, the parameter values used are intended not to represent a specific policy program, but rather to comparatively assess the potential effects of alternative institutional arrangements on macroeconomic equilibrium.

5.4. Sensitivity Analysis

In order to evaluate whether the model results are sensitive to the design of the PAYG pension system, a sensitivity analysis is conducted for the replacement rate parameter ϱ, following the standard use of sensitivity analysis in calibrated structural macroeconomic models (Heer & Maussner, 2024). Since ϱ determines the ratio of pension transfers to wages, it directly affects the contribution rate through the PAYG budget identity $\tau = \rho D.$ Accordingly, in addition to the baseline value $\rho = 0.50$, two alternative values are considered: $\rho = 0.40$and $\rho = 0.60$. These values represent lower, baseline, and higher pension transfer burdens, respectively, and allow the responsiveness of the model outcomes to pension system parameters to be examined. The results of this sensitivity analysis are reported in Section 6.2.

6. Findings

This section presents the results of the dynamic simulations conducted under the calibrated OLG–PAYG model. The analyses examine the ten-period transition paths of the economy under three different scenarios (S0: baseline equilibrium, S1: population aging, S2: reform scenario). The findings are evaluated based on five main outcome variables: the contribution rate τ, capital intensity k, the real interest rate r, the level of output y, and intergenerational welfare W.

The replacement rate parameter

$$\rho = 0.50$$

is used as the baseline parameter value in the simulations. Table 2 summarizes the long-run equilibrium values toward which the economy converges under different scenarios. The following subsections provide a detailed interpretation of the economic mechanisms underlying these results.

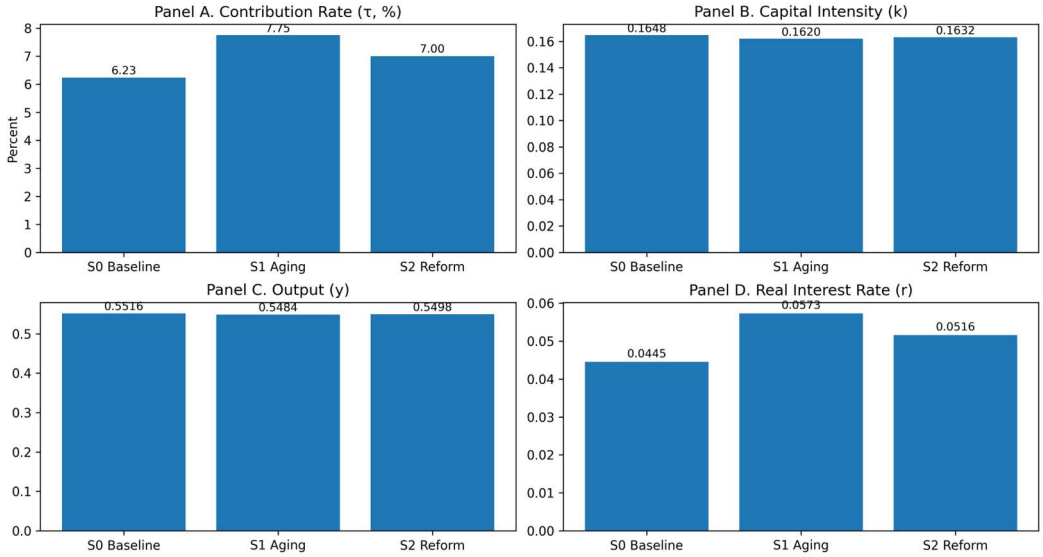
6.1. Scenario Simulation Results $\rho = 0.50$

Table 2. OLG–PAYG Model: Long-Run Equilibrium Values Across Scenarios $\rho = 0.50$

Variable	S0 Baseline	S1 Aging	S2 Reform
Contribution rate (τ), %	6.23	7.75	7.00
Capital intensity (k)	0.1648	0.1620	0.1632
Real interest rate (r)	0.0445	0.0573	0.0516
Output (y)	0.5516	0.5484	0.5498
Intergenerational welfare (W)	-2.3390	-2.3728	-2.3564

Note: k denotes capital per unit of effective labor, r represents the net real return on capital, and W indicates the life-cycle welfare of the representative generation.
Source: Author's calculations.

Figure 1. Scenario-Based Comparison of Macroeconomic Outcomes under ϱ=0.50



Note: The figure reports the long-run equilibrium values of the contribution rate, capital intensity, output, and the model-implied real interest rate under the baseline, aging, and reform scenarios.
Source: Author's calculations.

Table 2 and Figure 1 summarize the long-run equilibrium outcomes of the model economy under the three scenarios and make the main transmission mechanisms more transparent. The results indicate that population aging increases the PAYG contribution rate, reduces capital intensity and output, and raises the model-implied real interest rate through the decline in capital accumulation. Although the reform scenario does not completely eliminate these adverse effects, it mitigates them to a certain extent by limiting the increase in the contribution burden and moderating the decline in capital intensity.

Contribution Rate Dynamics

As shown in Table 2, the increase in the old-age dependency ratio exerts direct pressure on the contribution rate in the PAYG system. In the baseline scenario, the contribution rate remains in equilibrium at

$$\tau = 6.23\%$$

In the aging scenario, however, this rate increases to

$$\tau = 7.75\%$$

This result is a natural consequence of the fact that, in the model, the contribution rate is determined directly by the relationship

$$\tau = \rho D$$

The increase in the contribution rate reduces the net wage income of the working generation and indirectly affects saving behavior. In the reform scenario, the contribution rate is limited to

$$\tau = 7.00\%$$

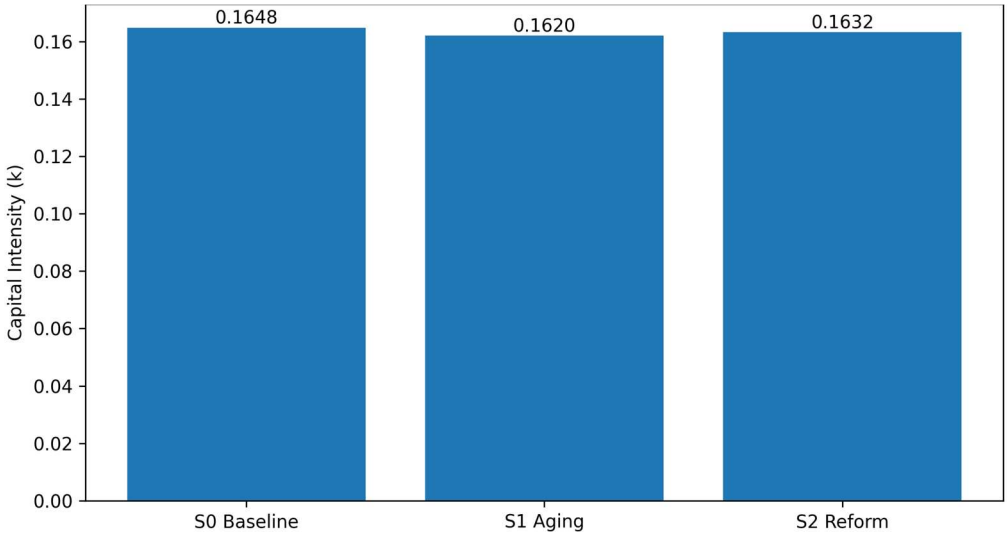
Thus, the reform scenario results in lower contribution pressure compared with the aging scenario. This finding is consistent with the literature emphasizing the fiscal pressure that increases in the old-age dependency ratio place on PAYG systems (Barr & Diamond, 2008).

Capital Intensity and Capital Accumulation

The model results indicate that the aging shock generates a two-sided effect on capital intensity. On the one hand, a slowdown in labor force growth may exert an upward effect on the level of capital per unit of effective labor. On the other hand, rising contribution rates may reduce the net income of the working generation and thereby lower the saving rate.

The simulation results show that, under this calibration, the second effect is more dominant. In the aging scenario, capital intensity converges over time to a lower equilibrium level. The reform scenario, by limiting the increase in the contribution rate, partially mitigates the decline in capital intensity. Accordingly, under this model, the PAYG contribution burden channel exerts downward pressure on the dynamics of capital accumulation.

Figure 2. Long-Run Capital Intensity across Scenarios under ϱ = 0.50



Note: The figure illustrates the long-run effect of the aging shock and the reform scenario on capital intensity relative to the baseline equilibrium.

Source: Author's calculations.

As shown in Figure 2, the aging scenario leads to a visible decline in long-run capital intensity relative to the baseline equilibrium. The reform scenario partially offsets this decline, indicating that policies limiting the increase in the PAYG contribution burden can moderate, but not fully eliminate, the adverse effect of population aging on capital accumulation.

Real Interest Rate (Model-Implied r)

In the model, the real interest rate is determined by the marginal product of capital. As shown in Table 2, in the aging scenario, capital intensity converges to a lower equilibrium level, which increases the marginal product of capital and, accordingly, raises the model-implied net real return:

$$r: 0.0445 \rightarrow 0.0573$$

In the reform scenario, the decline in capital intensity is more moderate because the contribution burden is more limited, and the increase in the real interest rate remains relatively lower $(r = 0.0516)$.

This result may differ from the natural rate of interest r^* channel frequently discussed in the literature. While many empirical studies interpret r^* as the long-run return on safe assets, this study generates a model-implied real return based on the marginal product of capital. Therefore, divergences in both direction and magnitude may emerge between the demography-driven decline in r^* and the dynamics of the model-implied r.

Output Level and Growth Dynamics

According to the results presented in Table 2, the level of output is determined by the combined effects of capital intensity and labor dynamics. In the aging scenario, the slowdown in labor force growth and the decline in capital intensity lead output to converge over time to a lower trajectory.

By contrast, the reform scenario partially offsets the loss in output, as it both reduces the contribution burden and limits the decline in the aggregate growth component. This result is a natural consequence of the joint interaction between the change in the aggregate growth component $(n + g)$, defined in Section 5, and the variation in capital intensity.

6.2. Sensitivity Analysis (Replacement Rate)

The sensitivity analysis confirms that the main qualitative findings of the model remain robust under alternative values of the replacement rate parameter. As ρ increases, the contribution rate in the PAYG system rises, reducing the net income of the working generation and exerting stronger downward pressure on saving behavior and capital accumulation. Conversely, when ϱ is lower, the contribution burden remains more limited, and the adverse effects on capital intensity and output are correspondingly weaker.

Despite these changes in magnitude, the direction of the main results remains broadly unchanged. Under different values of ρ, population aging continues to increase the contribution rate and weaken capital accumulation, while the reform scenario continues to moderate these adverse effects. This finding indicates that the results are not driven solely by the baseline calibration of the replacement rate parameter but reflect the broader PAYG mechanism linking demographic pressure to contribution burdens, savings, and capital accumulation. The magnitude of these effects, however, depends on the transfer rate of the pension system, which is consistent with the literature emphasizing the macroeconomic importance of pension system design (Barr & Diamond, 2008).

6.3. Transitional Generational Welfare

The model results indicate that population aging affects not only macroeconomic aggregates but also the distribution of welfare across generations. The welfare indicator W reported in Table 2 represents a measure of welfare reflecting the life-cycle utility of the representative generation within the model. This indicator is calculated by taking into account the effect of consumption levels during both the working period and retirement on total utility.

Although the values presented in Table 2 provide a summary welfare indicator for the long-run equilibrium, these results should be evaluated together with the intergenerational welfare differences that arise particularly during the transition period. The simulation results indicate that the generations born after the realization of the aging shock experience a noticeable decline in welfare levels. This outcome is associated with the reduction in the net wage income of working generations due to the increase in contribution rates within the PAYG system, which in turn lowers life-cycle consumption.

In the reform scenario, by contrast, the welfare loss remains lower than in the aging scenario because the increase in the contribution rate is more limited. Accordingly, social

security system reforms appear to have important implications not only for macroeconomic equilibrium but also for the distribution of welfare across generations.

These findings are consistent with the classical literature emphasizing that PAYG systems, due to their intergenerational transfer mechanism, may generate significant effects on welfare distribution (Samuelson, 1958; Barr & Diamond, 2008). Therefore, in the context of demographic aging, the design of pension systems emerges as a policy domain that must be evaluated not only in terms of fiscal sustainability but also in terms of intergenerational welfare balance.

7. Discussion

This section evaluates the simulation findings of the study within the context of the OLG literature examining the macroeconomic effects of population aging. The objective is to identify the points at which the results align with the existing literature, where they diverge, and how these divergences can be explained by the structural characteristics of the model. In this framework, the discussion first addresses the consistency and divergence of the findings with the literature, then analytically examines the dimensions of intergenerational transfers and welfare, and finally evaluates the assumptions under which the results of the study hold as well as the main limitations of the model.

7.1. Consistency and Divergence of the Findings with the Literature

The OLG approach is one of the most widely used theoretical frameworks in the literature examining the macroeconomic effects of demographic change. There is broad consensus across three main points between the classical OLG models (Samuelson, 1958; Diamond, 1965) and the demographic transition literature (Bloom, Canning, & Fink, 2010; Lee & Mason, 2011). First, population aging exerts downward pressure on potential growth by reducing labor supply. Second, saving behavior changes as life expectancy increases and the retirement period expands. Third, shifts in the savings–investment balance generate persistent effects on interest rates and capital accumulation.

The findings obtained in this study are generally consistent with the aforementioned literature. The simulation results indicate that under the aging scenario the contribution rate increases, capital intensity weakens, the level of output declines, and intergenerational welfare decreases. These results are consistent with the literature emphasizing that increases in the old-age dependency ratio impose additional burdens on the working generation through the PAYG system, and that these burdens are transmitted to savings and production dynamics (Barr & Diamond, 2008; Feldstein, 1974).

Nevertheless, the study produces a result that partially diverges from the natural rate of interest (r^*) channel frequently discussed in the literature. In the simulations, the model-implied real interest rate increases under the aging shock. This difference arises because the interest variable used in this study does not correspond to the natural rate of interest discussed in the empirical literature, but rather to the model-implied real return on capital (r) derived from the marginal product of capital. In the literature, the natural rate of interest is often interpreted as the return on safe assets and as the long-run anchor of monetary policy, whereas the interest rate path obtained here is derived from the production structure and changes in capital intensity. Therefore, demographic aging should not necessarily be expected to generate effects in the same direction on safe asset returns in financial markets and on production-based returns to capital. This divergence illustrates the importance of distinguishing conceptual variables when evaluating the relationship between demography and interest rates.

7.2. Intergenerational Transfers and the Welfare Dimension

One of the important features of the OLG approach is its ability to analyze the effects of economic decisions on different generations within the same analytical framework. The coexistence of different generations within the economy implies that policies implemented in a given period may generate different welfare outcomes across generations over time (Blanchard, 1985; Weil, 1987).

In this study, public debt is not explicitly incorporated into the model. Nevertheless, the PAYG mechanism inherently creates an intergenerational transfer structure. When the old-age dependency ratio increases, the contribution rate paid by the working generation rises, generating a redistributive effect that operates in favor of the current retired generation and to the detriment of the younger generation. The deterioration of the welfare indicator under the aging scenario in the simulation results clearly illustrates the impact of this intergenerational transfer mechanism on welfare outcomes.

This finding is consistent with the literature emphasizing the effects of PAYG systems on intergenerational welfare balance (Samuelson, 1958; Auerbach & Kotlikoff, 1987; Barr & Diamond, 2008). In particular, during transition periods, younger generations may face a higher contribution burden, which can have important implications not only for the fiscal sustainability of the system but also for the intergenerational distribution of welfare. The more limited welfare loss observed in the reform scenario suggests that demographic pressure can be partially mitigated through institutional arrangements.

7.3. Sensitivity of the Results to Assumptions and Model Limitations

The interpretation of the findings should take into account the assumptions underlying the model. The framework employed in this study is a standard OLG–PAYG model consisting of representative agents with a two-period life cycle, operating under the assumptions of a closed economy and the absence of uncertainty. While this structure provides analytical clarity for tracing the core mechanisms of demographic change, it also limits the scope of the results.

First, the model does not incorporate income and wealth heterogeneity. In reality, however, the effects of population aging and pension reforms on saving behavior and welfare may differ substantially across income and wealth groups. Since the present framework is based on a representative-agent structure, the welfare indicator reported in the simulations should be interpreted as an average life-cycle welfare measure rather than as a distribution-sensitive welfare outcome. In this respect, the welfare loss generated by higher PAYG contribution rates may be much more severe for low-income households with limited savings, borrowing constraints, and a higher dependence on public pension transfers, whereas higher-income households with greater asset holdings may be better able to absorb such shocks. Heterogeneous-agent models show that precautionary saving behavior, borrowing constraints, and wealth distribution can significantly alter aggregate and welfare outcomes (Huggett, 1993; Aiyagari, 1994; De Nardi, 2015). Accordingly, although the findings presented here illustrate the direction and core mechanism of demographic pressure, they should not be interpreted as capturing the full distributional consequences of aging and pension reform.

Second, the model is constructed under the assumption of a closed economy. As a result, international capital flows, external saving opportunities, migration movements, and country-risk-related financing conditions are excluded from the analysis. This assumption provides analytical tractability by ensuring that domestic savings are directly transformed into domestic investment and that the model-implied return on capital is determined internally through the marginal product of capital. However, it also limits the direct applicability of the results to open economies such as Türkiye, where external financing conditions and international capital flows may significantly affect interest rates, investment decisions, and the savings–investment balance. If international capital mobility were explicitly incorporated into the model, the equilibrium interest rate would not be determined solely by domestic saving and capital accumulation, but would also depend on external capital inflows, global financial conditions, and country risk premia. In such a setting, foreign capital inflows could partly offset the decline in domestic savings caused by population aging and thereby moderate the fall in capital accumulation and output. Conversely, tighter external financing conditions or a reversal of capital flows could amplify the adverse effects of aging by raising financing costs and constraining investment. Therefore, the closed-economy framework used in this study should be

interpreted as isolating the domestic demographic and PAYG mechanisms, rather than providing a full representation of Türkiye's open-economy macroeconomic environment. Future research could extend the present framework by incorporating international capital mobility, external borrowing constraints, and risk premia in order to examine how demographic aging interacts with external financing conditions (Obstfeld & Rogoff, 1996).

Third, the model does not incorporate uncertainty, risk, or financial market frictions. Consequently, factors that are important in the natural rate of interest literature—such as safe asset demand, risk premia, and financial conditions—are not directly included in the model. This omission is one of the reasons for the divergence between the model-implied real interest rate and empirical estimates of r^*.

In addition, the model does not explicitly incorporate discrete institutional policy shocks such as the EYT regulation introduced in Türkiye in 2023. Such reforms may affect the model outcomes by changing the effective retirement age, the number of pension beneficiaries, and the contributor-beneficiary ratio in the PAYG system.

Finally, the study examines the potential effects of demographic aging in the Turkish economy within a structural and scenario-based framework. However, the demographic and institutional changes used in the scenarios are not derived from econometric estimates but are instead counterfactual assumptions based on calibration. Therefore, the results should not be interpreted as point forecasts, but rather as structural findings illustrating the direction and relative magnitude of specific mechanisms.

Relatedly, the exclusion of the post-2022 period should also be considered when interpreting the long-run implications of the model. The post-2022 macroeconomic environment in Türkiye has been characterized by high inflation, a period of deeply negative real interest rates, and subsequently tighter financial conditions as part of the disinflation process (CBRT, 2024; IMF, 2023, 2024). Such conditions may affect the mechanisms emphasized in the model through several channels. First, high and volatile inflation may weaken the link between the model-implied real return on capital and observed financial-market interest rates, since nominal yields, inflation expectations, and risk premia become more important in determining actual borrowing and saving decisions. Second, negative real interest rates may discourage domestic financial saving and alter portfolio preferences, thereby changing the savings–investment balance relative to the benchmark calibration period. Third, tighter monetary and financial conditions during the disinflation process may constrain investment and capital accumulation in the short to medium run, even if the long-run demographic mechanisms remain unchanged. Therefore, the exclusion of the post-2022 period does not invalidate the structural interpretation of the model, but it implies that the results should be read as long-run demographic and PAYG mechanisms abstracting from the exceptional inflationary and monetary-policy environment. Future research may explicitly incorporate inflation dynamics, monetary policy reactions, and financial frictions in order to evaluate how demographic aging interacts with macroeconomic instability and disinflation episodes in Türkiye.

Despite these limitations, the model makes it possible to examine within a single general equilibrium framework the effects of population aging on the social security system, capital accumulation, production, and intergenerational welfare. In this respect, the study provides a useful analytical foundation for discussing the macroeconomic consequences of aging, particularly in economies undergoing demographic transition such as Türkiye.

8. Policy Implications

Population aging represents a significant demographic transformation that requires long-term structural adjustments in macroeconomic policy design. The simulation results obtained under the OLG–PAYG model developed in this study indicate that an increase in the old-age dependency ratio generates a substantial financing pressure on the social security system. Under the PAYG mechanism, the direct linkage between the contribution

rate and the demographic structure implies that, in an aging economy, the financial burden borne by the working generation increases. This, in turn, may create indirect effects on saving behavior, capital accumulation, and production dynamics.

The model findings suggest that the design of the pension system constitutes a critical policy domain in the context of demographic change. An increase in the old-age dependency ratio raises contribution rates, thereby reducing the net wage income of the working generation. This mechanism may exert downward pressure on long-term capital accumulation. Accordingly, from the perspective of social security sustainability, it is important to reassess pension policies in a manner consistent with demographic trends. As frequently emphasized in the literature, the development of institutional adjustment mechanisms within pension systems may help contain contribution pressures and contribute to preserving the intergenerational balance of welfare.

At the same time, pension reforms should not be evaluated solely from the perspective of fiscal sustainability. Since the present model is based on a representative-agent framework, the welfare losses reported in the simulations reflect average effects and may conceal substantial differences across income groups. In practice, increases in contribution rates, reductions in replacement rates, or changes in retirement eligibility conditions may impose a heavier burden on low-income workers and retirees, who have limited private savings and depend more strongly on public pension benefits. Therefore, reform packages designed in response to population aging should include gradual, income-sensitive, and redistributive elements that protect vulnerable groups while maintaining the financial sustainability of the PAYG system. Policy instruments such as progressive contribution schedules, minimum pension guarantees, targeted social transfers, or differentiated transition rules may help reduce the regressive effects of pension reforms and preserve intergenerational as well as intragenerational equity. In this respect, social security reform should aim not only to stabilize contribution rates and pension balances, but also to prevent the adjustment burden from falling disproportionately on lower-income groups (Barr & Diamond, 2008; Holzmann & Hinz, 2005).

In the Turkish context, recent institutional arrangements also highlight the importance of considering pension-related policy shocks. In particular, Law No. 7438, commonly known as the regulation on those affected by the retirement age requirement (EYT), removed the age condition for eligible individuals who had fulfilled the other statutory requirements for retirement. Such an institutional change may be interpreted within the present OLG–PAYG framework as a policy shock that increases the effective number of retirees, raises the old-age dependency ratio relevant for the pension system, and strengthens the contribution burden on the working generation. Although the current model does not explicitly simulate the EYT regulation as a separate policy experiment, its effects can be conceptually mapped onto the model through an increase in the dependency ratio and/or the replacement burden. Accordingly, reforms that reduce the effective retirement age may amplify PAYG financing pressures, weaken net wage income and savings, and thereby intensify the adverse effects on capital accumulation and intergenerational welfare. Conversely, policies that increase the effective retirement age, extend working lives, or raise labor force participation may operate in the opposite direction by reducing the number of beneficiaries relative to contributors and mitigating the rise in contribution rates. Therefore, the model is sensitive not only to demographic aging but also to institutional changes that alter the contributor-beneficiary balance in the pension system (Social Security Institution [SGK], 2023; Law No. 7438, 2023).

The macroeconomic consequences of demographic aging are not limited to pension systems. The relative decline in the working-age population may also exert pressure on labor supply and productive capacity. Therefore, it is important that labor market policies be designed in a manner that facilitates adaptation to demographic transformation. In particular, policies aimed at increasing labor force participation rates, extending working

lives, and supporting productivity-enhancing structural reforms may play a significant role in preserving the growth potential of aging economies.

Moreover, in the context of demographic aging, the sustainability of economic growth becomes increasingly dependent on productivity improvements. As labor force growth slows, strengthening capital-intensive technologies and innovation capacity may become a key factor in enabling the production structure to adapt. In this regard, policies supporting education, human capital development, and technological investment constitute important instruments for stabilizing the long-term growth trajectory of aging economies.

When evaluated in the context of Türkiye, although the current demographic structure still reflects a relatively younger population composition compared with many advanced economies, demographic projections indicate that the old-age dependency ratio is likely to increase significantly in the coming decades. Consequently, the development of a comprehensive policy framework—one that simultaneously addresses the sustainability of the social security system, labor market policies, and productivity-enhancing investments—will be essential for managing the macroeconomic consequences of demographic transformation.

9. Conclusion

Population aging is one of the most significant demographic transformations affecting long-run macroeconomic equilibria in modern economies. Declining fertility rates and increasing life expectancy alter not only the structure of the population but also directly influence key macroeconomic variables such as saving behavior, capital accumulation, interest rates, and the sustainability of social security systems. This study has examined the macroeconomic implications of this demographic transformation within the framework of the Overlapping Generations (OLG) model and analyzed the economic equilibrium effects of population aging through a calibrated OLG–PAYG model based on data from the Turkish economy.

The model developed in this study incorporates individuals' life-cycle consumption and saving decisions, the production process, and a Pay-As-You-Go (PAYG) pension system within a unified general equilibrium framework. Following calibration using demographic and macroeconomic indicators for Türkiye, the model was evaluated through dynamic simulations under three alternative scenarios: the baseline equilibrium, a population aging shock, and a reform scenario.

The findings yield three main conclusions. First, population aging generates a significant contribution pressure on the social security system. In the model, the contribution rate is defined as the product of the old-age dependency ratio and the replacement rate parameter; therefore, an increase in the old-age dependency ratio directly leads to a higher contribution rate. This mechanism reduces the net wage income of the working generation and may negatively affect saving behavior and, consequently, the dynamics of capital accumulation.

Second, demographic aging produces substantial effects on the economy's dynamic transition paths. Simulation results indicate that under the aging shock scenario, capital intensity and output converge toward a lower equilibrium trajectory over time. In contrast, under the reform scenario, these adverse effects are partially mitigated. This finding suggests that although pension system reforms and labor market policies may not completely eliminate the macroeconomic consequences of demographic pressure, they can substantially alleviate its effects.

Third, population aging is shown to have pronounced implications for the intergenerational distribution of welfare. Simulation results reveal that younger cohorts born during the transition period experience a noticeable decline in welfare. This outcome is associated with the rising contribution rates in the PAYG system, which constrain the life-cycle consumption possibilities of the working generation. Under the reform scenario,

however, the welfare loss is relatively smaller due to the more limited increase in contribution pressure.

These findings indicate that demographic aging affects not only the social security system but also capital accumulation, production, and the intergenerational balance of welfare. Consequently, policy design in aging economies requires a comprehensive approach that simultaneously addresses pension system reforms, labor market regulations, and productivity-enhancing investments.

Nevertheless, the study has several limitations. First, the model is constructed under the assumption of representative agents and therefore does not incorporate income and wealth heterogeneity. Second, the model operates under the assumption of a closed economy and excludes international capital flows and migration dynamics. In addition, financial market frictions, uncertainty, and risk are not incorporated into the analytical framework. Accordingly, the results should be interpreted as a structural framework illustrating the direction and core mechanisms of demographic change rather than as precise empirical predictions.

Future research could extend this framework by integrating heterogeneous-agent structures, human capital dynamics, and open-economy interactions into OLG models in order to analyze the macroeconomic effects of demographic aging more comprehensively. Furthermore, for economies undergoing demographic transition, such as Türkiye, combining micro-data–based empirical analyses with structural model outcomes may provide valuable contributions to the literature.

In conclusion, population aging is not merely a demographic transformation but also a structural process that influences the long-run equilibrium of the macroeconomic system. The OLG-based analysis conducted in this study provides an important analytical framework for understanding the effects of demographic change on social security systems, capital accumulation, and the intergenerational distribution of welfare.

Accordingly, the findings should not be interpreted as precise forecasts for the Turkish economy. Rather, they should be understood as scenario-based structural results derived from an OLG–PAYG framework calibrated with Turkish data, aimed at illustrating the potential macroeconomic consequences of demographic aging.

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