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POPULATION AGING, RELATIVE PRICES AND CAPITAL FLOWS ACROSS THE GLOBE

by Andrea Papetti*

Abstract

This paper develops a multi-country two-sector overlapping-generations model to study the impact of demographic change on the relative price of nontradables and current account balances. An aging population expands the relative demand for nontradables, exerting upward pressure on their relative price (structural transformation), and entails a willingness to save more, as households discount higher survival probabilities, and invest less, as firms face increasing labor scarcity. The general equilibrium reduction of the real interest rate (secular stagnation) dampens the increase in the relative price as savings become less profitable, thus lowering consumption at older ages. The model robustly predicts that faster-aging countries will face greater increases in the relative price of nontradables and unprecedented accumulations of net foreign asset positions (global imbalances) over the twenty-first century.

JEL Classification: E21, F21, J11, O11, O14.
Keywords: population aging, relative prices, capital flows, overlapping generations, tradable nontradable, secular stagnation, structural transformation, global imbalances.
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Contents

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[...] *aging speeds up the structural transformation process since older households consume more services.*

— Cravino et al. (2020), Population Aging and Structural Transformation

[...] *Bernanke (2005)'s "global savings glut" has just begun.*

— Auclert et al. (2020), Demographics, Wealth, and Global Imbalances in the Twenty-First Century

1 Introduction[1]

Population aging, i.e. the process of declining fertility and mortality rates leading to increasing old dependency ratios in all major economies (Figure 1a),[2] is an underlying force of three important international macroeconomic trends: secular stagnation (Eggertsson et al., 2019), global imbalances (Auclert et al., 2020) and structural transformation (Cravino et al., 2020). This paper provides the first contribution to connect these three phenomena in a multi-country dynamic general-equilibrium quantitative model with heterogeneous agents by age, focusing the analysis on the impact of demographic change on capital flows and the relative prices of nontradable goods.

It is understood that the increasing scarcity of effective labor and longer life expectancy tend to make capital relatively more abundant, thus bearing an environment with declining real interest rates (secular stagnation, Figure 1b). Likewise, researchers have explored to what extent different patterns of aging across countries can determine international capital flows in the attempt of explaining the observed global imbalances (Figure 1c–1d). However, these studies have generally focused on a single composite sector of the economy, thus missing a potentially important part of why aging might matter for international macroeconomics. Namely, an older population features a propensity to demand relatively more nontradables, thus contributing to the sectoral reallocation of resources away from the tradable sector with an ensuing adjustment of the relative prices (structural transformation, Figure 1e–1f).

This paper stresses the importance of considering the three macroeconomic phenomena in a unified general equilibrium framework, for multiple reasons. First, since all countries are aging, one could expect the same qualitative macroeconomic response to demographic change of each country if considered as a "small-open economy" (i.e. in a partial equilibrium environment with given real interest rate). For example, as aging tends to induce more savings and less investment one could predict that each country runs a current account surplus – which, of course, cannot happen at the world level. Second, in a world where all countries are willing to save more and invest less due to aging, the real interest rate is reduced. Such a reduction, as it will be shown, could have tangible effects on the sectoral reallocation of resources and relative prices so that, if not taken into account, could bias the estimate of the impact of aging on structural transformation. Third, the aging-induced sectoral reallocation could be itself a driver of capital flows and secular stagnation – a channel that has not featured prominently into the research on the topic in spite of the original

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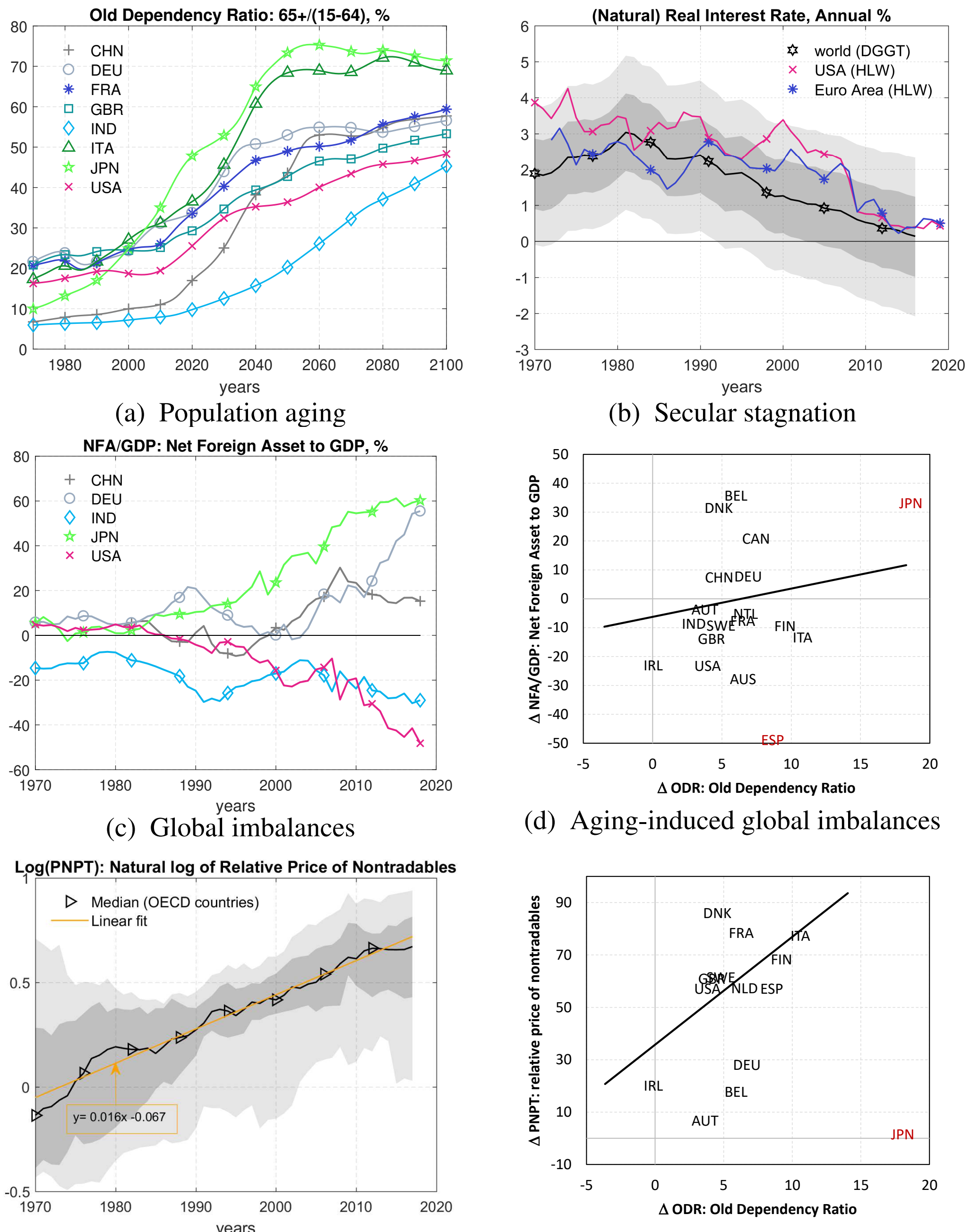
[2]According to the old-dependency-ratio depicted in Figure 1a, no country is yet near to its long term level of population aging. While the identification of a person as "old" evidently depends on a threshold that might be appropriate to change over time, "chronological [age measured in calendar years] population aging is inevitable" (Lee, 2016).



(a) Population aging

(b) Secular stagnation

(c) Global imbalances

(d) Aging-induced global imbalances

(e) Structural transformation

(f) Aging-induced structural transformation

Figure 1: Population aging, secular stagnation, global imbalances, structural transformation

Note. (1a) The indicator in the figure is the the number of people aged more than 64 over the number of people aged between 15 and 64. Data from the United Nations (UN, 2019) *World Population Prospects 2019, Online Edition. Rev. 1*, medium variant after year 2019. (1b) Trend in global real rates estimated by Del Negro et al. (2019) (DGGT) on yield data provided by Jordá et al. (2019) (JST). The continuous line is the posterior median; shaded areas show the 68 and 95% posterior coverage intervals. Natural real interest rate estimates by Holston et al. (2017) (HLW). (1c) Data on net foreign asset to GDP corresponding to "Estimated IIP (net of gold)/GDP" provided by Lane and Milesi-Ferretti (2018). (1d) 1991-2018 average percentage point deviations from the 1970-1990 average. JPN and ESP are outliers. (1e) Data on relative price of nontradables described in Appendix F. Shaded areas show the 16-84 and 2.5-97.5th percentile ranges. (1f) 1991-2017 average percentage point deviations from the 1970-1990; JPN is outlier.

formulation of the secular stagnation hypothesis (as noted by Lee (2016)).[3] Fourth, in spite of the common projected aging pattern, countries differ not only in terms of population size but also by timing, extent and speed of the aging process. The interaction of such demographic differences can play an important role not only in determining magnitude and direction of capital flows but also in identifying those countries that can face more or less impact on their relative price of nontradables with respect to the trading partners, hence on their real exchange rate.

The paper proceeds in three main steps. First, the developed overlapping generations (OLG) model is described and characterized in its equilibrium dynamics. Second, the model is calibrated with population data and projections (UN, 2019) for nine euro area countries (EA9 henceforth) to examine if the historical data generated by the model can explain real-world capital flows and finely measured relative prices.[4] Third, the model is used for an extended set of countries – eighteen major world economies – to make predictions of the main outcome variables in the twenty-first century.

The OLG model developed in this paper builds especially on the multi-country large-scale OLG model of the world by Domeij and Flodén (2006) and Krueger and Ludwig (2007) to incorporate two sectors, each producing either tradable or nontradable composite goods.[5] The model has two key distinctive features. First, consistently with the empirical evidence (Cravino et al., 2020; Giagheddu and Papetti, 2018), older households have a preference to consume relatively more nontradables. Second, working hours are imperfectly substitutable between sectors. This latter feature allows relative demand changes to matter for the relative price of nontradables (De Gregorio et al., 1994) and to be consistent with the long-run persistence of sectoral hourly wage differentials found empirically (Cardi and Restout, 2015). Countries are allowed to differ in all the main parameter values both on the household and on the firm side in both sectors, as well as on the generosity of the pension system. Hence the main channels in the models are mediated by a complex interconnection of differences that contribute to the final outcome in an environment where, as it is standard in OLG models, falling mortality (fertility) rates tend to encourage (discourage) savings (investment). To the standard savings/investment decisions, the model adds the sectoral reallocation as a potential driver of international capital flows.

From the perspective of the perfect-foresight OLG model, in the face of aging each country reacts with a willingness to save more and invest less, i.e. with a willingness to run current account surpluses. The reason is that higher survival probabilities lead agents to be willing to save more in order to smooth consumption over a longer life. The more so the lower the generosity of the pay-as-you-go public pension system. At the same time, constant returns to scale technology in production means that firms are willing to demand less capital for investment as the growth rate of the effective

[3] Hansen (1939) – who first formulated the secular stagnation hypothesis (Summers, 2013, 2014) – suggested that population aging can tilt the composition of consumption demand toward services, and particularly health care, that require relatively little capital, potentially exacerbating the problem of deficient investment demand. The OLG model in this paper allows for such a channel.

[4] The focus is on EA9 to rely on a dataset for relative prices compiled by Berka et al. (2018) with a high degree of cross-country comparability and granularity in the tradable versus nontradable split.

[5] It is a reformulation of a model first appeared in Giagheddu and Papetti (2018) as detailed in section 2.

labor force decreases. Both factors dampen the return on capital in general equilibrium and imply that the countries which are relatively more populous (i.e. more capital abundant), aging faster (i.e. more willing to save), have higher effective labor productivity growth (i.e. higher economic growth) and less generous public pension systems (i.e. less crowding-out effect on capital) tend to develop a positive net foreign asset position over time. Sectoral allocations can play a role here, especially given that there are sectoral differences in capital intensity.

There are three main channels in the model through which aging affects the relative price of nontradables. First, a demand composition effect: as the population distribution tilts towards older ages the relative demand for nontradable rises thus inducing an increase in the relative demand for labor in the nontradable sector. To attract labor in this sector, in the presence of imperfect labor mobility, the relative wage has to increase in turn translating into a higher relative price.

A second channel concerns the standard life-cycle consumption-savings decisions. Discounting higher survival probabilities, individuals save more. For given real interest rate (i.e. in partial equilibrium), this translates into higher expected consumption at older ages. As nontradable consumption needs to be met by domestic production (while tradable consumption can be freely met with imports from abroad), relative labor in the nontradable sector needs to increase for the nontradable good market to clear, and so the relative wage and the relative price of nontradables. These two channels predict for all countries an increase of the relative price of nontradables due to aging, in partial equilibrium. In this sense, aging can be a driver of structural transformation.[6]

The third channel pertains to the presence of different capital intensities between sectors. A decrease of the rental rate of capital decreases the relative price of the product that uses capital intensively. This effect owes famously to the Stolper and Samuelson (1941) theorem (above stated by reversing its underlying logic) which in the current setting is "amended" because the sectoral reallocation associated with the decrease in the rental rate of capital is mediated by a related change in the relative wage (i.e. there is no wage equalization as in the original theorem) which, in turn, depends crucially on the degree of sectoral labor mobility. In other words, by changing factor prices aging might matter for the relative price of nontradables in the presence of different capital intensities between sectors, all the more so in the presence of imperfect labor mobility.

As explained above and as well documented in the literature (see later in the introduction), aging does decrease the real interest rate in general equilibrium. Hence the third channel above will apply providing upward (downward) pressure on the relative price of nontradables depending on weather

[6]The model in this paper allows for a non-unitary elasticity of substitution in consumption between the two composite goods which, however, is not essential to have structural transformation led by aging. Structural transformation is often attributed to a process where the exogenously constantly growing relative TFP in the goods sector leads to a constantly growing relative price of services in turn associated with a growing services share in consumption as goods and services are complements in consumption, i.e. the consumption elasticity is smaller than one (see e.g. seminal contribution by Ngai and Pissarides (2007)). Here the mechanism through which an elasticity smaller than one might elicit structural transformation is similar but the exogenous trigger is demographic change. Furthermore, the model in this paper allows for differences in factor proportions between sectors, a feature deemed to be important for structural transformation (Acemoglu and Guerrieri, 2008), while it does not allow for nonhomothetic preferences in turn deemed to be an important feature (Boppart, 2014; Lewis et al., 2018).

in a country the tradable sector is more (less) capital intensive than the nontradable sector. At the same time, however, the upward pressure on the relative price of nontradables stemming from the first two channels above will be dampened as savings become less profitable thus discouraging consumption at later ages (which is biased towards nontradables).

The general equilibrium predictions of the model are validated on annual data for the relative price of nontradables *relative* to trading partners provided by Berka et al. (2018) for the EA9 countries and on standard annual data for the current account balances to GDP (provided by the IMF WEO). The primary quantitative exercise in the paper involves regressing these data on the corresponding simulated series generated by the calibrated model. Running a fixed effect specification it is found that the model can account for a portion of the *within* country variation for both the relative prices and the current account balances, where for the latter the relevance is particularly true for the sample periods that start between 2001 and 2007, always ending in 2020. For these sample periods the coefficient of interest is significantly close to unity, and the model explains between 15% and 30% of the current account to GDP fluctuations, judging by the coefficient of determination (R^2_{within}). For the relative price of nontradables – whose data are only available for the 1995-2007 period – the R^2_{within} is about 7%. Running *between* and pooled OLS estimations reveal again a positive and statistically significant coefficient, very close to unity in certain cases, with a fairly high R^2. This suggests that the model, where demographic change is the only driver, can to a certain extent explain also level differences across countries.

Given that the model finds some validation in the empirics, it is then used to run historical counterfactuals in order to isolate the main channels. Judged as median across the EA9 countries, the relative price of nontradables has constantly increased by about 1.4% per annum in the data over the 1996-2017 period.[7] The model over the same period predicts an annual growth rate of about 0.56% in partial equilibrium (i.e. at constant return to capital), that is 40% of the empirical counterpart. Running a counterfactual where the age-varying sectoral consumption shares are fixed at the average level prevailing until age 50, it is found that the demand composition channel (first channel above) accounts for only about one-fifth of that 40%. Finally, in partial equilibrium all countries are willing to run current account surpluses of about 5% of GDP, at least for the first half of the twenty-first century. The demand composition channel does not seem to play a relevant role for capital flows.

Turning to general equilibrium results, the return on capital decreases significantly dampening the appreciating impact of aging on the relative price of nontradables which tends to grow by about four-fifth less than in partial equilibrium. Therefore, it can be argued that demographic change can account between 40% (partial equilibrium) and 8% (general equilibrium) of structural transformation.[8] For most countries the role of differences in capital intensities between sectors

[7] To have the *absolute* level of the relative price of nontradables for each country, in this case the data source is EUKLEMS. The dataset on the price indices has inferior granularity compared to the one provided by Berka et al. (2018) but extends more in time (until 2017 rather than 2007).

[8] When structural transformation is judged by the nontradable share of consumption, demographic change can account

(third channel above) explains around a fourth of the general equilibrium absolute deviation of the relative price of nontradables from the initial level. Overall, the dynamics of capital flows is not strongly influenced by sectoral reallocation while standard consumption-savings decisions are key.

Finally, when the model is extended to have a world economy with eighteen countries covering about 70% of world GDP, 60% of trade (i.e. exports of goods and services) and 50% of world population, the most striking result is that, consistently with Auclert et al. (2020), the model predicts China and India to become the sole countries with a positive net foreign asset position over the twenty-first century. These countries are populous (covering and projected to cover together more than 70% of the world population considered in the model) and are expected to age faster than the trading partners (see Figure 1), hence with a greater willingness to accumulate savings. Since these countries are also those that the model predicts to have the biggest demographics-induced growth of labor productivity (GDP per unit of effective labor employed), demographic change features as a factor that can alleviate the "allocation puzzle" (Gourinchas and Jeanne, 2013), as also noticed by Bárány et al. (2019) and Sposi (2019).[9] The model of this world economy predicts a clear positive relationship between the growth rate of the old-dependency ratio and the growth rate of the relative price of nontradables, both in partial and general equilibrium, thus confirming existing empirical estimates (Groneck and Kaufmann, 2017).

Related literature. The macroeconomic impact of demographic change is certainly a long-standing issue (Lee (2016) for a review). Recently, the revival of Hansen (1939)'s "secular stagnation" hypothesis – thanks to Summers (2013, 2014) – has fostered macroeconomic research mostly focused on the impact of aging on the (natural) real interest rate and output, analyzing primarily closed economies with OLG models in the spirit of Auerbach and Kotlikoff (1987) (Gagnon et al. (2016), Eggertsson et al. (2019), Bonchi and Caracciolo (2020) for the US, Cooley et al. (2019), Bielecki et al. (2020), Papetti (2020) for Europe, Sudo and Takizuka (2019) for Japan, Cooley and Henriksen (2018) for US and Japan); or in the spirit of Gertler (1999)'s simpler life-cycle model (Carvalho et al. (2016) for a representative OECD economy, Kara and von Thadden (2016) for euro area, Rachel and Summers (2019) for a world economy modeled as a unique block). These models tend to robustly predict a downward impact of population aging on output and return on capital, similarly to the framework here developed.[10]

Mutli-country one-sector OLG models have been widely used to study capital flows. Here

between 19% (partial equilibrium) and 10% (general equilibrium) of the observed variation in the median nontradable share of consumption between 1995 and 2015 (as reported in Table 4, cf. Figure E.4). Comparably, by means of an empirical decomposition based on Boppart (2014)'s theoretical structure, Cravino et al. (2020) find for the United States that "changes in the age-structure of the population accounted for 20% of the observed change in the service expenditure share over this period [1982–2016]".

[9] A standard neo-classical growth model predicts that countries enjoying higher productivity growth should receive more net capital inflows. A prediction that does not square with the data and has been therefore labeled 'allocation puzzle" by Gourinchas and Jeanne (2013). Cf. Lucas (1990); Prasad et al. (2007).

[10] Challenges to such a prediction have been provided in modeling frameworks where the increasing scarcity of labor induced by aging can be compensated by human capital formation (Fougère and Mérette, 1999; Ludwig et al., 2012) and by the adoption of automation technology (Acemoglu and Restrepo, 2017, 2018; Basso and Jimeno, 2020).

the main references are: Brooks (2003), Domeij and Flodén (2006), Krueger and Ludwig (2007), Attanasio et al. (2007), Backus et al. (2014); and more recently: Bárány et al. (2019), Auclert et al. (2020). Compared to them, the paper exhibits a two-sector model that hence makes possible to study sectoral reallocation as well as relative prices. Rausch (2009) (chapter 4) is an exception in the literature, employing a fully-fledged OLG model with multiple sectors. The focus, however, is on a single country (Germany) modeled as a closed-economy. Galor (1992) is the seminal contribution in the literature that paved the way to the resolution of two-sector OLG models that, however, have been rarely used in an open-economy setting (Bajona and Kehoe (2006); Mountford (1998); Naito and Zhao (2009); Sayan (2005) have all kept analytical tractability to the detriment of capturing the full age-structure of the population).[11]

Some empirical work has studied the impact of the relative demand shift caused by aging on structural transformation (Börsch-Supan, 2003; Cravino et al., 2020), specifically on the relative price of nontradables (Groneck and Kaufmann, 2017) and on the real exchange rate (Giagheddu and Papetti, 2018). This last reference offers also the main theoretical framework which the model in the paper has built upon, extending the two-country static analysis there in a dynamic multi-country analysis with additional degrees of heterogeneity at both the secotral and country levels.

Essentially, by adding two sectors to the frontier multi-country large scale overlapping generations (OLG) models, this paper bridges two strands of the literature in international macroeconomics. On the one hand, those contributions that study the impact of demographic change on capital flows in a one-sector OLG model, cited above. On the other hand, those contributions that study the long-term determinants of relative prices, with focus on tradables versus nontradables, that have thus far mostly focused on models with a single representative agent that cannot take into account the permanent nature of certain changes such as those brought about by aging. Within this latter wide set of contributions, Berka et al. (2018) (and the references therein) offer a closely related assessment with a focus on the evolution of sectoral productivity in the euro area; Cardi and Restout (2015) offer the main evidence in support of the long-run persistence of sectoral wage differentials, at the heart of the theoretical framework here developed.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 describes how to calibrate and solve the model. Section 4 compares relative prices and capital flows implied by the model with real-world data for nine euro area countries. Section 5 runs historical counterfactuals to isolate the main channels. Section 6 extends the analysis to eighteen countries covering about 70% of world GDP to make predictions into the twenty-first century. Section 7 explores the relationship between capital flows and sectoral reallocation. Section 8 concludes.

[11] The focus of the present analysis in studying capital flows and hence global imbalances is uniquely on the contribution of demographic change. Obviously, this does not exclude concurrent explanations such as e.g. different levels of financial development across countries that might translate into a different strength of the precautionary saving motive (Mendoza et al., 2009) as surveyed in Gourinchas and Rey (2014).

2 The model

This section presents a multi-country overlapping-generation (OLG) neoclassical growth model that expands on the work by Domeij and Flodén (2006) and Krueger and Ludwig (2007) to incorporate two sectors. It is a reformulation of a model first appeared in Giagheddu and Papetti (2018).[12] Each country is populated by overlapping generations of households that solve a life-cycle consumption problem. Only two goods are produced and consumed: a composite tradable (T) good that can be freely shipped between countries and serves as numeraire, and a composite nontradable (N) good that cannot leave the country in which it is produced. The production technology is identical between countries and sectors, while it can differ in its parameter values. Labor is immobile while capital can perfectly move between countries. The model is purely real, abstracting from nominal frictions. The demographic variables are exogenous. One period corresponds to one year. The two distinctive features of the model are: (*a*) age-dependent sectoral consumption shares; (*b*) imperfect labor mobility between sectors.

Households. Each household consists of a single individual. Households within each cohort j are identical and their exogenous mass $N_{i,t,j}$ for time-period t in country i evolves recursively according to:

$$N_{i,t,j} = N_{i,t-1,j-1} s_{i,t,j} \tag{2.1}$$

where $s_{i,t,j}$ is the conditional survival probability.[13]

For each period t the life-cycle problem is such that the representative household born in t chooses consumption in each sector $c^N_{i,t+j,j}$, $c^T_{i,t+j,j}$ and the amount of assets to hold the sequent period $a_{i,t+j+1,j+1}$ for each age $j \in \{0, 1, 2, \cdots J\}$ under the assumption of perfect domestic annuities market;[14] how to allocate in each sector an exogenously given amount of hours to work, $h_{t+j,j}$, for

[12] Aside from considering more than two countries and the transition dynamics, the main difference with that version is to allow for non-unitary elasticity of substitution both in intertemporal consumption and between the two goods consumption, further allowing for differences across countries and between sectors in the capital-output ratios and in the factor intensities.

[13] Given that an individual is aged $j-1$ at time $t-1$, $s_{i,t,j}$ is the probability to be alive at age j at time t in country i. Following Domeij and Flodén (2006), data are taken for $N_{i,t,j}$ for each considered i, t, j to get the implied survival probabilities $s_{i,t,j}$ which therefore can exceed 1 due to migration flows. The underlying assumption is that immigrants enter the economy without assets and are adopted by domestic households: assets are carried over between periods by a domestic cohort and then split among its survivors and the asset-less immigrants in the same age class.

[14] The assumption of "perfect annuities market" means that the agents within each age group j agree to share the assets of the dying members of their age group among the surviving members. Using the notation just introduced, consider those that at time t are aged j (omit the country index i for simplicity). The total amount of assets of the dying members is: $a_{t,j}(1 - s_{t,j})N_{t-1,j-1}$, while the number of surviving members is: $N_{t,j} = N_{t-1,j-1}s_{t,j}$. Hence, in the budget constraint the asset holding in period $t+1$ will depend on what as been accumulated plus this sort of 'equal gift' from the dying members given the real interest rate (r_t) at which these assets can be invested (minus

each age $j \in \{0, 1, 2, \cdots j_r\}$ choosing $h^N_{i,t+j,j}$, $h^T_{i,t+j,j}$, solving the following problem:

$$\max_{c^N_{i,t+j,j}, c^T_{i,t+j,j}, h^N_{i,t+j,j}, h^T_{i,t+j,j}, a_{i,t+j+1,j+1}} \left\{ \sum_{j=0}^{J} \beta^j \pi_{t+j,j} \frac{c^{1-\sigma}_{t+j,j}}{1-\sigma} \right\} \tag{2.2}$$

subject to

$$c_{i,t+j,j} = \left[\alpha_{i,j}^{-\frac{1}{\phi_i}} (c^T_{i,t+j,j})^{\frac{\phi_i+1}{\phi_i}} + (1-\alpha_{i,j})^{-\frac{1}{\phi_i}} (c^N_{i,t+j,j})^{\frac{\phi_i+1}{\phi_i}} \right]^{\frac{\phi_i}{\phi_i+1}} \tag{2.3}$$

$$h_{i,t+j,j} = \left[\theta_i^{-\frac{1}{\varepsilon_i}} (h^T_{i,t+j,j})^{\frac{\varepsilon_i+1}{\varepsilon_i}} + (1-\theta_i)^{-\frac{1}{\varepsilon_i}} (h^N_{i,t+j,j})^{\frac{\varepsilon_i+1}{\varepsilon_i}} \right]^{\frac{\varepsilon_i}{\varepsilon_i+1}} \tag{2.4}$$

$$a_{i,t+j+1,j+1} = \frac{a_{i,t+j,j}(1+r_{t+j})}{s_{i,t+j,j}} - c^T_{i,t+j,j} - P^N_{i,t+j} c^N_{i,t+j,j} + y_{i,t+j,j} \tag{2.5}$$

$$y_{i,t+j,j} = (1-\tau_{i,t+j})(w^N_{i,t+j} h^N_{i,t+j,j} + w^T_{i,t+j} h^T_{i,t+j,j}) I(j < \mathcal{J}_i) + d_{i,t+j,j} I(j \geq \mathcal{J}_i) \tag{2.6}$$

$$a_{i,t+J+1,J+1} = 0 \tag{2.7}$$

$$a_{i,t,0} = 0 \tag{2.8}$$

where $\pi_{i,t+j,j} = \prod_{k=0}^{j} s_{i,t+k,k}$ represents the unconditional survival probability with $s_{i,t,0} = 1$ for all i, t; β is the discount factor; $I(\cdot)$ is an indicator function where $\mathcal{J}_i$ denotes the exogenous retirement age; $d_{i,t+j,j}$ denotes the pension benefit. Prices (taken as given by the household) are: $w^T_{i,t}, w^N_{i,t}, r_t, P^N_{i,t}$ denoting the real wage in the tradable and non-tradable sector, the real interest rate on assets, and the the relative price of nontradables respectively. The household's labor supply in efficiency units, $h_{i,t+j,j} = h_{i,j}$, is exogenous and depends on age but is constant over time.[15]

The two distinctive features of the model are represented by constraints (2.3) and (2.4): the parameter $0 < \alpha_{i,j} < 1$ denotes the age-dependent share of consumption expenditure devoted to tradables; with $0 < \theta_i < 1$, the parameter ε_i denotes the degree of substitutability between hours supplied in the two sectors (both at the individual and at the aggregate level) with the case of perfect labor mobility represented by $\varepsilon_i \to \infty$; correspondingly, $\varepsilon_i \to 0$ represents immobility.[16]

consumption plus income):

$$a_{t+1,j+1} = a_{t,j}(1+r_t) + \frac{a_{t,j}(1+r_t)(1-s_{t,j})N_{t-1,j-1}}{N_{t-1,j-1}s_{t,j}} - c_{t,j} + y_{t,j} = \frac{a_{t,j}(1+r_t)}{s_{t,j}} - c_{t,j} + y_{t,j}$$

which is the budget constraint written in the main text.

[15] Particularly, it varies by age in accordance with productivity and labor market participation by age similarly to what assumed in Domeij and Flodén (2006).

[16] This modeling choice of sectoral hours serves the main purpose of allowing demand factors (such as the change in demand composition induced by aging) to influence relative prices, coherently with the empirical finding that wages tend not to be equalized between sectors in the long-run (Cardi and Restout, 2015). It amounts to assuming that households have a preference to diversify labor despite wage differences between sectors. It can be thought to broadly capture structural forces in an economy, including compositional differences of the work-force between sectors, that might be responsible for the long-run persistence of sectoral wage differences detected in the data. In neoclassical models with perfect factor mobility the long-run relative price of nontradables is independent of

Firms. The representative firm in each sector $s \in \{T, N\}$ and in each period t hires (hours in efficiency units of) labor $L^s_{i,t}$ at a given hourly wage rate $w^s_{i,t}$ and rents capital $K^s_{i,t}$ at price r_t (real interest rate) subject to yearly depreciation rate δ_i so as to solve:

$$\max_{K^s_{i,t}, L^s_{i,t}} \left\{ P^s_{i,t} (K^s_{i,t})^{\psi^s_i} (Z^s_i L^s_{i,t})^{1-\psi^s_i} - w^s_{i,t} L^s_{i,t} - (r_t + \delta_i) K^s_{i,t} \right\} \tag{2.9}$$

where $P^T_{i,t}$ is normalized to unity for all i, t, $0 < \psi^s_i < 1$ is the output elasticity to capital and Z^s_i is the sector-specific labor-augmenting technology.

Government. Given a certain level of generosity of the pay-as-you-go (PAYG) pension system, i.e. the replacement rate $\bar{d}_i$ defined as the pension benefit $d_{i,t}$ received by each household per unit of the average labor income $w_{i,t}(1 - \tau_{i,t})\bar{h}_i$, the government sets a tax rate $\tau_{i,t}$ such that its budget is balanced in each period:[17]

$$d_{i,t} = \bar{d}_i w_{i,t} (1 - \tau_{i,t}) \bar{h}_i \tag{2.10}$$

$$\tau_{i,t} w_{i,t} L_{i,t} = d_{i,t} \sum_{j=\mathcal{J}}^{J} N_{i,t,j} \tag{2.11}$$

where $w_{i,t} = \left[\theta_i (w^T_{i,t})^{1+\varepsilon_i} + (1 - \theta_i)(w^N_{i,t})^{1+\varepsilon_i} \right]^{\frac{1}{1+\varepsilon_i}}$, $L_{i,t} = \sum_{j=0}^{J} h_{i,j} N_{i,j}$.

Clearing. The labor market in each sector $s \in \{T, N\}$ and the market for nontradables clear in each period t:

$$L^s_{i,t} = \sum_{j=0}^{J} h^s_{i,t,j} N_{i,t,j} \tag{2.12}$$

$$(K^N_{i,t})^{\psi^N_i} (Z^N_i L^N_{i,t})^{1-\psi^N_i} = \sum_{j=0}^{J} N_{i,t,j} c^N_{i,t,j} \tag{2.13}$$

The international capital market clears:[18]

$$\sum_i \left(K^T_{i,t+1} + K^N_{i,t+1} \right) = \sum_i \sum_j a_{i,t+1,j+1} N_{i,t,j} \tag{2.14}$$

Equilibrium. Given the exogenous demographic development (fully characterized by the incoming cohort size $N_{t,0}$ and the conditional survival probabilities $s_{t,j}$ according to (2.1)) in all

consumer demand patterns (see Obstfeld and Rogoff (1996), ch. 4). There are other ways to allow for demand factors to matter (e.g. having diminishing returns to scale in at least one sector (Galstyan and Lane, 2009); or assuming that an economy is partially shut off from world capital markets (Froot and Rogoff, 1994)). This modeling choice owes to its intuitiveness and close link with some recent literature. Giagheddu and Papetti (2018) provide further elaborations on this assumption. Other works employing a CES aggregator to capture imperfect sectoral labor mobility include: Horvath (2000), Kim and Kim (2006), Bouakez et al. (2009), Iacoviello and Neri (2010), Bouakez et al. (2011), Altissimo et al. (2011), Cardi and Restout (2015), Groneck and Kaufmann (2017), Cantelmo and Melina (2018).

[17] Have: $\bar{h}_i = \sum_{j=0}^{\mathcal{J}_i - 1} h_{i,j} / \mathcal{J}_i$.

[18] By Walras' law the world market for the tradable good clears too (a superfluous condition in terms of computation once all the conditions above are satisfied).

periods $t = 0, 1, ..., \infty$, for all cohorts $j = 0, 1, ..., J$ for all considered countries i, the equilibrium for this (perfectly competitive) economy is a sequence of prices $\left\{w^T_{i,t}, w^N_{i,t}, P^N_{i,t}, r_t\right\}_{t=0}^{\infty}$, quantities $\left\{K^T_{i,t}, K^N_{i,t}, L^T_{i,t}, L^N_{i,t}\right\}_{t=0}^{\infty}$, $\left\{\left\{c^T_{i,t,j}, c^N_{i,t,j}, h^T_{i,t,j}, h^N_{i,t,j}, a_{i,t,j}\right\}_{j=0}^{J}\right\}_{t=0}^{\infty}$, policies $\{\tau_{i,t}\}_{t=0}^{\infty}$ and transfers $\{d_{i,t}\}_{t=0}^{\infty}$ such that:

1. households solve the optimization problem (2.2) subject to constraints (2.3)–(2.8);

2. firms maximize profits solving problem (2.9);

3. the fiscal authority sets a tax rate (2.11) such that its budget is balanced in each period given the individual pension transfer (2.10);

4. factor markets (2.12), the nontradable good market (2.13) and the international capital market (2.14) clear.

Capital flows. The net foreign asset position of a country ($F_{i,t}$) and its change, namely the current account ($CA_{i,t}$), are auxiliary variables stemming from the difference between the national capital supply, $\mathcal{A}_{i,t} \equiv \sum_j a_{i,t+1,j+1} N_{i,t,j}$, and demand, $K_{i,t} \equiv K^N_{i,t} + K^T_{i,t}$:

$$F_{i,t+1} = \mathcal{A}_{i,t} - K_{i,t+1} \tag{2.15}$$

$$CA_{i,t} = F_{i,t+1} - F_{i,t} \tag{2.16}$$

By (2.14), it must be: $\sum_i CA_{i,t} = 0$. In the reminder, the main variable of interest will be the current account relative to the gross domestic product ($GDP_{i,t}$):

$$ca_{i,t} = \frac{CA_{i,t}}{GDP_{i,t}} \tag{2.17}$$

where $GDP_{i,t} = Y^T_{i,t} + P^N_{i,t} Y^N_{i,t}$, $Y^s_{i,t} = (K^s_{i,t})^{\psi^s_i} (Z^s_{i,t} L^s_{i,t})^{1-\psi^s_i}$ for $s \in \{T, N\}$.

3 Calibration and solution

The goal of the subsequent quantitative analysis is to study the transition dynamics of the macroeconomic system of section 2 from an initial to a final stationary equilibrium, where the unique perfectly-anticipated exogenous driving process is the time-varying demographic structure. The main focus is on two outcomes: the relative price of nontradables and the current account.

Experiment. Embracing the working hypothesis of Berka et al. (2018) – who postulate that a common currency is a fertile ground for finding evidence on the role of fundamentals (their priority is sectoral productivity) on the relative price of nontradables (thus on the real exchange rate) – the model economy consists of the same nine euro area countries (EA9 henceforth) in their analysis, which are assumed to compose a closed economy and will serve to evaluate the model's performance to explain real-world data since the 1995 (when the dataset they complied starts).[19]

One period of the model corresponds to one year. It is assumed that in the initial stationary equilibrium the system has the demographics prevailing in year 1996 in the data.[20] Following Domeij and Flodén (2006), equation (2.1) is directly used to retrieve the conditional survival probabilities using data on the number of people, $N_{t,j}$, by single age-group j for each year t (the time-range available is: 1950-2100). Data are taken from the United Nations (UN, 2019) *World Population Prospects 2019, Online Edition. Rev. 1*, including the medium variant projections until year 2100.

The experiment is such that while in 1995 (as well as in all previous periods) the system is assumed to be in the initial stationary equilibrium, in 1996 there is the information shock: agents learn about the new demographic development for all subsequent years, and what this implies for macroeconomic variables in a perfect-foresight environment. In year 2100 the conditional survival probabilities and the incoming cohort size start remaining fixed forever. This implies an evolution of the demographic structure that eventually gets stationary again.[21]

Given the demographics, the structural model parameters and the implied solution values for the initial and final stationary equilibrium, the dynamic equilibrium is solved using a standard deterministic simulation set-up where the numerical problem of solving a nonlinear system of simultaneous equations is managed by means of a Newton-type method.[22]

Common parameters. Table 1 summarizes the model parameters whose value is assumed to be equal across countries. In line with the main references on multi-country general equilibrium OLG models, the discount factor, β, is set to 0.9606 (or 0.99 at the quarterly frequency) – see e.g. Bárány et al. (2019); the inverse of the elasticity of intertemporal substitution (*e.i.s.*), σ, is set to 2 (see e.g. Attanasio et al. (2007); Bárány et al. (2019); Domeij and Flodén (2006)).[23] The labor augmenting technology in the nontradable sector, Z^N, is normalized to one so that Z^T will identify the (country-specific) relative labor augmenting technology of the tradable sector.

For what concerns demographics, it is assumed that households enter the world as workers at age 15, all retiring at age 65 which correspond to $\mathcal{J} = 50$ (this implies that h_j drops abruptly to zero

[19]EA9 is composed by the following countries: Austria (AUT), Belgium (BEL), Germany (DEU), Spain (ESP), Finland (FIN), France (FRA), Ireland (IRL), Italy (ITA), Netherlands (NLD).

[20]That is, for all $j = 0, 1, ..., J - 1$ the demographic structure is given by: $N_{1996,j+1} = \pi_{1996,j+1} N_{1996,0}$.

[21]Therefore, population growth is zero in both the initial and final stationary equilibrium.

[22]To solve for the transition dynamics, an algorithm can be designed, in the spirit of e.g. Krueger and Ludwig (2007) or Attanasio et al. (2007), where one needs to guess the paths of the world real interest and the country-specific relative price of nontradables ($P^N_{i,t}, \forall i, t$), once solved for the initial and final stationary equilibrium. The full set of equilibrium equations in Appendix A makes it evident. In practice, the solution method can be handled under the "perfect foresight solver" available in *Dynare*, solving separately for the initial and final stationary equilibrium. Specifically, the Jacobian of the system has dimension 3934×400 given that there are 437 endogenous variables for each of the 9 countries plus the real interest rate which is common to all countries over 400 periods (years). Therefore, the terminal period is year 2395, which is more than sufficiently far into the future for the model to reach the final stationary equilibrium.

[23]As noted by Bárány et al. (2019), $\sigma = 2$ is in the mid-range of empirical estimates. The reader is redirected there for the main empirical references.

after age 64). This is a standard assumption based on the reported retirement ages for European economies (see Carvalho et al. (2016), Table 2). Households live at most until age 99 corresponding to $J = 84$ so that in each year there are 85 overlapping generations. The individual labor supply in efficiency units, h_j, is interpolated using the data-points provided by Domeij and Flodén (2006), obtained by interacting the profiles of both productivity and the participation rates allowing the age-labor income profile from the model to be consistent with its empirical counterpart (see Figure 2a and the note therein).[24] The age-varying share parameter in the CES consumption aggregator (2.3) is assigned values from the empirical consumption shares in tradable goods inferred from the US Consumer Expenditure Survey (CEX), where a cubic interpolation is adopted for missing data on extreme age-bins. The note under Figure 2b details the tradable versus nontradable classification adopted while further details and analyses hinging upon the CEX-based dataset complied by Aguiar and Hurst (2013) are provided in Giagheddu and Papetti (2018).[25] It is apparent that while the share of consumption devoted to nontradables is fairly constant between ages 15 and 60, after age 60 it increases dramatically. On average, a person aged 85 has nontradable share in the consumption basket which is about 15 percentage points bigger than a person aged 50.[26]

Table 1: Baseline calibration: common parameters across countries

Parameter	Value	Description	Source
β	0.99^4	discount factor	standard, e.g. Bárány et al. (2019)
σ	2	inverse *e.i.s.*	standard, e.g. Domeij and Flodén (2006)
Z^N	1	NT productivity	normalization
$\mathcal{J}$	age 65	retirement age	Tab. 2 in Carvalho et al. (2016)
h_j	Figure 2a	labor supply efficiency	Domeij and Flodén (2006), Hansen (1993)
α_j	Figure 2b	T consumption share	Giagheddu and Papetti (2018), Aguiar and Hurst (2013)

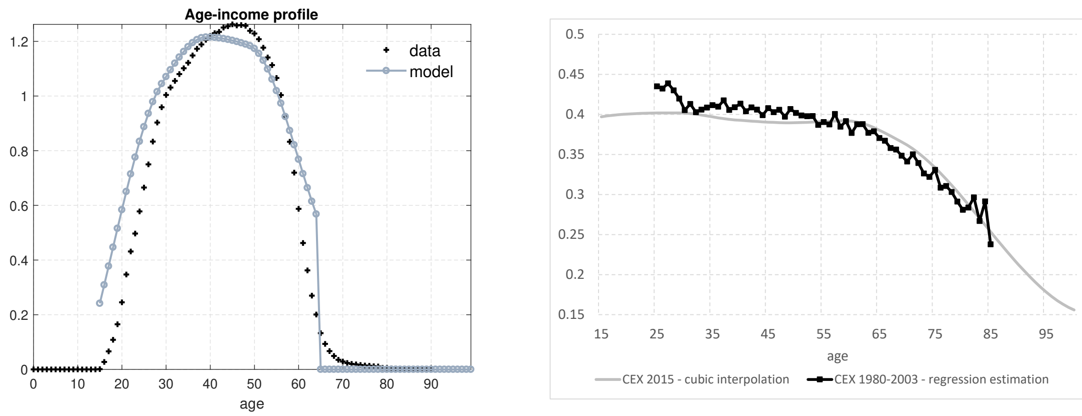
Country-specific parameters. As summarized in Table 2, the values of the main parameters determining the sectoral allocations are taken from Bertinelli et al. (2020) (see their Table 4) who update the analysis in Cardi and Restout (2015) (see their Table 5) with a more recent release of EUKLEMS data.[27] Specifically, the intra-temporal sectoral elasticities of substitution in consumption, φ, and in labor supply, ε, are structurally estimated deriving testable equations rearranging the

[24]Following a common assumption in OLG modeling (that can be found in most of the literature mentioned in this paper), labor force participation rates are assumed to be constant over time. Hence, the model is not tailored to directly capture structural changes such as the increase in female labor force participation.

[25]While some data on age-varying consumption shares by sector are available for some European countries (cf. Giagheddu and Papetti (2018)), the US data were preferred due to their higher level of detail.

[26]This feature is robust to different years of analysis and to a different, more disaggregated, classification of the consumption categories into tradable and nontradable as proven by the marked-black line in Figure 2b. It closely resemble the age-varying consumption pattern found by Cravino et al. (2020), based on CEX data too, where the focus is on services versus goods rather than on nontradables versus tradables.

[27]Bertinelli et al. (2020) employ a sectoral concordance between the March 2011 and July 2017 releases (including also data for Canada and Norway from the OECD STAN database), where the former provides data for eleven 1-digit ISIC-rev.3 industries over the period 1970-2007 while the latter provides data for thirteen 1-digit-rev.4 industries over the period 1995-2013 (see Table F.1 in Appendix E). The structural parameter estimation is conducted on a panel of 17 OECD countries with annual data running from 1970 to 2013.



(a) (b)

Figure 2: Age dependent: age income profile ($w_{\text{EA9}}h_j$) and tradable shares of (private) consumption expenditure (α_j)

Note. **Panel (a)**. The labor supply in efficiency units (h_j) is obtained as cubic interpolation on data points provided in Domeij and Flodén (2006). These data points are the product of participation rates provided by Fullerton (1999) and productivity provided by Hansen (1993). The figure shows h_j multiplied by the simple average across countries of the wage rate prevailing in the initial steady state (w_{EA9}), then normalized on the mean for persons 50-60 years old. The empirical counterpart is the "smooth mean" of the `labor_income` series provided by the *National Transfers Accounts* (NTA), cf. Lee and Mason (2011), presented as median of the available countries. The European countries for which data is available are (year used in parenthesis - often only one year is available, results are not sensitive to the specific year used): Austria (2005), Finland (2004), France (2005), Germany (2003), Italy (2008), Spain (2000). **Panel (b)**. *US data source*: Consumer Expenditure Survey (CEX). The *continuous grey* line is a cubic interpolation on CEX, 2015, "Table 1300. Age of reference person: Shares of annual aggregate expenditures and sources of income" from which the average private consumption expenditure (measured in millions of US dollars) is computed. The following categories are classified as tradable: food at home, alcoholic beverages, furnishings and equipment, apparel and services, transportation, tobacco products and smoking supplies; as nontradable: food away from home, housing minus furnishings and equipments, healthcare, entertainment, personal care products and services, reading, education. The *marked black* line reports the estimated coefficient values on the constant and age dummies of an OLS regression of the share of consumption on tradables on a constant, age dummies and (normalized) year dummies. The dataset employed is complied by Aguiar and Hurst (2013) based on the multiple cross-sections of households of CEX for all years between 1980 and 2003. The 49 consumption categories are classified into tradable and non-tradable with further details and analyses in Giagheddu and Papetti (2018).

optimal rules deriving from the aggregate versions of the CES aggregators (2.3), (2.4). The sectoral capital shares of income, ψ^T and ψ^N, are obtained as complements of the respective average labor share of income (i.e. the ratio of labor compensation to value added).[28] The share parameter in the CES aggregator (2.4) is obtained as average tradable share in hours worked.

To calibrate the social security systems in all countries, measures of the *effective* replacement rates, $\bar{d}$, provided (and kindly shared) by Bárány et al. (2019) were adopted. These measures

[28] Labor compensation is total labor costs that include compensation of employees and labor income of the self-employed and other entrepreneurs.

upgrade the official replacement rates to take into account concerns about measurement errors or potential biases in the percentages of retirees receiving benefits and working-age population contributing to pensions.[29]

Table 2: Baseline calibration: country-specific parameters

Country (pop share)	Empirical target		Parameter							
	K/Y	Q^N	δ	Z^T	ψ^T	ψ^N	θ	φ	ε	$\bar{d}$
	capital -output ratio	rel. N price rel. to EU15	capital deprec. rate	rel. T pro-duc-tivity	T capital share of income	N capital share of income	T share in labor	T/N consum. elas-ticity	T/N labor elas-ticity	pension replacem. rate
AUT (0.03)	1.97	0.97	0.10	1.41	0.32	0.32	0.40	1.52	1.10	0.65
BEL (0.04)	1.76	1.06	0.12	1.82	0.34	0.33	0.36	1.24	0.61	0.43
DEU (0.29)	1.92	1.16	0.09	2.06	0.24	0.36	0.40	0.58	1.01	0.31
ESP (0.14)	1.53	0.95	0.18	1.34	0.40	0.34	0.40	1.39	1.02	0.59
FIN (0.02)	2.18	1.07	0.07	1.32	0.35	0.26	0.42	0.85	0.43	0.67
FRA (0.21)	1.87	1.14	0.09	1.80	0.28	0.31	0.36	0.89	1.40	0.40
IRL (0.01)	1.66	0.95	0.19	1.22	0.49	0.31	0.42	1.35	0.22	0.23
ITA (0.21)	1.75	0.93	0.10	1.30	0.26	0.33	0.42	0.72	1.66	0.58
NLD (0.06)	1.79	1.09	0.11	1.45	0.39	0.26	0.33	0.52	0.22	0.25
EA9 (1.00)	1.82	1.04	0.12	1.52	0.34	0.31	0.39	1.01	0.85	0.46
Source	WDI	Berka et al.	implied		Bertinelli et al. (2020)					Bárány et al.

Note. The population shares in parenthesis refer to year 1995. EA9 reports the simple average.

Given the assigned values to the common parameters across countries summarized in Table 1 and to the country-specific parameters $\{\psi^T, \psi^N, \theta, \varphi, \varepsilon, \bar{d}\}$, as well as the initial demographic structure, the calibration procedure involves solving numerically the initial stationary equilibrium for the real interest rate as well as for the country-specific capital depreciation rate, δ, and the relative labor augmenting technology of the tradable sector, Z^T, to target the empirical capital-output ratios and the initial relative prices of nontradables.

As mentioned above, the empirical counterpart for the relative prices of nontradables comes from the series complied by Berka et al. (2018) which covers, at the annual frequency, the period 1995-2007, and that was chosen because of its high degree of detail in the items composing the consumer's basket determining the sectoral price level indices.[30] A complication arises because this series is measured in relative terms with respect to the average across 15 European countries

[29] A measure for Ireland was missing in Bárány et al. (2019) and was constructed following their methodology. Particularly, the "share of population above legal retirement age in receipt of a pension" (0.647) and the "active contributors to a pension scheme in the working age population" (0.639) from the ILO (2010) Tab. 21 were averaged to multiply the official "net replacement rate" (0.359) reported in the OECD database. Bárány et al. (2019) report that the measure of the official replacement rate by the OECD (which does not distinguish between social security benefits and alternative pension schemes) correlates very highly (above 0.8) with the measure they developed for European countries, justifying its adoption here.

[30] The series is based on data provided by Eurostat as part of the Eurostat-OECD PPP Programme where price level indices are available for 146 "basic headings" of consumer goods and services covering 100 of the consumption basket. Their online Appendix details the data construction including the breakdown into tradable vs nontradable (see their Table A1). The series used here is what in their paper is labeled as q_n.

(EU15 henceforth).[31] As a consequence, to target the empirical relative price of nontradables in each EA9 country relative to the EU15 average, denote it by $Q_i^N = P_i^N/P_{EU15}^N$, the model was first solved for the EU15 area in its dynamics as an aggregate and then the data point $P_{EU15,1995}^N$ was taken to solve the initial stationary equilibrium targeting $P_i^N = Q_{i,1995}^N P_{EU15,1995}^N$ (Appendix D details calibration and solution for the EU15 aggregate).

The empirical target for the capital-output ratios are obtained as average over the period 1970-1995 constructing a series for the capital stock based on data from the *World Development Indicators* (WDI) applying the standard perpetual inventory method (cf. e.g. Caselli (2005)).[32]

Initial and final stationary equilibrium results. The calibration strategy delivers as result (see Table 2) that the capital depreciation rates, δ, are in line with the 10% annual rate usually assumed for European countries (e.g. Bielecki et al. (2020)) except for Ireland and Spain where the relatively high number is due to the relatively low level of the targeted empirical capital-output ratio, given the unique real interest rate assumed to be common to all countries. Furthermore, it implies that for all countries the tradable sector is relatively more productive, on average about 50% more – in line with what commonly assumed (e.g. by Cardi and Restout (2015) for a representative OECD economy based on Ghironi and Melits (2005)).

The real interest rate in the initial and final stationary equilibrium endogenously result to be 6.63% and 4.40% per annum, respectively. That is, the real interest rate is projected to decrease by about 2.23 percentage points in the long-run due to demographic change alone. The long-run decrease of the real interest rate due to aging is a well-established result of OLG models that in the present setting can be attributed to the permanent increase of the survival probabilities at all ages.[33] Compared to the initial level, the relative price of nontradables in the long-run ranges from a minimum of about 2% smaller level to a maximum of about 18% higher level. The magnitude of this change is due to the interaction of relative demand (appreciating) forces and relative supply (depreciating) forces that tend to compensate each other in presence of a declining real interest rate, as discussed in the next section. Finally, the country that sees the biggest decrease in the net-foreign asset position to GDP (F/GDP) faces in the long-run a decrease in that variable of more than 80 percentage points; conversely, the country that improves the most the external position faces an increase in F/GDP of more than 200 percentage points. This figure entails sizable capital flows

[31] In addition to the EA9 countries (see footnote 19), EU15 is composed by Denmark (DNK), United Kingdom (GBR), Greece (GRC), Luxembourg (LUX), Portugal (PRT), Sweden (SWE).

[32] The series used here are: "Gross fixed capital formation (constant LCU)" and "GDP (constant LCU)". The initial capital stock (the base year is 1970, the first year data are available for all EA9 countries) is computed using the formula: $K_{1970} = I_{1970}/(g_I + \delta_K)$ where I_{1970} corresponds to the gross capital formation in 1970, g_I is the average growth rate (over the period 1970-1995), while δ_K is set to 10% for all countries. The capital stock is obtained via the law-of-motion: $K_{t+1} = (1-\delta)K_t + I_t$ for all years t from 1970 onward.

[33] A non-exhaustive set of papers featuring this result based on the seminal Auerbach and Kotlikoff (1987) OLG model formulation include: Domeij and Flodén (2006), Krueger and Ludwig (2007), Attanasio et al. (2007), Bárány et al. (2019), Auclert et al. (2020) for a world economy with different countries/areas; Gagnon et al. (2016), Eggertsson et al. (2019), Bonchi and Caracciolo (2020) for the US, Bielecki et al. (2020), Papetti (2020) for the euro area, Sudo and Takizuka (2019) for Japan.

along the transition dynamics, as shown in the next sections.

4 Validation on euro area countries: model versus data

This section examines to what extent the relative prices and capital flows implied by the model can explain the real-world data counterparts in the sample of EA9 countries used to calibrate the model. To test the predictive power of the model, following Domeij and Flodén (2006), a linear regression analysis is conducted on the fixed-effects (FE) panel specification

$$y_{i,t} = \rho_i^0 + \rho^1 x_{i,t} + u_{i,t} \tag{4.1}$$

and the pooled OLS specification

$$y_{i,t} = \rho^0 + \rho^1 x_{i,t} + u_{i,t} \tag{4.2}$$

where $x_{i,t} \in \{Q_{i,t}^{N,m}, \widetilde{ca}_{i,t}^m\}$ denotes the series generated by the model on the relative price of non-tradables relative to the EU15 and the demeaned current account to GDP ratio ($\widetilde{ca}_{i,t}^m = ca_{i,t}^m - \overline{ca}_t^m$) for each country i; $y_{i,t} \in \{Q_{i,t}^{N,d}, \widetilde{ca}_{i,t}^d\}$ denotes the respective counterparts in the data; while $u_{i,t}$ denotes a residual capturing the variation in the data that is orthogonal to the model. Following Bárány et al. (2019), the current account to GDP ratio is demeaned in the cross section period by period to deal with the fact that the capital market clears among euro area countries in the model but not in the data.[34]

Table 3: Regression results for baseline specification: reg. data on model

	(1) Pooled	(2) FE	(3) Pooled	(4) FE
QN model	0.823	0.674		
	(0.000)	(0.015)		
ca model			0.522	0.441
			(0.000)	(0.002)
Time period	1995-2007	1995-2007	1997-2020	1997-2020
Countries	7 (*ex.* ES, IE)	7 (*ex.* ES, IE)	9 (*All*)	9 (*All*)
Observations	91	91	216	216
R^2	0.774	0.8286	0.058	0.4825
R^2_{within}		0.0696		0.0437

Note. p-values in parentheses. R^2_{within} is the variance explained by the single regressor of interest, i.e. excluding the country fixed-effects (FE).

[34] Notice that running specification (4.2) on demeaned series, $\widetilde{ca}_{i,t}$, is equivalent to running the regression: $ca_{i,t}^d = \rho^0 + \rho^1 ca_{i,t}^m + f_t + u_{i,t}$ where f_t is a period fixed effect.

As detailed in the previous section, the calibration of the model is such that the model matches by construction the initial (year 1995) data point for the series on relative prices provided by Berka et al. (2018). This data series is available at the annual frequency for the period 1995-2007 for all EA9 countries. Data on annual current account to GDP ratios are provided by the IMF WEO (*World Economic Outlook*, April 2020) for all countries of interest from 1995 to 2020.[35]

Figure E.1 in the Appendix presents model versus data series for all countries over time since the 1995, offering a glimpse of the model's performance on the *within* variation (namely the ability of the model to explain fluctuations for each variable over time, for each country considered singularly). It is apparent that the model can capture some long-term variation while, of course, many shocks other than demographics, not captured by the model, impinge upon relative prices and capital flows. It is likewise apparent that especially for Ireland and Spain the relative price of nontradables in the data moves far away from what predicted by the model. This might have to do with the "hypertrophy of the non-tradable sector" (Piton, 2017) in the 1995-2008 period for the euro area "periphery" (Italy, Ireland, Greece, Portugal, Spain) driven by non-fundamental factors, particularly for Ireland and Spain where the abnormal increase in the relative price of nontradables happened in conjunction with a housing bubble. Therefore, Ireland and Spain will be excluded from the sample when evaluating the model's performance to explain the relative price variation.

Table 3 presents the main regression results for all periods available in the sample.[36] Notice that, according to this regression metrics, the theoretical model is the more successful the higher the coefficient of determination (R^2, R^2_{within}) and the closer ρ^1 is to unity. The first result that emerges is that the coefficient of interest (ρ^1) is statistically significant and has the correct sign in all regressions. Secondly, a relevant fraction of both relative prices and current account fluctuations is explained by the model. This can be judged by the R^2_{within} which is almost 7% for relative prices and slightly more than 4% for current account balances.

Figure 3 provides results of further regressions on current account data where the sample, given its greater width compared to the one for relative prices, is progressively decreased starting one at a time from a later year. It is found that while the pooled OLS coefficient remains fairly stable at a value close to 0.5 (and the associated R^2 at a value close to 5%), the FE coefficient increases progressively getting closer to one with an R^2_{within} which stands in-between 15% and 30% when the sample starts in the periods from 2002 and 2007 (always ending in 2020). Therefore, the model can account for a relevant portion of the *within* variation for both the relative prices and the current account balances, where for the latter this relevance is particularly true for the sample periods starting after year 2001.

While R^2_{within} shows the goodness-of-fit for fluctuations over time, R^2 can indicate to what

[35]The results subsequently presented are essentially unaffected if year 2020 (which owes to the IMF WEO projections) is excluded from the sample.

[36]For the sample on current account to GDP ratios the first two years (1995, 1996) are dropped to exclude the abstraction of the model which needs to start at zero current account for all countries in the initial stationary equilibrium (as can be detect in the bottom panel of Figure E.1).

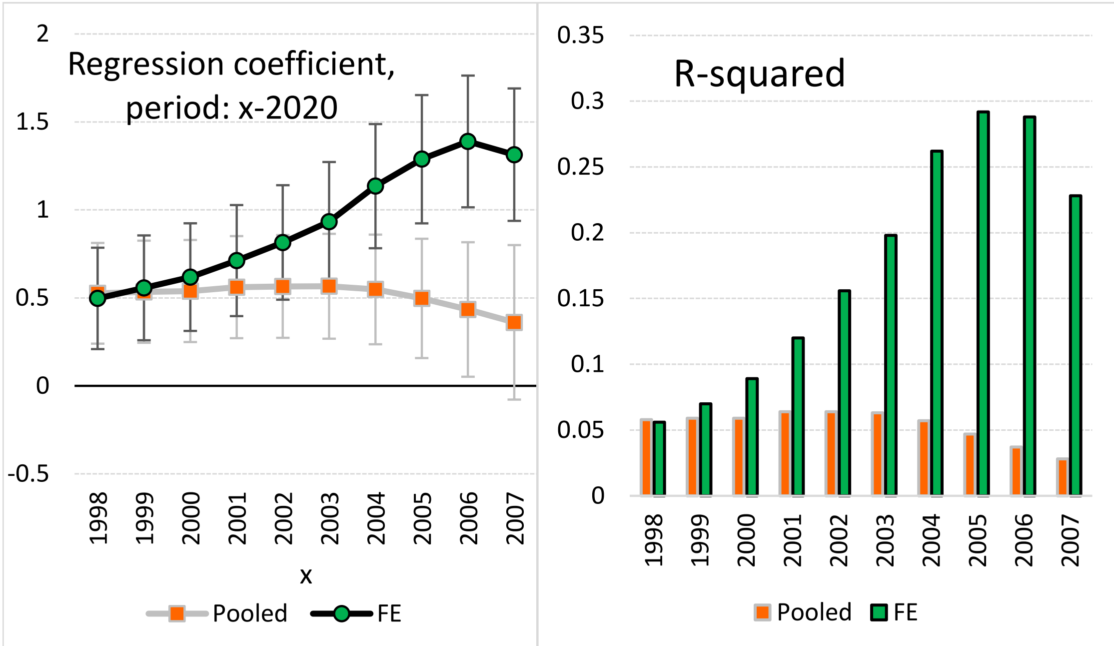


Figure 3: Current account: time-varying linear regression coefficients

Note. Coefficients obtained by running the Pooled and Fixed Effects (FE) OLS regressions of current account (as percent of GDP) data on the corresponding series generated by the model. The sample time-span is decreased incrementally by one year at a time, always ending in year 2020. The vertical bars correspond to the 95% confidence interval. The coefficient of determination (`R-squared`) measures the *within* variation for the case of the FE estimator.

extent the model explains level differences across countries. The value of R^2 for the current account balances is limited to slightly less than 6% while it is almost 80% for the case of relative prices. In this latter case it partly depends on the calibration strategy which matches for each country the initial level of the relative price. To explore how the model performs in the *between* dimension, Figure E.2 in the Appendix plots for each country and outcome variable the respective mean over time in the 1995–2007 period. The regression lines conforms remarkably well with the 45 degree line in both cases. With the exception of Ireland, Spain and Germany, most countries lie very closely to the 45 degree line in the case of relative prices. Hence the R^2 in this case has the high value of about 93%. In the case of current account balances, there is more dispersion so that the R^2 is smaller at about 23%.

In sum, there is evidence that the theoretical model (where demographic change is the only driver) can capture some trends in the data, explaining a relevant fraction of the empirical variation of the relative price of nontradables (relative to the trading partners) and current account (relative to GDP) balances both across and within countries over time. This is the basis to further employ the model for historical counterfactuals and predictions into the future, as done in the next sections.

The real interest rate. A key general equilibrium outcome is the real interest rate resulting from the international capital market clearing (with the assumption of perfect mobility of capital).

Under the baseline calibration, the real interest rate decreases by more than 2 percentage points between 1995 and 2020, with an additional decrease of almost 1 percentage point by 2030 (blue thick line in Figure 4). This dynamics is consistent, while remaining at their lower bound, with the estimates of the natural real interest rate obtained by employing the methodology developed in Holston et al. (2017) (red dotted line) and the trend in the world real interest rate for safe and liquid assets as estimated by Del Negro et al. (2019) (black hexagram).[37] As mentioned above, the decrease of the real interest rate induced by aging is well documented in the context of OLG models (see footnote 33) and the quantitative estimate provided here is in the ballpark of available estimates via OLG models for the euro area, remaining though at the low end. As pointed out e.g. by Bárány et al. (2019), Auclert et al. (2020) and Papetti (2020), the magnitude of this decrease is particularly sensitive to the value of the intertemporal elasticity of substitution in consumption (i.e. the inverse of σ) which here is assumed to be at the standard value of 0.5. Higher values of this elasticity mitigate the decrease of the real interest rate but do not overturn, for sensible values, the downward impact of aging stemming especially from higher survival probabilities. Figure 4 report the simulation result on the real interest rate for $\sigma = 1$ compared with the baseline ($\sigma = 2$).[38]

5 Understanding the sectoral mechanics of demographic change

While the previous section has solely evaluated the outcome variables of interest comparing the model's simulation results with the analog objects in the data, this section explores the channels through which population aging triggers sectoral reallocation in the model running counterfactual simulations. To do so, start from the firms optimal conditions (see Appendix A) the relative price of nontradables satisfies the following expression for each country i and year t:

$$P_{i,t}^N = \left(\frac{Z_i^T w_{i,t}^N}{Z_i^N w_{i,t}^T}\right)^{1-\psi_i^N} \left(\frac{1}{r_t+\delta_i}\right)^{\frac{\psi_i^T-\psi_i^N}{1-\psi_i^T}} \left(\frac{1-\psi_i^T}{1-\psi_i^N}\right)^{1-\psi_i^N} \frac{(\psi_i^T)^{\frac{\psi_i^T(1-\psi_i^N)}{1-\psi_i^T}}}{(\psi_i^N)^{\psi_i^N}} \tag{5.1}$$

Furthermore, from the households' optimal sectoral labor supply in the aggregate, it holds:

$$\frac{w_{i,t}^N}{w_{i,t}^T} = \left(\frac{\theta_i}{1-\theta_i}\frac{L_{i,t}^N}{L_{i,t}^T}\right)^{\frac{1}{\varepsilon_i}} \tag{5.2}$$

[37] The series on the euro area natural rate can be found, regularly updated, at https://www.newyorkfed.org/research/policy/rstar.

[38] Notice, however, that when one changes the intertemporal elasticity of substitution there is also a level effect. In the initial stationary equilibrium the real interest rate is 6.63% for $\sigma = 2$, 5.1% for $\sigma = 1$, given that the discount factor is kept fixed at $\beta = 0.99^4$. Alternatively, to keep the same initial level for the real interest rate one needs to recalibrate the discount factor β. A change that *per se* influences the transitional path of the real interest rate. Some experimentation, here not reported, revealed that general equilibrium results on the relative price of nontradables and capital flows are robust to sensible changes (in the range of available empirical estimates) in the value for σ. See section 6.3 for results with $\sigma = 1, 0.5$ for the world economy described in section 6.

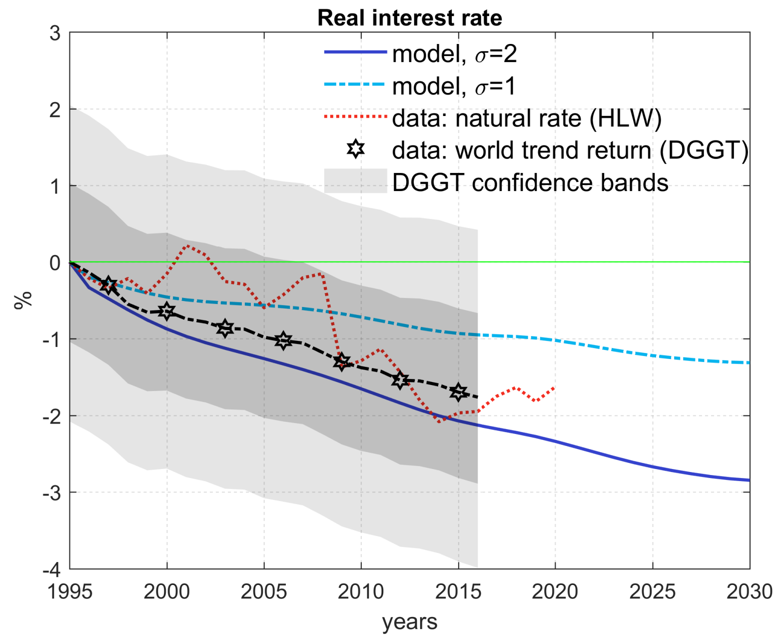


Figure 4: Real interest rate: % per annum $[1995 = 0]$

Note. The "natural rate" is the econometric estimate of the natural real interest rate for the the euro area provided by Holston et al. (2017) (HLW). Trend in global real rates estimated by Del Negro et al. (2019) (DGGT) on yield data provided by Jordá et al. (2019) (JST). The continuous line is the posterior median; shaded areas show the 68 and 95% posterior coverage intervals.

To understand the drivers of sectoral reallocation due to aging in the current setting, notice that in absence of imperfect substitutability of hours worked between sectors (i.e. imperfect mobility) and sectoral differences in capital intensity there would be no effect of aging on relative prices.[39] That is, changes in the relative demand of nontradables that might be associated with aging can matter for the relative price of nontradables only if ε_i does not tend to infinity. If ε_i is finite, whenever the nontradable sector needs to attract relative working hours ($L^N_{i,t}/L^T_{i,t}$) the relative wage ($w^N_{i,t}/w^T_{i,t}$) needs to increase correspondingly (equation (5.2)). Such a relative wage increase translates into an increase of the relative price of nontradables (equation (5.1)). In addition, as aging determines a change in factor prices (a marked decrease in the rental rate of capital, see Figure 4), the relative price of nontradables will be affected as long as $\psi^T_i \neq \psi^N_i$ (equation (5.1)), even in the presence of perfect substiutability of labor between sectors.

To isolate these sectoral channels of demographic change, the current section compares the baseline results with four counterfactual experiments: (a) a partial equilibrium (PE) scenario, i.e.

[39] In this case, differences in the relative price level across countries would only reflect differences in $(Z^T_i/Z^N_i)^{1-\psi^N_i}$, i.e. in the relative productivity of the tradable sector – the standard Balassa-Samuelson effect (Balassa, 1964; Samuelson, 1964) – that in the current setting are assumed to be time-invariant and independent from demographics. See Cardi and Restout (2015) for a reappraisal of the Balassa-Samuelson effect in presence of imperfect substitutability of working hours between sectors.

fixing the real interest rate at its initial level in all periods; (b) a partial equilibrium scenario where, in addition, the sectoral consumption shares parameters are assumed to be age-invariant such that $\alpha_j = \bar{\alpha}$ for all j where $\bar{\alpha}$ is the average over the ages from 15 to 50; (c) a general equilibrium (GE) scenario, i.e. the real interest rate is the one that allows the international capital market to clear (as in the baseline), assuming that there is no difference in capital intensities between sectors, i.e. $\psi_i^T = \psi_i^N = \bar{\psi}_i$ for each country i where $\bar{\psi}_i$ is the average between the two; (d) a general equilibrium scenario where in addition to the assumptions in (c) it is assumed that there is perfect substitutability of hours worked between sectors, i.e. there is wage equalization.

By comparing the first scenario with the second, one can quantify the impact of the change in demand composition purely due to the change in the demographic distribution tilting towards more elderly who have a preference to consume relatively more nontradables. Variations in the outcome variables that are not due to such a demand composition variation can be attributed to the standard life-cycle consumption-savings decisions for given real interest rate. In the model economy, falling fertility (mortality) rates tend to discourage (encourage) investment (savings). In general equilibrium, any national discrepancy between savings and investment finds an international capital market where the real interest allows endogenously its clearing and so the clearing of the tradable good market. In partial equilibrium, on the contrary, an increase of aggregate consumption, for example, needs to be met by domestic production if pertaining to the nontradable sector, while it can be freely imported from abroad, with no real interest rate adjustment, if pertaining to the the tradable sector. As a consequence, since the international capital market does not clear, capital flows in this partial equilibrium reflect the purely national willingness to save and invest and to differentiate by sector in the face of aging. In addition, notice that with a non-unitary consumption elasticity ($\varphi_i \neq 1$), the relative price of nontradables enters the expression for the nontradable consumption share amplifying ($\varphi_i < 1$) or weakening ($\varphi_i > 1$) the increase in the relative demand for labor in the nontradable sector.[40]

By comparing the third scenario with the fourth, one can isolate what might be labeled as 'amended Stolper Samuelson theorem effect'. Reversing the underlying logic in the Stolper and Samuelson (1941) theorem, a decrease of the rental rate of capital decreases the relative price of the product that uses capital intensively (equation (5.1)). Here the effect is 'amended' because the sectoral reallocation associated with the decrease in the rental rate of capital is mediated by a related change in the relative wage which depends not only on the degree of sectoral labor mobility (ε_i) but also on how much the relative price of nontradables covaries with the aggregate nontradable consumption share (φ_i).[41]

Figure 5 compares the baseline general equilibrium results with the four counterfactual scenarios described above. The first striking result is that the partial equilibrium effect of demographic

[40]The age-dependent nontradable share of consumption is given by: $P^N_{i,t}c^N_{i,t,j}/(P^N_{i,t}c^N_{i,t,j} + c^T_{i,j}) = (1 - \alpha_j)/[\alpha_j(P^N_{i,t})^{\varphi_i - 1} + 1 - \alpha_j]$, cf. Appendix A.

[41]Piton (2017, 2020) provides evidence of the impact of country-specific exogenous changes of the real interest rate with different capital intensity between the tradable and the nontradable sector for euro area countries.

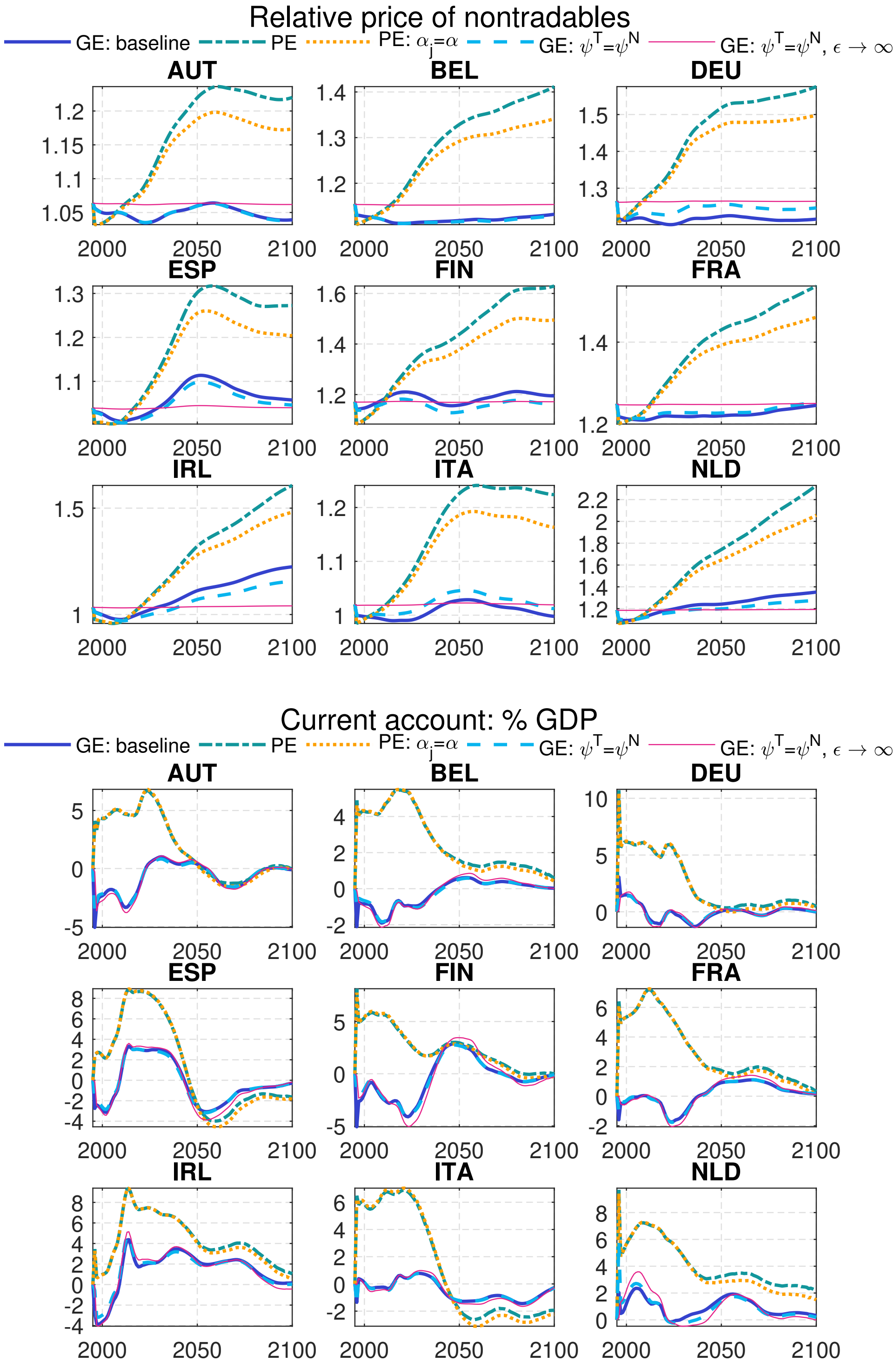


Figure 5: Baseline vs counterfactual scenarios: 1995-2100

Note. Partial (PE) versus general (GE) equilibrium. Baseline versus scenarios (a) to (d) as explained in the main text. Due to issues in the numerical solution, the PE model for NLD has been solved imposing an exogenous path for the real interest rate that after year 2100 smoothly converge toward 0.0545 (instead of the 0.0664, the initial stationary equilibrium value that prevails in all other periods of the transition for all countries). Perfect mobility: ε is set to 27.5.

change on the relative price of nontradables is huge (green dashed-dotted lines). As all countries are aging, all countries face a partial equilibrium upward pressure on the relative price of nontradables which is predicted to increase by a compound growth rate of almost 0.5% per annum, as average across countries over the 1997-2050 period. This upward pressure is projected to be the strongest in the incoming decade (2020-2030) with an annual average growth rate of more than 0.65%.

A stylized fact of "structural transformation" (i.e. the systematic reallocation of resources from the goods sector to the services sector) is that the relative price of services grows at a constant rate over time.[42] This holds true also when one splits industries into tradable versus nontradable sector (see Figure 1e above).[43] As shown in Figure 6 and reported in Table 4, in the sample comprising the EA9 countries over years 1996 to 2017, the median relative price of nontradables has increased on average by about 1.4% per annum in the data. The model over the same period predicts a growth rate of about 0.56%. In other words, demographic change can account for 40% of structural transformation. When this process is judged by the nontradable share of consumption the order of magnitude is comparably smaller but in the same ballpark. Precisely, in partial equilibrium demographic change explains 1.07 of the 5.66 percentage points of increase observed in the data for the median nontradable share of consumption between 1996 and 2015 thus accounting for almost 20% of the observed variation (see Figure 6 and Table 4).

This is reminiscent of the results in Cravino et al. (2020) where it is found, for the United States, that "changes in the age-structure of the population accounted for 20% of the observed change in the service expenditure share over this period [1982–2016]". With two caveats that the theoretical framework here adopted can highlight. First, the model suggests that it is a *partial* equilibrium result. Second, the demand composition channel – the fact that older households have a preference to consume relatively more nontradables – does not play the most prominent role.

This latter fact can be appreciated from the yellow dotted line in Figure 5. When households aged more than 50 are assumed to have the same sectoral consumption shares of younger households, the relative price of nontradables increases by less over time, but not so much. Of the overall partial equilibrium discrepancy from the initial stationary equilibrium the demand composition channel accounts only about 23% over the whole period (1995–2100), about 20% over the projected horizon (2020–2100). Therefore, most of the discrepancy is attributable to standard life-cycle savings-consumption decisions. Households react to higher survival probabilities with a willingness to save more. For a given real interest rate, more savings translate into a higher level of consumption at later ages. In the presence of imperfect substitutability of labor between sectors, the only way to attract relatively more labor in the nontradable sector to accommodate the higher nontradable consumption – which by definition can only be absorbed domestically – is to have an equilibrium higher relative wage in the nontradable sector (equation (5.2)) which, in turn, translates into a higher relative price of nontradables (equation (5.1)).

[42] Cf. seminal contributions: Baumol (1967), Ngai and Pissarides (2007), Herrendorf et al. (2014).

[43] Indicatively, even more so given that a conspicuous fraction of services results to be tradable (Gervais and Jensen, 2019), thus potentially subject to international price competition.

The overall willingness to save more in the face of aging is all-pervading, as can be seen from the bottom panel of Figure 5, picturing the evolution of the current account (as percent of GDP) over time. In a partial equilibrium economy, where euro area countries can freely import or export capital from abroad at the given real interest rate, all EA9 countries react to aging with sizable current account surpluses for essentially all periods of the twenty-first century. The underlying partial equilibrium dynamics can be understood in relation to the exogenous demographics by plotting over time the current account balance as percent of GDP together with the growth rate of the population to effective labor ratio.[44] Figure E.3 in the Appendix shows that there is a clear positive co-movement between the two series for all countries. The main intuition behind this result is twofold (cf. Ikeda and Saito (2014), Papetti (2019)): first, a decrease of the growth rate of the effective-labor population ratio is akin to a slowdown in total factor productivity for output per capita growth, which leads firms to demand less capital investment; second, when the growth rate of the number of effective workers in support of the number of total consumers (the population size) is shrinking, the motive of smoothing consumption into the future is such that in the aggregate there is more willingness to supply capital savings. The prevalence of these considerations points to the relatively inconsequential implication of the aging-induced sectoral reallocation for the determination of capital flows, as demonstrated by the almost perfect overlap of the two partial equilibrium series in the bottom panel of Figure 5.

In general equilibrium, the willingness to save and invest that manifests in partial equilibrium finds a feedback from the endogenous adjustment of the real interest rate so that the overall absolute amount of capital flows is reduced. Countries that in partial equilibrium tend to have a bigger current account surplus tend have a relatively more favorable balance in general equilibrium. Except that, in an economy where the sum of all the current account balances needs to be zero, the size of a country matters. Hence, for example, while Germany manifests roughly the same current account to GDP of Italy in partial equilibrium, the former has a current account surplus until 2010 corresponding to a small current account deficit by the latter. It turns out that the only two countries with a positive current account balance until 2010 are Germany and Netherlands (see also Figure E.1). Shutting down the sectoral capital intensity differentials and the imperfect substitutability of sectoral labor is essentially inconsequential for the capital flows dynamics in general equilibrium, suggesting again the minor role of sectoral reallocation for capital flows.

The sizable reduction of the real interest rate in general equilibrium dampens significantly the appreciating effect of aging on the relative price of nontradables, as shown in Figure 6 and reported in Table 4. In the historical period, the model in general equilibrium predicts that the median relative price of nontradables grows on average 0.1% per annum. Hence, general equilibrium forces kill by more than 80% the appreciating force of aging that can be obtained at constant return to capital, thus explaining only about 8% of the average historical variation of the median relative

[44]The population to effective labor ratio in each period t for each country i is: $\sum_j N_{i,t,j} / \sum_j (h_j N_{i,t,j})$.

price of nontradables.[45] The continuous increase of the nontradable share of consumption is less dampened by general equilibrium forces. Under this lens, demographic change explains about 10% of structural transformation, a contribution cut in half compared to the partial equilibrium results.

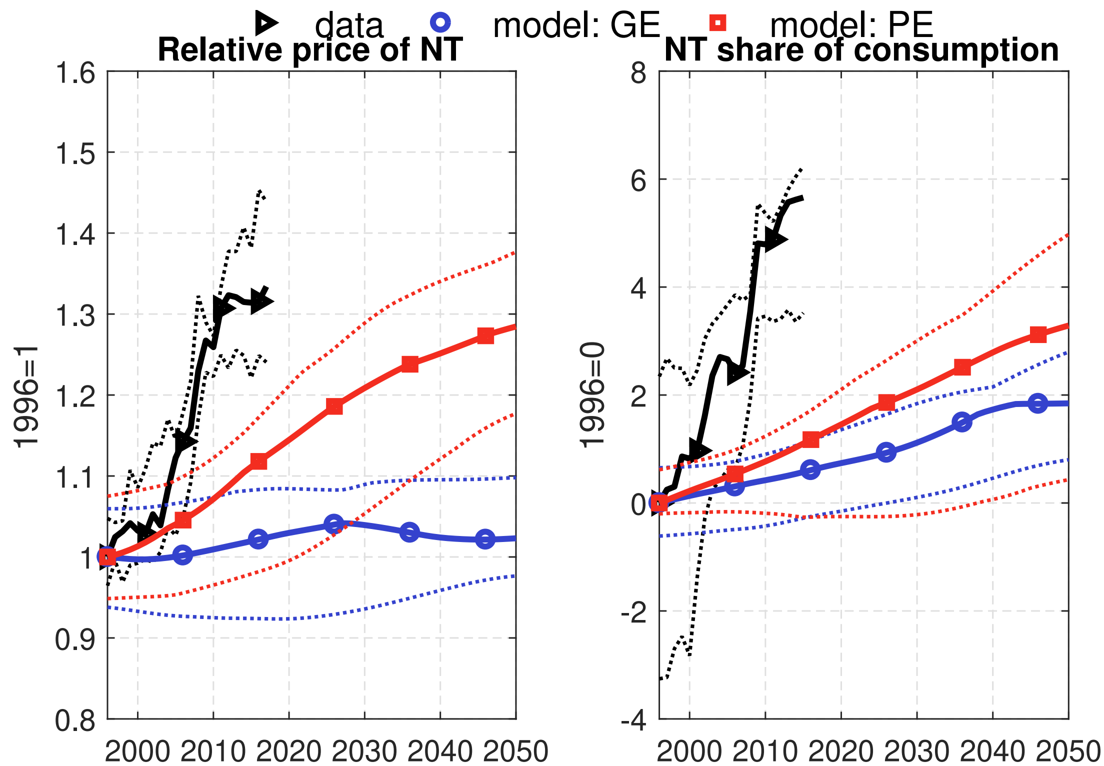


Figure 6: Model vs data. Relative price and consumption share of nontradables (NT) - median (thick) and 25th-75th percentiles (dotted). General (GE) vs partial (PE) equilibrium.

Note. Data description in Appendix F. Ireland excluded from relative price values as outlier in the data (in most periods its value is more than two standard deviations smaller than the median). Austria excluded from consumption share values due to lack of data. See Figure E.4 in the Appendix for country-specific series.

Table 4: Demographic contribution to structural transformation, median

	Relative price			**NT consumption share**		
	Data	**PE**	**GE**	**Data**	**PE**	**GE**
Average annual growth 1996-2017, %	1.40	0.56	0.11			
Percentage point change 1996-2015				5.66	1.07	0.59
Demographic contribution, %		40	8		19	10

Note. Results based on median values reported in Figure 6.

[45] Going to 2050, the relative price of nontradables grows on average across countries about 0.5% per annum in partial equilibrium, 0.1% in general equilibrium. Again, general equilibrium forces kill by about 80% the partial equilibrium appreciating force of aging.

In spite of these smaller general equilibrium numbers, it is interesting to notice the impact of the endogenously declining real interest rate on the relative price of nontradables given that the economy features country-specific capital intensity differentials between sectors. Countries whose tradable sector is calibrated to be more capital intensive than the nontradable sector (BEL, ESP, FIN, IRL, NLD, see Table 2) end up with a slightly higher relative price of nontradables, throughout the whole transition period, compared to a situation where there is no capital intensity differentials (compare the blue continuous and the lightblue dashed lines in Figure 5). Vice versa for the other countries. Even though the light-blue dashed lines are outclassed by the partial equilibrium results, this channel is not irrelevant. For example, on average over the entire plotted period (1995–2100), in general equilibrium Germany would face more than 50% smaller deviation of the relative price of nontradables from the initial level. For France this number is about 20% until 2050 and even higher thereafter. For the other countries too (except for Austria and Belgium where the discrepancy between ψ^T and ψ^N is nil and negligible) this channel explains around a fourth of the general equilibrium absolute deviation of the relative price of nontradables from the initial level. The residual effect is due to the presence of imperfect sectoral labor mobility as can be seen by the comparison with the (empirically irrelevant) case of perfect labor mobility ($\varepsilon_i \to \infty$) and same capital intensity between sectors (see the thin violet line in the top panel of Figure 5). Recalling equation (5.1), in this case the relative price of nontradables remains at its initial steady state level equal to the relative labor augmenting technology of the tradable sector.

6 Relative prices and capital flows in an aging world

This section extends the previous analysis studying a world economy comprising 18 countries. Other than the EA9 countries studied above, the world economy is now populated by the following additional countries: Australia (AUS), Canada (CAN), China (CHN), Denmark (DNK), United Kingdom (GBR), India (IND), Japan (JPN), Sweden (SWE), United States (USA). The focus on these countries is mostly due to data availability, suited to the calibration of the model. Taken together, these 18 countries account for about 70% of the world GDP, 60% of trade (i.e. exports of goods and services) and about 50% of the world population (all in 2019).[46]

6.1 Calibration

The calibration strategy follows closely the one in section 3 with one main difference: countries are now allowed to differ in the discount factor (β) value in order to match the initial empirical level of the net-foreign-asset to GDP ratio. Since the focus is on the future, the transition dynamics is assumed to start in 2012, with the empirical targets provided by data in 2011 (when the system is assumed to be in the initial stationary equilibrium). With the exception of the discount factor, all

[46]Demographic data for China do not include Hong Kong and Macao, Special Administrative Regions (SAR) of China, and Taiwan Province of China.

Table 5: World model calibration: country-specific parameter values

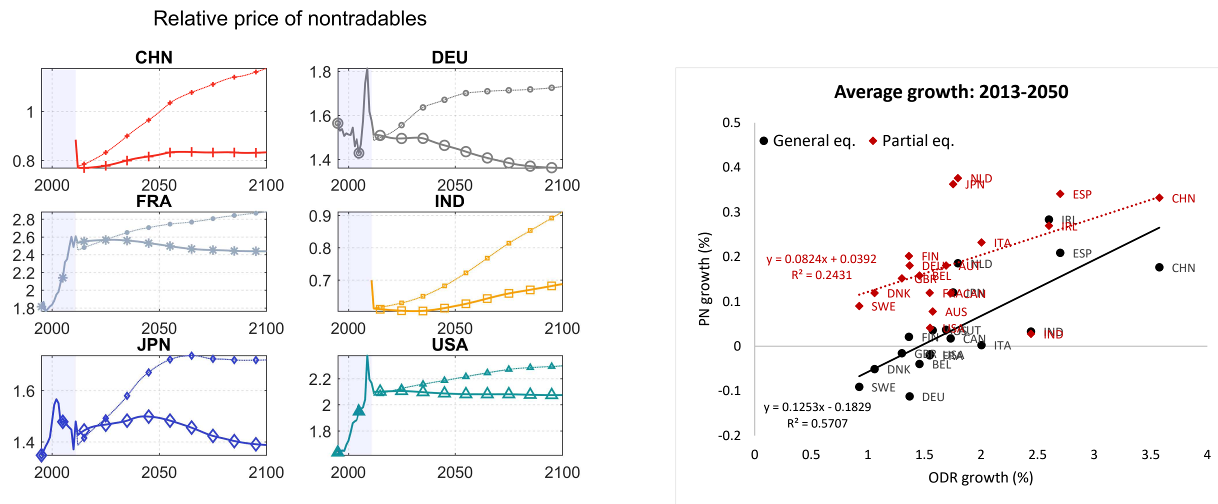
Country	Empirical target		Parameter							
	F/Y	P^N	β	Z^T	ψ^T	ψ^N	θ	φ	ε	$\bar{d}$
(pop share %)	NFA -output ratio	rel. NT price	discout factor	rel. T pro-duc-tivity	T capital share of income	N capital share of income	T share in labor	T/N consum. elas-ticity	T/N labor elas-ticity	pension replac. rate
AUS (0.7)	-0.57	1.70	0.99	2.42	0.41	0.33	0.36	0.40	0.37	0.22
AUT (0.3)	-0.04	1.96	0.99	3.81	0.32	0.32	0.40	1.52	1.10	0.65
BEL (0.3)	0.58	1.95	0.99	4.13	0.34	0.33	0.36	1.24	0.61	0.43
CAN (1.1)	-0.14	1.15	1.00	1.64	0.46	0.38	0.33	0.75	0.39	0.30
CHN (41.3)	0.21	0.88	1.03	0.78	0.52	0.50	0.53	0.92	0.90	0.11
DEU (2.6)	0.25	1.58	0.98	3.26	0.24	0.36	0.40	0.58	1.01	0.31
DNK (0.2)	0.24	2.11	0.98	4.46	0.35	0.30	0.34	1.08	0.29	0.15
ESP (1.5)	-0.86	1.92	0.99	3.21	0.40	0.34	0.40	1.39	1.02	0.59
FIN (0.2)	0.13	1.85	0.99	2.11	0.35	0.26	0.42	0.85	0.43	0.67
FRA (1.9)	-0.33	2.61	0.98	5.44	0.28	0.31	0.36	0.89	1.40	0.40
GBR (1.9)	-0.17	1.63	0.98	2.32	0.30	0.26	0.35	0.48	0.60	0.30
IND (32.0)	-0.18	0.70	1.04	0.24	0.55	0.46	0.65	0.92	0.90	0.00
IRL (0.1)	-0.90	1.07	0.99	0.77	0.49	0.31	0.42	1.35	0.22	0.23
ITA (1.9)	-0.25	1.91	0.98	3.42	0.26	0.33	0.42	0.72	1.66	0.58
JPN (4.1)	0.57	1.48	0.99	1.94	0.40	0.34	0.39	1.05	0.87	0.39
NLD (0.5)	0.29	1.82	0.99	2.22	0.39	0.26	0.33	0.52	0.22	0.25
SWE (0.3)	-0.08	2.07	0.98	2.82	0.33	0.26	0.35	0.51	0.53	0.52
USA (9.2)	-0.27	2.17	0.99	4.37	0.38	0.38	0.30	0.82	3.22	0.33
Tot (100.0)	-0.09	1.70	0.99	2.74	0.38	0.34	0.40	0.89	0.87	0.36
Source	EWN	KLEMS	implied		Bertinelli et al. (2020), KLEMS					Bárány et al.

Note. The population shares in parenthesis refer to year 2011. Tot is simple average across countries.

the values for the common parameters in Table 1 hold for all countries. It is further assumed that the depreciation rate of capital is common to all countries, set to the annual rate of 8% (following Bárány et al. (2019)). Hence the capital-output ratios are determined endogenously, with resulting values in the ballpark of standard estimates.[47]

Table 5 reports the country-specific parameter values together with the empirical target values. The grey-shaded areas identify the extra-EA9 countries. The initial empirical target values for the net foreign asset position (NFA) to GDP are taken from the updated and extended version of "External Wealth of Nations" (EWN) dataset constructed by Lane and Milesi-Ferretti (2007). For the relative price of nontradables the empirical target is provided by the EUKLEMS (2011, 2019) releases with price indexes constructed as described in Appendix F. Data for Australia are available only until 2011. It was opted to set its initial relative price of nontradables level considering its average level with respect to the United States in all jointly available years (1977–2007), assuming that this average level is maintained also in 2011. Similarly, lacking data on China, India and Canada, the level for these countries reported by Thomas et al. (2009) (Fig. 1) relative to the

[47]The simple average across countries of the investment-output ratio in the initial stationary equilibrium is about 25%.



(a) P^N: data (1995-2011), model (2011-2100)   (b) P^N vs empirical ODR av. growth

Figure 7: Relative price of nontradables (P^N): model projections and their correlations with old dependency ratio (ODR), partial vs general equilibrium

Note. **Panel (7a)**: dotted lines show the partial equilibrium outcome, i.e. fixing the real interest rate at the initial stationary equilibrium value throughout the whole transition. Data plotted in the shaded area. **Panel (7b)**: Red (black) squares (circles) represent the partial (general) equilibrium results for the relative price of nontradables average annual growth rates in the period 2013-2050. On the x-axis the variable is the average annual growth rate over the same period for the old-dependency ratio (the number of people aged 65 or more over those aged 15-64) as depicted in Figure 1.

United States (as average over 1990 to 2007) has been taken to infer the value for 2011 given the 2011 value for the United States.

The values of $\{\psi^T, \psi^N, \theta, \phi, \varepsilon\}$ are taken from Bertinelli et al. (2020), consistently with what calibrated for EA9 countries (cf. Table 2), for all countries with the exception of China and India. For them, the values of $\{\psi^T, \psi^N, \theta\}$ are taken from the latest available WORLD KLEMS releases applying the same logic adopted for the other countries using the sectoral split, at its best approximation, provided in Appendix F (Table F.1).[48] Lacking estimates of $\{\varphi, \varepsilon\}$ for China and India, the values in this case is simply set to the sample average for both parameters.

6.2 Main results

Figures 7 and 8 report the dynamics of the relative price of nontradables, the net foreign asset to GDP and the current account balances to GDP for the main countries in the model (in terms of population size). The main results of the previous section are confirmed. General equilibrium forces compensate, in certain cases more than entirely, the potential appreciating force of aging on the relative price of nontradables which manifests in partial equilibrium (dotted lines in Figure 7a)

[48]The implied values for the sectoral elasticities of output to capital, measured as complement of the labor share in gross value added, are found to be consistent with what one would obtain using data compiled by Chong-En and Zhenjie (2010) considering their "agriculture" and "industry" as tradable, "construction" and "service" as nontradable.

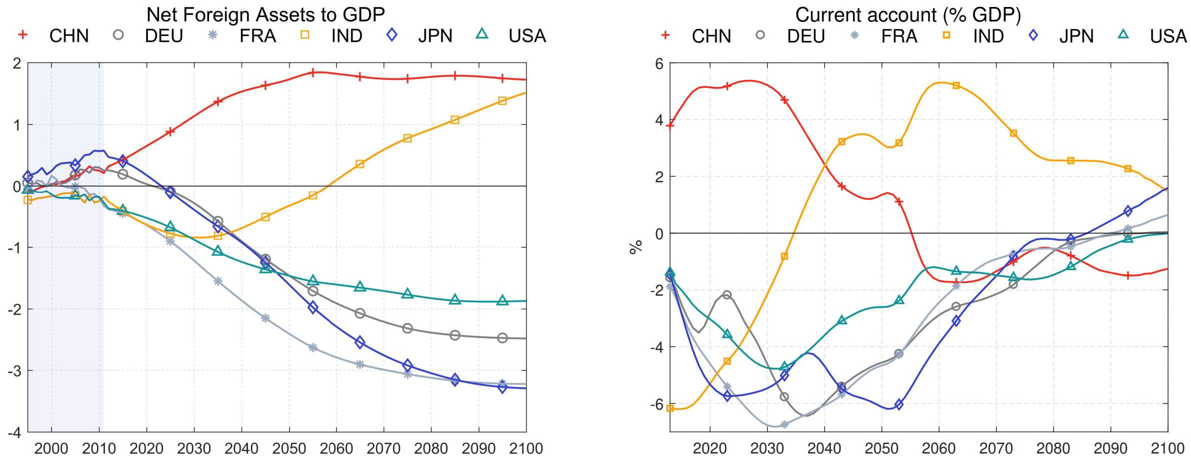


Figure 8: Net foreign asset positions and current account balances to GDP

Note. General equilibrium results under calibration of Table 5. Data plotted in the shaded area.

for all countries. Notice that China and India are calibrated to have a much smaller level of the relative price of nontradables compared to the other countries, corresponding to a much smaller level of the relative labor augmenting technology of the tradable sector (Z^T in Table 5). This is how the model captures the different degree of economic development across countries.

Countries aging faster experience a greater increase of the relative price of nontradables in the model. There is a clear positive cross-country correlation between the average growth rate of the old-dependency ratio and that of the relative price of nontradables, as can be seen in Figure 7b. Such a correlation is actually stronger in general equilibrium but the intercept stands at a lower level compared to partial equilibrium. Therefore, the model generates a relationship between two variables that has been tested empirically both directly on the relative prices of nontradables (Groneck and Kaufmann, 2017) and more indirectly on the real (effective) exchange rate (Giagheddu and Papetti, 2018).

As the inclusion of the new countries speeds up the global aging process, the real interest rate decreases more compared to the EA9 economy analyzed in the previous sections.[49] Between 2015 and 2030 it decreases by about 1.4 percentage points in the baseline. When the elasticity of intertemporal substitution is increased to have logarithmic preferences in consumption (σ goes from 2 of the baseline to 1) the decreases of the real interest rate is mitigated, being about 0.8 percentage points between 2015 and 2030 (see Figure 14). Irrespective of the magnitude of the real interest rate decrease, the model generates huge global imbalances in the net foreign asset positions relative to GDP (see Figure 12). Figure 8 shows that the two most populous and fastest aging (see Figure 1) countries, namely China and India, are projected to become the two main net

[49]This result is also found in Bárány et al. (2019): "In our study, the impact of including emerging countries on the current and future fall in the interest rate is an order of magnitude larger. By 2080, the world interest rate falls by one percentage point more in the baseline compared to the rich-country experiment".

creditors in the twenty-first century. As also found by Auclert et al. (2020): "The relatively rapid aging of these large countries [China and India] in turn implies that the positive asset positions of current large savers, such as Germany and Japan, reverse, while the US continues into more negative territory". The right panel of Figure 8 shows that China is projected to have current account surpluses hovering around 5% of GDP until around 2030, then slowly declining to be soon accompanied and then replaced by persistent current account surpluses of India. The other economies face relevant current account deficits throughout the whole twenty-first century. The relative abundance of capital in China and India is also due to the fact that they are calibrated to have less generous pay-as-you-go pension systems (see last column of Table 5).

Finally, in light of the model's prediction, notice that demographic change can offer an alleviation to the "allocation puzzle" (Gourinchas and Jeanne, 2013). Fast-aging countries (China and India) are also those whose GDP per working hour grows faster (see Figure G.1 in Appendix G). Since these countries are also those experiencing current account surpluses throughout the twenty-first century, demographic change might help explaining why the standard neoclassical model fails to account for the positive correlation between current account balances and (productivity) growth found in the data.[50]

6.3 Sensitivity

Pension generosity. To explore the role of the PAYG pension system generosity, the baseline results (obtained under the assumption of time-invariant replacement rates) are compared with the results of two parametric variations meant to capture likely scenarios. In the first scenario, the new assumption is that in China and India the replacement rates converge smoothly in the long-run to the sample average of the other countries, that is to 39.5% (see Figure 9). In the second scenario, it is assumed that on top of Chinese and Indian convergence, in the other countries the replacement rates evolve according to the following rule (cf. Bárány et al. (2019)):

$$\log\left(\bar{d}_{i,t}\right) = \log\left(\bar{d}_{i,2011}\right) - (1-\mathcal{D})\log\left(\frac{\text{ODR}_{i,t}}{\text{ODR}_{i,2011}}\right)$$

where $ODR_{i,t}$ denotes the old dependency ratio (i.e. number of individuals aged 65 and above over those aged 15-64) which increases over time in all countries (see Figure 1a); $\bar{d}_{i,2011}$ corresponds to the country-specific replacement rate in year 2011 (initial stationary equilibrium) whose values are reported in Table 5; $0 < \mathcal{D} < 1$ is an *ad hoc* sensitivity parameter whose value is assumed to be 0.5. As shown in Figure 9, this value is such that the replacement rates decrease by about 13 percentage points in the long run on average across countries (except China and India).[51]

[50] Similar argumentation can be found in Bárány et al. (2019) and Sposi (2019).

[51] This decrease is consistent with what assumed e.g. by European Commission (2018) where the "benefit ratio" (i.e. the average pension as a share of the economy-wide average gross monthly earnings) is projected to decrease by 12 to 12.7 percentage points from 2016 to 2070 on average for European countries (see Table II.1.17 in that document).

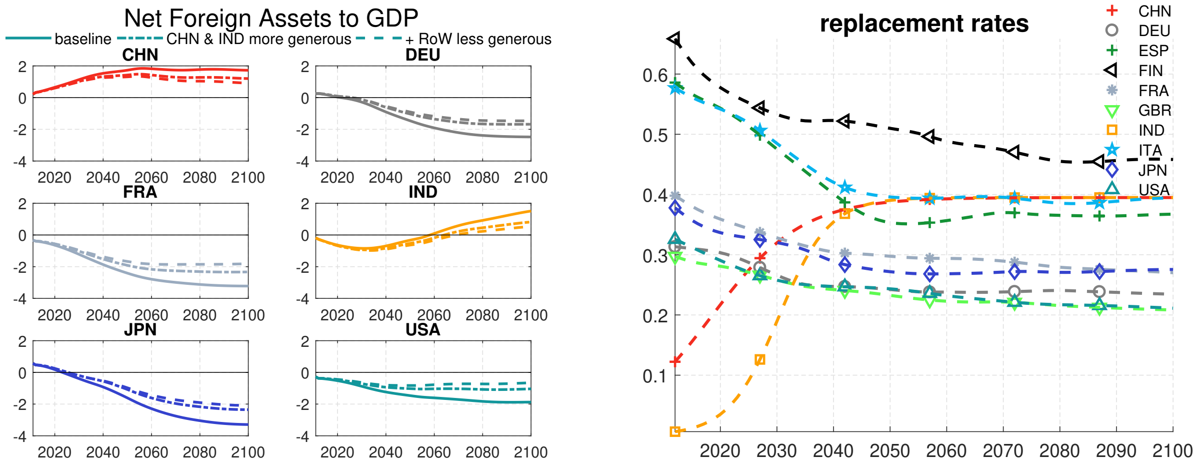


Figure 9: Net foreign asset to GDP under different pension replacement rate projections

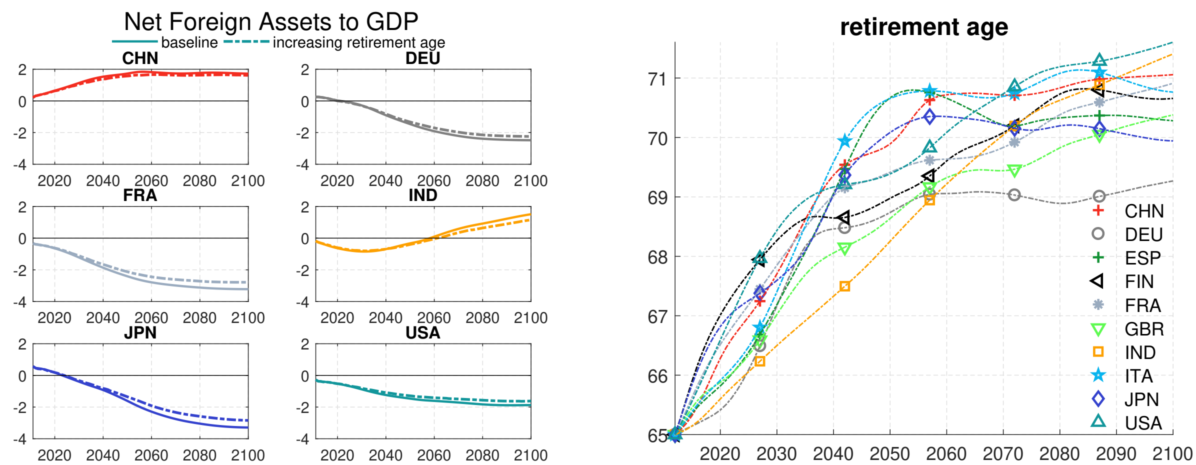


Figure 10: Net foreign asset to GDP under increasing retirement age projections

As plotted in Figure 9, the impact of more generosity over time of the Chinese and Indian pension systems does not alter the model's forecast on the direction of the net-foreign-asset (NFA) to GDP across countries. Nonetheless, the impact can be quantitatively significant, especially in the long-run. For example, in China by 2050 the NFA to GDP is 1.4 compared to 1.7 in the baseline. For the United States by the same year the NFA to GDP is about -1, compared to about -1.5 in the baseline. For all countries the gap widens further going to 2100. Hence, the projected global imbalances are somewhat reduced by more pension generosity in China and India that increase intergenerational transfers. The reason is that the two main net creditors of the twenty-first century face crowding-out effects on capital accumulation thus tending to provide less capital to the world, compared to the baseline. This is confirmed by the evolution of the real interest rate (Figure 14) which, however, decreases by only 0.5 percentage points less in the very long-run – while the impact on the proximate future is close to insignificant.

Specularly, global imbalances get even further reduced when all countries other than China and India decrease their pension system generosity. The reason is that the net-debtors of the twenty-first century now all decrease their intergenerational transfers thus favoring private savings and mitigating their negative NFA to GDP positions. Hence, capital is relatively more abundant in this second scenario compared to the first, with the consequent slightly bigger decrease of the real interest rate in the long-run (Figure 14). Again, the impact can be quantitatively significant but only over the long-run as the pension reforms are assumed to be implemented smoothly over the years.

The evolution of the relative price of nontradables is only marginally affected by the pension reforms here considered and therefore are not reported (available upon request).

Retirement age. Another likely pension system reform is the increase of the retirement age to keep pace with increasing life expectancy. To capture such a scenario, the baseline results (obtained under the assumption that the retirement age is constant over time and equal across countries, at the age of $\mathcal{J}_{i,2011} = 65$) are compared with the results under a parametric variation that links the retirement age to the evolution of the old dependency ratio in each country. Similarly to what done above, it is assumed that the retirement age evolves overtime according to the following rule:

$$\mathcal{J}_{i,t} = \mathcal{J}_{i,2011} \left(\frac{\text{ODR}_{i,t}}{\text{ODR}_{i,2011}} \right)^{\Upsilon_i}$$

The resulting retirement ages are plotted in Figure 10 and are discretized to the closest round number when employed in the model simulations.[52] As can be seen, it is assumed that the retirement age increases by about 5 years on average across countries by 2070.[53] To run the experiment it is assumed that the labor efficiency profile, $h_{i,j}$, declines slowly over the ages according to a logistic function after age 65. Hence, it is assumed that whenever the retirement age is increased above 65 there is also a change in the average life-cycle efficiency of labor compared to the baseline.[54]

The impact of the postulated increases in the retirement age is not so consequential for the macroeconomy compared to the baseline. The net foreign asset positions to GDP reach only slightly smaller levels in all countries (Figure 10) while the world real interest rate decreases only marginally less (Figure 14).[55] As one could expect, increasing the retirement age makes effective labor less scarce thus mitigating the macroeconomic effect of aging. However, the additional effective labor released by such a reform is relatively meager because individuals are calibrated to be not so much productive and participative after a certain age.[56] Furthermore, while the period in which households decumulate savings to finance consumption is reduced thus lessening the necessity of

[52]The *ad hoc* parameter Υ_i is assumed to be 0.14 for all countries, except for China and India (assumed to be 50% smaller), and for Spain and Ireland (assumed to be 25% smaller).

[53]This is about double what assumed by European Commission (2018), cf. their Graph I.2.2, for European countries.

[54]This is captured by the parameter $\bar{h}_i = \sum_{j=0}^{\mathcal{J}_i} h_{i,j}/\mathcal{J}_i$.

[55]Similar inconsequential patterns compared to the baseline are followed by the relative price of nontradables and other variables whose results are therefore not reported (available upon request).

[56]To match the labor income profile (Figure 2a), labor efficiency at age 65 is already quite low compared to the middle-ages so that the scope for significant efficiency gains thereafter is limited accordingly.

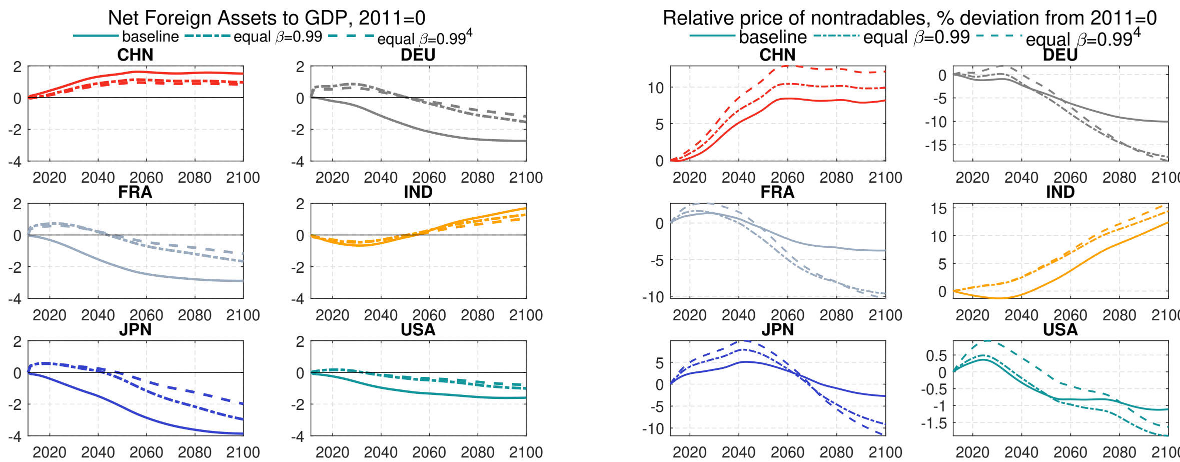


Figure 11: Net foreign asset to GDP and relative prices under different discount factor (β)

private savings during the working age, the government reduces the labor income tax rate to have the budget balanced in the face of a shrinking share of retirees (equation (2.11)). Hence, there is less crowding-out effect on savings in the economy so that the effect of less labor scarcity can be partly compensated by more capital abundance. Finally, since what matters for the evolution of NFA to GDP is how much the supply of capital of a country changes with respect to the average change in the world (cf. Auclert et al. (2020)), given that all countries in the world are increasing the retirement age in a similar manner there is little scope for significant deviations of NFA to GDP from the baseline.

Discount factor. To match the empirical NFA to GDP ratio in each country in 2011 the baseline calibration has entailed to numerically find country-specific discount factors (β, reported in Table 5). To do a sensitivity analysis on this parametrization, Figure 11 reports the results on the evolution of NFA to GDP and relative prices when it is assumed that the value of β is equal across countries first fixed at 0.99 (which is the average value across countries reported in Table 5), then at 0.99^4 (as in the baseline of section 3 for European countries, cf. Table 1). The initial *level* of most variables is inevitably altered by such a perturbation.[57] Furthermore, the results in Figure 11 show that this parameter can be important quantitatively. For what concerns the relative prices, the impact of aging is amplified in either direction so that there is a steepening of the positive relationship between the growth rates of the old dependency ratio and the relative price (depicted in Figure 7). The global imbalances in the net foreign asset positions are reduced. For example, compared to the baseline, when $\beta = 0.99^4$ the NFA to GDP by 2100 is almost halved for both China and India. On the opposite sign, countries like France, Germany and Japan have a NFA to GDP which is more than halved compared to the baseline by 2100. However, the overall prediction of the model remains robust. Namely, since the initial stationary equilibrium, those countries that age relatively

[57] For example, the initial level of the real interest rate goes from 3.2% of the baseline to 5.6% and and 9.4% when β has value of 0.99 and 0.99^4, respectively.

more (such as China and India) tend to increase to unprecedented levels their external position over the twenty-first century, vice versa the other countries.

Elasticity of intertemporal substitution. The elasticity of intertemporal substitution – assumed to be constant in the model, equal to the inverse of σ – determines the willingness to save by individuals, substituting future consumption for present consumption. As such it is key for the life-cycle theory embedded in the model. A lower value of σ by making the consumption-smoothing motive weaker would tend to lessen the increase of household's savings in response to the exogenously increasing survival probabilities. In recent studies (Auclert et al., 2020; Bárány et al., 2019; Papetti, 2020), it is found to quantitatively matter for the the impact of aging on the real interest rate. The model here employed makes no exception. If the real interest rate decreases by about 3.5 percentage points going to 2100 in the baseline ($\sigma = 2$), it decreases only by 2 (1) percentage points when the value of σ is reduced to about 1 (0.5), as depicted in Figure 14.[58]

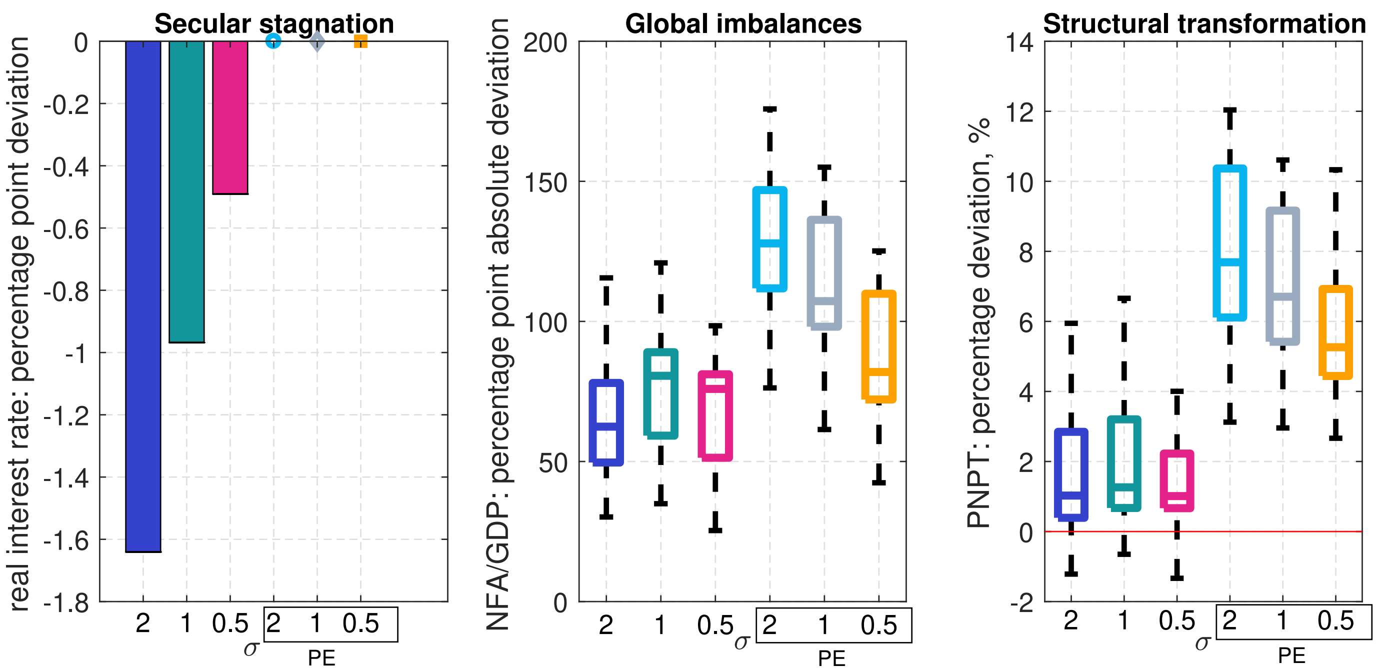


Figure 12: 2013-2030 variations: general and partial (PE) equilibrium results for different (inverse of) elasticity of intertemporal substitution (σ).

Note. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme datapoints the algorithm considers to be not outliers.

Figure 12 summarizes the dynamic results of the sensitivity exercise for different values of σ in general and partial (PE) equilibrium.[59] While secular stagnation is assessed in terms of percentage

[58]For each new value of σ, the model is recalibrated in the initial stationary equilibrium following the same procedure of section 6.1. This leads to different country-specific values of β, Z^T and to the same initial real interest rate at about 3.2% per annum (as in the baseline).

[59]While the value of σ equal to 2 assumed in the baseline is in the mid-range of the empirical estimates (see e.g. review

point deviation of the real interest rate between 2013 and 2030, global imbalances and structural transformation are assessed by the percentage point absolute deviation of NFA to GDP and by the percentage deviation of the relative price of nontradables over the same period, respectively.

As discussed in the previous sections, the two essential features of population aging are to encourage savings and to discourage investments in response to falling mortality and fertility rates, respectively, thus leading countries to unavoidably run surpluses in the current account – the difference between aggregate savings and investment – in partial equilibrium, i.e. when the real interest rate is kept fixed at the initial level.[60] As shown in the boxplots corresponding to partial equilibrium (PE) of Figure 12, as σ decreases the (positive) deviations of the NFA to GDP get smaller since the willingness to increase savings in response to higher survival probabilities vanishes. This tends to be reflected in a lower deviation of the relative price of nontradables via the savings channel discussed in the previous sections. The deviations in partial equilibrium are huge. Evaluated by the median, countries would like to have more than 120 percentage points more positive NFA to GDP by 2030 in the baseline ($\sigma = 2$), more than 100 (80) percentage points when σ is equal to 1 (0.5). Similarly, the median country would face about 8% higher relative price of nontradables from 2013 to 2030 in the baseline, 7% (5%) when σ is equal to 1 (0.5).

In general equilibrium, the real interest rate decreases by about 1 (0.5) percentage points between 2013 and 2030 for σ equal to 1 (0.5), compared to the baseline where it decreases by 1.6 percentage points. However, the monotonic downsizing of secular stagnation for lower values of σ does not translate into a similar downsizing of global imbalances and structural transformation. As highlighted by Auclert et al. (2020), for global imbalances the real interest rate variation matters as long as there are differences across countries in the sensitivities of capital demand and supply. Given that σ is the same across countries, its variation is unlikely to produce big variations in the NFA to GDP positions which are likely to stem from the interaction with differences across countries in the discount factor β. Judging by the results, a similar reasoning might apply to the determination of the relative price of nontradables, suggesting that in general equilibrium the relative wage channel (with imperfect labor mobility) tend to compensate the real interest rate channel (with different intersectoral factor intensities) – recall equation (5.1) – providing roughly the same impact of aging under different values of σ.

Finally, notice the sizable quantitative difference between partial and general equilibrium results. The 25th-75th percentile range for the absolute deviation of the NFA to GDP is between 50

in Bárány et al. (2019), cf. Havranek (2013)), in this section σ is experimented to only take lower levels. The reason is that, as noted by Attanasio et al. (2007), in a frictionless modeling context where intertemporal considerations linked to demographic change are the only drivers of savings one might wonder whether the equilibrium real interest rate is too sensitive to demographic changes. OLG modelers have commonly opted to set σ either to a value of 1 (Auclert et al., 2020; Gagnon et al., 2016; Krueger and Ludwig, 2007) or 2 (Attanasio et al., 2007; Bárány et al., 2019; Domeij and Flodén, 2006) in their baseline.

[60] Of course, it is trivially unrealistic to consider 18 big economies in partial equilibrium, incapable of influencing the world real interest rate. This amounts to assuming that there exists a second earth to absorb the current account surpluses. Nonetheless, it is a useful case study to isolate general equilibrium effects and think in terms of an exogenous interest rate driven by forces other than aging.

and 90 percentage points in general equilibrium across the different perturbations of σ, between 70 and 150 percentage points in general equilibrium. The same range for the percentage deviation of the relative price of nontradables is between 0.4% and 3% in general equilibrium, between 4% and 10% in partial equilibrium.

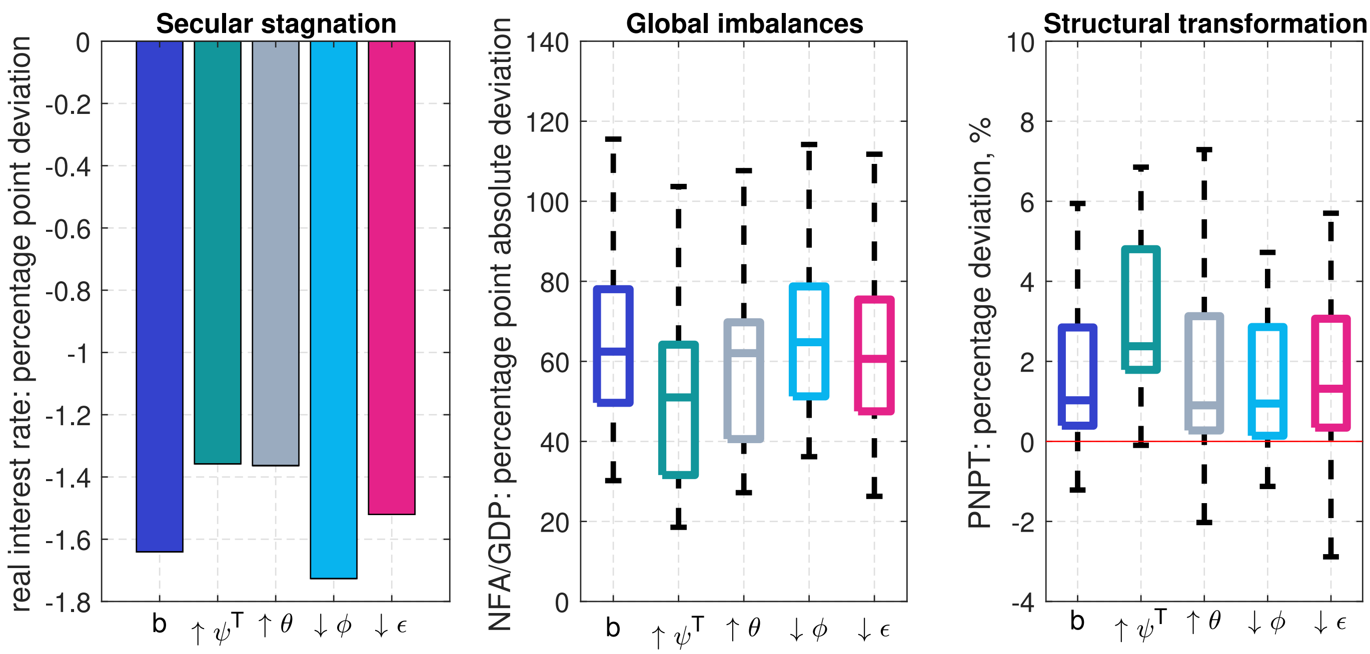


Figure 13: 2013-2030 variations: results for different sector-specific parameters vs baseline (b)

Note. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme datapoints the algorithm considers to be not outliers.

Intersectoral dynamics parameters. Figure 12 compares the baseline results ('b') with four perturbed versions of the model depending on the values of the parameters governing the sectoral differences in the model (see Table 5) in each country: (i) the capital intensity in the tradable sector (ψ^T) is increased by 5.5% and, correspondingly, the one in the nontradable sector (ψ^N) is decreased by the same percentage amount so that the average discrepancy $\psi^T - \psi^N$ across countries becomes twice as big compared to the baseline (about 8 versus 4 percentage points); (ii) the bias towards tradable labor (θ) in the CES aggregator (equation (2.4)) becomes 50% bigger; (iii) the intersectoral elasticity of substitution in consumption (φ) becomes 50% smaller; (iv) the intersectoral labor mobility becomes 50% smaller.[61] For each of these perturbations, the model is recalibrated in the

[61] The rational for these changes are the following: (i) some studies find a higher discrepancy in capital intensity between tradable and nontradable industries than the one reported in Table 5, see e.g. Table A.4 in Piton (2020), Table 1 in Acemoglu and Guerrieri (2008); (ii) it might be sensible to think that the share of what is tradable is actually higher than what commonly measured (Gervais and Jensen, 2019); (iii) some studies use a smaller value than the average in Table 5 for φ, e.g. Stockman and Tesar (1995) estimate an elasticity of substitution between traded and nontraded goods of 0.44; (iv) the empirical estimates in Cardi and Restout (2015) (Table 5) result in smaller values for ε than what later estimated by Bertinelli et al. (2020).

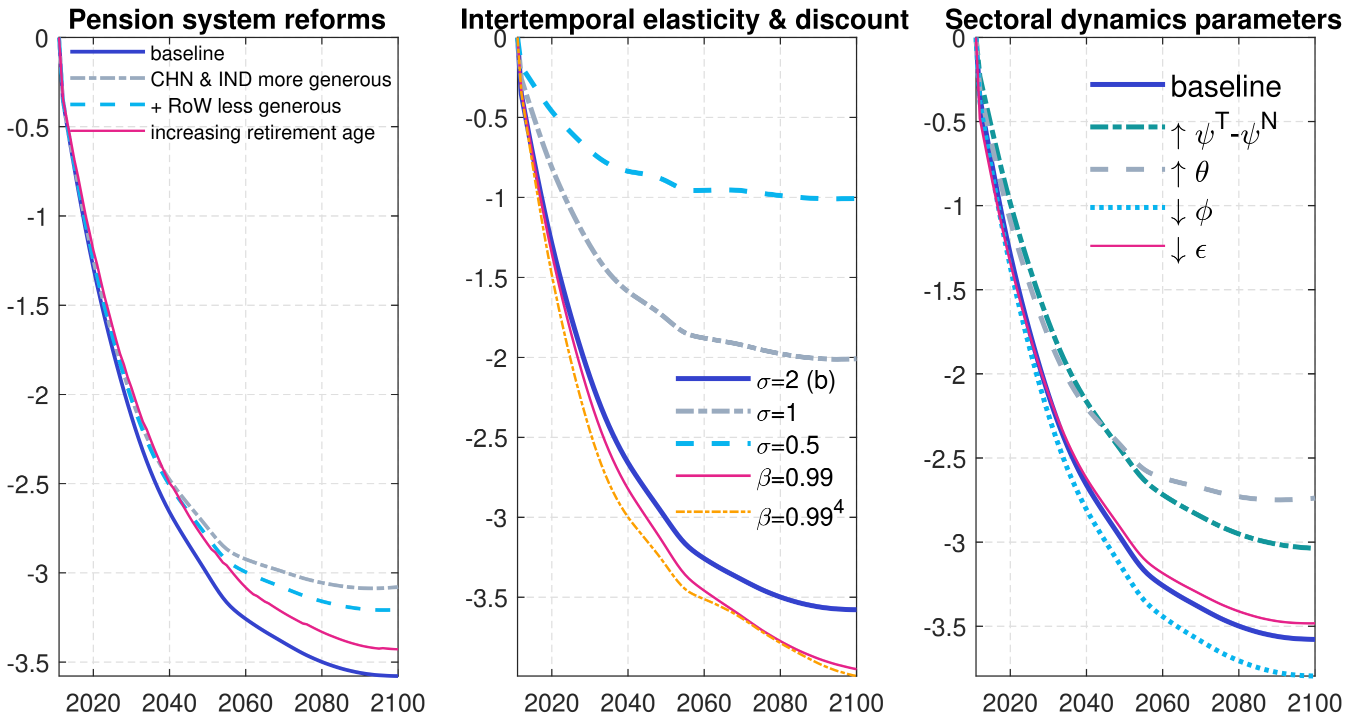


Figure 14: Real interest rate [2011=0] under different sensitivity specifications

initial stationary equilibrium with the same procedure described in section 6.1.

The (perhaps surprising) result is that none of these perturbations alter significantly the quantitative predictions of the model (Figure 13) with the exception of case (ii) which, as expected, increases the impact of aging on the relative price of nontradable by increasing its sensitivity to real interest rate changes. These results point, once again, to the relative stronger importance of the savings decisions rather than sectoral reallocation decisions in determining the quantitative predictions of the model.

Overall, the results in this section provides some evidence that the quantitative predictions of the model are robust to sensible perturbations of the main parameters, especially for what concerns global imbalances and structural transformation.

7 Sectoral reallocation and capital flows

Section 5 has hinted to the fairly inconsequential role of aging-induced sectoral reallocation for the dynamics of capital flows. This section explores more explicitly whether this is the case by comparing the capital flow outcomes of the baseline two-sector model with those of a one-sector analog. Appendix H provides the set of equilibrium equations characterizing the latter where the

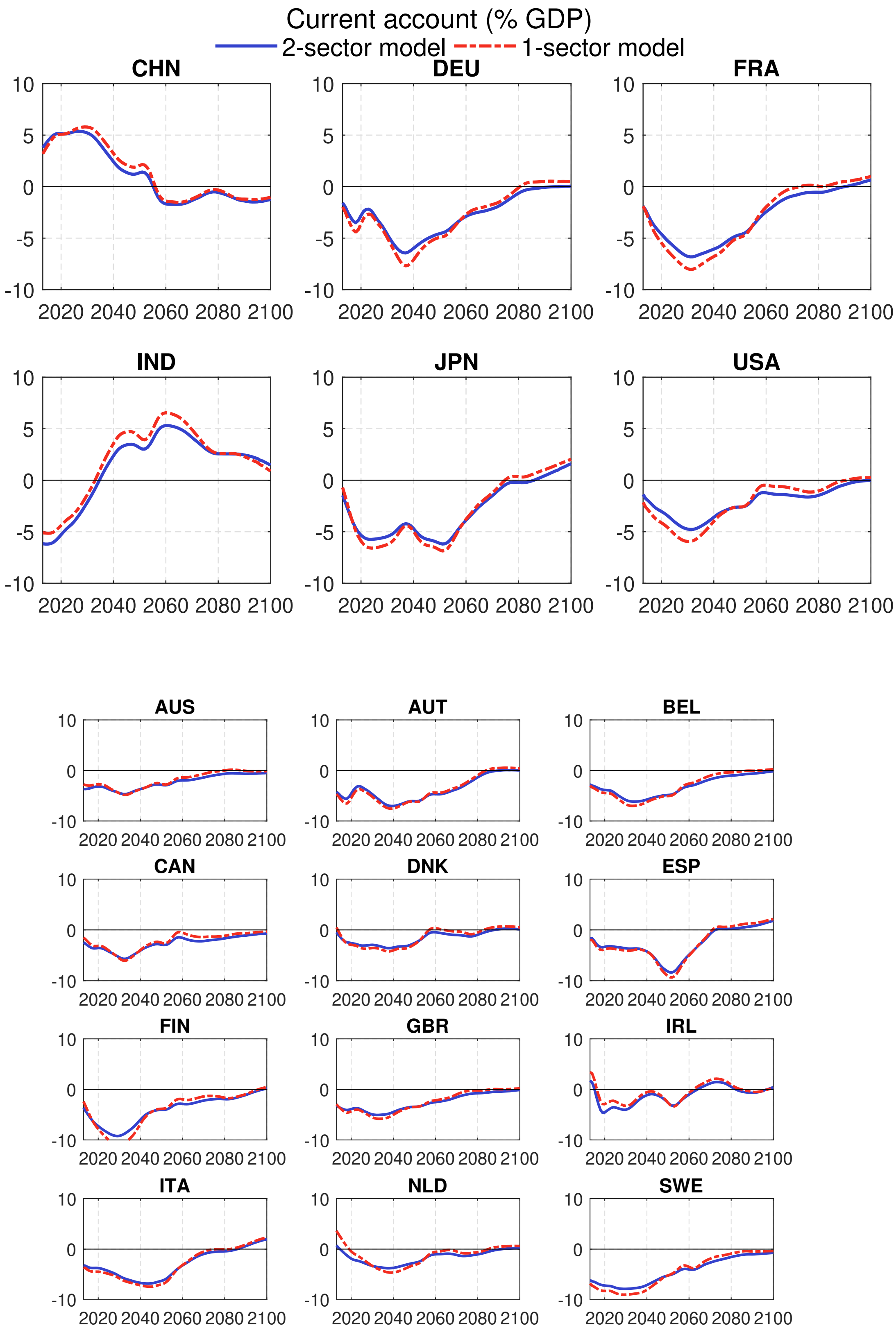


Figure 15: Current account balances to GDP: 2-sector vs 1-sector model

single composite good in the economy is assumed to be fully tradable.[62]

To be consistent with the two-sector calibration procedure: (a) the output elasticity to capital ψ_i is set to the average value between ψ_i^T and ψ_i^N in Table 5; (b) the value for the capital depreciation rate $\delta_i = \delta$ for all counties i is solved endogenously in the initial stationary equilibrium to have the same return on capital;[63] (c) the labor technology parameter Z_i is set to the value for Z_i^T in Table 5; (d) the country-specific discount factor is still such that the model matches by construction the empirical level of the net foreign asset position.

In the context of the current modeling framework, Figure 15 confirms the negligibleness of sectoral reallocation to determine the dynamics of capital flows. The continuous blue line and the dashed-dotted red line do not perfectly overlap but the quantitative implications of the two models are essentially the same. These results give support to previous works which have mostly used one-sector OLG models to study the impact of aging on capital flows (Attanasio et al., 2007; Auclert et al., 2020; Backus et al., 2014; Bárány et al., 2019; Domeij and Flodén, 2006; Krueger and Ludwig, 2007) and are consistent with the study by Rausch (2009) (although in the context of a closed-economy) who finds that while "the demographic transition induces substantial changes in the sectoral composition of output" it "has only minor quantitative effects on aggregate variables". He attributes this finding to the fact that total consumption expenditures by older households (aged more than 60) make up only a small fraction of total private consumption (between 24% and 30% by 2050 for Germany) with an order of magnitude that finds correspondence for the countries in the model employed in this paper.

Obviously, the results in this section do not exclude that other mechanisms, not envisaged in the model, could make sectoral reallocation more relevant for capital flows. One could envisage, for example, that technological progress originates endogenously in the sector towards which the demand of an aging population is directed (Schön et al., 2017); or that capital inflows engender a reallocation of resources towards the nontradable sector that depresses the relative productivity of the tradable sector (Benigno et al., 2020). These provide potentially valuable extensions of the OLG model here presented that are left to explore for future research, together with the relaxation of the assumption that capital in both sectors is a tradable good.

8 Concluding remarks

This paper develops a multi-country two-sector large-scale general-equilibrium overlapping generations model showing that demographic change can explain a relevant fraction of the empirical variation of the relative price of nontradables and capital flows. The model predicts that countries aging faster will tend to face a higher growth of the relative price of nontradables driven by a higher

[62]Beginning with the two-sector model in Appendix A, the one-sector model can be obtained by setting $P_{i,t}^N = 1$, $\alpha_{i,j} = 1$, $\phi_i = 1$, $\psi_i^N = \psi_i^T = \psi$, $w_{i,t}^N = w_{i,t}^T = w_{i,t}$ and $Z_i^N = Z_i^T = Z_i$.

[63]It results $\delta = 0.0769$.

relative demand for nontradables with ensuing adjustment of the supply side (structural transformation). An effect, however, whose size will be dampened if the real interest rate will decrease (secular stagnation) as robustly implied by population aging – the only force analyzed in this paper. Lower return on savings reduce consumption at older ages thus limiting the scope for older populations to determine a shift of the relative demand in favor of nontradables. Meanwhile, the model predicts unprecedented global imbalances in the net foreign asset positions driven by standard saving/investment decisions in the presence of different and unsynchronized cross-country patterns of aging and different public pension systems, where sectoral reallocation does not seem to play a key role. More populous, faster aging, higher GDP-per-hour growth countries with less generous pension systems are predicted to become the net creditors in the twenty-first century.

The model has a rich structure of heterogeneity that is only partly exploited in the paper. There is a number of research issues that the model would be well suited to address and that might be relevant for the resulting relative prices and capital flows, especially in the projected horizon. One could easily study different pension system reforms across countries acting on the retirement age, the replacement and participation rates. By changing the saving behavior and the relative scarcity of the effective labor force, such reforms could have an impact on the direction of capital flows as well as on the relative demand pattern and thus on the relative price. Another exercise would be to feed the model with exogenous time-varying series of relative productivity growth rates to check how much variation of the relative price of nontradables could be explained by the "Balassa-Samuelson effect" in comparison with demographic change, and how much they could affect capital flows as long as different rates prevail across countries. Relatedly, one could endogenize sectoral productivity, which has a direct impact on the relative price, perhaps envisioning that technological progress originates endogenously in the sector towards which the demand of an aging population is directed.

Finally, this paper relies on the UN (2019) median demographic projections to predict to what extent demographic change can be a relevant driver of structural transformation, secular stagnation and global imbalances in the twenty-first century. Predictions obviously suffer from many factors of uncertainty, including the demographic projections themselves (in spite of the well definite time lags with which demographic statistics seem to evolve). In any event, these predictions are meant to provide a conscience of the risks in order to act on them in practice, certainly not to be taken as a fate to which one ought to be resigned.

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Appendix

A Set of equilibrium equations

In an equilibrium with perfect foresight, the following optimal conditions hold for each country i and time period t.

Households:

for $j = 0, 1, ..., J-1$:

$$c^T_{i,t+1,j+1} = [\beta(1+r_{t+1})]^{\frac{1}{\sigma}} c^T_{i,t,j} \left(\frac{\alpha_{i,j+1}}{\alpha_{i,j}}\right)^{\frac{1-\sigma}{(\phi_i-1)\sigma}} \left[\frac{1+\frac{1-\alpha_{i,j+1}}{\alpha_{i,j+1}}(P^N_{i,t+1})^{1-\phi_i}}{1+\frac{1-\alpha_{i,j}}{\alpha_{i,j}}(P^N_{i,t})^{1-\phi_i}}\right]^{\frac{1-\sigma\phi_i}{(\phi_i-1)\sigma}} \tag{A.1}$$

for $j = 0, 1, ..., J$:

$$(P^N_{i,t})^{\phi_i} c^N_{i,t,j} = \frac{1-\alpha_{i,j}}{\alpha_{i,j}} c^T_{i,t,j} \tag{A.2}$$

$$h^T_{i,t,j} = \theta_i h_{i,j} \left(\frac{w^T_{i,t}}{w_{i,t}}\right)^{\varepsilon_i} \tag{A.3}$$

$$h^N_{i,t,j} = (1-\theta_i) h_{i,j} \left(\frac{w^N_{i,t}}{w_{i,t}}\right)^{\varepsilon_i} \tag{A.4}$$

$$c^T_{i,t,j} + P^N_{i,t} c^N_{i,t,j} + a_{i,t+1,j+1} = \frac{a_{i,t,j}(1+r_t)}{s_{i,t,j}} + w_{i,t} h_{i,j} (1-\tau_{i,t}) I(j < \mathcal{J}_i) + d_{i,t} I(j \geq \mathcal{J}_i) \tag{A.5}$$

with:

$$a_{i,t,0} = a_{i,t,J+1} = 0 \tag{A.6}$$

$$w_{i,t} = \left[\theta_i (w^T_{i,t})^{1+\varepsilon_i} + (1-\theta_i)(w^N_{i,t})^{1+\varepsilon_i}\right]^{\frac{1}{1+\varepsilon_i}} \tag{A.7}$$

Government:

$$\tau_{i,t} = \frac{\bar{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,t,j}}{L_{i,t} + \bar{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,t,j}} \tag{A.8}$$

$$d_{i,t} = \bar{d}_i \bar{h}_i w_{i,t} (1-\tau_{i,t}) \tag{A.9}$$

Firms:

$$w^T_{i,t} = (1-\psi^T_i) Z^T_i \left(\frac{\psi^T_i}{r_t+\delta_i}\right)^{\frac{\psi^T_i}{1-\psi^T_i}} \tag{A.10}$$

$$w^N_{i,t} = (1-\psi^N_i) Z^N_i \left(\frac{\psi^N_i}{r_t+\delta_i}\right)^{\frac{\psi^N_i}{1-\psi^N_i}} (P^N_{i,t})^{\frac{1}{1-\psi^N_i}} \tag{A.11}$$

$$K^T_{i,t} = L^T_{i,t} Z^T_i \left(\frac{\psi^T_i}{r_t+\delta_i}\right)^{\frac{1}{1-\psi^T_i}} \tag{A.12}$$

$$K^N_{i,t} = L^N_{i,t} Z^N_i \left(\frac{\psi^N_i P^N_{i,t}}{r_t+\delta_i}\right)^{\frac{1}{1-\psi^N_i}} \tag{A.13}$$

Aggregates:

$$Y^T_{i,t} = (K^T_{i,t})^{\psi^T_i}(Z^T_i L^T_{i,t})^{1-\psi^T_i} \tag{A.14}$$
$$Y^N_{i,t} = (K^N_{i,t})^{\psi^N_i}(Z^N_i L^N_{i,t})^{1-\psi^N_i} \tag{A.15}$$
$$Y_{i,t} = Y^T_{i,t} + P^N_{i,t} Y^N_{i,t} \tag{A.16}$$
$$C^T_{i,t} = \sum_{j=0}^{J} c^T_{i,t,j} N_{i,t,j} \tag{A.17}$$
$$C^N_{i,t} = \sum_{j=0}^{J} c^N_{i,t,j} N_{i,t,j} \tag{A.18}$$
$$L^T_{i,t} = \sum_{j=0}^{J} h^T_{i,t,j} N_{i,t,j} \tag{A.19}$$
$$L^N_{i,t} = \sum_{j=0}^{J} h^N_{i,t,j} N_{i,t,j} \tag{A.20}$$
$$\mathcal{A}_{i,t} = \sum_{j=0}^{J} a_{i,t+1,j+1} N_{i,t,j} \tag{A.21}$$
$$K_{i,t} = K^T_{i,t} + K^N_{i,t} \tag{A.22}$$

Clearing:

$$Y^N_{i,t} = C^N_{i,t} \tag{A.23}$$
$$\sum_i K_{i,t+1} = \sum_i \mathcal{A}_{i,t} \tag{A.24}$$

B Expressing the initial consumption

Consider the per period household's budget constraint (which is from the perspective of an individual that is born, $j = 0$, at time t) for all $j \in \{0, 1, 2, \cdots, J\}$ for a country (the country index i is omitted for simplicity):

$$a_{t+j+1,j+1} = \frac{a_{t+j,j}(1 + r_{t+j})}{s_{t+j,j}} - c^T_{t+j,j} - P^N_{t+j} c^N_{t+j,j} + y_{t+j,j}$$

Extensively:

$$\begin{aligned}
a_{t+1,1} &= \frac{a_{t,0}(1+r_t)}{s_{t,0}} - c^T_{t,0} - P^N_t c^N_{t,0} + y_{t,0} \\
a_{t+2,2} &= \frac{a_{t+1,1}(1+r_{t+1})}{s_{t+1,1}} - c^T_{t+1,1} - P^N_{t+1} c^N_{t+1,1} + y_{t+1,1} \\
a_{t+3,3} &= \frac{a_{t+2,2}(1+r_{t+2})}{s_{t+2,2}} - c^T_{t+2,2} - P^N_{t+2} c^N_{t+2,2} + y_{t+2,2} \\
&\vdots \\
a_{t+J+1,J+1} &= \frac{a_{t+J,J}(1+r_{t+J})}{s_{t+J,J}} - c^T_{t+J,J} - P^N_{t+J} c^N_{t+J,J} + y_{t+J,J}
\end{aligned}$$

Substitute recursively, e.g.:

$$\begin{aligned}
s_{t,0}s_{t+1,1}s_{t+2,2}a_{t+3,3} = a_{t,0}(1+r_{t+2})(1+r_{t+1})(1+r_t) \\
+\left[-c^T_{t,0} - P^N_t c^N_{t,0} + y_{t,0}\right](1+r_{t+2})(1+r_{t+1})s_{t,0} \\
+[-c^T_{t+1,1} - P^N_{t+1} c^N_{t+1,1} + y_{t+1,1}](1+r_{t+2})s_{t+1,1}s_{t,0} \\
+\left[-c^T_{t+2,2} - P^N_{t+2} c^N_{t+2,2} + y_{t+2,2}\right]s_{t+2,2}s_{t+1,1}s_{t,0}
\end{aligned}$$

to have:

$$\pi_{t+J,J}a_{t+J+1,J+1} = a_{t,0}\prod_{j=0}^{J}(1+r_{t+j}) + \sum_{j=0}^{J}\pi_{t+j,j}(y_{t+j,j} - c^T_{t+j,j} - P^N_{t+j}c^N_{t+j,j})\prod_{s=j}^{J-1}(1+r_{t+s+1})$$

Given $a_{t+J+1,J+1} = a_{t,0} = 0$ and multiplying both sides by $1/\prod_{s=1}^{J}(1+r_{t+s})$, it results:

$$c^T_{t,0} + P^N_t c^N_{t,0} + \sum_{j=1}^{J}\pi_{t+j,j}\left(c^T_{t+j,j} + P^N_{t+j}c^N_{t+j,j}\right)\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right) = y_{t,0} + \sum_{j=1}^{J}\pi_{t+j,j}y_{t+j,j}\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right)$$

Consider the *intra*-temporal condition:

$$c^N_{t+j,j} = \frac{1-\alpha_j}{\alpha_j}c^T_{t+j,j}(P^N_{t+j})^{-\phi} \tag{B.1}$$

to substitute into the last expression for the budget constraint to have:

$$\begin{aligned}
c^T_{t,0}\left[1 + \frac{1-\alpha_0}{\alpha_0}(P^N_t)^{1-\phi}\right] + \sum_{j=1}^{J}\pi_{t+j,j}c^T_{t+j,j}\left[1 + \frac{1-\alpha_j}{\alpha_j}(P^N_{t+j})^{1-\phi}\right]\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right) \\
= \sum_{j=0}^{J}\pi_{t+j,j}y_{t+j,j}\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right)
\end{aligned} \tag{B.2}$$

Then, consider the *inter*-temporal condition:

$$c^T_{t+j+1,j+1} = [\beta(1+r_{t+j+1})]^{\phi}c^T_{t+j,j}\frac{\alpha_{j+1}}{\alpha_j}\left(\frac{c_{t+j+1,j+1}}{c_{t+j,j}}\right)^{1-\sigma\phi} \tag{B.3}$$

which solved forward reads:

$$c^T_{t+j,j} = c^T_{t,0}\frac{\alpha_j}{\alpha_0}\left(\frac{c_{t+j,j}}{c_{t,0}}\right)^{1-\sigma\phi}\prod_{k=1}^{j}[\beta(1+r_{t+k})]^{\phi} \tag{B.4}$$

The initial consumption in T-goods is useful because it is sufficient to have express all subsequent consumption levels (for given real interest rate r, relative price P_i^N and parameters). To obtain such expression one needs to manage equation (B.4). To this end, first manage the composite consumption:

$$c_{t+j,j} = \left[\alpha_j^{\frac{1}{\phi}}(c^T_{t+j,j})^{\frac{\phi-1}{\phi}} + (1-\alpha_j)^{\frac{1}{\phi}}(c^N_{t+j,j})^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}$$

which can be rewritten as:

$$c_{t+j,j} = c^T_{t+j,j}\alpha_j^{\frac{1}{\phi-1}}\left[1+\left(\frac{1-\alpha_j}{\alpha_j}\right)^{\frac{1}{\phi}}\left(\frac{c^N_{t+j,j}}{c^T_{t+j,j}}\right)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}$$

Plug-in equation (B.1) to have:

$$c_{t+j,j} = c^T_{t+j,j}\alpha_j^{\frac{1}{\phi-1}}\left[1+\left(\frac{1-\alpha_j}{\alpha_j}\right)^{\frac{1}{\phi}}\left[\frac{1-\alpha_j}{\alpha_j}(P^N_{t+j})^{-\phi}\right]^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}$$

i.e.

$$c_{t+j,j} = c^T_{t+j,j}\alpha_j^{\frac{1}{\phi-1}}\left[1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P^N_{t+j})^{1-\phi}\right]^{\frac{\phi}{\phi-1}} \tag{B.5}$$

Plug this expression into (B.4) to have:

$$c^T_{t+j,j} = c^T_{t,0}\frac{\alpha_j}{\alpha_0}\left(\frac{c^T_{t+j,j}\alpha_j^{\frac{1}{\phi-1}}\left[1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P^N_{t+j})^{1-\phi}\right]^{\frac{\phi}{\phi-1}}}{c^T_{t,0}\alpha_0^{\frac{1}{\phi-1}}\left[1+\left(\frac{1-\alpha_0}{\alpha_0}\right)(P^N_t)^{1-\phi}\right]^{\frac{\phi}{\phi-1}}}\right)^{1-\sigma\phi}\prod_{k=1}^{j}[\beta(1+r_{t+k})]^{\phi}$$

i.e.

$$c^T_{t+j,j} = c^T_{t,0}\left\{\left(\frac{\alpha_j}{\alpha_0}\right)^{1+\frac{1-\sigma\phi}{\phi-1}}\left[\frac{1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P^N_{t+j})^{1-\phi}}{1+\left(\frac{1-\alpha_0}{\alpha_0}\right)(P^N_t)^{1-\phi}}\right]^{\frac{\phi(1-\sigma\phi)}{\phi-1}}\prod_{k=1}^{j}[\beta(1+r_{t+k})]^{\phi}\right\}^{\frac{1}{\sigma\phi}}$$

i.e.

$$c^T_{t+j,j} = c^T_{t,0}\left(\frac{\alpha_j}{\alpha_0}\right)^{\frac{1-\sigma}{(\phi-1)\sigma}}\left[\frac{1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P^N_{t+j})^{1-\phi}}{1+\left(\frac{1-\alpha_0}{\alpha_0}\right)(P^N_t)^{1-\phi}}\right]^{\frac{1-\sigma\phi}{(\phi-1)\sigma}}\prod_{k=1}^{j}[\beta(1+r_{t+k})]^{\frac{1}{\sigma}} \tag{B.6}$$

To find the desired expression for the initial consumption in T-goods plug the Euler equation solved forward (B.6) into the budget constraint (B.2), to have:

$$c_{t,0}^T\left[1+\frac{1-\alpha_0}{\alpha_0}(P_t^N)^{1-\phi}\right]+$$
$$\sum_{j=1}^{J}\pi_{t+j,j}c_{t,0}^T\left(\frac{\alpha_j}{\alpha_0}\right)^{\frac{1-\sigma}{(\phi-1)\sigma}}\left[\frac{1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P_{t+j}^N)^{1-\phi}}{1+\left(\frac{1-\alpha_0}{\alpha_0}\right)(P_t^N)^{1-\phi}}\right]^{\frac{1-\sigma\phi}{(\phi-1)\sigma}}\prod_{k=1}^{j}[\beta(1+r_{t+k})]^{\frac{1}{\sigma}}\left[1+\frac{1-\alpha_j}{\alpha_j}(P_{t+j}^N)^{1-\phi}\right]\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right)$$
$$=\sum_{j=0}^{J}\pi_{t+j,j}y_{t+j,j}\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right)$$

i.e.

$$c_{t,0}^T\left[1+\frac{1-\alpha_0}{\alpha_0}(P_t^N)^{1-\phi}\right]+$$
$$c_{t,0}^T\left[1+\left(\frac{1-\alpha_0}{\alpha_0}\right)(P_t^N)^{1-\phi}\right]^{-\frac{1-\sigma\phi}{(\phi-1)\sigma}}\times$$
$$\sum_{j=1}^{J}\pi_{t+j,j}\left(\frac{\alpha_j}{\alpha_0}\right)^{\frac{1-\sigma}{(\phi-1)\sigma}}\left[1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P_{t+j}^N)^{1-\phi}\right]^{\frac{1-\sigma}{(\phi-1)\sigma}}\prod_{k=1}^{j}[\beta(1+r_{t+k})]^{\frac{1}{\sigma}}\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right)$$
$$=\sum_{j=0}^{J}\pi_{t+j,j}y_{t+j,j}\prod_{s=1}^{j}\left(\frac{1}{1+r_{t+s}}\right)$$

which identifies $c_{t,0}^T$ in closed-form. In a stationary equilibrium it results:

$$c_0^T=\frac{\sum_{j=0}^{J}\pi_j y_j\left(\frac{1}{1+r}\right)^j}{\left[1+\frac{1-\alpha_0}{\alpha_0}(P^N)^{1-\phi}\right]+\left[1+\left(\frac{1-\alpha_0}{\alpha_0}\right)(P^N)^{1-\phi}\right]^{-\frac{1-\sigma\phi}{(\phi-1)\sigma}}\sum_{j=1}^{J}\pi_j\left(\frac{\alpha_j}{\alpha_0}\right)^{\frac{1-\sigma}{(\phi-1)\sigma}}\left[1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P^N)^{1-\phi}\right]^{\frac{1-\sigma}{(\phi-1)\sigma}}[\beta(1+r)]^{\frac{j}{\sigma}}\left(\frac{1}{1+r}\right)^j}$$

A special case is when the intertemporal elasticity of substitution is equal to the elasticity of substitution between sectors, i.e. $1/\sigma=\phi$. In this case, c_0^T does not depend on aggregate consumption. If in addition to this assumption, one sets $\phi=1$, then the expression for c_0^T does not depend on the relative price P^N thus simplifying further to:

$$c_0^T=\frac{\alpha_0\sum_{j=0}^{J}\frac{\pi_j y_j}{(1+r)^j}}{\sum_{j=0}^{J}\pi_j\beta^j}$$

To have a recursive-form expression for the Euler equation, plug (B.5) into (B.3):

$$c_{t+j+1,j+1}^T=[\beta(1+r_{t+j+1})]^{\phi}c_{t+j,j}^T\frac{\alpha_{j+1}}{\alpha_j}\left(\frac{c_{t+j+1,j+1}^T\alpha_{j+1}^{\frac{1}{\phi-1}}\left[1+\left(\frac{1-\alpha_{j+1}}{\alpha_{j+1}}\right)(P_{t+j+1}^N)^{1-\phi}\right]^{\frac{\phi}{\phi-1}}}{c_{t+j,j}^T\alpha_j^{\frac{1}{\phi-1}}\left[1+\left(\frac{1-\alpha_j}{\alpha_j}\right)(P_{t+j}^N)^{1-\phi}\right]^{\frac{\phi}{\phi-1}}}\right)^{1-\sigma\phi}$$

i.e.

$$c_{t+j+1,j+1}^T=[\beta(1+r_{t+j+1})]^{\frac{1}{\sigma}}c_{t+j,j}^T\left(\frac{\alpha_{j+1}}{\alpha_j}\right)^{\frac{1-\sigma}{(\phi-1)\sigma}}\left[\frac{1+\frac{1-\alpha_{j+1}}{\alpha_{j+1}}(P_{t+j+1}^N)^{1-\phi}}{1+\frac{1-\alpha_j}{\alpha_j}(P_{t+j}^N)^{1-\phi}}\right]^{\frac{1-\sigma\phi}{(\phi-1)\sigma}}$$

C Solving the stationary equilibrium numerically

Consider a country i in a stationary equilibrium for given variables r, P_i^N and demographics. At an optimum, the following must hold:

$$w_i^T = (1-\psi^T) Z_i^T \left(\frac{r+\delta}{\psi^T}\right)^{-\frac{\psi^T}{1-\psi^T}} \tag{C.1}$$

$$w_i^N = P_i^N (1-\psi^N) Z_i^N \left(\frac{r+\delta}{\psi^N P_i^N}\right)^{-\frac{\psi^N}{1-\psi^N}} \tag{C.2}$$

$$w_i = \left[\theta_i (w_i^T)^{\varepsilon_i+1} + (1-\theta_i)(w_i^N)^{\varepsilon_i+1}\right]^{\frac{1}{\varepsilon_i+1}} \tag{C.3}$$

$$L_i = \sum_{j=0}^{j_r-1} h_{i,j} N_{i,j} \tag{C.4}$$

$$\bar{h}_i = \frac{\sum_{j=0}^{j_r-1} h_{i,j}}{j_r} \tag{C.5}$$

$$d_i = \overline{d}_i w_i (1-\tau_i) \bar{h}_i \tag{C.6}$$

$$\tau_i = \frac{\overline{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,j}}{L_i + \overline{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,j}} \tag{C.7}$$

$$y_{i,j} = (1-\tau_i) w_i h_{i,j} I(j < j_r) + d_i I(j \geq j_r) \tag{C.8}$$

$$c_{i,0}^T = \frac{\sum_{j=0}^{J} \pi_{i,j} y_{i,j} \left(\frac{1}{1+r}\right)^j}{\left[1 + \frac{1-\alpha_{i,0}}{\alpha_{i,0}} (P_i^N)^{1-\phi_i}\right] + \left[1 + \left(\frac{1-\alpha_{i,0}}{\alpha_{i,0}}\right) (P_i^N)^{1-\phi_i}\right]^{-\frac{1-\sigma\phi_i}{(\phi_i-1)\sigma}} \sum_{j=1}^{J} \pi_{i,j} \left\{\frac{\alpha_{i,j}}{\alpha_{i,0}} \left[1 + \left(\frac{1-\alpha_{i,j}}{\alpha_{i,j}}\right) (P_i^N)^{1-\phi_i}\right]\right\}^{\frac{1-\sigma}{(\phi_i-1)\sigma}} \frac{[\beta(1+r)]^{\frac{j}{\sigma}}}{(1+r)^j}} \tag{C.9}$$

$$c_{i,j}^T = c_{i,0}^T \left\{ \left(\frac{\alpha_{i,j}}{\alpha_{i,0}}\right)^{1+\frac{1-\sigma\phi_i}{\phi_i-1}} \left[\frac{1+\frac{1-\alpha_{i,j}}{\alpha_j}(P_i^N)^{1-\phi_i}}{1+\frac{1-\alpha_{i,0}}{\alpha_{i,0}}(P_i^N)^{1-\phi_i}}\right]^{\frac{\phi_i}{\phi_i-1}(1-\sigma\phi_i)} [\beta(1+r)]^{j\phi_i} \right\}^{\frac{1}{\sigma\phi_i}} \tag{C.10}$$

$$c_{i,j}^N = \frac{1-\alpha_{i,j}}{\alpha_{i,j}} c_{i,j}^T (P_i^N)^{-\phi_i} \tag{C.11}$$

$$h_{i,j}^T = \theta_i h_{i,j} \left(\frac{w_i^T}{w_i}\right)^{\varepsilon_i} \tag{C.12}$$

$$h_{i,j}^N = (1-\theta_i) h_{i,j} \left(\frac{w_i^N}{w_i}\right)^{\varepsilon_i} \tag{C.13}$$

$$a_{i,j+1} = \frac{a_{i,j}(1+r)}{s_{i,j}} - c_{i,j}^T - P_i^N c_{i,j}^N + y_{i,j} \tag{C.14}$$

$$L_i^T = \sum_{j=0}^{J} h_{i,j}^T N_{i,j} \tag{C.15}$$

$$L_i^N = \sum_{j=0}^{J} h_{i,j}^N N_{i,j} \tag{C.16}$$

$$K_i^T = Z_i^T L_i^T \left(\frac{r+\delta}{\psi_i^T}\right)^{-\frac{1}{1-\psi_i^T}} \tag{C.17}$$

$$K_i^N = Z_i^N L_i^N \left(\frac{r+\delta}{P_i^N \psi_i^N}\right)^{-\frac{1}{1-\psi_i^N}} \tag{C.18}$$

Then, one needs to solve numerically the following set of equations, for r, P_i^N for each country i:

$$(K_{i,t}^N)^{\psi_i^N} (Z_i^N L_i^N)^{1-\psi_i^N} = \sum_{j=0}^{J} N_{i,j} c_{i,j}^N \tag{C.19}$$

$$\sum_i (K_i^T + K_i^N) = \sum_i \sum_{j=0}^{J} a_{i,j+1} N_{i,j} \tag{C.20}$$

D Calibration of the EU15 aggregate economy

Table D.1: Calibration of EU15: country-specific parameters

Country (pop share)	Empirical target		Parameter							
	K/Y	Q^N	δ	Z^T	ψ^T	ψ^N	θ	φ	ε	$\bar{d}$
	capital -output ratio	rel. N price rel. to EU15	capital deprec. rate	rel. T pro-duc-tivity	T capital share of income	N capital share of income	T share in labor	T/N consum. elas-ticity	T/N labor elas-ticity	pension replac. rate
AUT (0.02	1.97	0.97	0.10	1.40	0.32	0.32	0.40	1.52	1.10	0.65
BEL (0.03)	1.76	1.06	0.12	1.81	0.34	0.33	0.36	1.24	0.61	0.43
DEU (0.22)	1.92	1.16	0.09	2.05	0.24	0.36	0.40	0.58	1.01	0.31
ESP (0.11)	1.53	0.95	0.18	1.33	0.40	0.34	0.40	1.39	1.02	0.59
FIN (0.01)	2.18	1.07	0.07	1.31	0.35	0.26	0.42	0.85	0.43	0.67
FRA (0.16)	1.87	1.14	0.09	1.80	0.28	0.31	0.36	0.89	1.40	0.40
IRL (0.01)	1.66	0.95	0.19	1.21	0.49	0.31	0.42	1.35	0.22	0.23
ITA (0.15)	1.75	0.93	0.10	1.29	0.26	0.33	0.42	0.72	1.66	0.58
NLD (0.04)	1.79	1.09	0.11	1.59	0.39	0.26	0.33	0.52	0.22	0.25
EA9 (0.75)	1.82	1.04	0.12	1.53	0.34	0.31	0.39	1.01	0.85	0.46
DNK (0.01)	1.4				0.35	0.30	0.34	1.08	0.29	0.15
GBR (0.16)	1.41				0.30	0.26	0.35	0.48	0.60	0.30
GRC (0.03)	1.91									0.66
LUX (0.00)	1.17									
PRT (0.03)	1.56									0.69
SWE (0.02)	2.06				0.33	0.26	0.35	0.51	0.53	0.52
EU15 (1.00)	1.75		0.09	1.50*	0.30	0.32	0.38	0.79	1.03	0.43
Source	WDI	Berka et al.	implied		Bertinelli et al. (2020)					Bárány et al.

Note. The population shares in parenthesis refer to year 1995. * This value is not implied but imposed. EU15 is obtained as average weighted by the population shares (rescaled in case of missing parameter values).

The transition dynamics for EU15 is solved with the information shock occurring in year 1951, i.e. the system is assumed to be at the initial stationary equilibrium in 1950 (and in all previous periods) with the 1951 demographics.

E EA9 economy: additional results

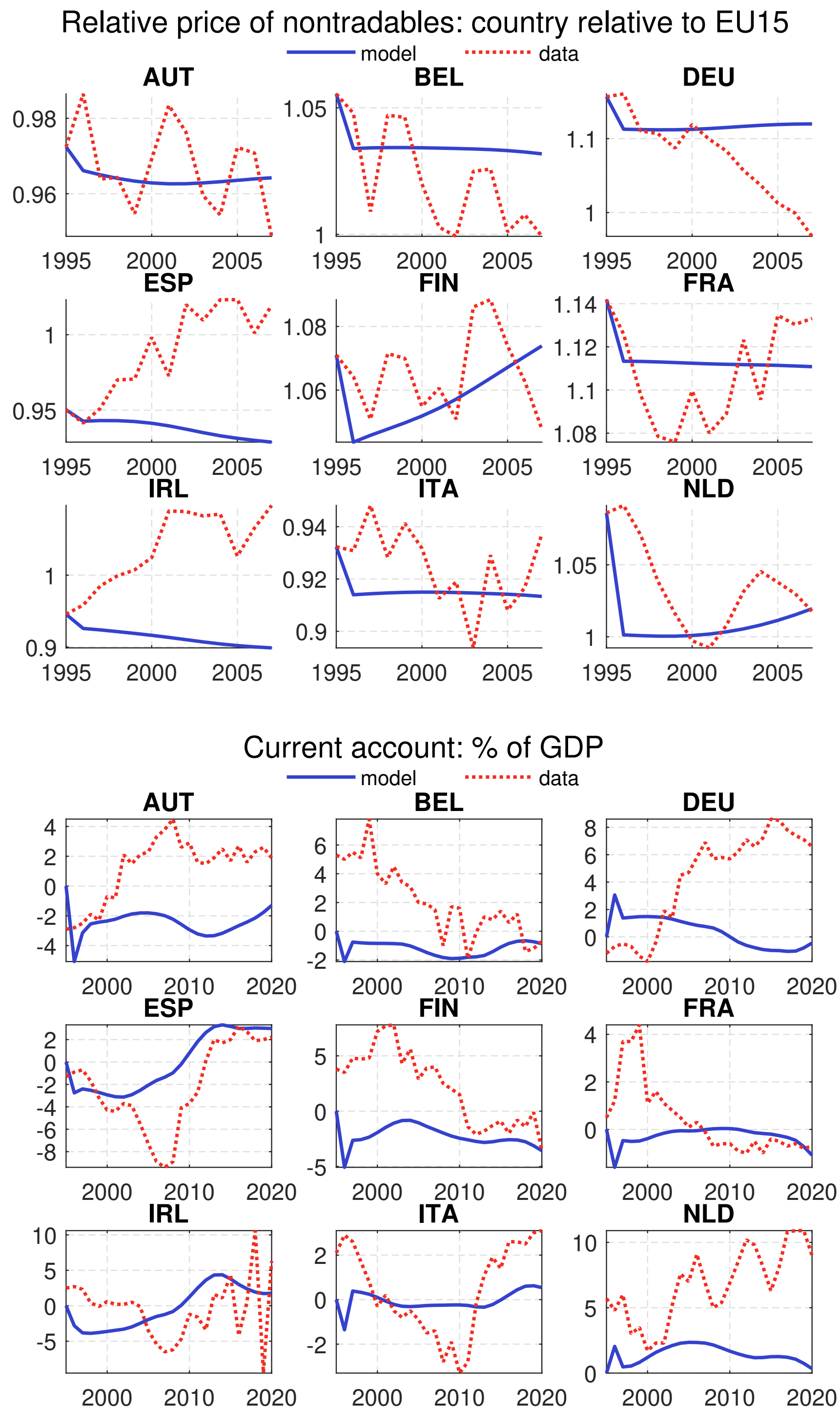

Figure E.1: Model versus data: *within* variation

Note. Data source: Berka et al. (2018) provide the series q_n which measures the relative price of nontradables relative to the EU15 average in logs. The figure plots $Q^N_{i,t} = \exp\{q_n\}$. Data on current account to GDP by IMF WEO.

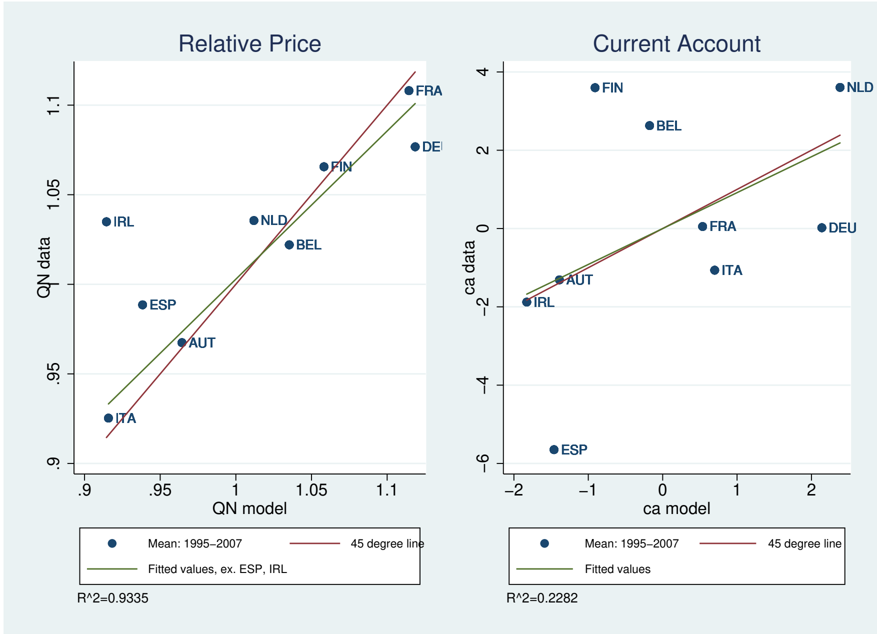

Figure E.2: Model versus data: *between* variation 1995-2007

Note. The linear regression coefficients are 0.83 for the relative price and 0.92 for the current account. In the period 1997-2020 (the same employed for the regressions in Table 3) the regression coefficient is still statistically significant at the 0.1% level at 0.63 with $R^2 = 0.0792$.

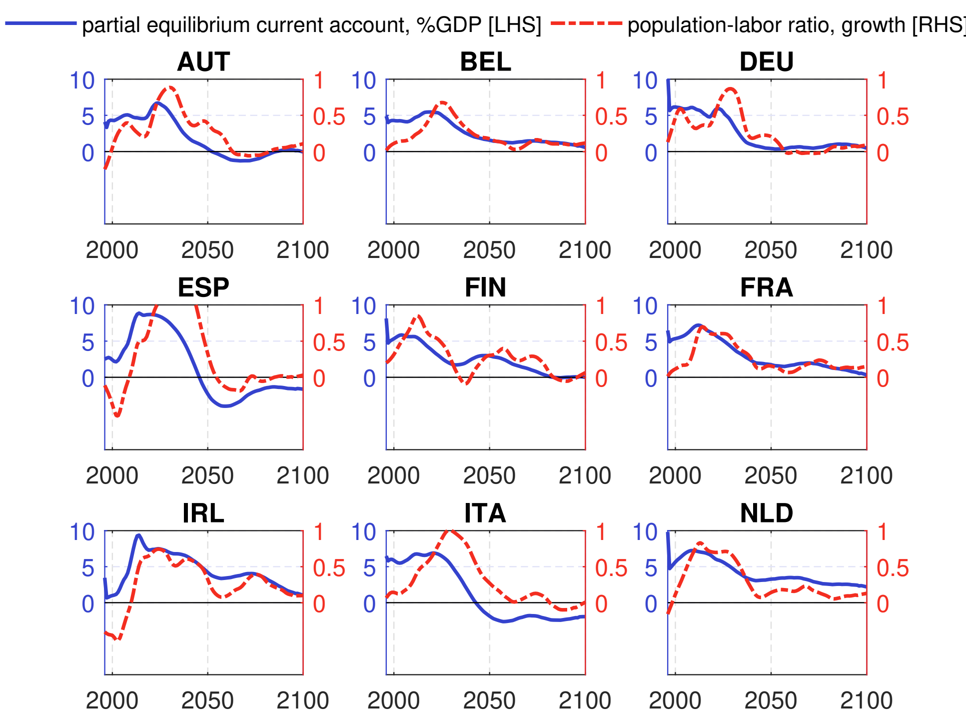

Figure E.3: Partial equilibrium capital flows (% GDP) [model, LHS] vs population to effective labor ratio (annual growth rate) [data, RHS]

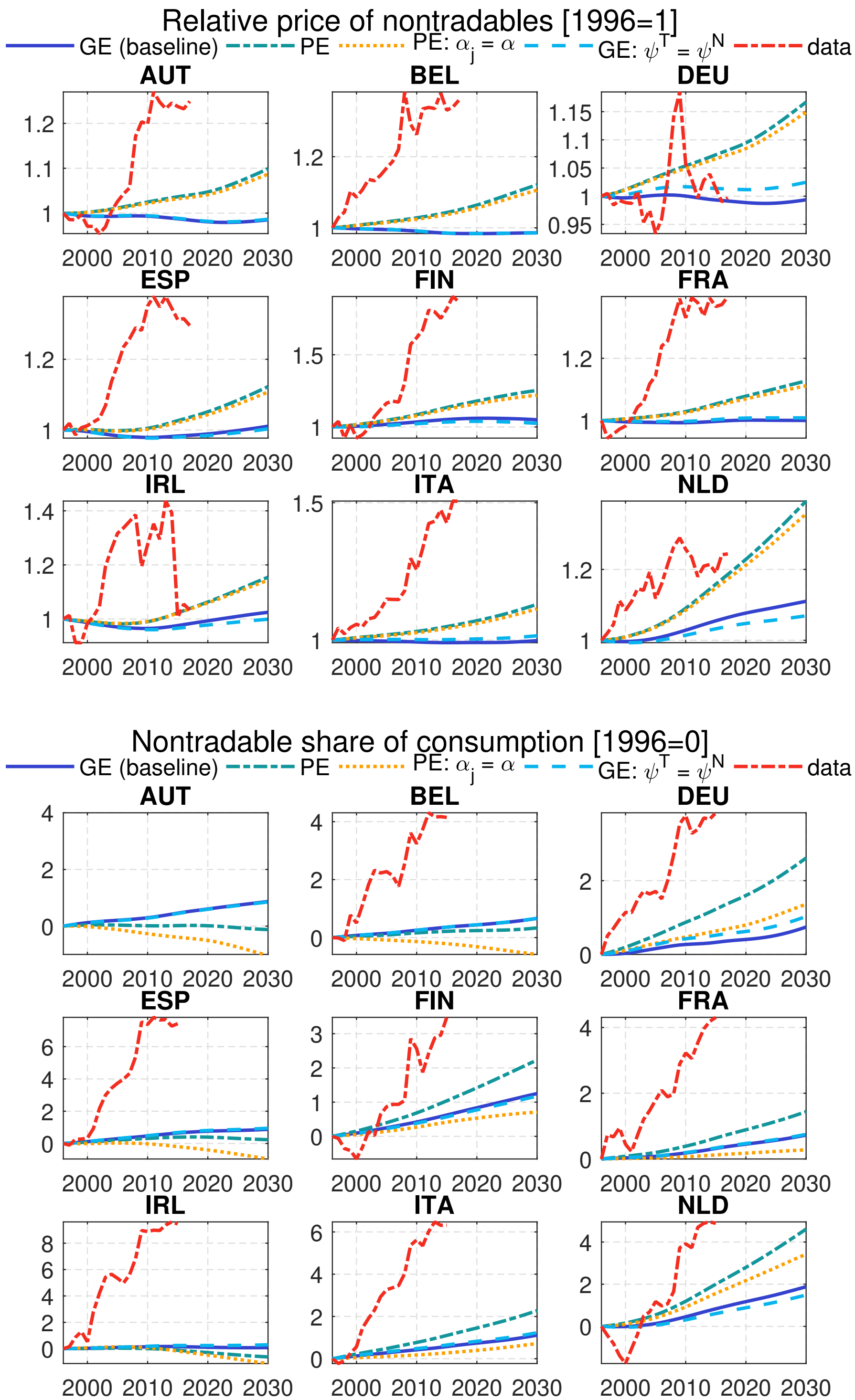

Figure E.4: Relative price of nontradables and nontradable share of consumption: model vs data

Note. Partial (PE) versus general (GE) equilibrium. Baseline versus scenarios (a) to (c) as explained in the main text. The same holds as in note under Figure 5. Unavailable data for Austria AUT). Data description in Appendix F. The bottom panel depicts percentage points deviations from the initial year (1996).

F Relative price and consumption share of nontradables: data

Relative price of nontradables. To construct the data series on the relative price of nontradables plotted in Figure E.4 the following procedure has been adopted on EUKLEMS data based on Bertinelli et al. (2020). The EUKLEMS March 2011 release, providing data for eleven 1-digit ISIC-rev.3 industries over the period 1970-2007, has been extended forward until 2017 using annual growth rates obtained from the EUKLEMS 2019 release. Industries are split into tradable and non-tradable sector according to the concordance Table F.1 (which reproduces Bertinelli et al. (2020) Table 7 which, in turn, is an update of the sectoral split employed in Cardi and Restout (2015)). The price index for each sector $s \in \{T, N\}$ is calculated by dividing value added at current prices ($\texttt{VA}^k_{i,t}$) by value added at constant prices ($\texttt{VA\_QI}^k_{i,t}$) such that for each country i and each year t:

$$P^s_{i.t} = \frac{\sum_{k \in s} \texttt{VA}^k_{i,t}}{\sum_{k \in s} \texttt{VA\_QI}^k_{i,t}}$$

Then, the relative price of nontradables is the ratio of the price indexes so identified: $P^N_{i,t}/P^T_{i,t}$.

Table F.1: EUKLEMS sectoral concordance

Sector	ISIC-rev.4 Classification (source: EUKLEMS 2019)		ISIC-rev.3 Classification (source: EUKLEMS 2011)	
	Industry	Code	Industry	Code
Tradable (T)	Agriculture, Forestry and Fishing	A	Agriculture, Hunting, Forestry and Fishing	AtB
	Mining and Quarrying	B	Mining and Quarrying	C
	Total Manufacturing	C	Total Manufacturing	D
	Transport and Storage	H	Transport, Storage and Communication	I
	Information and Communication	J		
	Financial and Insurance Activities	K	Financial intermediation	J
Non-Tradable (N)	Electricity, Gas and Water Supply	D-E	Electricity, Gas and Water Supply	E
	Construction	F	Construction	F
	Wholesale and Retail Trade, Repair of Motor Vehicles and Motorcycles	G	Wholesale and Retail Trade	G
	Accommodation and Food Service Activities	I	Hotels and Restaurants	H
	Real Estate Activities	L	Real Estate, Renting and Business Services	K
	Professional, Scientific, Technical, Administrative and Support Service Activities	M-N		
	Community Social and Personal Services	O-U	Community Social and Personal Services	LtQ

Sectoral share of consumption. *Source*: EUROSTAT. Available period: 1995-2015. Two series are added: private and public consumption evaluated at current prices (euro). For private consumption: "Final consumption expenditure of households by consumption purpose (COICOP 3 digit) [nama_10_co3_p3]"; for public consumption: the item "Final consumption expenditure of general government" of the "GDP and main components (output, expenditure and income) [nama_10_gdp]". 'Public' consumption is invariably classified as nontradable. The items of 'private' consumption classified as *tradable* are: Food and non-alcoholic beverages; Alcoholic beverages, tobacco and narcotics; Clothing and footwear; Furnishings, household equipment and routine household maintenance; Transport; Communications; Financial services n.e.c.; those classified as *nontradable* are: Housing, water, electricity, gas and other fuels; Health; Recreation and culture; Education; Restaurants and hotels; Miscellaneous goods and services minus financial services.

G World economy: additional results

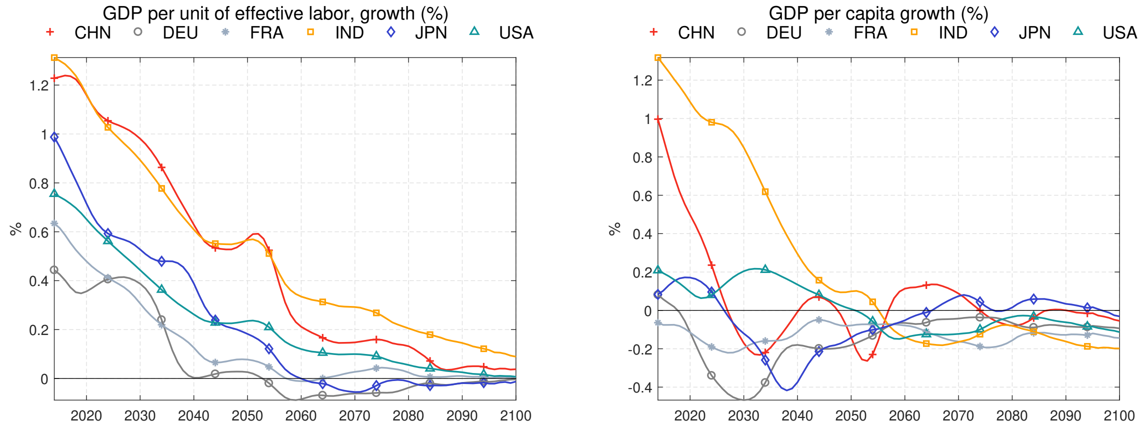

Figure G.1: Model: GDP per unit of effective labor and per capita, annual growth rate

Note. Baseline calibration (see Table 5)

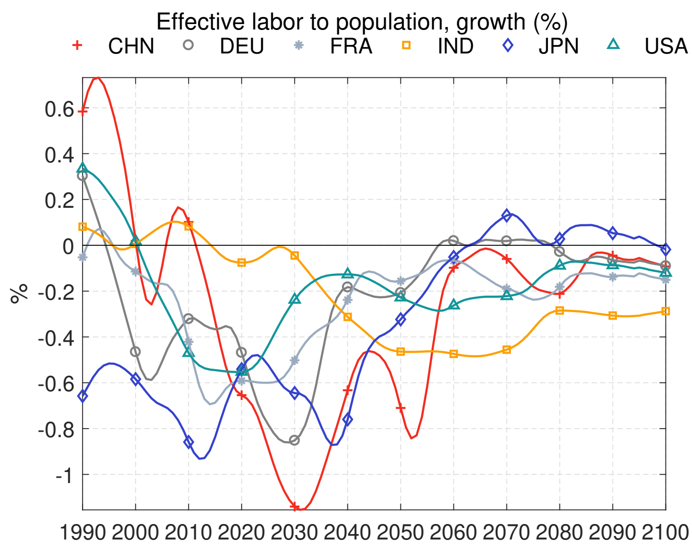

Figure G.2: Exogenous demographics: effective labor to population, annual growth rate

Note. The effective labor to population ratio in each period t for each country i is: $\sum_j (h_j N_{i,t,j}) / \sum_j N_{i,t,j}$ where the demographic data on the number of individuals $N_{i,t,j}$ are provided by the United Nations (UN, 2019) *World Population Prospects 2019, Online Edition. Rev. 1*, medium variant after year 2019.

H One sector model

H.1 Set of equilibrium equations

In an equilibrium with perfect foresight, the following optimal conditions hold for each country i and time period t.

Households:

for $j = 0, 1, ..., J-1$:

$$c_{i,t+1,j+1} = [\beta(1+r_{t+1})]^{\frac{1}{\sigma}} c_{i,t,j} \tag{H.1}$$

$$c_{i,t,j} + a_{i,t+1,j+1} = \frac{a_{i,t,j}(1+r_t)}{s_{i,t,j}} + w_{i,t}h_{i,j}(1-\tau_{i,t})I(j < \mathcal{J}_i) + d_{i,t}I(j \geq \mathcal{J}_i) \tag{H.2}$$

with: $$a_{i,t,0} = a_{i,t,J+1} = 0 \tag{H.3}$$

Government:

$$\tau_{i,t} = \frac{\bar{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,t,j}}{L_{i,t} + \bar{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,t,j}} \tag{H.4}$$

$$d_{i,t} = \bar{d}_i \bar{h}_i w_{i,t}(1-\tau_{i,t}) \tag{H.5}$$

Firms:

$$w_{i,t} = (1-\psi_i) Z_i \left(\frac{\psi_i}{r_t + \delta_i}\right)^{\frac{\psi_i}{1-\psi_i}} \tag{H.6}$$

$$K_{i,t} = L_{i,t} Z_i \left(\frac{\psi_i}{r_t + \delta_i}\right)^{\frac{1}{1-\psi_i}} \tag{H.7}$$

Clearing:

$$\sum_i K_{i,t+1} = \sum_i \sum_j a_{i,t+1,j+1} N_{i,t,j} \tag{H.8}$$

H.2 Stationary equilibrium

$$w_i = (1-\psi) Z_i \left(\frac{r+\delta}{}\right)^{-\frac{\psi}{1-\psi}} \tag{H.9}$$

$$L_i = \sum_{j=0}^{j_r-1} h_{i,j} N_{i,j} \tag{H.10}$$

$$\bar{h}_i = \frac{\sum_{j=0}^{j_r-1} h_{i,j}}{j_r} \tag{H.11}$$

$$d_i = \overline{d}_i w_i (1-\tau_i) \bar{h}_i \tag{H.12}$$

$$\tau_i = \frac{\overline{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,j}}{L_i + \overline{d}_i \bar{h}_i \sum_{j=j_r}^{J} N_{i,j}} \tag{H.13}$$

$$y_{i,j} = (1-\tau_i) w_i h_{i,j} I(j < j_r) + d_i I(j \geq j_r) \tag{H.14}$$

$$c_{i,0} = \frac{\sum_{j=0}^{J} \pi_{i,j} y_{i,j} \left(\frac{1}{1+r}\right)^j}{\sum_{j=0}^{J} \pi_{i,j} \frac{[\beta(1+r)]^{\frac{j}{\sigma}}}{(1+r)^j}} \tag{H.15}$$

$$c_{i,j} = c_{i,0} \left[\beta(1+r)\right]^{\frac{j}{\sigma}} \tag{H.16}$$

$$a_{i,j+1} = \frac{a_{i,j}(1+r)}{s_{i,j}} - c_{i,j} + y_{i,j} \tag{H.17}$$

$$K_i = Z_i L_i \left(\frac{r+\delta}{\psi_i}\right)^{-\frac{1}{1-\psi_i}} \tag{H.18}$$

Then, one needs to solve numerically the following equation for r:

$$\sum_i K_i = \sum_i \sum_j a_{i,j+1} N_{i,j} \tag{H.19}$$

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