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Demographic Changes and Real Exchange Rates: Future of an Aging Economy

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Abstract

We examine the role of demographic change in long-run real exchange rate (RER) determination. Demographic shifts affect saving and investment behavior, labor supply, and the relative demand for tradable and non-tradable goods, and may therefore influence RERs beyond standard macroeconomic fundamentals. We estimate a panel cointegration model for 75 countries over 1970–2024 that augments a standard long-run RER specification with four demographic variables: the old-age dependency ratio, fertility, life expectancy, and net migration. Demographic variables remain informative even after controlling for productivity. We also complement the baseline specification with a full age-distribution approach, which provides an internally consistent representation of demographic change. Combining the estimated long-run relationships with projections from the United Nations World Population Prospects, we construct conditional RER projections through 2050. Economies projected to age more rapidly tend to face long-run real appreciation pressure.

JEL Classification: D31; E21; F41; J11

Keywords: Real exchange rate; Demographic changes; Panel cointegration; UN World Population Prospects; Out-of-sample projections

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1 Introduction

Understanding the determinants of real exchange rates (RERs) is central to open economy macroeconomics and international finance, as exchange rate movements affect economic stability, trade balances, and capital flows, with broad implications for policymakers and markets. Although exchange rates are well known for their short-run unpredictability (Meese and Rogoff, 1983), a large body of work has documented that they exhibit meaningful long-run relationships with economic fundamentals (Engel and West, 2005; Rossi, 2013; Sarno and Schmeling, 2014). Accordingly, traditional frameworks have linked RERs to a range of macroeconomic fundamentals, including productivity differentials, terms of trade, external imbalances, fiscal policy, and trade openness.

A smaller but important literature has also examined the role of demographic change in shaping real exchange rates. Early reduced-form evidence by Andersson and Österholm (2006) shows that population age structure helps explain real exchange rates in a panel of OECD economies. Rose, Supaat and Braude (2009) focus on fertility and document that declines in fertility are associated with real depreciations in a broad cross-country panel. Aloy and Gente (2009) develop a structural model for the Yen/USD and argue that demographic change can explain an important share of Japan's long-run real appreciation. Finally, Groneck and Kaufmann (2017) emphasize a related channel operating through the relative price of non-tradables rather than the aggregate real exchange rate itself. Taken together, these studies establish that demographic forces matter for external relative prices. At the same time, they remain partial in important respects: they typically focus on a single demographic margin, a relatively small set of advanced economies, or a narrower relative-price channel.[1]

This leaves a gap in the literature. Relative to the large and rapidly growing body of work on demographics and the real interest rate (Carvalho, Ferrero and Nechio, 2016; Eg-

[1]See Hassan, Salim and Bloch (2011) for a survey of the broader literature on demography, savings, capital flows, and real exchange rates.

gertsson, Mehrotra and Robbins, 2019; Auclert, Malmberg, Martenet and Rognlie, 2021; Papetti, 2021; Platzer and Peruffo, 2022; Ferreira and Shousha, 2023; Fuhrer and Herger, 2024), the evidence on demographics and RERs remains limited, fragmented, and rarely integrated into a unified empirical framework. Yet the underlying mechanisms are closely related. Changes in fertility, longevity, migration, and the age distribution affect savings, investment, labor supply, and the relative demand for tradable and non-tradable goods, all of which are natural candidates for long-run RER determination. As demographic transitions increasingly diverge across countries—with rapid aging in many advanced economies and much younger populations in many emerging and developing economies—these forces are likely to generate persistent cross-country differences in equilibrium real exchange rates.[2]

Our paper contributes to this literature in three main ways. First, we move beyond the narrow demographic focus of most existing studies. Rather than concentrating on a single margin such as fertility (Rose et al., 2009; Aloy and Gente, 2009) or age shares alone (Andersson and Österholm, 2006), we study four demographic indicators together—the old-age dependency ratio, fertility, life expectancy, and immigration—that capture complementary dimensions of demographic transition in aging economies. This broader specification allows us to assess which demographic margins matter for long-run RERs while still maintaining a parsimonious empirical framework.

Second, we considerably broaden the country coverage of the existing literature. Much of the previous evidence is based either on a single-country case study (Aloy and Gente, 2009) or on panels of advanced economies (Andersson and Österholm, 2006; Groneck and Kaufmann, 2017). By contrast, we assemble a panel of 75 countries from 1970 to 2024, spanning advanced economies as well as emerging market and developing economies. This wider sample is important not only because it substantially increases statistical power,

[2]For example, aging populations may initially raise saving rates due to precautionary motives, but as more individuals retire, aggregate savings decline, affecting the current account and RER. Conversely, younger populations typically drive higher investment and consumption, resulting in distinct dynamics in trade and capital flows.

but also because it introduces much richer variation in both demographic transition and macroeconomic structure. In this sense, our paper speaks to a more general question: whether demographic forces are a systematic determinant of long-run RERs across countries at very different stages of development and population aging.

Third, and most importantly, we extend the literature from retrospective estimation to forward-looking quantification. To the best of our knowledge, this is the first paper to provide long-horizon country-level RER projections for a large cross-section of economies based explicitly on demographic transition. Using projected demographic paths from the UN World Population Prospects, we trace the implications of population aging for bilateral RERs vis-à-vis the United States through 2050. In doing so, we deliberately hold other standard RER determinants constant in relative terms at their 2024 values. This assumption is not intended as a literal forecast of all fundamentals.[3] Rather, it provides a transparent benchmark that isolates the contribution of demographic change from that of other slow-moving or highly endogenous macroeconomic forces. This exercise is especially relevant because demographic variables are considerably more predictable over long horizons than standard exchange-rate determinants such as productivity, capital flows, or fiscal policy. Our projections should therefore be interpreted as demographic-pressure benchmarks for long-run RER adjustment rather than short-run forecasting exercises.

A potential concern is that these demographic indicators are not independent state variables. Even if their contemporaneous correlations are modest, fertility, longevity, migration, and dependency ratios are all jointly determined by the underlying population age distribution, especially over the long horizons relevant for projections. To address this issue, we complement our baseline specification with an alternative approach that models demographic effects using the full population age distribution, following Higgins (1998). This specification delivers an in-sample fit similar to that of the baseline model, but it is

[3] Relatedly, studies like Rossi (2013) and Ca'Zorzi and Rubaszek (2023) convincingly showed that including more variables (i.e., increasing parameters to be estimated) does not improve a forecast of real exchange rates.

internally more coherent for projection purposes because it respects the accounting consistency of the age distribution across cohorts. For this reason, we place greater weight on the population-distribution approach in our projection analysis.

Our empirical results point to a meaningful role for demographic forces in long-run RER determination. In a cointegrating framework for 75 countries over 1970–2024, demographic variables retain explanatory power even after controlling for standard macroeconomic fundamentals. In particular, real appreciation is associated with higher old-age dependency and fertility, and with lower life expectancy. The alternative specification based on the full age distribution implies an inverted U-shaped relationship between the real exchange rate and demographic structure: larger shares of the young and the old are associated with RER appreciation, whereas a larger share of middle-aged cohorts is associated with RER depreciation. This pattern corroborates the baseline results and is consistent with demographic effects operating through saving-investment imbalances, the demand for non-tradable goods, and labor supply.

Our projection exercises also yield rich cross-country implications. The incremental explanatory power of demographic variables is more pronounced, on average, in emerging market and developing economies. More broadly, countries projected to age more rapidly tend to experience long-run real appreciation under both empirical approaches, whereas countries that have already undergone substantial aging often exhibit a subsequent reversal in appreciation pressures. We also examine the role of migration by comparing population projections with and without migration. For countries with large directional migration flows, such as Canada and Mexico, migration has economically meaningful effects on projected long-run RER paths.

To interpret these empirical patterns, we present a simple open-economy two-sector overlapping-generations model. The model is deliberately parsimonious and abstracts from TFP growth, thereby isolating demographic mechanisms from the Balassa-Samuelson effect as in our empirical model. It highlights three channels through which population aging can appreciate the real exchange rate: (i) a saving–investment channel, whereby a higher dependency ratio leads to greater dissaving by the old, thereby adding appreciation pressure on the RER, (ii) a non-tradables-demand channel, in which older cohorts increase aggregate demand for non-tradable goods, and (iii) a complementary labor–supply channel, whereby a shrinking workforce raises wages and domestic prices.

The remainder of the paper is organized as follows. Section 2 discusses the determinants of the real exchange rate and the demographic mechanisms emphasized in the paper. Section 3 describes the data, including projected demographic variables, and outlines the empirical methodology. Section 4 presents the estimation results and long-run projections and relates them to the open-economy two-sector OLG framework. Section 5 concludes.

2 Theoretical Channels

This section reviews the channels through which macroeconomic fundamentals affect the real exchange rate. We first summarize the standard determinants emphasized in the literature and then discuss how demographic forces may influence the real exchange rate.

2.1. Traditional channels

A central determinant of the real exchange rate is relative productivity, particularly through the Balassa–Samuelson mechanism. Higher productivity growth in the tradable sector raises economy-wide wages and, in turn, the relative price of non-tradable goods. Countries with higher productivity therefore tend to exhibit more appreciated real exchange rates. Early empirical work often used relative GDP per capita as a proxy for tradable-sector productivity and documented a strong cross-country relationship between income levels and real exchange rates (Rogoff, 1996; Lane and Milesi-Ferretti, 2002). Subsequent studies using total factor productivity or labor productivity generally also find a positive association between productivity and real appreciation, although the strength of the relationship may vary across countries and income levels (Canzoneri, Cumby and Diba, 1999; Lee and Tang, 2007; Cardi and Restout, 2015; Hassan, 2016; Bordo, Choudhri, Fazio and MacDonald, 2017).

Another standard determinant is the commodity terms of trade (CTOT). For commodity exporters, an improvement in the terms of trade typically raises export income and increases demand for domestic goods, generating real appreciation (Neary, 1988).[4] Relatedly, Chen and Rogoff (2003) and Cashin, Céspedes and Sahay (2004) show that increases in export prices tend to raise the relative price of non-tradables, much as productivity gains in tradables do in the Balassa–Samuelson framework.

A third channel operates through net foreign assets (NFA) and the classic transfer problem. In standard intertemporal open-economy models, countries with higher net external liabilities require more depreciated real exchange rates in the long run to generate the trade surpluses needed to service those liabilities. Consistent with this logic, Faruqee (1995) and Lane and Milesi-Ferretti (2004) find that stronger net foreign asset positions are associated with more appreciated real exchange rates.

Government consumption is another commonly studied determinant. When public spending falls disproportionately on non-tradable goods, an increase in government consumption raises the relative price of non-tradables and thereby appreciates the real exchange rate. For example, Monacelli and Perotti (2010) show that in a standard two-sector model government spending shocks appreciate the real exchange rate in the long run, although short-run effects may differ in the presence of frictions. This prediction is consistent with the evidence in Galstyan and Lane (2009) and Ferrara, Metelli, Natoli and Siena (2021).

Finally, trade openness may also matter. Greater openness typically reflects lower

[4] Mendoza (1995) develops a small open economy model with incomplete markets and three categories of goods—exportables, importables, and non-tradables—in which positive terms-of-trade shocks appreciate the real exchange rate both directly and through non-tradable prices.

trade barriers and more competitive domestic prices, which tend to be associated with real depreciation. In particular, trade liberalization may induce an equilibrium depreciation of the real exchange rate in a general-equilibrium setting (Goldfajn and Valdes, 1999). Openness may also shape the size of real exchange rate adjustment during current account rebalancing (Romelli, Terra and Vasconcelos, 2018). While additional fundamentals may matter in specific settings, we keep the empirical specification parsimonious in order to isolate the independent role of demographic channels.

2.2. Demographic channels

Demographic forces may affect the real exchange rate even abstracting from their effects on productivity. In particular, they may operate through the saving–investment balance and through shifts in the relative demand for tradable and non-tradable goods. Although demographic change may also influence productivity (Maestas, Mullen and Powell, 2023), we abstract from that channel by controlling for per capita GDP or total factor productivity. Since one of our main objectives is to construct long-run projections of real exchange rates, and since productivity is much harder to project over long horizons than demographic variables, we focus on demographic mechanisms that operate through channels other than productivity.[5]

Whether population aging leads to real appreciation or depreciation is ultimately an empirical question, because theory implies offsetting effects. From the saving–investment perspective, a higher share of older households may reduce aggregate saving through life-cycle dissaving, thereby tending to appreciate the real exchange rate (e.g., Leff, 1969; Modigliani, 1986; Kim and Lee, 2007).[6] Similarly, a decline in the share of the young may depreciate the real exchange rate by raising aggregate saving (e.g., Higgins, 1998).

[5]In earlier versions of the paper, omitting productivity controls did not alter the qualitative role of demographic variables.

[6]A higher old-age dependency ratio need not imply aggregate dissaving; see, for example, Auclert et al. (2021).

By contrast, longer life expectancy may increase precautionary saving and thereby exert depreciation pressure (e.g., Palumbo, 1999; De Nardi, French and Jones, 2009).

Demographic change may also affect the real exchange rate through sectoral demand. A higher old-age dependency ratio raises demand for non-tradable services such as health care (Cravino, Levchenko and Rojas, 2022), which tends to appreciate the real exchange rate (Groneck and Kaufmann, 2017). Similarly, a decline in the fertility rate or in the youth share may depreciate the real exchange rate by reducing spending on non-tradable services such as education (e.g., Rose et al., 2009). Migration provides an additional demographic channel. Because immigrants may differ from natives in their saving and consumption behavior (e.g., Bauer and Sinning, 2011; Dustmann, Fasani and Speciale, 2017), changes in migration can exert an independent effect on the real exchange rate (e.g., Furlanetto and Robstad, 2019).

Taken together, these mechanisms imply that demographic transition may affect the real exchange rate through multiple, potentially offsetting channels. To capture these effects in a parsimonious way, our empirical specification embeds several dimensions of demographic change in an otherwise standard long-run real exchange rate framework.

3 Data and Empirical Analysis

3.1. Data

Our main dataset covers 75 countries—32 advanced economies (AEs) and 43 emerging market and developing economies (EMDEs)—at annual frequency over 1970–2024. Table A1 in Online Appendix A lists the baseline sample and country classifications. We include only countries with at least 25 years of consistent data for the main regressors. The dependent variable is the log of the CPI-based RER vis-à-vis the United States, so that an increase in the RER denotes a real depreciation against the U.S. consumption basket. We use the bilateral RER in the baseline and employ the real effective exchange rate

(REER) as a robustness check. Additional details on variable definitions, sources, and construction are provided in Online Appendix A.

The set of fundamentals, motivated by the discussion in the previous section, includes: (i) log real GDP per capita, (ii) log commodity terms of trade, (iii) net foreign assets as a share of GDP, (iv) nominal government consumption as a share of GDP, (v) trade openness, measured as exports plus imports relative to GDP, (vi) the old-age dependency ratio, (vii) the fertility rate, (viii) life expectancy, and (ix) the net migration rate. All variables except the commodity terms of trade and NFA-to-GDP ratio are expressed relative to the United States to match our definition of the RER.[7]

We begin with productivity. The Balassa–Samuelson hypothesis is ideally framed in terms of sectoral productivity differences between tradable and non-tradable sectors (Berka, Devereux and Engel, 2018). In practice, however, comparable cross-country measures of sectoral productivity are not consistently available for a broad panel spanning EMDEs. We therefore follow the standard approach in the literature and use real GDP per capita as a proxy, while checking robustness with total factor productivity (TFP). Countries with higher income or overall productivity levels typically also have higher productivity in tradable sectors, making these variables reasonable proxies for the Balassa–Samuelson channel. Both real GDP per capita and TFP are taken from the Penn World Table (Feenstra, Inklaar and Timmer, 2015).

We next consider the commodity terms of trade. These data are drawn from the comprehensive database constructed by Gruss and Kebhaj (2019), which covers 45 commodities and uses country-specific trade weights. The measure is constructed as a weighted average of a country's main export commodity prices divided by a weighted average of its primary commodity import prices. Importantly, all commodity prices are expressed relative to an index of manufactured export prices from advanced economies and denominated in U.S. dollars. Exchange rate movements therefore do not mechanically enter the

[7] Expressing the CTOT and NFA/GDP variables in relative terms does not affect the main results.

measure, unlike in conventional terms-of-trade series. We use the logarithm of the index for ease of interpretation.

Our measure of external positions is net foreign assets as a share of GDP. The data come from the latest version of the *External Wealth of Nations* database (Milesi-Ferretti, 2022), which provides standardized and comprehensive cross-country coverage of external asset and liability positions.

Government consumption is measured as government spending on goods and services, including compensation of employees, relative to GDP. The data are from the World Bank and are comparable across countries. Relative to broader expenditure aggregates used in some earlier cross-country studies (e.g., Edwards, 1988), this measure more directly captures the government-demand channel emphasized in the literature. Trade openness is defined as exports plus imports relative to GDP, also using World Bank data.

All demographic variables—the old-age dependency ratio, fertility rate, life expectancy at birth, and the net migration rate—are taken from the UN World Population Prospects. The old-age dependency ratio is defined as the population aged 65 and above relative to the population aged 15–64. The net migration rate is defined as the difference between immigrants and emigrants relative to total population.[8] In addition to historical estimates, the database provides population projections through 2100 under a range of plausible demographic scenarios.

Table 1 reports summary statistics for the key variables used in the baseline estimation. Because our real exchange rate is defined relative to the United States, we also report the corresponding statistics for the U.S. economy. As shown in the top panel, all demographic variables exhibit substantial dispersion, reflecting both the cross-sectional and time-series variation in our sample.

To illustrate how population aging reshapes the key demographic variables, Figure

[8] We use the 2024 Revision of the World Population Prospects produced by the Population Division of the United Nations Department of Economic and Social Affairs. The underlying estimates and projections incorporate information from 1,910 national population censuses, vital registration systems, and 3,189 nationally representative sample surveys.

Table 1: Summary statistics

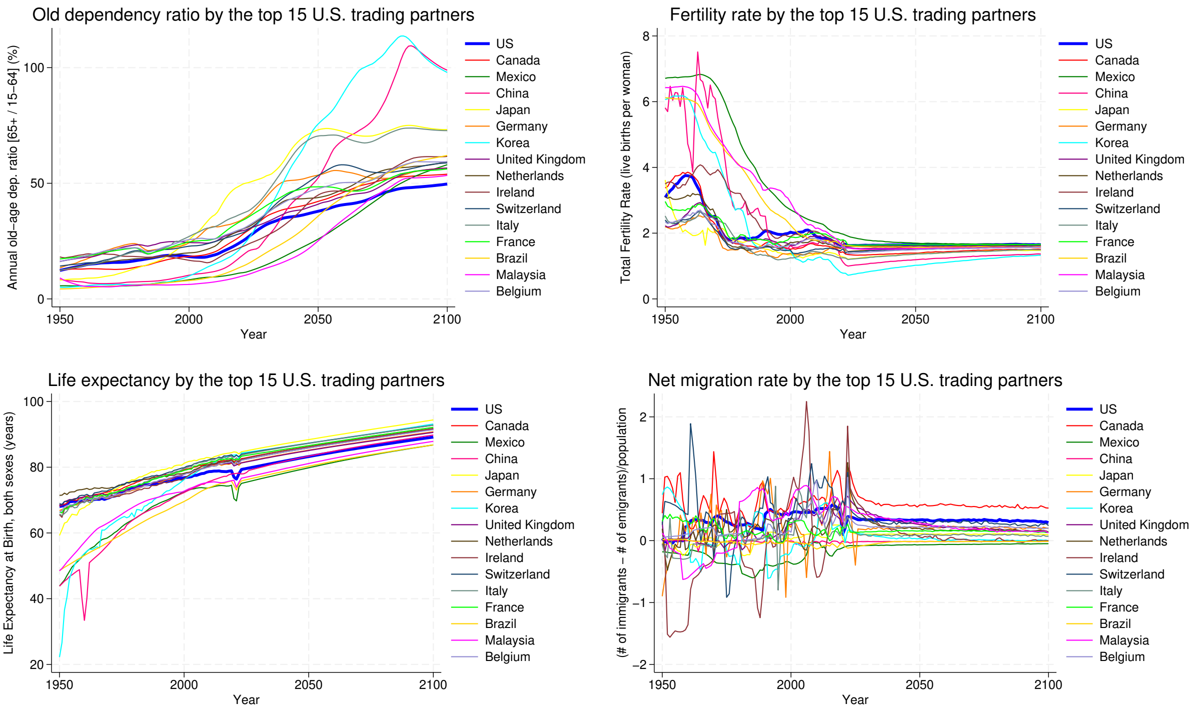
Variables	Mean	SD	Median	P1	P99	Obs
Baseline sample						
Log RER	3.01	2.62	2.31	−1.16	8.79	3,410
Log real GDP per capita	−1.21	1.04	−1.01	−4.23	0.38	3,410
CTOT	4.58	0.05	4.59	4.42	4.63	3,410
NFA/GDP	−0.19	0.85	−0.25	−1.66	2.52	3,410
Govt consumption/GDP	0.16	0.05	0.17	0.06	0.30	3,410
Trade openness	0.82	0.62	0.66	0.18	3.60	3,410
Dependency ratio (%)	14.96	8.62	14.77	3.37	35.57	3,410
Fertility rate (%)	2.79	1.69	1.99	1.02	7.31	3,410
Life expectancy	71.21	9.26	73.57	45.74	83.56	3,410
Net migration rate (%)	0.12	0.80	0.05	−1.79	2.58	3,410
United States						
Log real GDP per capita	10.77	0.28	10.80	10.25	11.20	55
CTOT	4.59	0.01	4.59	4.58	4.61	55
NFA/GDP	−0.17	0.23	−0.10	−0.83	0.05	55
Govt consumption/GDP	0.15	0.01	0.15	0.14	0.18	55
Trade openness	0.22	0.05	0.23	0.11	0.31	55
Dependency ratio (%)	19.04	2.91	18.42	15.74	27.69	55
Fertility rate (%)	1.91	0.16	1.89	1.62	2.52	55
Life expectancy	76.02	2.39	76.38	70.73	79.46	55
Net migration rate (%)	0.39	0.12	0.42	0.10	0.58	55

Note: This table provides summary statistics of the main variables for 75 countries in the baseline sample (top) and the United States (bottom).

1 plots the evolution of the old-age dependency ratio, fertility rate, life expectancy at birth, and net migration rate from 1950 to 2100 for the top 15 U.S. trading partners—Canada, Mexico, China, Japan, Germany, Korea, the United Kingdom, the Netherlands, Ireland, Switzerland, Italy, France, Brazil, Malaysia, and Belgium—together with the United States. Although these countries are selected based on their importance in U.S. trade, they display substantial heterogeneity in demographic transition.

Two patterns stand out. First, fertility rates display broad convergence across countries. Dispersion in fertility was substantial through 2000, but much of that gap had narrowed by 2024, with the main exceptions being a few economies with ultra-low fertility,

Figure 1: Demographic trends



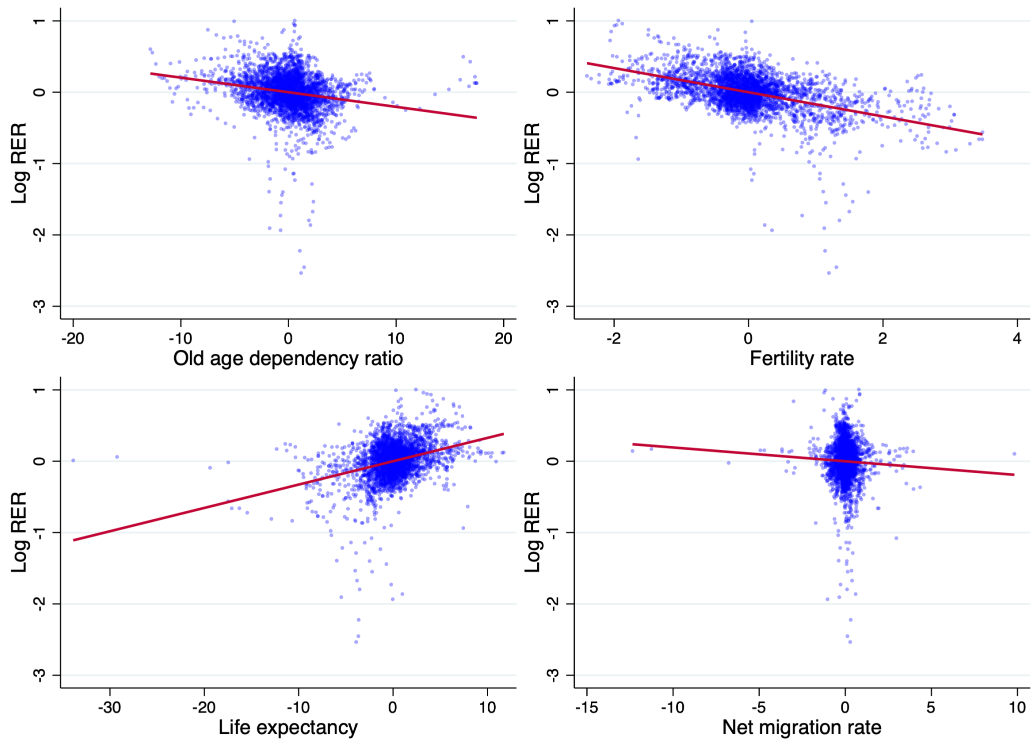
Note: This figure provides the old-age dependency ratio, total fertility rate, life expectancy in years, and net migration rate for the top 15 U.S. trading partners from 1950 to 2100. Data is taken from the 2024 Revision of World Population Prospects.

such as China and Korea. Since low fertility has become a common feature of industrial economies, this convergence is likely to persist.

Second, the old-age dependency ratio displays the opposite pattern: divergence is projected to increase markedly over time. This difference reflects the fact that fertility is a flow variable, whereas the old-age dependency ratio is a stock variable. Even seemingly modest differences in fertility and life expectancy can generate large differences in old-age dependency when sustained over long horizons. For example, the old-age dependency ratios in Italy and Japan—economies already far advanced in the aging process—are projected to level off after 2050. By contrast, the ratios in China and Korea are projected to continue rising sharply and to exceed 100 percent over the next 50 years.

Because our primary focus is on real exchange rates vis-à-vis the United States, the U.S. demographic path is of particular interest. Although the United States was among the countries with the highest old-age dependency ratios in the 1950s, its ratio in 2024 lies below the sample median. Looking forward, the United States is projected to have one of the lowest old-age dependency ratios in the long run, below even those of emerging economies such as Brazil, Malaysia, and Mexico. This reflects its relatively high fertility, positive net migration, and lower life expectancy than many major trading partners. These distinctive demographic features of the United States help interpret the real exchange rate projections in Section 4.4..

Figure 2: Demographic variables and real exchange rate



Note: This figure provides the correlation between the real exchange rate and (i) old-age dependency ratio, (ii) total fertility rate, (iii) life expectancy in years, and (iv) net migration rate. Each dot corresponds to a country-year observation after absorbing country-fixed effects.

Figure 2 plots the in-sample relationship between the real exchange rate and each of the four demographic variables, measured relative to the United States, after absorbing country fixed effects. Real appreciation is associated with a higher old-age dependency ratio, a higher fertility rate, a lower life expectancy, and a higher net migration rate. We examine these patterns more formally in the panel cointegration analysis below.

3.2. Empirical model

Table 2 presents the results of Pesaran (2007) panel unit root test, accounting for cross-sectional dependence. Over the sample period, most of the variables exhibit unit root behavior. Thus, as in Ricci, Milesi-Ferretti and Lee (2013), we apply the dynamic ordinary least squares (DOLS) method, developed by Stock and Watson (1993), to estimate this long-term (cointegrating) equilibrium relationship between the RER and the set of explanatory variables. Kao and Chiang (2001) and Mark and Sul (2003) convincingly supported the use of DOLS to obtain reliable long-run coefficients.

Table 2: Panel unit root statistics

Variable	**Baseline sample**	**Balanced sample**
Log RER	−3.829*	−4.062*
Real GDP per capita	−2.326	−1.897
CTOT	−7.356*	−4.451*
NFA/GDP	1.231	2.052
Govt consumption/GDP	−0.450	−0.263
Trade openness	0.810	1.422
Dependency ratio	−2.282	−3.019*
Fertility rate	−3.201*	−2.814*
Life expectancy	1.246	1.893
Net migration rate	−6.051*	−4.570*

Note: The unit root test statistic is based on Pesaran (2007). * means that the test does not reject the one-sided null hypothesis of the unit root at 5% significance level.

Given the moderate time-series dimension of the panel—55 years for most countries—we pool the data rather than estimate country-by-country RER equations. This approach improves the precision of the estimated long-run relationship between the RER and its fundamentals. Specifically, we estimate

$$rer_{i,t} = \alpha_i + \beta \tilde{X}_{i,t} + \sum_{s=-p}^{s=p} \gamma_s \Delta \tilde{X}_{i,t+s} + u_{i,t}, \tag{1}$$

where $rer_{i,t}$ denotes the log of the real exchange rate of country i against the United States in year t, and $\tilde{X}_{i,t}$ is the vector of explanatory variables $X_{i,t}$, expressed relative to the United States. The term α_i denotes country fixed effects, which absorb time-invariant country characteristics and thereby reduce omitted-variable bias.[9] The vector β contains the long-run cointegrating coefficients. Here, Δ denotes the first-difference operator so that γ_s captures leads and lags of changes in the regressors.[10] $u_{i,t}$ is the residual.

The long-run relationship should be interpreted as an equilibrium association rather than a causal one. Although reverse causality may be relevant for some regressors, such as net foreign assets, it is much less likely to be a first-order concern for the demographic variables that are central to our analysis.

4 Estimation Results

4.1. Main results

Table 3 reports the baseline estimates of equation (1) using a panel of 75 countries over 1970–2024. Column (1) presents a specification that excludes demographic variables, allowing us to assess whether the broader sample delivers results consistent with theoretical priors and the existing empirical literature. Because the specification includes country fixed effects, identification comes from within-country variation over time.

The estimates are broadly consistent with standard predictions. First, relative per capita income enters with a negative and highly significant coefficient, implying that countries that become relatively richer tend to experience real exchange rate appreciation. Second, improvements in the commodity terms of trade are significantly associated with real appreciation, consistent with the related literature (e.g., Lane and Milesi-Ferretti, 2004; Ricci et al., 2013).

[9] Because both the dependent and independent variables are defined relative to the United States, we do not include time fixed effects in the baseline specification. Reassuringly, the main results are unchanged when time fixed effects are added.

[10] In the baseline specification, we include two years of leads and lags, as suggested by the Akaike information criterion. The main results are robust to using one, three, or four years instead.

Table 3: Baseline results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log real GDP per capita	-0.241***	-0.224***	-0.241***	-0.271***	-0.237***		-0.246***
	(0.035)	(0.034)	(0.030)	(0.033)	(0.035)		(0.031)
Log CTOT	-0.764*	-0.656*	-0.835**	-0.960***	-0.791**		-0.844***
	(0.391)	(0.375)	(0.331)	(0.352)	(0.392)		(0.325)
NFA/GDP	0.063***	0.068***	0.033**	0.021	0.064***		0.025
	(0.017)	(0.016)	(0.014)	(0.016)	(0.017)		(0.016)
Gov. consumption/GDP	0.135	0.382	-0.532**	-0.285	0.129		-0.434
	(0.316)	(0.305)	(0.270)	(0.286)	(0.317)		(0.267)
Trade openness	0.176***	0.223***	0.195***	0.167***	0.185***		0.210***
	(0.041)	(0.040)	(0.035)	(0.037)	(0.041)		(0.035)
Dependency ratio		-0.024***				-0.012***	-0.010***
		(0.004)				(0.003)	(0.003)
Fertility rate			-0.180***			-0.136***	-0.136***
			(0.012)			(0.016)	(0.015)
Life expectancy				0.040***		0.012***	0.016***
				(0.004)		(0.004)	(0.004)
Net migration rate					-0.013	-0.004	-0.004
					(0.017)	(0.015)	(0.014)
Constant	-0.592***	-0.470***	-0.586***	-0.619***	-0.595***	-0.398***	-0.550***
	(0.042)	(0.045)	(0.036)	(0.038)	(0.042)	(0.036)	(0.039)
Within R-squared	0.040	0.083	0.266	0.172	0.041	0.230	0.279
Number of countries	75	75	75	75	75	75	75
Observations	3,405	3,405	3,405	3,405	3,405	3,405	3,405

Note: This table provides the results of estimating equation (1) with a sequential introduction of demographic variables. *, **, *** denote statistical significance at the 10%, 5%, and 1%, respectively, based on standard errors robust to serial correlation. Standard errors are reported in parentheses.

Third, higher net foreign asset positions are associated with real depreciation. Although the standard wealth effect would predict the opposite sign, this result is consistent with alternative mechanisms under which countries with persistently strong net foreign asset positions often run sustained current account surpluses in practice—for example, saving-surplus Asian economies—and therefore require relatively depreciated real exchange rates to maintain external balance.[11] Fourth, government consumption as a share of GDP is not robustly correlated with the real exchange rate, possibly reflecting measure-

[11] Alternatively, this result may reflect the concern raised by Ahn, Mano and Zhou (2020) that the choice of deflator is crucial in assessing the link between real exchange rates and external balances.

ment error or greater heterogeneity introduced by the inclusion of many EMDEs. This is also in line with the broader literature, which often finds mixed effects of government spending on the real exchange rate (e.g., Ravn, Schmitt-Grohé and Uribe, 2012; Ferrara et al., 2021). Finally, more open economies tend to exhibit more depreciated real exchange rates, consistent with Goldfajn and Valdes (1999).

We next introduce the demographic variables sequentially, one at a time (Columns (2)–(5)), then jointly without the standard covariates (Column (6)), and finally jointly with them (Column (7)). The estimated signs and significance levels of the demographic variables are stable across specifications, suggesting that they capture distinct dimensions of population aging that are not subsumed by the standard determinants of the real exchange rate. We therefore focus on the preferred specification in Column (7). Comparing Columns (1) and (7) also shows that the fit improves substantially once demographic channels are included, with the explanatory power rising from 0.04 to 0.28.

First, the old-age dependency ratio is significantly associated with real appreciation, consistent with both life-cycle saving behavior and stronger demand for non-tradable goods by older households. Quantitatively, a 1 percent increase in the old-age dependency ratio is associated with about a 1.0 percent real appreciation.

Second, the fertility rate is also highly significant. A 0.1 percent decline in fertility is associated with a 1.4 percent real depreciation. This suggests that, in an aging economy, lower fertility offsets part of the appreciation pressure generated by a rising share of older households.[12]

Third, higher life expectancy is associated with real depreciation, consistent with the precautionary-saving channel emphasized by Palumbo (1999) and De Nardi et al. (2009). One additional year of life expectancy is associated with a 1.6 percent real depreciation.

Finally, a higher net migration rate—that is, more immigration than emigration—is

[12]The fertility effect may also reflect shifts in the composition of non-tradable demand. For example, lower fertility directly reduces demand for youth-specific non-tradable services, such as education and childcare, thereby lowering their relative price and contributing to real depreciation independently of the old-age dependency ratio (e.g., Rose et al., 2009; Groneck and Kaufmann, 2017; Papetti, 2021).

associated with real appreciation but this effect is not statistically significant and is quantitatively small. Overall, three demographic dimensions of an aging economy—old-age dependency, fertility, and life expectancy—are robustly associated with the real exchange rate.

4.2. Robustness checks

In this subsection, we examine the robustness of the main findings reported in Table 3. Our baseline results are obtained from a broad panel of 75 countries over more than 50 years, substantially larger than in most related cross-country studies, including Ricci et al. (2013), Andersson and Österholm (2006), Groneck and Kaufmann (2017), Mano, Buitron, Ricci and Vargas (2019), and Giagheddu and Papetti (2020). As emphasized by Rose et al. (2009), a broad sample is useful for capturing the distinct demographic trajectories of advanced economies (AEs) and emerging market and developing economies (EMDEs). At the same time, this choice raises concerns about comparability with existing studies and about data quality in less developed countries. To address these concerns, we progressively narrow the estimation sample and assess whether the main results are sensitive to sample composition.

Table 4 summarizes the results. In Column (1), we exclude the 17 euro-area countries, given the distinct behavior of real exchange rates under a currency union. In Column (2), we use a fully balanced panel over 1970–2024, which reduces the sample to 67 countries. Across these alternative samples, the estimated coefficients on the demographic variables remain stable in both sign and significance.

A related concern is that pooling AEs and EMDEs may impose overly restrictive common coefficients, since the two groups are often at different stages of demographic transition. To address this possibility, Columns (3) and (4) estimate the model separately for AEs and EMDEs. The signs and statistical significance of both the macroeconomic and demographic variables remain broadly similar across the two subsamples, which allevi-

Table 4: Robustness check: different samples, data, and alternative estimation method

Method	(1) DOLS Without EZ	(2) DOLS Balanced	(3) DOLS AEs	(4) DOLS EMDEs	(5) DOLS TFP	(6) FMOLS Balanced	(7) DOLS Levels
Real GDP per capita (or TFP)	-0.199***	-0.269***	-0.135**	-0.199***	-0.049	-0.260***	-0.165***
	(0.046)	(0.042)	(0.064)	(0.057)	(0.055)	(0.034)	(0.039)
CTOT	-0.540	-0.685*	-0.682**	-1.313*	-0.835***	-0.561**	-1.035***
	(0.412)	(0.363)	(0.279)	(0.778)	(0.312)	(0.264)	(0.312)
NFA/GDP	-0.003	0.039*	0.030*	-0.016	0.013	0.037**	-0.012
	(0.018)	(0.021)	(0.016)	(0.025)	(0.014)	(0.016)	(0.016)
Gov. consumption/GDP	-0.172	-0.132	0.580	-0.408	0.384	-0.404	-0.517
	(0.385)	(0.339)	(0.379)	(0.477)	(0.337)	(0.248)	(0.349)
Trade openness	0.203***	0.148***	0.066*	0.319***	0.086**	0.143***	0.128***
	(0.060)	(0.046)	(0.038)	(0.094)	(0.042)	(0.039)	(0.045)
Dependency ratio	-0.012**	-0.009**	-0.007**	-0.018**	-0.008**	-0.009***	-0.010***
	(0.005)	(0.004)	(0.003)	(0.008)	(0.003)	(0.003)	(0.004)
Fertility rate	-0.149***	-0.115***	0.002	-0.156***	-0.132***	-0.140***	-0.117***
	(0.019)	(0.018)	(0.031)	(0.021)	(0.016)	(0.015)	(0.020)
Life expectancy	0.015***	0.019***	0.019**	0.015**	-0.003	0.015***	0.012**
	(0.006)	(0.005)	(0.009)	(0.007)	(0.005)	(0.004)	(0.005)
Net migration rate	0.005	-0.004	0.000	0.018	0.023	-0.010	-0.001
	(0.026)	(0.023)	(0.023)	(0.033)	(0.021)	(0.012)	(0.022)
Constant	-0.535***	-0.565***	-0.522***	1.883***	-0.461***	-0.558***	2.516
	(0.080)	(0.071)	(0.051)	(0.167)	(0.062)	(0.062)	(1.765)
Within R-squared	0.314	0.289	0.066	0.345	0.194	0.290	0.259
Number of countries	58	67	32	43	66	67	75
Observations	2,627	3,058	1,547	1,853	3,021	3,062	3,405

Note: This table reports results from a series of robustness checks. Column (1) excludes euro area countries. Column (2) uses a balanced sample. Column (3) includes advanced economies only, while Column (4) includes emerging market and developing economies. In Column (5), total factor productivity replaces per-capita real GDP. Column (6) reports FMOLS estimates for the balanced sample. Column (7) estimates the model in levels. Standard errors, robust to serial correlation, are reported in parentheses. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

ates this concern. At the same time, consistent with the greater cross-country variation among EMDEs, the quantitative effects and explanatory power of demographic variables are generally larger in that group.

In Column (5), we replace real GDP per capita with total factor productivity to address the concern that per capita income may partly reflect equilibrium outcomes shaped by other macroeconomic forces, including demographic change, and may therefore absorb some of the demographic variation of interest. The estimated coefficients on the demographic variables remain similar in both magnitude and significance to those in the baseline specification, with the exception of life expectancy, which becomes less precisely estimated.

We also consider an alternative estimator, fully modified ordinary least squares (FMOLS). Following Ricci et al. (2013), we implement the panel FMOLS estimator of Kao and Chiang (2001), which requires a balanced panel. We therefore apply it to the balanced sample of 67 countries over 1970–2024. As shown in Column (6), the main results remain remarkably similar under this alternative method.

The baseline results are based on bilateral real exchange rates against the United States, with all demographic variables expressed relative to their U.S. counterparts. This raises the concern that U.S. variables may exert disproportionate influence on the estimated coefficients. We address this concern in two ways. First, in Column (7) of Table 4, we re-estimate the model using macroeconomic fundamentals and demographic variables in levels rather than in differences relative to the United States. The demographic coefficients retain their signs and statistical significance, indicating that the baseline findings are not driven by the relative formulation.

Second, we replace the dependent variable with the log of the real effective exchange rate (REER) and estimate

$$reer_{i,t} = \alpha_i + \alpha_t + \beta X_{i,t} + \sum_{s=-p}^{p} \gamma_s \Delta X_{i,t+s} + u_{i,t}, \tag{2}$$

where $reer_{i,t}$ denotes the log of the REER of country i in year t and α_t denotes time fixed effects. Following Rose et al. (2009), we include time fixed effects because the REER is defined relative to a trade-weighted basket rather than to the United States alone. Accordingly, unlike in the bilateral RER specification, none of the regressors enter in relative terms to U.S. variables. This specification also includes the United States in the sample.

Table B1 in Online Appendix B reproduces the robustness checks in Table 3 using the REER. Since an increase in the REER denotes appreciation, the coefficients on the demographic variables switch sign relative to the bilateral RER regressions, exactly as expected. Their statistical significance and magnitudes are otherwise remarkably similar to the baseline estimates. Overall, these results suggest that our main findings are not driven by the particular role of the United States in the baseline specification.

4.3. Accounting for joint dynamics in demographic variables

Our baseline specification uses a small set of demographic indicators in order to preserve parsimony and facilitate interpretation. These variables are intuitive summaries of demographic conditions, but they are not independent state variables. Rather, they are jointly determined by the underlying population age distribution, especially at the long horizons relevant for our analysis. For example, changes in fertility today affect the size of future working-age cohorts and, with a lag, the elderly population. Likewise, improvements in life expectancy mechanically raise the share of older individuals in the future. The demographic indicators used in the baseline analysis should therefore be viewed as reduced-form summaries of a common demographic process.

This creates two related challenges. First, even if contemporaneous correlations among these indicators are modest, they are linked dynamically, which complicates the interpretation of individual coefficients. Second, the issue is more severe in projection exercises. If demographic indicators are projected separately, the resulting paths need not be internally consistent. This is because the evolution of the age structure is governed by demographic accounting identities that link fertility, mortality, migration, and cohort sizes.

To address these issues, we complement the baseline specification with an approach that models demographic effects through the full population age distribution rather than through a small set of demographic indicators. This follows the methodology of Fair and Domínguez (1991) and Higgins (1998), who use polynomial approximations to allow macroeconomic outcomes to depend flexibly on the age structure of the population.

Polynomial representation of the age distribution. Let $p_{j,i,t}$ denote the share of the population in country i at time t belonging to age group j, where $j = 1, \ldots, J$ indexes age cohorts. A fully flexible specification would augment the baseline model without demographic indicators with all age shares:

$$rer_{i,t} = \alpha_i + \beta' \tilde{X}_{i,t} + \sum_{s=-p}^{p} \gamma_s \Delta \tilde{X}_{i,t+s} + \sum_{j=1}^{J} \delta_j p_{j,i,t} + u_{i,t}. \tag{3}$$

In practice, however, this specification is unattractive because the age shares sum to one and adjacent cohorts are highly correlated. Following Fair and Domínguez (1991) and Higgins (1998), we therefore impose a smoothness restriction and assume that the age coefficients lie on a cubic polynomial:

$$\delta_j = \theta_0 + \theta_1 j + \theta_2 j^2 + \theta_3 j^3. \tag{4}$$

Because the age shares sum to unity, the constant term in this polynomial is not separately identified from the regression intercept. As in the polynomial-age-profile literature, we therefore work with transformed age moments. Defining

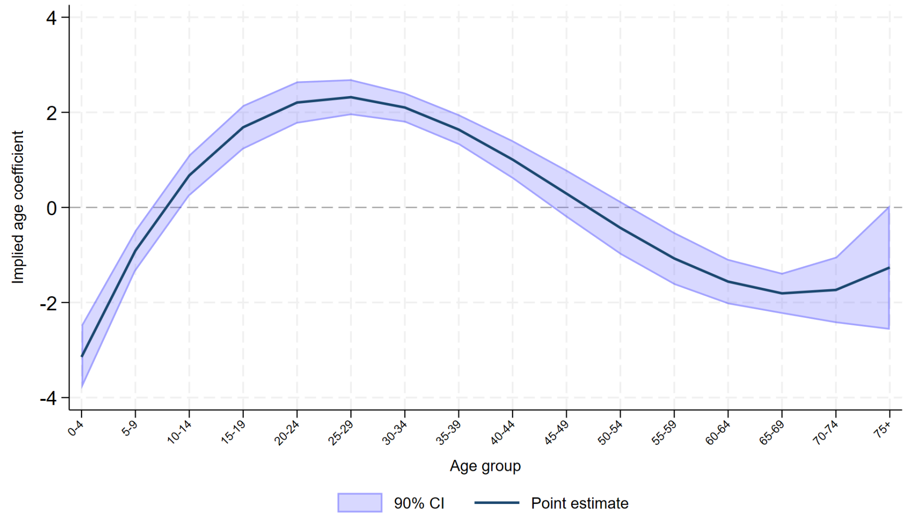
$$D_{k,i,t} = \sum_{j=1}^{J} j^k p_{j,i,t} - \frac{1}{J} \left(\sum_{j=1}^{J} j^k \right) \left(\sum_{j=1}^{J} p_{j,i,t} \right) \qquad \text{for } k \in \{1, 2, 3\}, \tag{5}$$

the regression can be written as

$$rer_{i,t} = \alpha_i + \beta' X_{i,t} + \sum_{s=-p}^{p} \gamma_s \Delta X_{i,t+s} + \theta_1 D_{1,i,t} + \theta_2 D_{2,i,t} + \theta_3 D_{3,i,t} + u_{i,t}. \tag{6}$$

This transformation compresses the information contained in the full age distribution into a small number of variables while preserving considerable flexibility in the demo-

Figure 3: Implied age-distribution coefficients



Note: This figure plots the implied effect of each five-year age group on the real exchange rate, based on the estimated coefficients on the cubic polynomial age-distribution terms (D_1, D_2, and D_3). A negative (positive) value indicates that a larger population share in that age group is associated with a real appreciation (depreciation) relative to the United States. The shaded band shows the 90% confidence interval constructed using the delta method. Estimation uses DOLS with lead and lag correction terms for all regressors, including D_1–D_3.

graphic profile.

Interpretation. The coefficients θ_1, θ_2, and θ_3 summarize how the population age distribution affects the real exchange rate. While these parameters are not directly interpretable at the cohort level, the implied age-specific effects can be recovered from the fitted polynomial, that is, from the sequence of δ_j across age groups. This approach has two advantages. First, it allows for nonlinear life-cycle patterns in demographic effects without requiring the researcher to select a small number of demographic indicators ex ante. Second, because it is based on the full age distribution, it is well suited for long-run projection exercises in which internal demographic consistency is essential.

Figure 3 reports the implied age-specific coefficients and their confidence intervals, recovered from the polynomial estimates in Table B2 in Online Appendix B. Whether age distribution terms are measured in level ($D_{k,i,t}$) or relative to those in the U.S. ($\tilde{D}_{k,i,t}$), the age profile is robustly nonlinear and broadly consistent with the baseline results based on summary demographic indicators. Larger shares of younger cohorts are associated with real appreciation, consistent with the role of fertility in the baseline estimates. By contrast, larger working-age shares are associated with real depreciation, consistent with life-cycle saving behavior. Finally, larger elderly shares are associated with real appreciation, consistent with the positive role of old-age dependency in the baseline specification. This qualitative pattern is also in line with Groneck and Kaufmann (2017), who apply the same cubic-polynomial approach in explaining the relative price of non-tradables.

4.4. Real exchange rate projections

Following Aksoy, Basso, Smith and Grasl (2019) and Papetti (2021), we combine our long-run estimates with the UN World Population Prospects to construct conditional projections of real exchange rates. As a first step, we compute the in-sample fitted values implied by the baseline specification, both with and without demographic variables. These fitted values isolate the component of the real exchange rate explained by the estimated fundamentals and therefore help assess the incremental contribution of demographic factors. We then use the final fitted observation as the starting point for the projection exercise.

For each country i, the h-year-ahead projected value of the bilateral real exchange rate is given by

$$\hat{rer}_{i,t+h|t} = \hat{rer}_{i,t} + \hat{\beta}_{dep}\Delta\tilde{dep}_{i,t+h|t} + \hat{\beta}_{fert}\Delta\tilde{fert}_{i,t+h|t} + \hat{\beta}_{exp}\Delta\tilde{exp}_{i,t+h|t}, \tag{7}$$

where $\tilde{x}_{i,t}$ denotes the value of variable x for country i relative to the United States.[13] The term $\Delta\tilde{x}_{i,t+h|t}$ denotes the change between the projected value at $t+h$ and the observed value at t. The coefficients $\hat{\beta}_{dep}$, $\hat{\beta}_{fert}$, and $\hat{\beta}_{exp}$ correspond to the estimated effects of the old-age dependency ratio, fertility, and life expectancy, respectively. Because the net mi-

[13]Consistent with the in-sample estimation, demographic variables enter the projection exercise in relative terms vis-à-vis the United States.

gration rate is not statistically significant in the baseline regression, we exclude it from the baseline projection exercise. We nevertheless allow migration to affect projections under the population-distribution approach. Throughout, all non-demographic determinants are held fixed relative to the United States at their 2024 values, while demographic variables evolve according to the UN projections.

To illustrate the role of demographic change, we focus on three countries with distinct aging profiles: the United Kingdom (Figure 4), whose demographic trajectory is relatively similar to that of the United States; Italy (Figure 5), which has already undergone rapid aging; and China (Figure 6), which is projected to age rapidly in the coming decades. Projections for the remaining U.S. major trade partner countries are reported in Online Appendix C.[14]

In each figure, Panel (a) presents projections based on the coefficients reported in Table 3. The contribution of demographic variables to the in-sample fit varies across countries—modest in some cases but substantial in others, particularly among EMDEs—consistent with the subgroup evidence in Table 4. Importantly, the estimated coefficients are not intended to account for the time-series evolution of real exchange rates in any individual country.

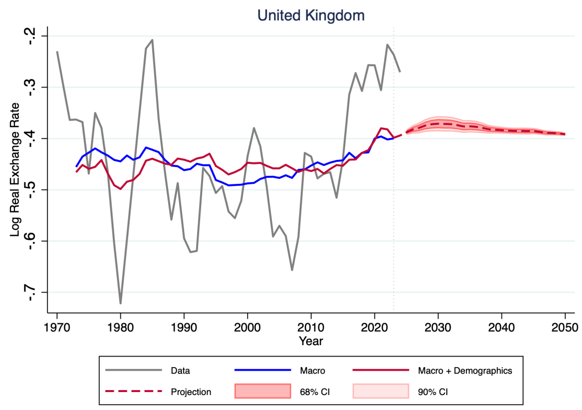
As discussed above, we also consider a more flexible specification that captures the full evolution of the population age distribution. This exercise serves as a check on the baseline framework. Using the age-distribution coefficients reported in Table B2 and Figure 3, Panel (b) reports projections under the assumption that only the relative population distribution evolves over time. Despite the different empirical formulation, the in-sample fit is close to that in Panel (a) for most countries, both AEs and EMDEs, which supports our interpretation of the baseline results. At longer horizons, however, the two approaches can generate different projections.

Because the population-distribution approach is internally consistent and more flexi-

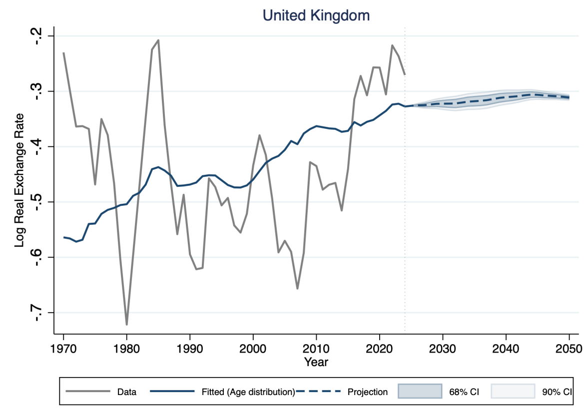
[14]Projection results for all countries are available upon request.

Figure 4: Real exchange rate projections for the UK

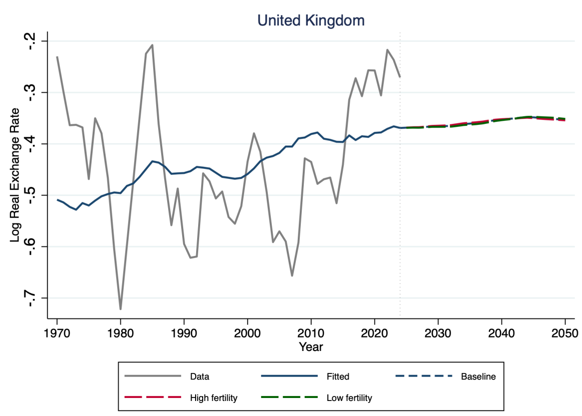
(a) Baseline projection



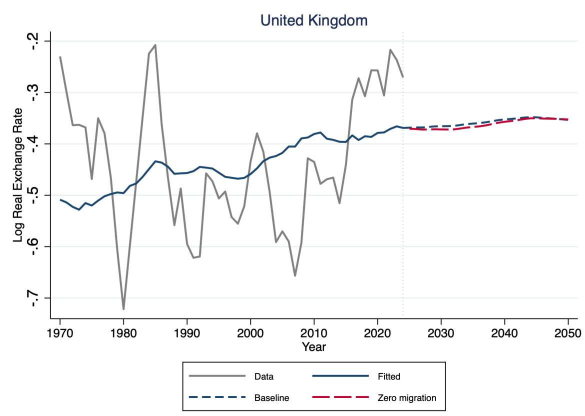
(b) Full-age distribution approach



(c) Alternative fertility scenario



(d) Alternative migration scenario



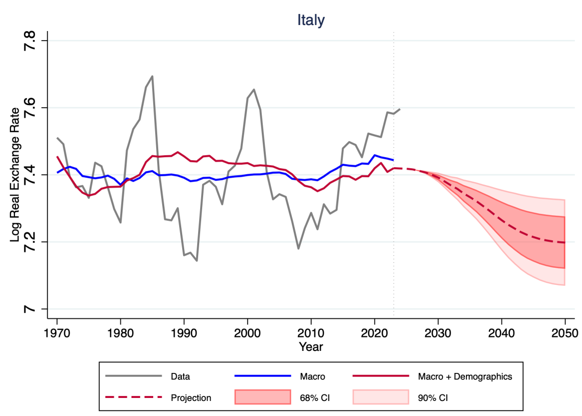
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using full-age distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

ble, we extend the analysis in two directions that are directly relevant for policy. First, demographic projections are themselves uncertain. To illustrate this source of uncertainty, Panel (c) reports projections under the high- and low-fertility scenarios from the UN World Population Prospects.

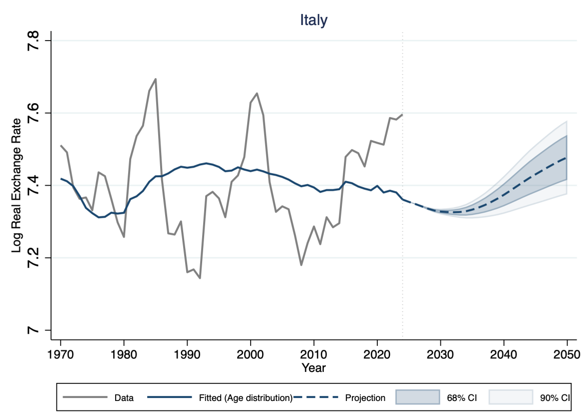
Second, we compare projections with and without migration. Although migration is not statistically significant in the baseline regression, this does not imply that migration is irrelevant for real exchange rate dynamics. Migration can materially alter the evolution of the population age structure, especially in countries with large inflows or outflows. Panel (d) therefore evaluates the contribution of migration through its effect on population composition.

Figure 5: Real exchange rate projections for Italy

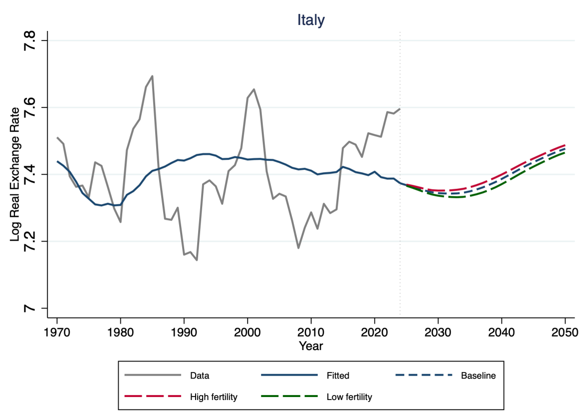
(a) Baseline projection



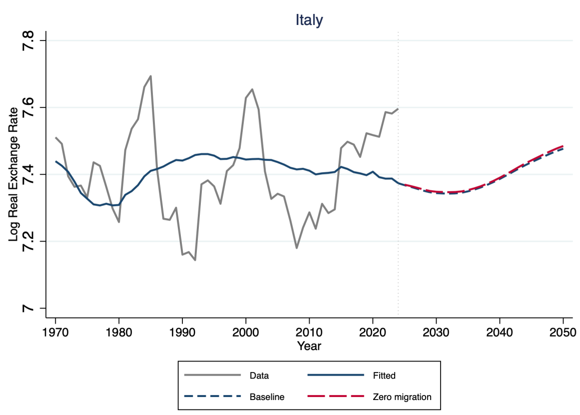
(b) Full-age distribution approach



(c) Alternative fertility scenario



(d) Alternative migration scenario



Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

The cross-country projection results can be summarized as follows. Economies projected to age more rapidly than the United States tend to appreciate in real terms, whereas those projected to age more slowly tend to depreciate relative to the United States. Because the United States is projected to age more slowly than many of its major trading partners (see Figure 1), the projections imply long-run real appreciation for a large set of countries.

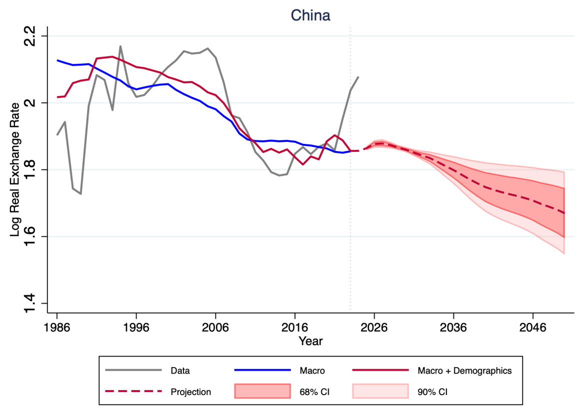
For example, even relatively young economies such as Brazil, Mexico, and Malaysia are projected to appreciate in real terms in the long run. Countries with ultra-low fertility and rapidly rising old-age dependency ratios, such as China and Korea, are projected to experience especially strong real appreciation by 2050. These patterns are consistent with Japan's experience of sustained real appreciation during a period of rapid population aging (Aloy and Gente, 2009). By contrast, in economies that have already undergone substantial aging, appreciation pressures tend to level off and may eventually reverse at longer horizons.

Allowing for uncertainty in future fertility yields heterogeneous implications across countries. For some economies, such as the United Kingdom, the quantitative effects are small. By contrast, for very low-fertility countries such as China and Korea, alternative fertility paths generate economically meaningful differences. A more favorable demographic scenario with higher future fertility gradually attenuates long-run appreciation pressures, as the associated increase in labor supply materializes only with a lag. The effects are not uniform, however. In some EMDEs, including Mexico and Malaysia, higher fertility instead strengthens appreciation pressures, implying that the demand effect from a younger age structure on non-tradable goods dominates.

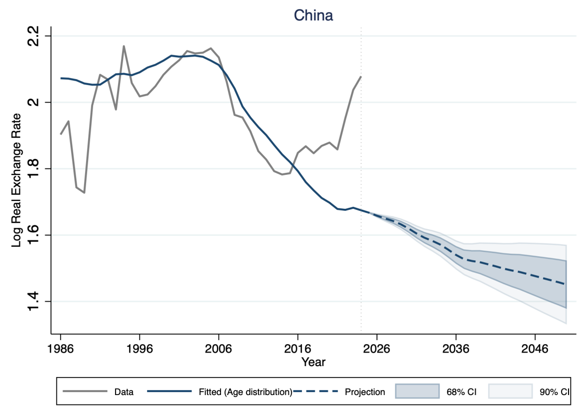
Finally, although migration is statistically insignificant in the baseline regression, it is quantitatively important for some countries in the population-distribution framework. For example, shutting down migration flows substantially affects long-run projections for countries such as Canada and Mexico, albeit in opposite directions. For Canada, which receives substantial immigration, eliminating migration implies stronger appreciation pressures. For Mexico, which experiences substantial emigration, it implies stronger

Figure 6: Real exchange rate projections for China

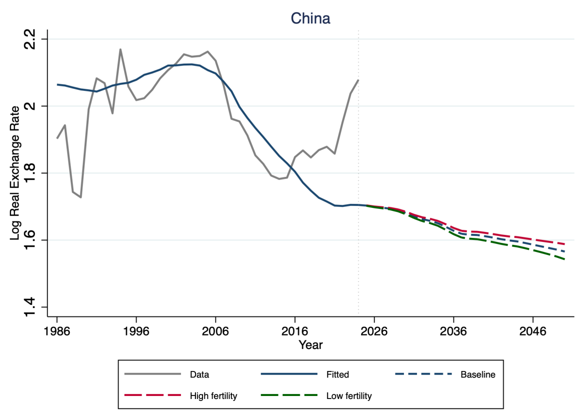
(a) Baseline projection



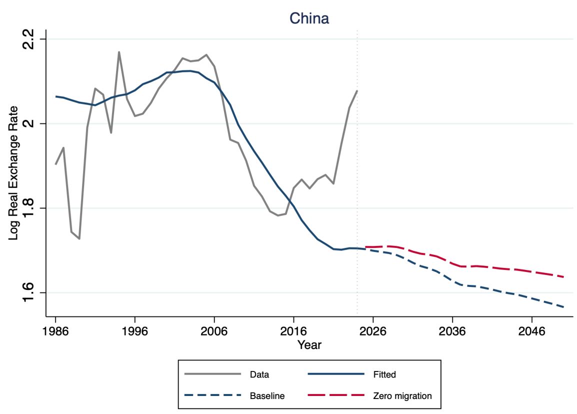
(b) Full-age distribution approach



(c) Alternative fertility scenario



(d) Alternative migration scenario



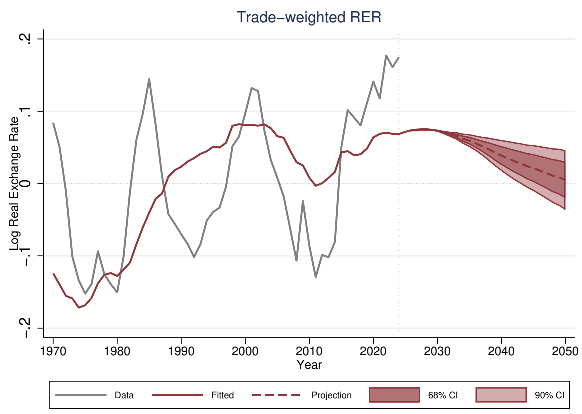
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

depreciation pressures. These patterns are consistent with the effect of immigration on the exchange rate documented by Furlanetto and Robstad (2019).

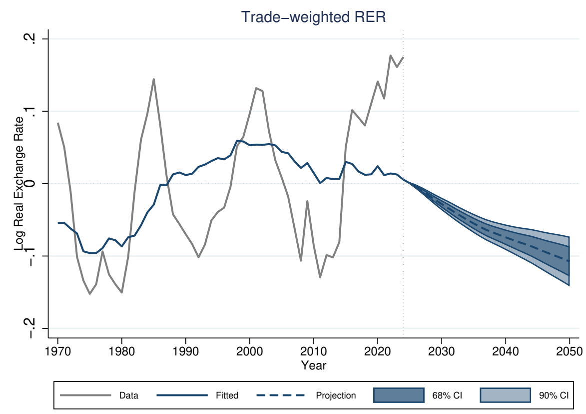
While our projections are expressed as bilateral real exchange rates vis-à-vis the United States, the broad country coverage also allows us to speak to the long-run trajectory of the U.S. dollar through the lens of demographic change. To this end, we construct a trade-weighted index of projected bilateral RERs across sample countries. Because RER levels are not directly comparable across countries, we first normalize the country-specific projected paths before aggregation. Panels (a) and (b) of Figure 7 report the resulting projected U.S. real exchange rate under the baseline specification and the full age-distribution approach, respectively. In both cases, the projections imply long-run real depreciation of the U.S. dollar, consistent with the relatively slow pace of population aging in the United States.

Figure 7: Real exchange rate projections for the United States

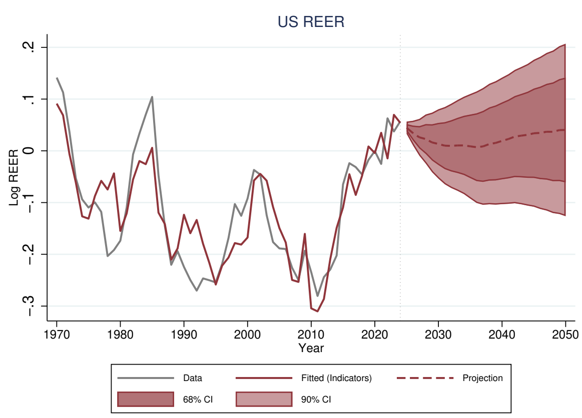
(a) Indirect projections: a baseline approach



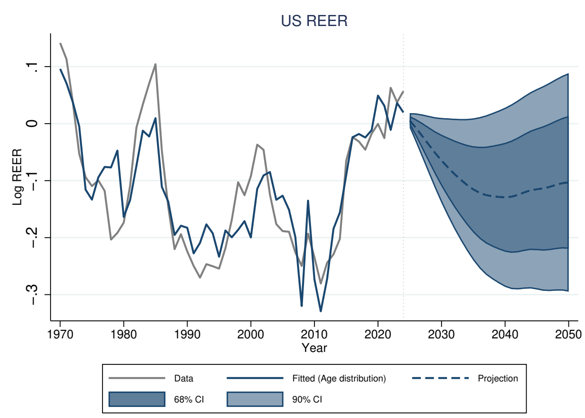
(b) Indirect projections: full-age distribution approach



(c) Direct projections: a baseline approach



(d) Direct projections: full-age distribution approach



Note: This figure plots the in-sample fit of the real exchange rate (solid line) and projections for 2025–2050 (dashed lines) for the United States. Panels (a) and (b) report indirect projections based on trade-weighted aggregates of bilateral RER projections across the 75-country sample, using the baseline specification and the full age-distribution approach, respectively. Panels (c) and (d) report direct projections based on estimation of the U.S. REER using the baseline specification and the full age-distribution approach, respectively. The full age-distribution approach follows Higgins (1998).

As a comparison and validity check, Panels (c) and (d) report direct projections based on estimates of equation (2) for the U.S. REER. Because the regression is fit directly to the U.S. real exchange rate, the in-sample fit is mechanically stronger. Even so, the projections again imply a long-run real depreciation of the U.S. dollar, especially under the full age-distribution specification, reinforcing our interpretation of the demographic channel. An important caveat is that these projections abstract from technological progress, which could appreciate the U.S. real exchange rate by raising investment demand.

4.5. Theoretical rationales

Our empirical results indicate that population aging—for example, an increase in the old-age dependency ratio—puts appreciation pressure on the real exchange rate in the long run. Importantly, this finding survives after controlling for productivity. We therefore interpret the estimated demographic effects as operating primarily through channels other than productivity adjustments. In particular, the evidence is more naturally rationalized by a combination of saving–investment dynamics and shifts in the relative demand for non-tradable goods. While the formal model is presented in Online Appendix D, this subsection summarizes the economic intuition in a parsimonious open-economy overlapping-generations framework with tradable and non-tradable sectors.

The first mechanism operates through saving, investment, and the external balance. In the model, young households are net savers, whereas old households finance consumption by running down previously accumulated assets. As the dependency ratio rises, the population composition shifts toward dissaving households, which tends to reduce aggregate saving. At the same time, lower population growth reduces the expected future labor force and thus lowers desired capital accumulation. The effect of aging on the trade balance, and ultimately on the real exchange rate, therefore depends on the relative magnitudes of the decline in saving and the decline in investment. If the decline in saving dominates, external surpluses shrink—or deficits widen—and appreciation pressure emerges. If the decline in investment dominates, the effect is weaker and can in principle go in the opposite direction. Our empirical results suggest that, on average across countries, the appreciation effect dominates. This logic is also consistent with our estimates based on the full age distribution: larger shares of older cohorts, who are more likely to dissave, are associated with real appreciation, whereas larger working-age shares are associated with real depreciation.

The second mechanism is a non-tradables-demand channel. In the model, older households place a larger expenditure weight on non-tradable goods and services than middle-age households do. Population aging therefore shifts aggregate demand toward non-tradables even when productivity is held fixed. If supply in that sector does not fully adjust, the relative price of non-tradables rises, increasing the domestic price level and appreciating the real exchange rate. This mechanism is distinct from the Balassa–Samuelson effect: it operates through changes in demand composition rather than through differential productivity growth across sectors. It also provides a natural interpretation for why the age-distribution estimates imply positive effects for older cohorts and, in some cases, for younger cohorts as well, to the extent that both groups consume relatively more non-tradable services than prime-age households.

Aging may also reinforce appreciation pressure through equilibrium wage adjustment. As the working-age population shrinks, labor becomes relatively scarcer, raising wages and production costs in labor-intensive non-tradable sectors even without TFP adjustments. Because tradable prices are pinned down in world markets, this wage pressure raises the relative price of non-tradables and further appreciates the real exchange rate. In this sense, labor-supply effects complement rather than replace the saving–investment and demand-composition channels emphasized above.

Taken together, these mechanisms provide a coherent interpretation of our empirical findings. Conditional on productivity, population aging appreciates the real exchange rate because it changes both intertemporal spending patterns and the sectoral composition of demand, while also placing upward pressure on the relative price of labor-intensive non-tradable goods and services.

5 Conclusion

We estimate the long-run relationship between the real exchange rate and its fundamentals, augmenting a standard macroeconomic specification with demographic variables. Demographic factors retain explanatory power even after controlling for standard macroeconomic fundamentals, including productivity. In particular, a higher old-age dependency ratio is associated with real appreciation, whereas higher life expectancy is associated with real depreciation, consistent with the coexistence of dissaving by older cohorts and stronger precautionary saving incentives.

Using an alternative specification based on the full population age distribution, we further show that the relationship between the real exchange rate and demographic structure is robustly nonlinear. Larger shares of younger and older cohorts are associated with real appreciation, whereas larger working-age shares are associated with real depreciation. This pattern is consistent with both life-cycle saving behavior and shifts in the composition of demand toward non-tradable goods and services.

We then combine the estimated long-run relationships with the UN World Population Prospects to construct conditional real exchange rate projections for each country in the sample. We complement the baseline indicator-based exercise with projections based on the full age-distribution approach, which preserves internal demographic consistency by construction. The projection results indicate that demographic variables add more explanatory power, especially in emerging market and developing economies and that countries projected to age more rapidly than the United States tend to experience long-run real appreciation.

Overall, our results suggest that demographic transition is an important source of long-run real exchange rate pressure. Once productivity effects are held fixed, faster population aging tends to appreciate the real exchange rate by shifting the population toward dissaving cohorts, raising demand for non-tradable goods and services, and tightening labor supply in labor-intensive non-tradable sectors. These findings imply that medium- and long-run assessments of external competitiveness and equilibrium exchange rates should account explicitly for demographic transition rather than treating it as a slow-moving background force.

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Online Appendix for "Demographic Changes and Real Exchange Rates: Future of an Aging Economy"

(Not for Publication)

A Data

This section provides detailed definitions, sources, and methodologies for constructing the variables used in the study, including their projection methodologies where applicable.

A.1 Real exchange rate and real effective exchange rate

The CPI-based bilateral real exchange rates (RER) are calculated as:

$$\mathrm{RER}_{ij} = \frac{\mathrm{E}_{ij} \times \mathrm{CPI}_j}{\mathrm{CPI}_i}$$

where E_{ij} represents the bilateral nominal exchange rate of domestic currency i per unit of foreign currency j (e.g., the United States), and $\mathrm{CPI}_i, \mathrm{CPI}_j$ are the domestic and foreign consumer price indices, respectively. The real effective exchange rate (REER) measures a country's price competitiveness relative to its trading partners. It is calculated as a trade-weighted geometric average of bilateral real exchange rates:

$$\mathrm{REER}_i = \prod_{j=1}^{N} \mathrm{RER}_{ij}^{w_{ij}}$$

where w_{ij} are trade weights based on bilateral trade shares. In our study, the REER is sourced from the IMF International Financial Statistics (IFS). Since the REER is expressed as an index, an increase denotes an appreciation of the domestic currency relative to its trading partners.

A.2 Per capita GDP and total factor productivity

Ideally, to capture the Balassa–Samuelson effect, sectoral productivity differences between tradable and non-tradable sectors should be employed. However, such detailed data are not consistently available for our broad, long-term panel of diverse countries. Hence, we consider two proxies for aggregate productivity: real GDP per capita and total factor productivity (TFP). Both series are sourced from the Penn World Table (PWT), version 11.0 (Feenstra et al., 2015), and expressed in natural logarithms as differentials relative to the United States.

First, following the standard literature, we employ real GDP per capita. This choice is motivated by the observation that countries with higher overall income levels typically exhibit higher productivity in the tradable sector. Specifically, we use expenditure-side real GDP evaluated at chained purchasing power parities (PPPs) to ensure that income levels are directly comparable across our sample of AEs and EMDEs.

Second, we also consider a more direct measure of productivity, or TFP at constant price. Per capita income is an equilibrium outcome that is likely to be strongly correlated with, and fundamentally shaped by, demographic transitions such as population aging. Using a direct measure of TFP helps address the concern that our productivity proxy might mechanically absorb some of the demographic variation we aim to isolate.

A.3 Commodity terms of trade

The commodity terms of trade (CTOT) index measures the ratio of export commodity prices to import commodity prices, capturing changes in trade income due to fluctuations in commodity prices. This variable is derived from the dataset constructed by Gruss and Kebhaj (2019), which provides country-specific commodity price indices for 45 individual commodities weighted using trade data. Historical annual data are available from 1962 to the present and are indexed to 2012 (2012 = 100). Commodity import prices are weighted by the ratio of imports to GDP. The dataset covers 182 economies and is updated regularly in line with the World Economic Outlook (WEO) cycle. In our analysis, the natural logarithm of the CTOT index is used.

As explained by Gruss and Kebhaj (2019), the CTOT captures the income effects of changes in international commodity prices at the country level. Unlike standard terms-of-trade indices, the CTOT accounts for a country's net export position for individual commodities, distinguishing between net exporters and importers. This distinction allows for a more accurate assessment of the real income impact of global price changes. For instance, a one-percent increase in the CTOT index corresponds to a change in aggregate disposable income equivalent to one percent of GDP. This measure abstracts from potential volume responses, isolating the pure price effect.

The CTOT index is defined as:

$$\Delta \log(\mathrm{CTOT}_{i,t}) = \sum_{j=1}^{J} \Delta P_{j,t} \cdot \Omega_{i,j,t}$$

where $\Delta P_{j,t}$ denotes the logarithmic change in the real international price of commodity j at time t, and $\Omega_{i,j,t}$ represents the trade weights calculated as:

$$\Omega_{i,j,t} = \frac{x_{i,j,t} - m_{i,j,t}}{\mathrm{GDP}_{i,t}}$$

Here, $x_{i,j,t}$ and $m_{i,j,t}$ represent the export and import values of commodity j for country i, expressed in USD, and $\mathrm{GDP}_{i,t}$ is the nominal GDP of country i. Time-varying weights ($\Omega_{i,j,t}$) are computed based on three-year rolling averages to account for shifts in trade composition over time. Fixed weights are also computed based on average trade shares from 1980–2015 for applications requiring consistent trade structures.

The CTOT index includes prices for 45 commodities grouped into four categories: energy, metals, agricultural raw materials, and food/beverages. Commodity prices are adjusted using the IMF's unit value index for manufactured exports. Data sources include the IMF Primary Commodity Prices Database, the World Bank, and the U.S. Energy Information Administration. Trade data are sourced from the United Nations Comtrade database, which provides detailed information on imports and exports by commodity, while GDP data are derived from the IMF's World Economic Outlook database.

A.4 Net foreign asset to GDP ratio

The Net Foreign Asset (NFA) to GDP ratio reflects a country's external net asset position relative to its GDP, indicating external solvency and the potential need for exchange rate adjustments. The ratio is expressed as:

$$\text{NFA/GDP}_{i,t} = \frac{\text{External Assets}_{i,t} - \text{External Liabilities}_{i,t}}{\text{GDP}_{i,t}}.$$

External assets and liabilities are recorded in millions of current U.S. dollars, converted using end-of-period exchange rates.[1] Data is sourced from the *External Wealth of Nations* (EWN) database by Milesi-Ferretti (2022), which provides annual estimates of external assets and liabilities for 210 economies. The EWN database includes detailed subcategories of external assets and liabilities, such as "portfolio investment: debt securities" and "other investment," where available (data coverage begins in 1995). For offshore financial centers, external assets and liabilities often exceed multiples of GDP and are imprecisely estimated. In such cases, only "identified" external assets and liabilities are reported.

Nominal GDP is expressed in USD using period-average exchange rates. GDP data primarily comes from the IMF's World Economic Outlook database (series "NGDPD"), complemented by sources such as the United Nations and the World Bank. Stock variables are recorded at market value and adjusted for valuation effects where possible, while flow variables like GDP are converted using period-average exchange rates.

[1] The NFA is measured at year-end to minimize the influence of short-term exchange rate fluctuations.

A.5 Government consumption to GDP ratio

The government consumption-to-GDP ratio quantifies the proportion of a country's GDP allocated to government expenditures on goods and services. General government final consumption expenditure includes salaries and wages for public sector employees, expenditures on goods and services for public administration, and spending on essential services such as healthcare and education. Expenditures on large military equipment are excluded as they are classified as capital formation.

Data for this variable is sourced from the World Bank national accounts and the OECD National Accounts databases, covering over 190 countries since 1960. Government consumption is expressed as a percentage of GDP and is derived from expenditure-side GDP measurements, which comprise household final consumption, government consumption, gross capital formation (including investments in fixed assets and inventories), and net exports of goods and services. These expenditures are recorded at purchaser prices and include net taxes on products.

Despite its comprehensiveness, this dataset is subject to limitations. Many countries primarily estimate GDP using the production approach due to its focus on output growth and ease of data collection relative to the expenditure approach. As a result, some components of expenditure-based GDP are indirectly derived using production-based estimates as control totals. This methodological limitation can lead to discrepancies in government consumption estimates for certain countries.

A.6 Trade openness

Trade openness measures a country's degree of integration into the global economy. It is calculated as the sum of exports and imports as a percentage of GDP:

$$\text{Trade Openness} = \frac{\text{Exports} + \text{Imports}}{\text{GDP}} \times 100$$

Exports and imports include goods and services traded internationally. Data is sourced from the World Bank and OECD national accounts databases and spans over 190 countries, with annual coverage starting in 1960.

A.7 Demographics

The 2024 Revision of World Population Prospects (WPP) draws on data from 1,910 national population censuses, supplemented by information from 3,189 nationally representative sample surveys and vital registration systems. Adjustments are systematically applied to address potential issues such as underreporting, misreporting, and gaps in data coverage. The WPP employs the cohort-component method for population projections. This method provides a comprehensive framework for projecting population changes by accounting for fertility, mortality, and migration. The methodology integrates advanced probabilistic and deterministic approaches to project demographic trends and their inherent uncertainties.

Fertility projections are based on a two-phase probabilistic model. The first phase models the decline in fertility rates using a double-logistic function, estimated through a Bayesian hierarchical framework. This model accounts for both country-specific historical trends and global patterns observed in other nations at similar stages of fertility transition. Once fertility rates reach low levels, a time-series approach projects long-term fluctuations around a country-specific equilibrium. These projections incorporate data from civil registration systems, demographic surveys, and censuses, ensuring robustness and cross-country comparability.

Mortality projections employ multiple methodologies tailored to the quality and availability of data for each country. For nations with high-quality mortality data, the modified Lee-Carter method is applied, capturing historical trends and age-specific mortality patterns. For countries with limited data, the Pattern of Mortality Decline (PMD) model estimates future improvements based on life expectancy trends. These mortality projections are constrained by model life tables, such as the Coale-Demeny and UN Far Eastern families, ensuring logical and consistent age-specific mortality patterns over time.

Migration projections are modeled using probabilistic approaches that incorporate historical migration trends and uncertainties. The methodology divides net migration into immigration and emigration components, applying the Rogers-Castro model to distribute flows by age and sex. For countries with irregular migration patterns or limited data, custom models are used to account for unique circumstances.

The cohort-component method itself applies matrix algebra to ensure demographic balance, adhering to the equation:

$$P(t+n) = P(t) + B(t \to t+n) - D(t \to t+n) + NM(t \to t+n),$$

where P represents population, B births, D deaths, and NM net migration within the projection interval. This approach reconciles historical estimates with future projections, iteratively refining inputs based on benchmarks and demographic consistency checks.

A.7.1 Dependency ratio

The dependency ratio is calculated as the ratio of the dependent population (individuals under the age of 15 and those aged 65 or older) to the working-age population (individuals aged 15 to 64). This ratio serves as a key indicator of the economic burden placed on the productive segment of the population. For the 2024 revision, dependency ratios were derived using population estimates and projections generated by the cohort-component method, which integrates fertility, mortality, and migration inputs. These estimates are informed by empirical data from censuses, vital registration systems, and household surveys, benchmarked against adjusted intercensal estimates to ensure consistency.

A.7.2 Fertility rate

The fertility rate is quantified as the total fertility rate (TFR), representing the average number of children a woman would bear if current age-specific fertility rates persisted throughout her reproductive years. The 2024 revision estimates annual TFRs from 1950 to 2023 using Bayesian hierarchical models, relying on empirical data from civil registration systems, demographic surveys, and population censuses. Age-specific fertility rates are further refined to single-year age intervals using the Calibrated Spline method. Future projections of fertility assume transitions based on country-specific trajectories, regional patterns, and global historical trends.

A.7.3 Life expectancy

Life expectancy at birth is defined as the average number of years a newborn is expected to live if current age-specific mortality rates remain constant throughout their life. This measure serves as a key summary indicator of mortality, reflecting the overall health and longevity of a population.

Life expectancy in the World Population Prospects is constructed using mortality data from civil registration systems with complete death registration. In cases where registration data is incomplete or unavailable, population censuses and demographic surveys are used. Adjustments are made to correct for underreporting or misclassification of deaths.

Historical estimates of life expectancy are derived using indirect demographic methods when mortality data is sparse. These methods rely on age distributions and other population indicators to infer age-specific mortality rates. Future life expectancy projections are generated using probabilistic models that incorporate historical trends in mortality decline. These models account for country-specific trajectories of mortality improvement, regional and global patterns influenced by health interventions and socio-economic development, and the principle of "convergence," where countries with lower life expectancies are expected to experience faster improvements than those with higher life expectancies.

A.7.4 Net migration

Net migration refers to the net balance of immigrants and emigrants over a given period. In the 2024 revision, the United Nations adopted probabilistic models to project net migration for all countries, incorporating historical trends and uncertainty measures. Estimates of migration are derived from census data, administrative records, and surveys, adjusted to align with age- and sex-specific population distributions. For countries with irregular migration patterns or limited data availability, further adjustments are applied. Projections of age-specific migration patterns integrate both immigration and emigration dynamics through a newly developed modeling framework.

Table A1: Baseline sample countries

Country	IFS Code	Advanced	Eurozone	Balanced	TFP
Algeria	612	0	0	0	0
Armenia	911	0	0	1	1
Australia	193	1	0	1	1
Austria	122	1	1	1	1
Bahrain	419	0	0	0	1
Belgium	124	1	1	1	1
Belize	339	0	0	0	0
Bolivia (Plurinational State of)	218	0	0	1	1
Brazil	223	0	0	1	1
Bulgaria	918	0	0	1	1
Burundi	618	0	0	1	1
Cameroon	622	0	0	1	1
Canada	156	1	0	1	1
Central African Republic	626	0	0	1	1
Chile	228	0	0	1	1
China	924	0	0	1	1
China, Hong Kong SAR	532	1	0	1	1
Colombia	233	0	0	1	1
Costa Rica	238	0	0	0	1
Croatia	960	1	1	1	1
Cyprus	423	1	1	1	1
Czechia	935	1	0	1	1
Côte d'Ivoire	662	0	0	0	1
Denmark	128	1	0	1	1
Democratic Republic of the Congo	636	0	0	1	0
Dominican Republic	243	0	0	1	1
Fiji	819	0	0	1	1
Finland	172	1	1	1	1
France	132	1	1	1	1
Gabon	646	0	0	1	1
Gambia	648	0	0	1	0
Georgia	915	0	0	1	0
Germany	134	1	1	1	1

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Country	IFS Code	Advanced	Eurozone	Balanced	TFP
Ghana	652	0	0	1	0
Greece	174	1	1	1	1
Hungary	944	0	0	1	1
Iceland	176	1	0	1	1
Iran (Islamic Republic of)	429	0	0	0	1
Ireland	178	1	1	1	1
Israel	436	1	0	1	1
Italy	136	1	1	1	1
Japan	158	1	0	1	1
Latvia	941	1	1	1	1
Luxembourg	137	1	1	1	1
Malaysia	548	0	0	1	1
Malta	181	1	1	1	1
Mexico	273	0	0	1	1
Morocco	686	0	0	1	1
Netherlands	138	1	1	1	1
New Zealand	196	1	0	1	1
Nicaragua	278	0	0	1	1
North Macedonia	962	0	0	1	0
Norway	142	1	0	1	1
Pakistan	564	0	0	1	0
Paraguay	288	0	0	1	1
Philippines	566	0	0	1	1
Poland	964	0	0	1	1
Portugal	182	1	1	1	1
Republic of Korea	542	1	0	1	1
Republic of Moldova	921	0	0	1	1
Romania	968	0	0	1	1
Russian Federation	922	0	0	0	1
Saudi Arabia	456	0	0	1	1
Singapore	576	1	0	1	1
Slovakia	936	1	1	1	1
South Africa	199	0	0	1	1

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(Continued)

Country	IFS Code	Advanced	Eurozone	Balanced	TFP
Spain	184	1	1	1	1
Sweden	144	1	0	1	1
Switzerland	146	1	0	1	1
Togo	742	0	0	1	1
Tunisia	744	0	0	1	1
Uganda	746	0	0	1	0
Ukraine	926	0	0	1	1
United Kingdom	112	1	0	1	1
Uruguay	298	0	0	0	1

Note: This table lists countries used in the baseline estimation. The value of 1 indicates "yes," whereas 0 implies "no." TFP denotes whether total factor productivity data from the Penn World Table are available for the country within the sample period.

B Robustness Checks

Table B1: Robustness check: using REER

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Real GDP per capita	0.452***	0.432***	0.402***	0.451***	0.453***		0.408***
	(0.026)	(0.027)	(0.028)	(0.027)	(0.027)		(0.029)
CTOT	0.142	0.104	0.209	0.118	0.137		0.151
	(0.358)	(0.353)	(0.350)	(0.348)	(0.359)		(0.344)
NFA/GDP	0.002	0.002	0.004	0.008	0.002		0.008
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)		(0.015)
Gov. consumption/GDP	0.885**	0.621*	0.793**	0.878**	0.890**		0.688*
	(0.367)	(0.368)	(0.357)	(0.356)	(0.368)		(0.357)
Trade openness	-0.133***	-0.170***	-0.179***	-0.136***	-0.132***		-0.183***
	(0.045)	(0.046)	(0.045)	(0.044)	(0.046)		(0.045)
Dependency ratio		0.013***				0.010**	0.007*
		(0.004)				(0.004)	(0.004)
Fertility rate			0.086***			0.097***	0.048**
			(0.018)			(0.025)	(0.021)
Life expectancy				-0.022***		-0.011*	-0.016***
				(0.005)		(0.006)	(0.005)
Net migration rate					-0.005	0.025	-0.003
					(0.019)	(0.021)	(0.018)
Constant	-4.365***	-4.197**	-4.424***	-2.624	-4.349***	0.934*	-3.031*
	(1.657)	(1.632)	(1.613)	(1.649)	(1.658)	(0.482)	(1.628)
Within R-squared	0.517	0.529	0.538	0.532	0.517	0.289	0.548
Number of countries	78	78	78	78	78	78	78
Observations	3,128	3,128	3,128	3,128	3,128	3,128	3128

Note: This table provides robustness checks using REER and estimates equation (2) with a sequential introduction of demographic variables. *, **, *** denote statistical significance at the 10%, 5%, and 1%, respectively, based on standard errors robust to serial correlation. Standard errors are reported in parentheses.

Table B2: Estimating age-distribution coefficients

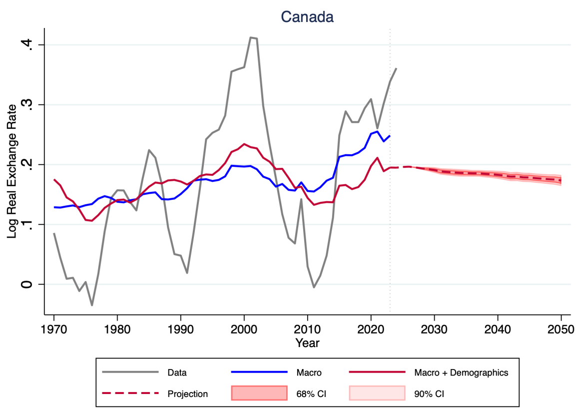
	(1)	(2)	(3)
Real GDP per capita	-0.173***	-0.078*	-0.173***
	(0.045)	(0.046)	(0.044)
CTOT	-0.819**	-1.093***	-0.179
	(0.379)	(0.343)	(0.397)
NFA/GDP	0.027	-0.004	-0.006
	(0.017)	(0.018)	(0.017)
Gov. consumption/GDP	0.460	-0.570	-0.369
	(0.347)	(0.399)	(0.363)
Trade openness	0.181***	0.123**	0.148***
	(0.048)	(0.051)	(0.047)
D1	3.363***	3.932***	2.639***
	(0.448)	(0.635)	(0.620)
D2	-0.407***	-0.467***	-0.315***
	(0.070)	(0.096)	(0.093)
D3	0.014***	0.016***	0.010***
	(0.003)	(0.004)	(0.004)
Constant	-0.480***	5.345***	2.057
	(0.077)	(1.574)	(1.826)
Within R-squared	0.241	0.181	0.373
Number of countries	75	75	75
Observations	3,475	3,405	3,405
Specification	Differences	Levels	Levels
Time fixed effects	No	No	Yes

Note: D_1, D_2, and D_3 denote the cubic polynomial age structure following Higgins (1998). Column (1) uses variables expressed relative to the United States, while columns (2) and (3) use levels. Time fixed effects are included in column (3). Country fixed effects and DOLS correction terms are included in all specifications. Standard errors are reported in parentheses. *, **, *** denote statistical significance at the 10%, 5%, and 1%, respectively.

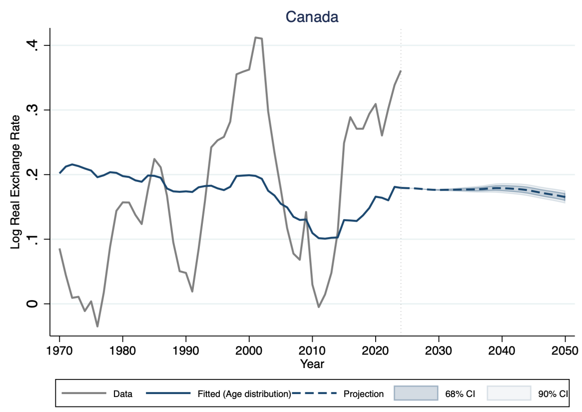
C RER Projections for the Top 15 U.S. Trading Partners

Figure C1: Real exchange rate projections for Canada

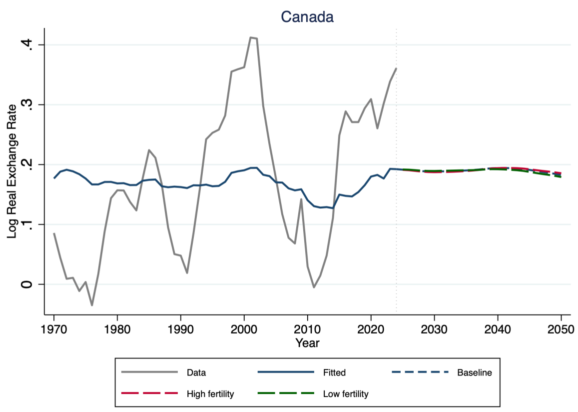
(a) Baseline projection



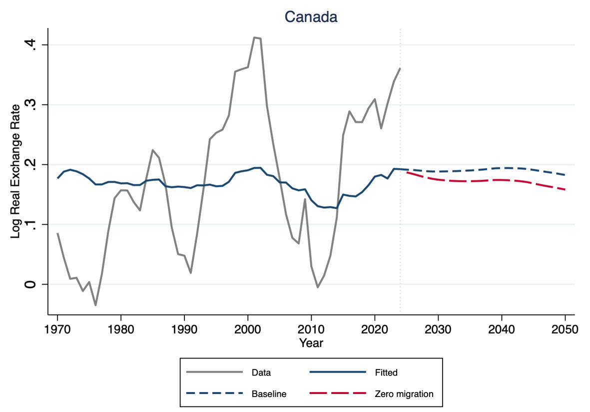
(b) Full-age distribution approach



(c) Alternative fertility scenario



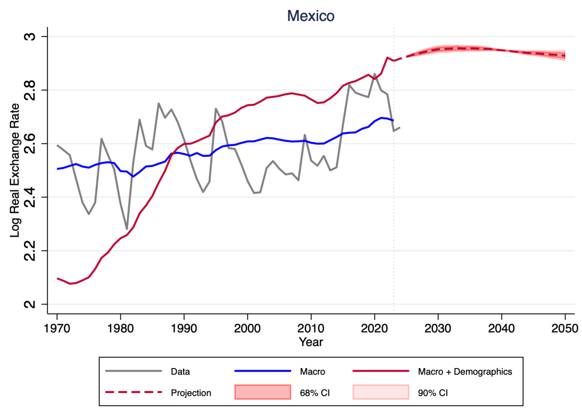
(d) Alternative migration scenario



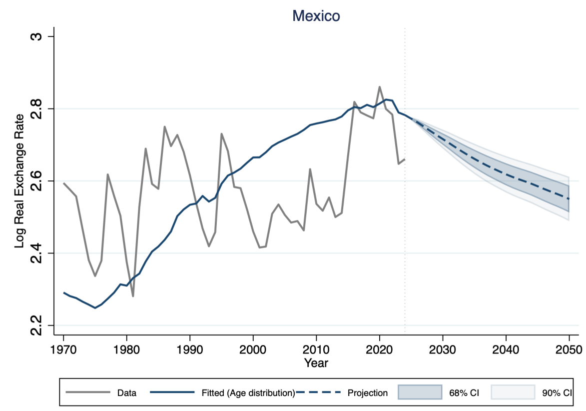
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C2: Real exchange rate projections for Mexico

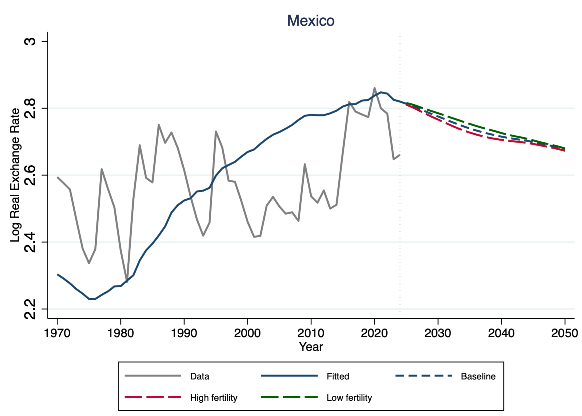
(a) Baseline projection



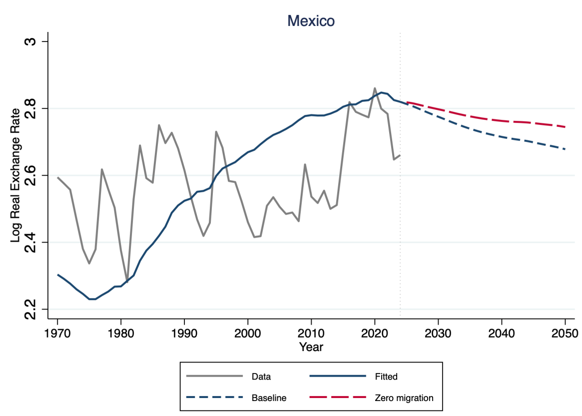
(b) Full-age distribution approach



(c) Alternative fertility scenario



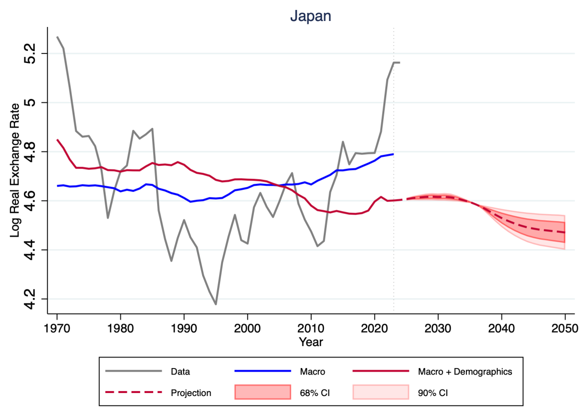
(d) Alternative migration scenario



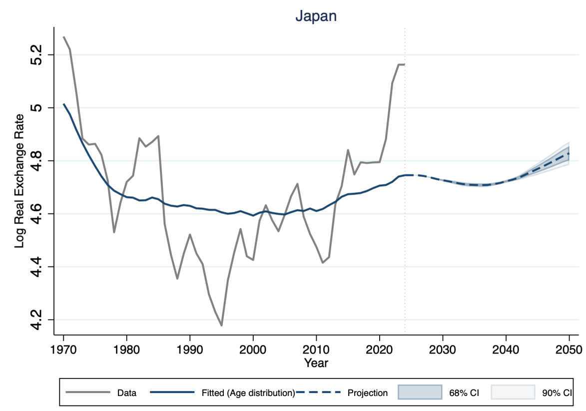
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C3: Real exchange rate projections for Japan

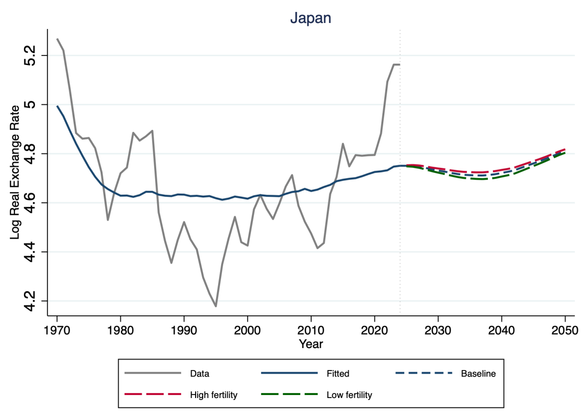
(a) Baseline projection



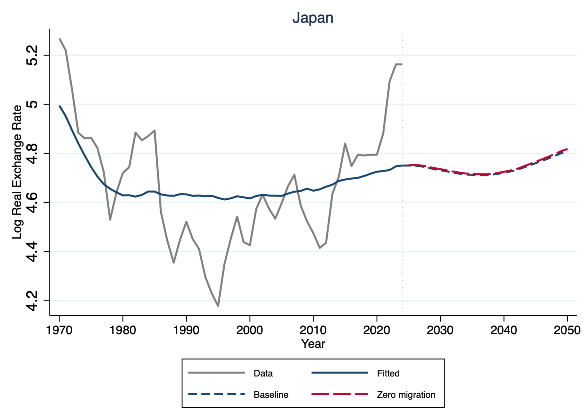
(b) Full-age distribution approach



(c) Alternative fertility scenario



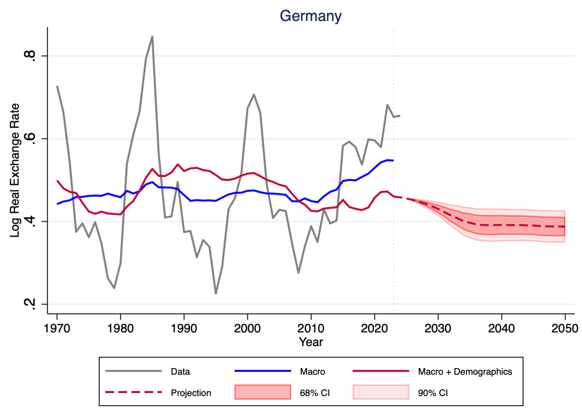
(d) Alternative migration scenario



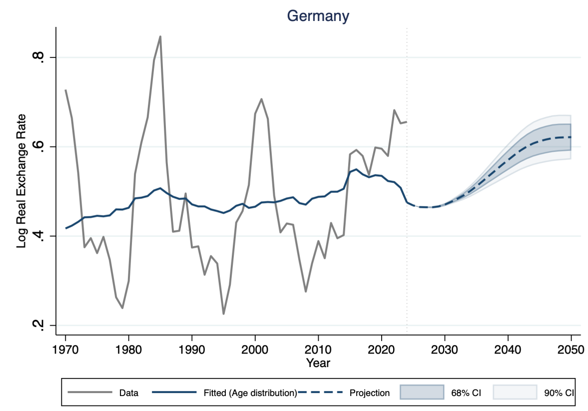
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C4: Real exchange rate projections for Germany

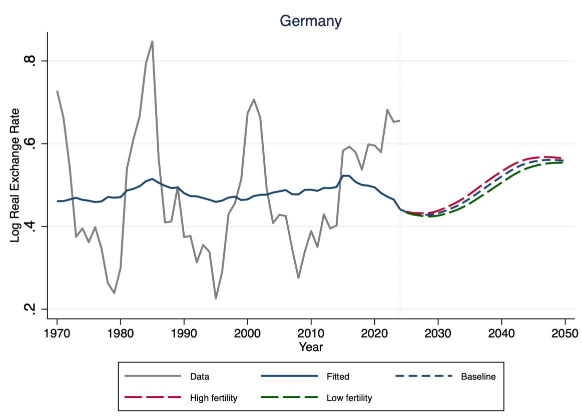
(a) Baseline projection



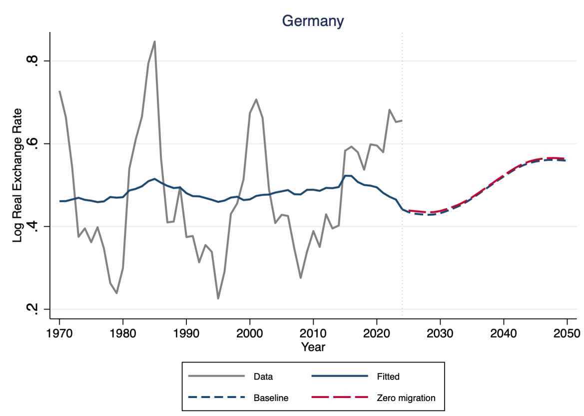
(b) Full-age distribution approach



(c) Alternative fertility scenario



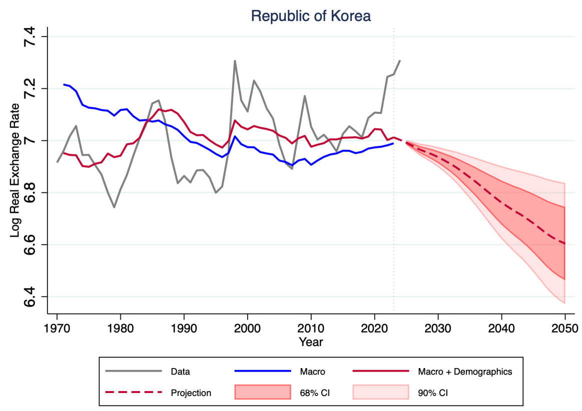
(d) Alternative migration scenario



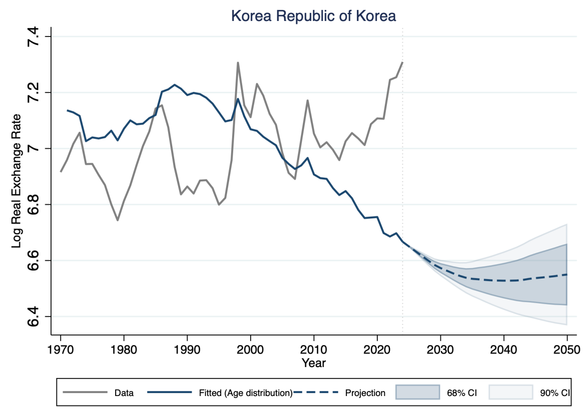
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C5: Real exchange rate projections for Korea

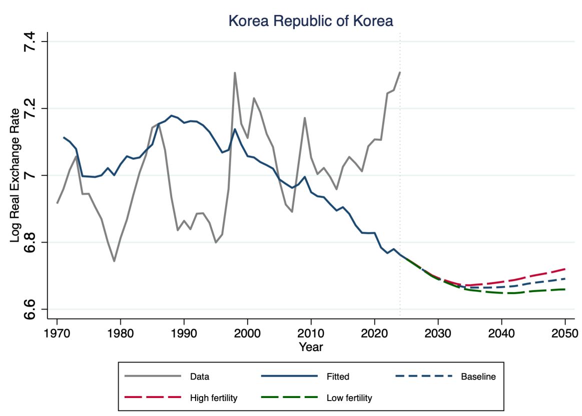
(a) Baseline projection



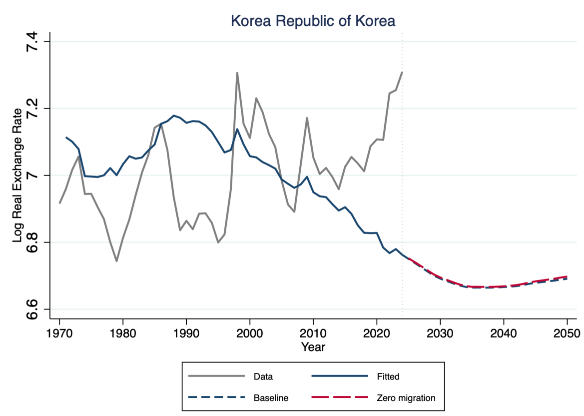
(b) Full-age distribution approach



(c) Alternative fertility scenario



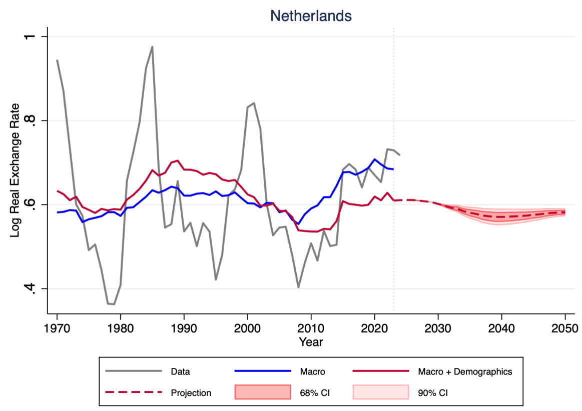
(d) Alternative migration scenario



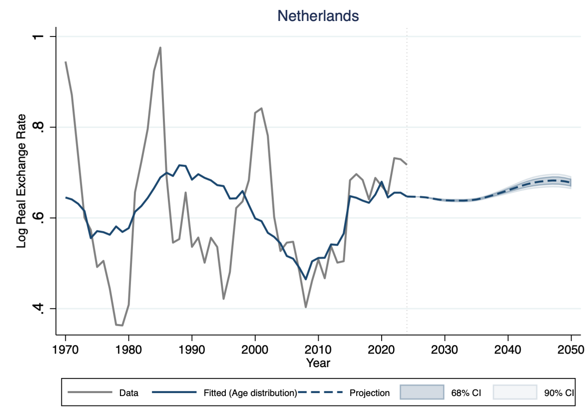
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C6: Real exchange rate projections for Netherlands

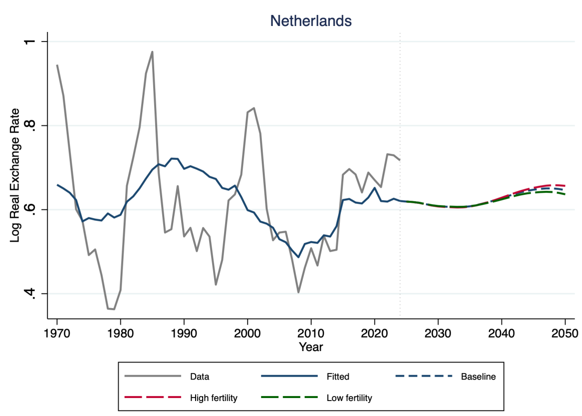
(a) Baseline projection



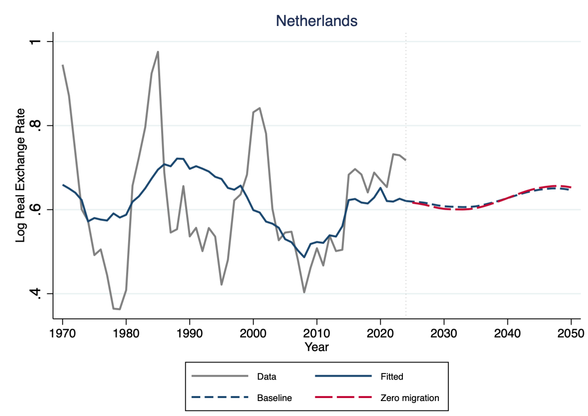
(b) Full-age distribution approach



(c) Alternative fertility scenario



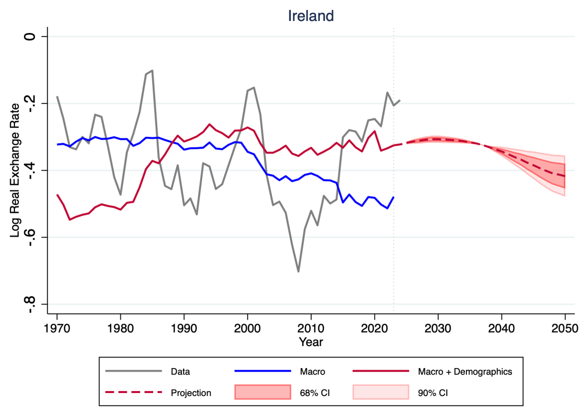
(d) Alternative migration scenario



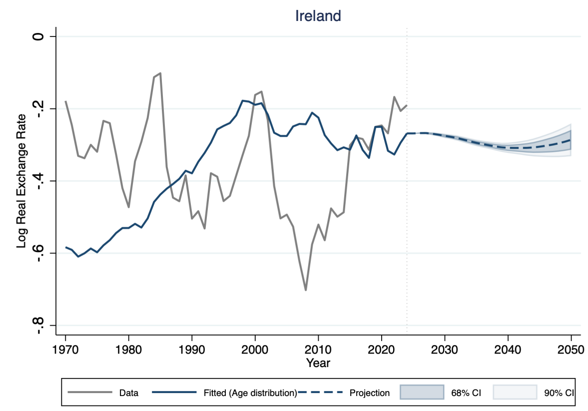
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C7: Real exchange rate projections for Ireland

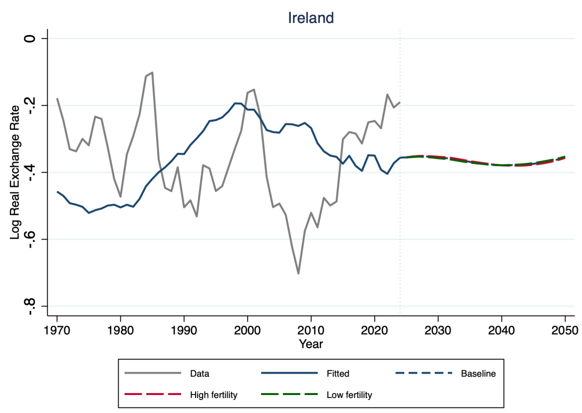
(a) Baseline projection



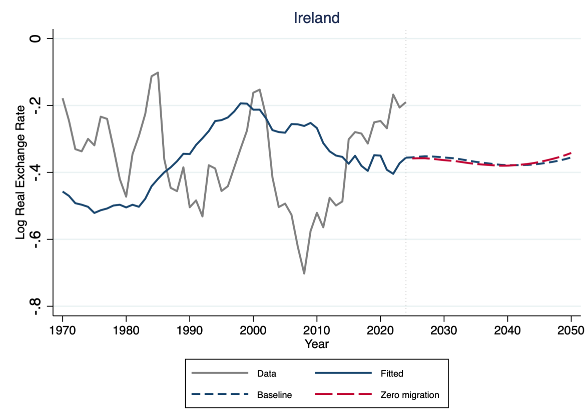
(b) Full-age distribution approach



(c) Alternative fertility scenario



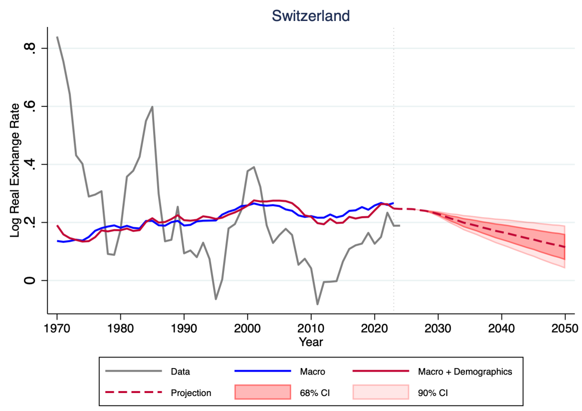
(d) Alternative migration scenario



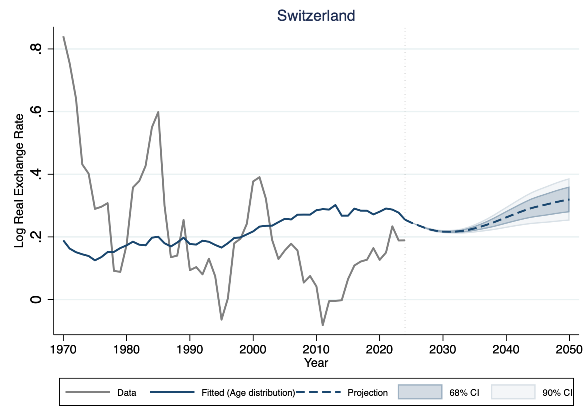
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C8: Real exchange rate projections for Switzerland

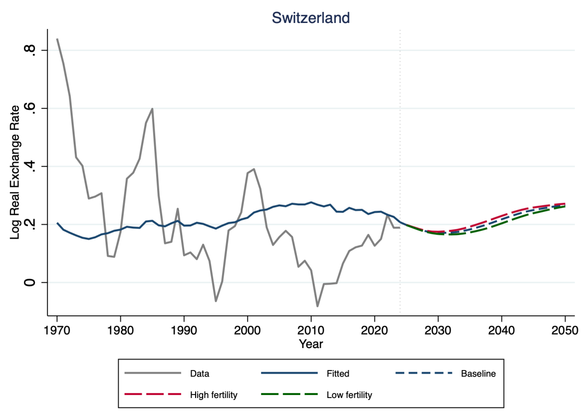
(a) Baseline projection



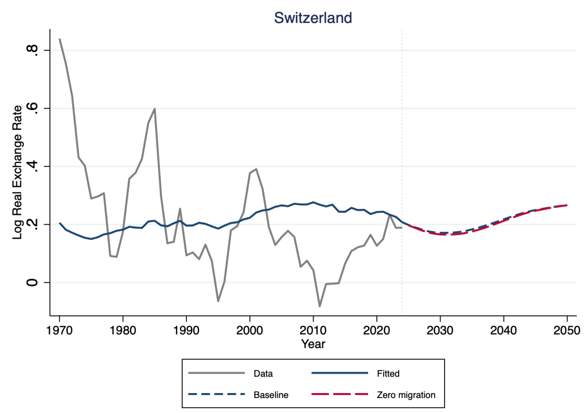
(b) Full-age distribution approach



(c) Alternative fertility scenario



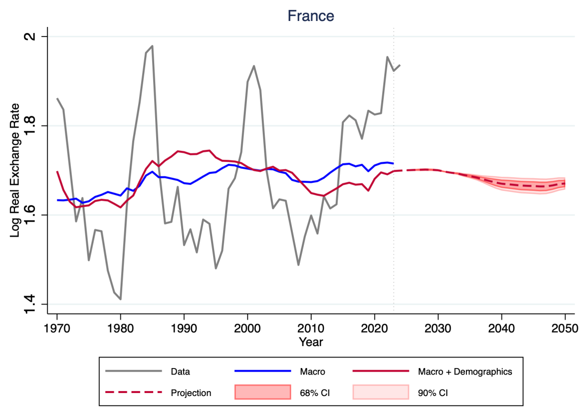
(d) Alternative migration scenario



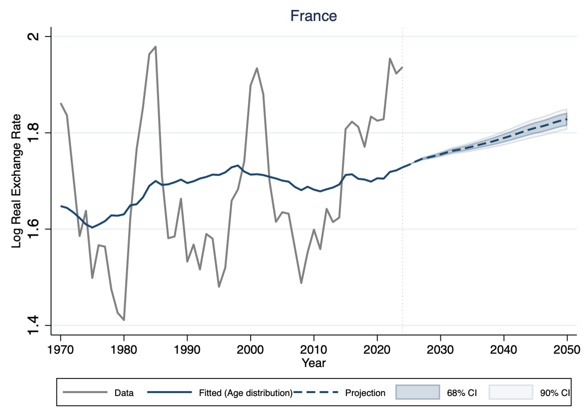
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C9: Real exchange rate projections for France

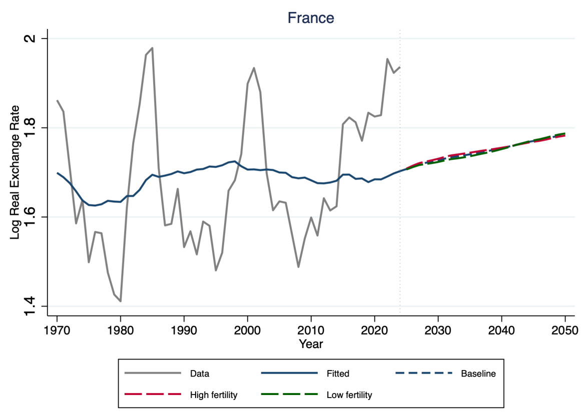
(a) Baseline projection



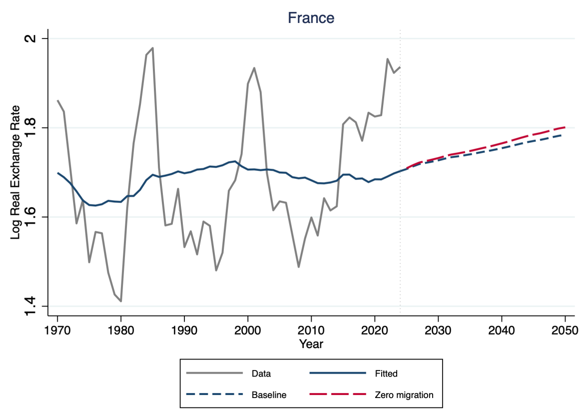
(b) Full-age distribution approach



(c) Alternative fertility scenario



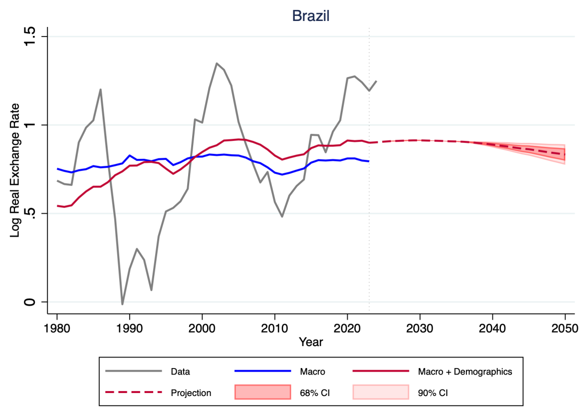
(d) Alternative migration scenario



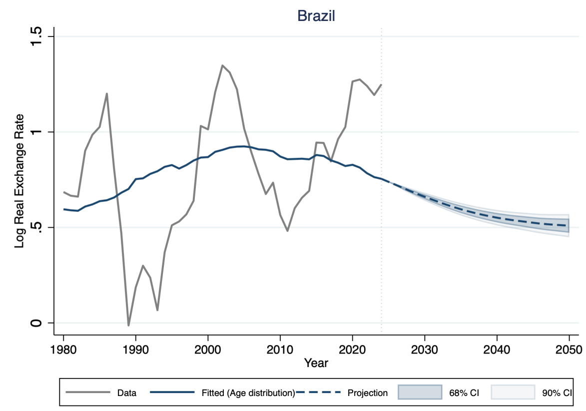
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C10: Real exchange rate projections for Brazil

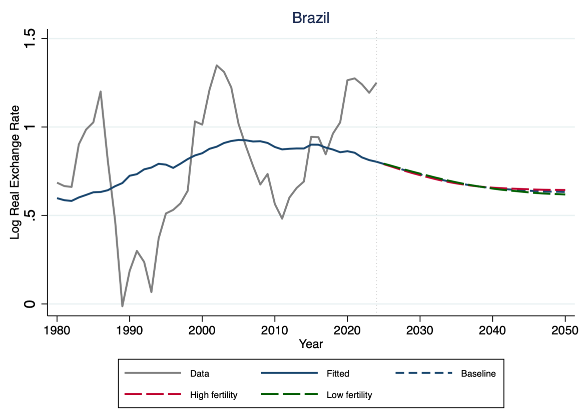
(a) Baseline projection



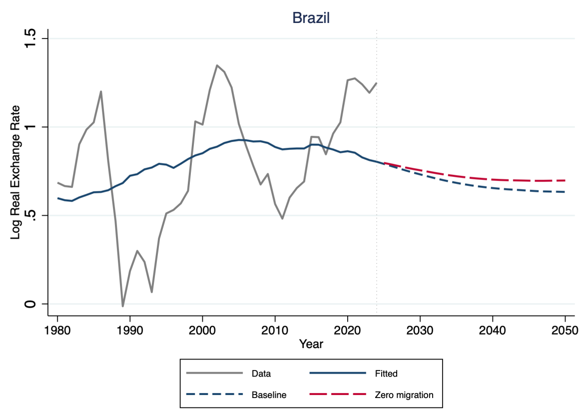
(b) Full-age distribution approach



(c) Alternative fertility scenario



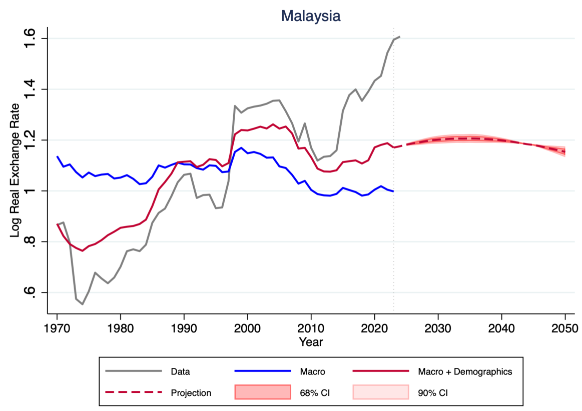
(d) Alternative migration scenario



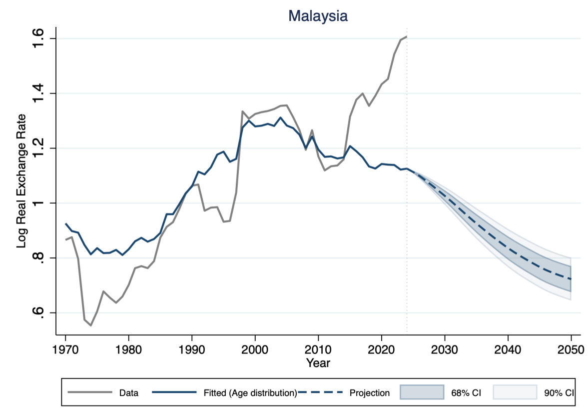
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C11: Real exchange rate projections for Malaysia

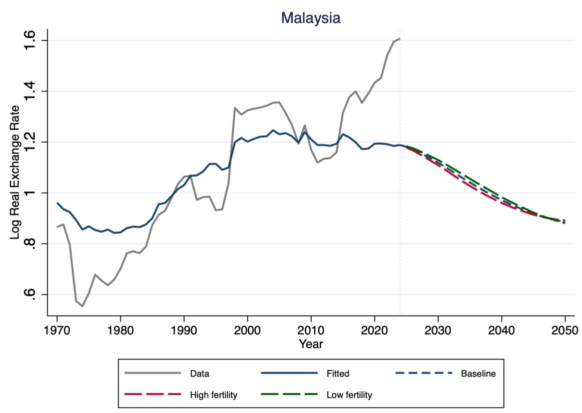
(a) Baseline projection



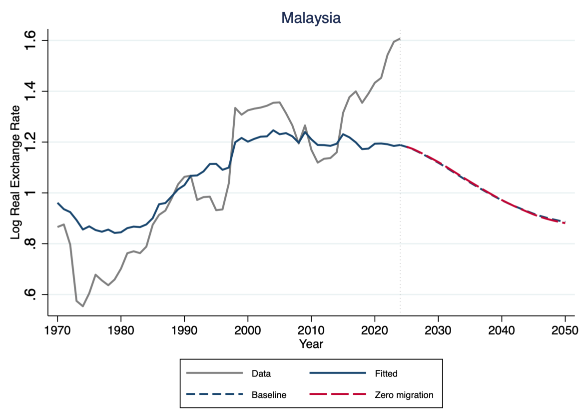
(b) Full-age distribution approach



(c) Alternative fertility scenario



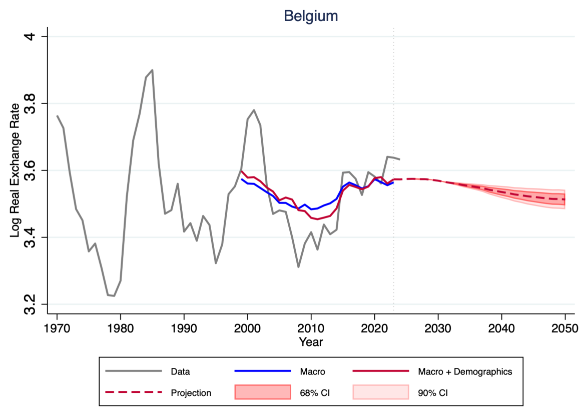
(d) Alternative migration scenario



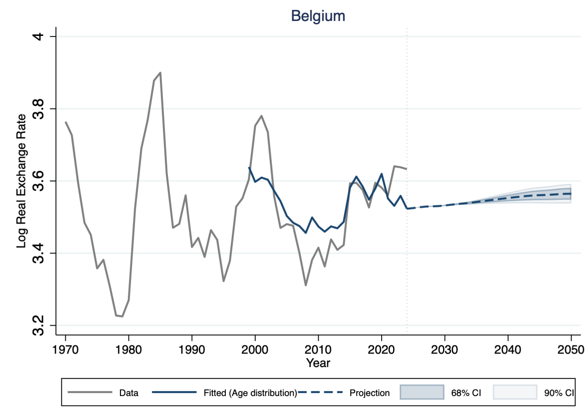
Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

Figure C12: Real exchange rate projections for Belgium

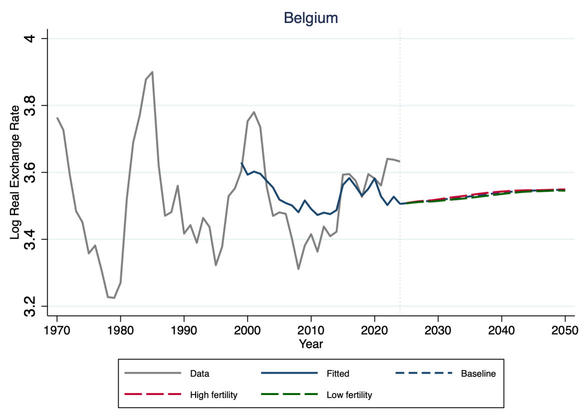
(a) Baseline projection



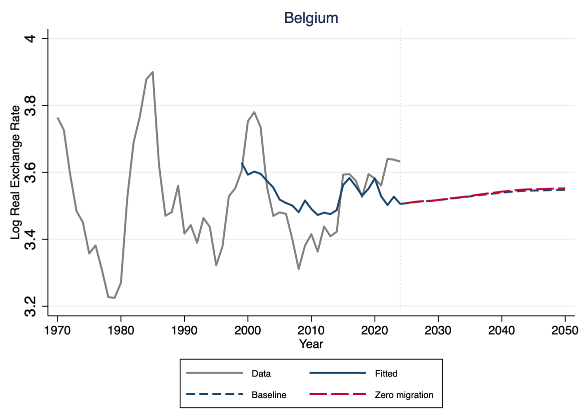
(b) Full-age distribution approach



(c) Alternative fertility scenario



(d) Alternative migration scenario



Note: This figure shows the in-sample fit of the real exchange rate (solid lines) and projections for 2025–2050 (dashed lines). Projections are based on (a) the baseline specification using the estimated coefficients reported in Table 3; (b) a flexible demographic specification using population distribution coefficients in Figure 3, following Higgins (1998); (c) the same specification as in (b), allowing for favorable (high-fertility) and unfavorable (low-fertility) scenarios; and (d) the same specification as in (b), assuming no migration. All population data are drawn from the 2024 UN World Population Prospects.

D Theoretical Rationales

D.1 Model setup

Our empirical results indicate that population aging appreciates the real exchange rate even after controlling for productivity. To rationalize this finding, we construct a parsimonious two-period overlapping-generations model of a small open economy with tradable and non-tradable sectors. The purpose of the model is not to provide a fully quantitative framework, but rather to isolate the demographic mechanisms that remain once productivity effects are controlled for in the data. Accordingly, the model abstracts from endogenous TFP adjustment and therefore shuts down the Balassa–Samuelson channel by construction. The emphasis instead is on three non-productivity mechanisms: a saving–investment channel, a non-tradables-demand channel, and a complementary labor-supply channel.

D.1.1 Demographics

Households live for two periods: young age ($i = 1$) and old age ($i = 2$). Let N_t denote the size of the young generation at time t, which evolves according to

$$N_{t+1} = (1 + n_t)N_t, \tag{A.1}$$

where n_t is the population growth rate. A decline in n_t captures population aging induced, for example, by lower fertility. The old-age dependency ratio is

$$D_t \equiv \frac{N_{t-1}}{N_t} = \frac{1}{1 + n_{t-1}}. \tag{A.2}$$

Thus, lower population growth implies a higher dependency ratio.

D.1.2 Households

Households derive lifetime utility from consumption when young and when old:

$$U_t = u(C_{1,t}) + \beta u(C_{2,t+1}), \tag{A.3}$$

where $u(\cdot)$ is increasing and concave, and $\beta \in (0,1)$ is the discount factor.

When young, households work, consume, and save. Their period-t budget constraint is

$$P_t^{T,H} C_{1,t}^{T,H} + P_t^{T,F} C_{1,t}^{T,F} + P_t^N C_{1,t}^N + S_t = W_t, \tag{A.4}$$

where $P_t^{T,H}$, $P_t^{T,F}$, and P_t^N are the price of tradable goods produced in the home country, that of imported foreign tradable goods, and that of non-tradable goods, respectively. S_t is savings and W_t is wages.

When old, households do not work and finance consumption out of accumulated assets:

$$P_{t+1}^{T,H} C_{2,t+1}^{T,H} + P_{t+1}^{T,F} C_{2,t+1}^{T,F} + P_{t+1}^N C_{2,t+1}^N = (1 + r_{t+1}) S_t. \tag{A.5}$$

Consumption is aggregated in two stages. First, domestically produced and imported tradable goods are combined into a tradable composite:

$$C_{i,t}^T = \left[\eta^{\frac{1}{\phi}} (C_{i,t}^{T,H})^{\frac{\phi-1}{\phi}} + (1-\eta)^{\frac{1}{\phi}} (C_{i,t}^{T,F})^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}, \tag{A.6}$$

where $\eta \in (0,1)$ and $\phi > 0$ is the elasticity of substitution between home and foreign tradables. The associated price index is

$$P_t^T = \left[\eta (P_t^{T,H})^{1-\phi} + (1-\eta)(P_t^{T,F})^{1-\phi} \right]^{\frac{1}{1-\phi}}. \tag{A.7}$$

Second, the tradable composite and non-tradable goods are combined into the final consumption bundle:

$$C_{i,t} = \left[\omega_i^{\frac{1}{\theta}} (C_{i,t}^T)^{\frac{\theta-1}{\theta}} + (1-\omega_i)^{\frac{1}{\theta}} (C_{i,t}^N)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \qquad i \in \{1,2\}, \tag{A.8}$$

where $\theta > 0$ is the elasticity of substitution between tradables and non-tradables and $\omega_i \in (0,1)$ is the age-specific weight on tradables. To capture the idea that older households devote a larger expenditure share to services such as health care and other age-related non-tradables, we assume $\omega_2 < \omega_1$. That is, old households place a relatively larger expenditure weight on non-tradables than young households.

The corresponding demand functions are

$$C_{i,t}^{T,H} = \eta \left(\frac{P_t^{T,H}}{P_t^T} \right)^{-\phi} C_{i,t}^T, \tag{A.9}$$

$$C_{i,t}^{T,F} = (1-\eta) \left(\frac{P_t^{T,F}}{P_t^T} \right)^{-\phi} C_{i,t}^T, \tag{A.10}$$

and

$$C_{i,t}^T = \omega_i \left(\frac{P_t^T}{P_{i,t}} \right)^{-\theta} C_{i,t}, \tag{A.11}$$

$$C_{i,t}^N = (1-\omega_i) \left(\frac{P_t^N}{P_{i,t}} \right)^{-\theta} C_{i,t}, \tag{A.12}$$

where the age-specific consumption price index is

$$P_{i,t} = \left[\omega_i (P_t^T)^{1-\theta} + (1-\omega_i)(P_t^N)^{1-\theta} \right]^{\frac{1}{1-\theta}}. \tag{A.13}$$

D.1.3 Firms

Tradable goods sector. The domestic tradable good is produced with capital and labor according to

$$Y_t^{T,H} = A^T (K_t^T)^\alpha (L_t^{T,H})^{1-\alpha}, \qquad 0 < \alpha < 1, \tag{A.14}$$

where A^T is exogenous productivity.[2] Firms solve

$$\max_{K_t^T, L_t^{T,H}} \Pi_t^{T,H} = P_t^{T,H} Y_t^{T,H} - W_t L_t^{T,H} - R_t K_t^T, \tag{A.15}$$

which yields

$$W_t = P_t^{T,H} (1-\alpha) A^T \left(\frac{K_t^T}{L_t^{T,H}} \right)^\alpha, \tag{A.16}$$

$$R_t = P_t^{T,H} \alpha A^T \left(\frac{K_t^T}{L_t^{T,H}} \right)^{\alpha - 1}. \tag{A.17}$$

Capital evolves according to

$$K_{t+1}^T = I_t + (1-\delta) K_t^T, \tag{A.18}$$

where δ is the depreciation rate.

Non-tradable goods sector. For simplicity, the non-tradable sector is labor intensive and uses labor only:[3]

$$Y_t^N = A^N L_t^N. \tag{A.19}$$

[2] By keeping productivity fixed, the model abstracts from demographic effects that operate through TFP adjustment. This is consistent with the empirical specification, which controls for productivity separately.

[3] This reflects the empirical evidence that non-tradable sector is largely composed of the service sector, which is labor-intensive (e.g., Groneck and Kaufmann, 2017).

Firms solve

$$\max_{L_t^N} \Pi_t^N = P_t^N Y_t^N - W_t L_t^N, \tag{A.20}$$

implying

$$W_t = A^N P_t^N. \tag{A.21}$$

This condition implies that higher wages translate directly into a higher relative price of non-tradables.

D.1.4 Real exchange rates

We assume the law of one price for tradables:

$$P_t^{T,H} = E_t P_t^{T,H,*}, \tag{A.22}$$

where E_t is the nominal exchange rate, defined as home currency per unit of foreign currency. The real exchange rate is

$$RER_t = \frac{E_t P_t^*}{P_t}, \tag{A.23}$$

where P_t and P_t^* denote the aggregate consumer price indices at home and abroad. Under this definition, a decline in RER_t corresponds to a real appreciation of the home currency. Because tradable prices are pinned down by world markets, demographic effects on the real exchange rate operate through the domestic price level, in particular through the price of non-tradables, and through the external-balance implications of saving and investment.

D.1.5 Market clearing conditions

Labor markets Only young households supply labor, so total labor supply is

$$L_t \equiv L_t^{T,H} + L_t^N = N_t. \tag{A.24}$$

Goods markets. The non-tradable market clears:

$$Y_t^N = N_t C_{1,t}^N + N_{t-1} C_{2,t}^N. \tag{A.25}$$

For domestically produced tradables,

$$Y_t^{T,H} = N_t C_{1,t}^{T,H} + N_{t-1} C_{2,t}^{T,H} + X_t, \tag{A.26}$$

where X_t denotes exports. Imports are

$$M_t = N_t C_{1,t}^{T,F} + N_{t-1} C_{2,t}^{T,F}. \tag{A.27}$$

Finally, the aggregate resource constraint is:

$$P_t^{T,H} Y_t^{T,H} + P_t^N Y_t^N = P_t^{T,H} C_t^{T,H} + P_t^{T,F} C_t^{T,F} + P_t^N C_t^N + I_t + TB_t, \tag{A.28}$$

where $TB_t = P_t^{T,H} X_t - P_t^{T,F} M_t$.

D.2 Demographic changes and the real exchange rate

We now use the model to clarify how demographic change affects the real exchange rate. Because the empirical specification controls for productivity, we focus on the channels that operate independently of TFP. The main mechanisms are a saving–investment channel and a non-tradables-demand channel. A labor-supply channel complements these effects by amplifying the response of non-tradable prices.

D.2.1 Saving–investment channel

The first mechanism operates through the external balance. Demographic change affects the real exchange rate by altering both aggregate saving and investment, which together determine the trade balance ($TB_t = S_t^{\text{agg}} - I_t$). As outlined in Section D.1.2, young households are net savers, whereas old households run down assets accumulated earlier in life. Aggregate saving at time t can therefore be written as the saving of the young minus the dissaving of the old:

$$\begin{aligned} S_t^{\text{agg}} &= N_t \left(W_t - P_{1,t} C_{1,t} \right) - N_{t-1} P_{2,t} C_{2,t} \\ &= N_t \left(S_t - D_t \, P_{2,t} C_{2,t} \right), \end{aligned} \tag{A.29}$$

where $P_{i,t}C_{i,t}$ denotes total expenditure on the composite consumption bundle of age group i. A rise in the dependency ratio shifts the population composition toward dissaving households and therefore tends to reduce aggregate saving.

At the same time, lower population growth reduces the expected future labor force and hence lowers desired capital accumulation in the tradable sector. From equation (A.14), the marginal product of capital is

$$MP_{K,t+1} = \alpha A^T \left(\frac{L_{t+1}^{T,H}}{K_{t+1}^T} \right)^{1-\alpha}. \tag{A.30}$$

A smaller future labor force lowers $MP_{K,t+1}$ and thereby reduces current investment demand.

The effect of aging on the trade balance, and ultimately on the real exchange rate, therefore depends on the relative magnitudes of the decline in aggregate saving and the decline in investment. If the fall in saving dominates, external surpluses shrink and appreciation pressure emerges. If the fall in investment dominates, the effect is weaker and can in principle go in the opposite direction. Our empirical results suggest that, on average across countries, the appreciation effect dominates.

This logic is also consistent with the age-distribution estimates in the main text: a higher share of older cohorts, who are more likely to dissave, is associated with real appreciation, whereas larger working-age shares are associated with real depreciation.

D.2.2 Non-tradables-demand channel

The second mechanism operates through the composition of demand. Aggregate demand for non-tradables is

$$\begin{aligned} C_t^N &= N_t C_{1,t}^N + N_{t-1} C_{2,t}^N \\ &= N_t \left(C_{1,t}^N + D_t C_{2,t}^N \right). \end{aligned} \tag{A.31}$$

Using total population $N_t^{\text{tot}} (= N_t + N_{t-1} = N_t(1 + D_t))$, this can be rewritten as

$$C_t^N = \frac{N_t^{\text{tot}}}{1 + D_t} \left(C_{1,t}^N + D_t C_{2,t}^N \right). \tag{A.32}$$

Holding total population fixed, the partial derivative with respect to the dependency ratio is

$$\left. \frac{\partial C_t^N}{\partial D_t} \right|_{N_t^{\text{tot}}} = \frac{N_t^{\text{tot}}}{(1 + D_t)^2} \left(C_{2,t}^N - C_{1,t}^N \right). \tag{A.33}$$

Because old households place a larger expenditure weight on non-tradables, the model implies $C_{2,t}^N > C_{1,t}^N$ as far as age-specific consumptions do not offset this shift. Hence,

$$\left. \frac{\partial C_t^N}{\partial D_t} \right|_{N_t^{\text{tot}}} > 0. \tag{A.34}$$

Population aging therefore raises aggregate demand for non-tradables through composition effects alone.

Given market clearing in equation (A.25), stronger demand for non-tradables raises the equilibrium price P_t^N unless supply is perfectly elastic. Since a higher non-tradable price raises the domestic price level, it follows that

$$\frac{\partial RER_t}{\partial D_t} = \frac{\partial RER_t}{\partial P_t} \frac{\partial P_t}{\partial P_t^N} \frac{\partial P_t^N}{\partial C_t^N} \frac{\partial C_t^N}{\partial D_t} < 0, \tag{A.35}$$

where $\partial RER_t / \partial P_t < 0$ under our definition of the real exchange rate. Thus, the non-tradables-demand channel implies that aging appreciates the real exchange rate.

D.2.3 Labor-supply channel

A complementary mechanism operates through labor supply. Because only the young work, an increase in the dependency ratio reduces aggregate labor supply:

$$L_t = N_t = \frac{N_{t-1}}{D_t}. \tag{A.36}$$

With labor market clearing, a decline in L_t raises the equilibrium wage W_t. Equation (A.21) then implies

$$\frac{\partial P_t^N}{\partial W_t} = \frac{1}{A^N} > 0. \tag{A.37}$$

Since tradable prices are pinned down by world markets, higher wages mainly raise the price of non-tradables and therefore the domestic CPI. Accordingly,

$$\frac{\partial RER_t}{\partial D_t} = \frac{\partial RER_t}{\partial P_t} \frac{\partial P_t}{\partial P_t^N} \frac{\partial P_t^N}{\partial W_t} \frac{\partial W_t}{\partial D_t} < 0. \tag{A.38}$$

This labor-supply channel is not the primary focus of the empirical interpretation, but it reinforces the appreciation effects generated by the saving–investment and demand-composition channels.

In sum, the model highlights three mechanisms through which population aging can appreciate the real exchange rate once productivity effects are held fixed. Aging shifts expenditure toward non-tradable goods, changes the saving–investment balance through the life cycle, and raises labor scarcity in labor-intensive non-tradable sectors. These forces provide a coherent theoretical rationale for the empirical evidence in the main text.