# Real interest rates and population growth across generations

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Working Paper 22.04

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June, 2022

**Abstract**

This paper empirically examines the effect of population growth on real interest rates. Although this effect is well founded in macroeconomic theory, the corresponding empirical results have been rather tenuous. Demographic interest rate theories are typically based on long-term relationships across generations. Accordingly, key population trends appear often only across decades, if not centuries, worth of data. To capture these trends, we distinguish between population growth resulting from a birth surplus and net migration. Within a panel covering 12 countries and the years since 1820, we find robust evidence that the birth surplus significantly affects the real interest rate.

*JEL classification: E43; E52; J11*

*Keywords: demographics; demographic transition; population growth; real interest rate*

*We are grateful to Petra Gerlach, Jörn Tenhofen, Kenneth D. West (the editor) as well as three anonymous referees for their helpful and constructive comments.The views, opinions, findings, and conclusions or recommendations expressed in this paper are strictly those of the authors. They do not necessarily reflect the views of the Swiss National Bank. The Swiss National Bank takes no responsibility for any errors or omissions in, or for the correctness of, the information contained in this paper.

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# 1 Introduction

Over recent decades, real interest rates have declined in many countries. In the academic literature, the contemporaneous reduction in population growth and ageing societies have been considered a possible explanation for this decline. However, despite the popularity of this "demographic interest rate theory", the empirical link between population variables and real interest rates has been rather tenuous. For example, in Borio *et al.* (2017, 2019), basic total population growth had a barely significant effect on the level of long-term real interest rates. Furthermore, the corresponding empirical effect has been surprisingly unstable when splitting the sample into subperiods covering different international currency systems, such as the classical gold standard (1870-1914), the interwar period (1919-1939), or the post-war era (since 1945). A similar result arose with the dependency ratio.

This paper emphasizes that the "demographic interest rate theory" is derived from relationships across generations and, therefore, typically associated with gradual population changes across long time periods. This observation might not be innocuous. More specifically, the empirical literature has hitherto neglected the distinction, emphasized by the so-called "demographic equation", between population growth resulting from a birth surplus—i.e. the difference between birth and mortality rates—and net migration—i.e. the difference between immigration and emigration (Peston and Bouvier, 2010, pp.5-7).[1] This distinction could be crucial because the birth surplus typically captures secular developments in mortality and birth rates as described by the well-known demographic transition theory (see i.e. Peston and Bouvier, 2010, pp.271-274). Conversely, net migration rates are often quite volatile and react relatively vividly to extraordinary events, such as wars and political and economic crises (Peston and Bouvier, 2010, pp.199ff.; Zaiceva and Zimmermann, 2016, pp.122-133). Therefore, the growth rate of the total population does not only capture the secular decline in mortality and birth rates observed around the world (see i.e. Zaiceva and Zimmermann, 2016, pp.127ff.). It is probably these long-term demographic trends, rather than the more erratic movements in migration, that can explain the abovementioned secular decline in real interest rates.

Against this background, this paper endeavors to contribute to the literature by studying the long-term relationship between the main components of population growth and real interest rates. Therefore, we collected the corresponding data for a sample covering 12 countries and annual observations beginning in 1820. Furthermore, the abovementioned demographic transition trends are identified by splitting total population growth rates into a component reflecting the development of birth and mortality rates and net migration. In a related vein, we have also collected data for the dependency ratio—i.e. the size of the population aged 19 and below or 65 and above as a fraction of the working-age population between 20 and 64. We also consider the difference between a young-age (referring to those aged 19 years or under) and an old-age dependency ratio (referring to those aged 65 years or above). By means of panel data regressions across countries and years, we find a positive and statistically significant relationship between long-term real interest rates and population growth resulting from the birth surplus. Significant effects arise also with the increase of the old-age cohorts in the dependency ratio. Conversely, there seems to be no strong and stable effect of total population growth and net migration on real interest rates. Taken together, these results seem to support the view, consistent with standard macroeconomic theory, that secular population trends, reflected by the gradual changes in the birth surplus and the ageing of societies, can affect the real interest rate. Applied to the most recent decades, our results indicate that these trends are associated with a decline in the long-term real interest rate of roughly one to two percentage points.

The paper is organized as follows. To set the context, the next section provides a synoptic review of the theoretical and empirical literature on the link between population growth

[1] The "birth surplus" is also called the "natural rate of population growth".

and interest rates. Based on this literature, Section 3 develops the empirical strategy, and Section 4 discusses the data. Section 5 presents the empirical results. Section 6 summarizes and concludes.

## 2 Related literature

Real interest rates have been the subject of an ancient debate in economics. In particular, the notion that positive real interest rates are a necessary side effect of productivity gains on private capital investments can be traced back to classical economists, such as Adam Smith (1776, ch.II.4). Without participation in these expected gains, investors would, indeed, have little incentive to postpone consumption and bear the financial risks of funding economic projects. An alternative to the classical theory of the real interest rate emerged with Paul Samuelson's (1958) seminal contribution to the overlapping generations (OLG) model, within which demographic variables matter (see also Lee, 2020). In particular, OLG frameworks recognise that society consists of generations of individuals, who do not produce and consume forever but are nevertheless connected across time through intergenerational relationships. Demographic developments can change the size and composition of subsequent generations and, in turn, affect their production and consumption possibilities. In a very rudimentary scenario, a growing population may expand the labor supply and, hence, increase the future potential output of the economy. Therefore, a kind of "demographic return" arises, which provides a broader basis for paying real interest rates to the current generation compared with a society witnessing demographic stagnation.[2]

The main interest rate determinants have recently resurfaced to attribute the persistently low, and in some countries even negative, nominal and real rates to a so-called "secular stagnation" in economic progress and population growth. The consequences of a permanent slowdown in economic progress and lower productivity gains are discussed in, e.g., Summers (2014, 2015) and Gordon (2014). In a similar vein, the effect of a secular decline in population growth on interest rates has received renewed attention amid the current ageing of societies in many parts of the world (see i.e. Ikeda and Saito, 2014; Gagnon *et al.*, 2016; Aksoy *et al.*, 2019; Busetti and Caivano, 2019; Eggertsson *et al.*, 2019a; Eggertsson *et al.*, 2019b; Ferrero *et al.*, 2019; Papetti, 2021). Although population structures within which members of the old generation outnumber members of the young generation are historically unprecedented, they have long been anticipated by the so-called "demographic transition theory", which describes the interrelated trends in birth and mortality rates since the dawn of the modern age (see, e.g., Peston and Bouvier, 2010, pp.271-274; Bloom and Luca, 2016, pp.14ff.). In particular, preindustrial societies typically subsisted in a "Malthusian world", where birth and mortality rates were high and, as a result, the growth rate of the population remained low. Since around the eighteenth century, improvements in nutrition, medical progress, such as the discovery of vaccines, and better hygienic standards have gradually reduced mortality rates (Peston and Bouvier, 2010, pp.125ff.; Bloom and Luca, 2016, p.16.). Because birth rates remained initially high, the early stages of industrialization were characterized by a marked upsurge in the birth surplus and, hence, population growth (Bloom and Luca, 2016, p.16.). Depending on the development of a country, this upsurge began as early as the second part of the eighteenth century but in some cases substantially later (Bloom and Luca, 2016, p.15.). Eventually, the combination between higher income, more generous pension systems, easier access to contraception, improvements in the status of women, and changing cultural attitudes towards having a family gave rise to declining birth rates (Peston and Bouvier, 2010, pp.59ff.; Bloom and Luca, 2016, pp.14ff.). During the last decades, these interrelated

[2]For a textbook introduction of this simple effect of population growth in an OLG environment, see Champ *et al.* (2016, pp.41ff.). Eggertsson *et al.* (2019a, pp.333ff.) and Eggertsson *et al.* (2019b, pp.8ff.) provide up-to-date versions of the OLG model to show that relatively high population growth rates are typically associated with high expected real interest rates. Canton and Meijdam (1996) suggest that demographic effects on macroeconomic variables crucially depend on the degree to which the current generation cares about the well-being of future generations.

trends have reduced the birth surplus in economically advanced countries and resulted in ageing societies (Bloom and Luca, 2016, pp.5ff.).

Real interest rates typically also depend on a range of economic variables, especially productivity growth (Ikeda and Saito, 2014; Carvalho *et al.*, 2016; Gagnon *et al.*, 2016; Bielecki *et al.*, 2020; Aksoy *et al.*, 2020; Papetti, 2021). Moreover, according to Carvalho *et al.* (2016), changes in the birth surplus can have knock-on effects on the dependency ratio. In particular, whereas young-age dependency ratios have decreased since the nineteenth century, the relative size of the old-age cohort has increased markedly in many countries across recent decades. As the various population cohorts differ in terms of their propensity to save, a changing dependency ratio can affect the capital supply and, in turn, the real interest rates (see Carvalho *et al.*, 2016, p.209). In a similar vein, an increase in life expectations arguably puts downward pressure on real interest rates because savings have to increase to finance longer pension payments (Carvalho *et al.*, 2016, p.209). Finally, among other things, Bielecki *et al.* (2020) focused on the demographic effect of migration on the equilibrium rate of interest. Obviously, the exact effect depends on the circumstances and, especially, on the associated cross-border transfers of financial and human capital. However, insofar as mainly individuals of working age move to other countries, positive net-migration rates tend to lower the dependency ratio (Bielecki et al., 2020, p.18). Following the argument above, this should result in a lower real interest rate.

Although demographic developments can arise through several interrelated variables, their effect on the real interest rate is theoretically based on secular developments, that is changes across generations. Hitherto, this has not been fully recognized by the empirical literature. Many contributions do suggest that the equilibrium rate of interest has recently declined by around one to two percentage points due to demographic factors alone (Ikeda and Saito, 2014; Carvalho *et al.*, 2016; Favero *et al.*, 2016; Gagnon *et al.*, 2016; Aksoy *et al.*, 2019; Busetti and Caivano, 2019; Ferrero *et al.*, 2019; Bielecki *et al.*, 2020; Papetti, 2021). However, all these calibrations and estimations have analyzed the effect of ageing during the last couple of decades and, therefore, account for only a small part of the long-term story told by the relevant OLG models, as well as the demographic transition theory discussed above. A study covering more than one hundred years of data was provided by Lunsford and West (2019). In particular, they found stable and positive correlations between the short-term real interest rate and the growth rate of labor force hours as well as the size of the working age population in a sample covering the United States in the years after 1890.[3] This result stands in sharp contrast to the remarkably unstable effect of total population growth rates on long-term interest rates as found in the studies of Borio *et al.* (2017, 2019), which also employed data covering the very long term. Against this background, this paper suggests that total population growth rates encapsulate vastly different demographic components, such as the birth surplus and the effects of emigration and immigration, with very different effects on real interest rates. However, before turning to this issue, the next section describes the empirical strategy.

# 3 Empirical strategy

The literature discussed in Section 2 suggests that in a given country $j$ in year $t$, the expected real interest rate $r^e_{jt}$ is primarily a function of secular productivity increases $x_{jt}$ and the growth rate of the population $n_{jt}$, that is

$$r^e_{jt} = f(n_{jt}, x_{jt}) + \alpha_j + \alpha_t + \epsilon_{jt}, \tag{1}$$

[3] In Lunsford and West (2019), a broad range of other variables, including economic growth and total factor productivity (TFP), had no consistent effect on US real interest rates. For a US sample covering a period beginning in the nineteenth century, Hamilton *et al.* (2016) reported a similar result of a somewhat tenuous relationship between economic growth and the equilibrium level of the short-term interest rate. However, their study ignored demographic variables.

where $\epsilon_{jt}$ represents an error term with expectation zero, and $\alpha_j$ and $\alpha_t$ reflect error terms as pertaining to, respectively, country $j$ and year $t$.

Similar to Hamilton *et al.* (2016, pp.664ff.) and Borio *et al.* (2019, pp.3ff.), $r^e_{jt}$ reflects an ex-ante real interest rate, which depends on inflation expectations denoted by $\pi^e_{jt}$, and is (approximately) given by

$$r^e_{jt} \approx i_{jt} - \pi^e_{jt}. \tag{2}$$

Inserting (2) back into (1) and assuming a linear relationship of $f(n_{jt}, x_{jt}) = \beta_1 n_{jt} + \beta_2 x_{jt}$ yields a panel data equation given by

$$i_{jt} - \pi^e_{jt} = \alpha_j + \alpha_t + \beta_1 n_{jt} + \beta_2 x_{jt} + \epsilon_{jt}, \tag{3}$$

where $\beta_1$ and $\beta_2$ denote coefficients to be estimated, and $\epsilon_{jt}$ represents the usual stochastic error term.[4] In (3), $\alpha_j$ and $\alpha_t$ represent unobserved effects. These could capture, among other things, entrenched deviations in forming expectations. Such deviations can arguably arise from the long-lasting legacies of prevailing currency regimes or from global money and credit cycles (see i.e. Borio *et al.*m 2017, pp.6ff.). Although it is typically difficult to measure the corresponding trends and cycles, their impact upon real interest rates can be at least partially absorbed by the year-specific fixed effect $\alpha_t$ or fixed effects pertaining to specific countries $\alpha_j$ to capture, e.g., their idiosyncratic monetary traditions.[5]

Further to the discussion of Section 2, according to which demographic effects develop over many years, a long-term interest rate is probably appropriate for $i_{jt}$ (see also Section 4). Moreover, to quantify the real interest rate of $i_{jt} - \pi^e_{jt}$ in (3), $\pi^e_{jt}$ has to be determined. Concurrent with Borio *et al.* (2017, p.8; 2019, p.6.) and Lunsford and West (2019, p.123), expected inflation is calculated via a recursive projection of an AR(1) model estimated over a rolling sample of 20 years.[6] To match the long-term interest rate, our baseline specification employs one-sided moving averages of these inflation expectations over the future five years as the relevant horizon to determine $\pi^e_{jt}$. However, other time horizons are considered for robustness checks.[7]

The way in which real interest rates are empirically constructed has implications for the specification of the coefficient standard deviations. In particular, contemplating inflation across overlapping annual sequences comprising five years is likely to introduce moving-average terms into the residuals of (3). To control for these terms, a panel data version of variance–covariance matrices that are robust to arbitrary serial correlation within country clusters is used (Wooldridge, 2002, pp.152–153; 262-263).

[4]To account for the potential dynamic interaction and the endogeneity between macroeconomic variables, such as $i_{jt} - \pi^e_{jt}$ and $x_{jt}$, Aksoy *et al.* (2019, pp.196ff.) specified their empirical relationship as a panel vector autoregression (VAR) with demographic characteristics, such as population growth $n_{jt}$, as an exogenous variable. According to Aksoy *et al.* (2019, pp.199ff.), this approach is useful for forecasting, which is not the focus of this paper. However, adopting a panel VAR would not have changed the essence of the baseline results reported below. In particular, in a panel VAR, a significantly positive coefficient arises for the effect of population growth on real interest rates.

[5]The potential correlation between $\alpha_j$ as well as $\alpha_t$ and the observed regressors introduces a major econometric issue when estimating panel data regressions, such as (3), with random effects. In particular, the monetary traditions reflected by $\alpha_j$ or the global monetary trends and cycles potentially absorbed by $\alpha_t$ could be correlated with the growth rate of the population $n_{jt}$ or productivity $x_{jt}$ (see, e.g., Wooldridge, 2002, pp.265ff.). For the results of Section 5, standard Hausman tests (see Baltagi, 2013, ch. 4.3) applied to equation (3) provide indeed evidence against using random effects. For the sake of brevity, the corresponding results are not reported here but are available on request.

[6]The corresponding AR(1) model is given by $\pi_{jt} = \phi\pi_{j,t-1} + \psi_j + \psi_t + \zeta_{jt}$, where $\phi$ is a coefficient, $\psi_j$ and $\psi_t$ are fixed effects, and $\zeta_{jt}$ denotes a stochastic error term.

[7]The quantification of inflation expectations is a delicate step in determining the expected real interest rate. As an alternative to the approach employed in previous papers, we have also experimented with taking averages over the *observed* values of future inflation. Our main results are robust to this modification.

# 4 Demographic and economic data

To uncover the empirical impact of demographic variables upon real interest rates across generations, data covering decades and preferably even centuries are required. Although population censuses go back to ancient times, economic and financial data appeared much later and are often only available for a handful of countries with sufficiently stable borders, solid monetary frameworks, and early developed capital markets. In particular, such countries include Belgium, France, Norway, Sweden, Switzerland, the United Kingdom, and the United States, for which data on interest rates, inflation, and per capita economic growth go back to the first part of the nineteenth century. For a second group of countries, including Australia, Canada, Denmark, Finland, and the Netherlands, the corresponding joint sample covers the years from 1870 onwards. Taken together, data have been collected as far back as the year 1820 and for a sample encompassing 12 countries, which either are located in Europe or emerged from European settler colonies.[8]

Table 3 of Appendix A provides the details of the sources and the definitions of the variables used in the empirical analysis below. In brief, similar to Borio *et al.* (2017, 2019), the annual growth of the residential population is used as a potential variable to explain real interest rate developments. The size of the residential population since 1820, from which the corresponding growth rate – denoted by $\tilde{n}_{jt}$ – can be calculated, is reported for a large number of countries in the Maddison project database (see Bolt *et al.*, 2018). However, according to the demographic equation, a country's population can grow thanks to a birth surplus or positive net migration rates (see Peston and Bouvier, 2010, pp.5-7). To distinguish between birth surplus and net migration effects, data on crude birth and mortality rates are collected from Mitchell (1992, 1995, 1998) for the years before 1960, and from the World Development Indicators (WDI) of the World Bank for the years thereafter. The difference between these rates determines the birth surplus, denoted here by $\ddot{n}_{jt}$. Net migration rates, denoted by $\hat{n}_{jt}$, can be indirectly derived by subtracting the birth surplus from the growth rate of the residential population, e.g., $\hat{n}_{jt} = \tilde{n}_{jt} - \ddot{n}_{jt}$. Finally, to capture alternative channels through which population growth manifests itself, data on dependency ratios have been collected (see Table 4 of Appendix A). Further to the discussion above, we have also split the total dependency ratio into a young-age and an old-age component. Unfortunately, for most countries, data on life expectations are not available for the nineteenth century and, in some cases, not even for large parts of the twentieth century. Hence, to preserve the long-term coverage of the sample, life expectations are used only for robustness checks.

Regarding the financial and economic variables, the interest rate $i_{jt}$ is measured by the annual yields on long-term government bonds. The main source is Homer (1977) for the years before 1960 and the Organisation for Economic Co-operation and Development (OECD) for the years thereafter.[9] Inflation $\pi_{jt}$ is measured by the percentage change of the Consumer Price Index (CPI) as reported by Mitchell (1992, 1995, 1998) and, for recent decades, by the OECD.[10] Finally, across a large number of countries and for the years between 1820 and 2016, the Maddison project database reports the real GDP per capita, from which economic growth rates can be calculated. These per capita growth rates are used as a proxy for

[8] Germany is a major European country that is missing in our dataset. The reason is that Germany became a unified country only during the 1870s and witnessed substantial border changes and monetary interruptions during the twentieth century (including the separation between East and West Germany between 1945 and 1990). Owing to these historical disruptions, it is difficult to construct a coherent time series for the German population, economic growth, or level of interest rates. Similar disruptions inhibit a long-term empirical analysis for countries such as Japan or Russia. Furthermore, Spain and Italy offer only patchy interest rate data during the nineteenth century.

[9] Although the same sources provide data on short-term discount and money market interest rates, they are probably not ideal for capturing the intergenerational demographic effects on the secular behavior of interest rates. Similar to Borio *et al.* (2017, p.7f.), the main results of the next section focus on long-term interest rates.

[10] When available, the inflation data have been collected back to the year 1800, such that inflation expectations can be calculated, as described in Section 3, from the year 1820 onwards.

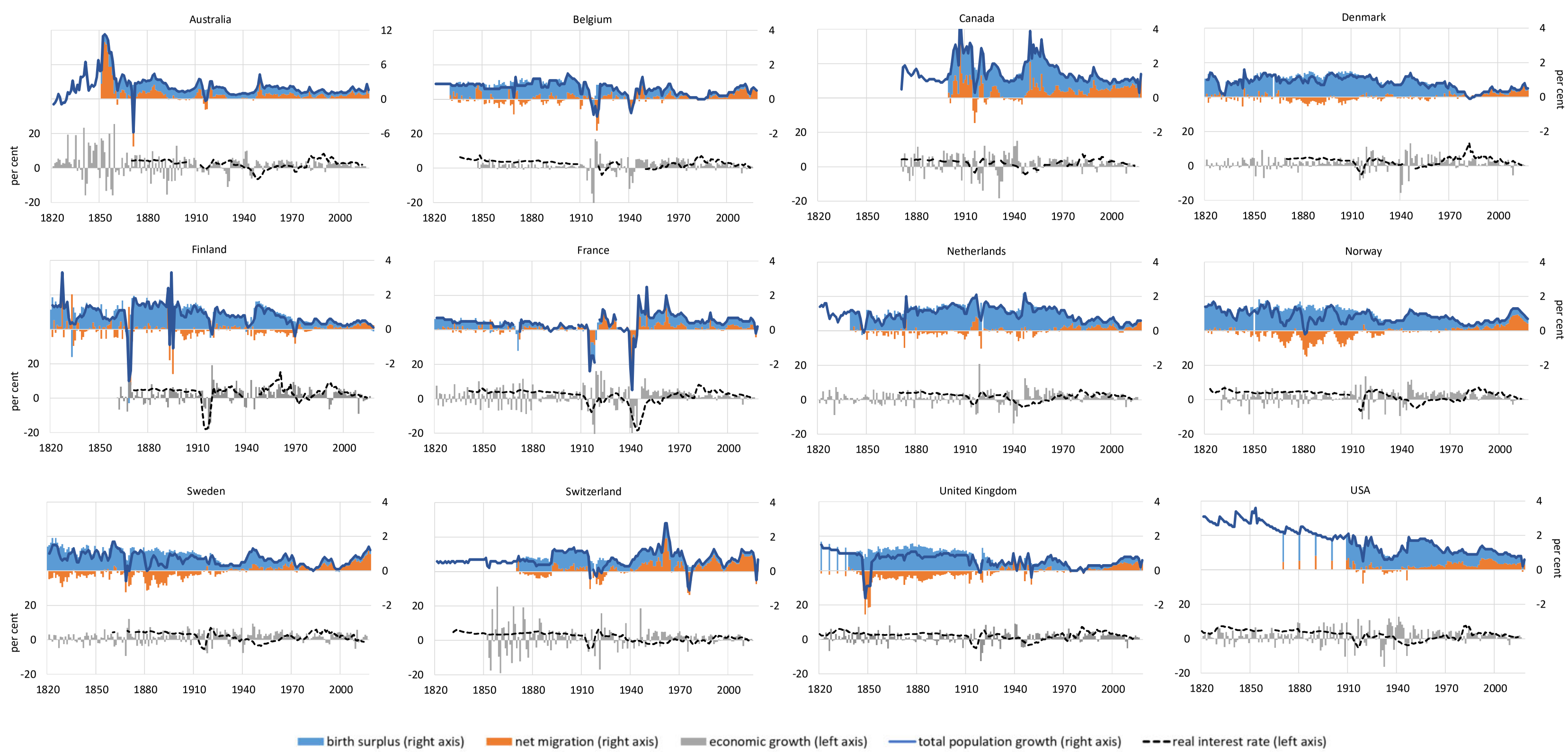
potential productivity gains on capital investments $x_{jt}$. Although alternative variables to proxy for $x_{jt}$ are available, e.g., the total factor productivity index reported in Bergeaud *et al.* (2016), these data do not go much further back than the twentieth century and, for the same reason as mentioned above, are used only for robustness checks.

Figure 2 provides an overview of the development of **real** interest rates (see lines in the bottom part of the graphs), real economic growth per capita (grey bars in the bottom part of the graphs), and the growth rates of the population and their components (line and areas in the top part of the graphs) for the 12 countries since 1820. Of note, real interest rates have been relatively stable. Nevertheless, they have also witnessed marked upsurges and downturns, especially in times of major political and economic instability. Above all, during and after World War I (1914-1918) and World War II (1939-1945), the belligerent countries often resorted to financial repression, which manifested itself in negative real interest rates to help finance the war effort. Similar levels of instability can be observed around major economic crises, such as the Great Depression of the 1930s. Finally, although economic growth rates have been positive, on average, since the dawn of the industrial age, recurrent recessions and occasional sharp downturns lie clearly in evidence.

In a similar vein, total population growth rates, which are marked by the solid line in the top part of the graphs in Figure 2, have been largely positive over the past two centuries. However, this growth has occasionally been interrupted due to the devastating effects of major wars and epidemics. Furthermore, especially in countries such as Australia, Canada, or the United States, subsequent waves of positive net migration have had a profound effect on population growth. From demographics, it is indeed well-known that migration is a relatively volatile component of population growth (Zaiceva and Zimmermann, 2016, pp.127ff.). Conversely, according to demographic transition theory, the birth surplus is characterized by secular trends. In Figure 2, the postulated hump-shaped development can indeed be observed in virtually all countries. It is this development that has recently led to a decline in non-migrant population growth rates by approximately one to two percentage points, which matters for the ongoing secular stagnation debate (see Papetti, 2021; Gagnon *et al.*, 2016; Ikeda and Saito, 2014). Related trends also arise with the dependency ratio, which followed an inverted hump shape in most countries in our sample.[11] More specifically, owing to the decreasing birth rate, which resulted in gradually smaller population cohorts below the age of 20, the dependency ratio initially dropped from the high levels of the nineteenth century. Conversely, the old-age dependency ratio has increased during the last decades reflecting the well-known ageing of society in most developed countries.

[11] A figure with the dependency ratio is not reported, but available from the authors upon request.

Figure 1: **Real** interest rates, per-capita economic growth, and population growth (1820-2018)



# 5 Results

## 5.1 Baseline results

Table 1 presents our baseline results of estimating (3). While the estimation in Column 1 follows Borio *et al.* (2017, p.14; 2019, p.8) by containing only country-specific fixed effects, Column 2 includes country- and year-specific fixed effects for, respectively, $\alpha_j$ and $\alpha_t$. According to the $R^2$, the specification without year-specific fixed effects (Column 1) explains approximately 28 per cent of the total variation in real interest rates. The $R^2$ increases considerably in Column 2, indicating that unobserved year-specific developments, such as global money and credit cycles, may play an important role. Furthermore, standard F-tests to determine whether or not the fixed effects are jointly insignificant and, hence, redundant (see e.g. Baltagi, 2013, ch. 3.2.1) are highly significant for both $\alpha_j$ and $\alpha_t$. Hence, it seems appropriate to employ the specification of Column 2 as the baseline model.

Further to the discussion of Section 4, the top panel of Table 1 employs total population growth, $\tilde{n}_{jt}$, to capture the demographic effect, while the bottom panel distinguishes between the contributions of the birth surplus, $\ddot{n}_{jt}$, and net migration, $\hat{n}_{jt}$. In Column 2 of Table 1, the "birth surplus" is positive and statistically significant. Conversely, the effects of total population growth in the top panel and net migration in the bottom panel are nonsignificant. The empirical impact of economic growth on real interest rates is generally positive and significant.

To analyse whether these population effects also occur across various subperiods, Columns 3 and 4 of Table 1 split the sample into observations before and after the year 1918. This year not only roughly divides the first and second centuries covered by the current sample, and hence preserves several generations worth of data, but also marks an important historical turning point. Taken together, the birth surplus has had a consistently positive and significant effect before and after the end of World War I in 1918, while a significantly positive impact of total population growth arises only within the first subperiod of Column 3. To uncover whether the World Wars have had an outstanding effect on our results, Columns 5 to 7 focus on, respectively, the period before 1914, the interwar years (1919-1939), and the period after 1945. Again, the effect of population growth can vary considerably, from significantly positive before World War I, to significantly negative during the interwar years and insignificant after World War II. In a similar vein, the effect of net migration in the bottom panel is virtually zero for the years before 1914, but significantly negative during the interwar years and the post World War II period. Conversely, the entries of the birth surplus are significant and positive across all subperiods. Taken together, these results lend further support to the view that a possible demographic effect on real-interest-rate levels arises mainly through secular population trends manifesting themselves e.g. in the slow-moving changes of the birth surplus. Probably, these trends are a better reflection of the intergenerational relationships that are arguably encapsulated in the long-term real interest rate, than the rather volatile development of international migration or total population growth.[12]

[12] Borio *et al.* (2017, 2019) noted an instable effect of variables, such as population growth, on real interest rates across different international currency regimes since the nineteenth century. It is indeed possible to restrict the sample further to contemplate e.g. the period of the classical Gold Standard (1870-1914), the Bretton Woods System (1946-1971), or the era of free floating (since 1971). We have estimated these results with the current data in a previous version of this paper (Fuhrer and Herger, 2021). This gave indeed rise to considerable coefficient instability as regards the total population growth and net-migration rates, and to a smaller extent also with the birth surplus. However, as international currency regimes have typically not lasted much longer than one generation, these results do not per se undermine the finding of a consistent effect of secular demographic trends in e.g. the birth surplus across *many* generations.

Table 1: Baseline results: Population effects on real interest rates

| Sample: | All | All | Pre 1918 | Post 1918 | Pre WWI 1820-1914 | Interwar 1919-1939 | Post WWII 1945-2019 |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Total population growth | | | | | | | |
| Population growth | 0.14 | 0.09 | 0.25** | 0.25 | 0.14** | -0.61*** | -0.15 |
| (total $\tilde{n}_{jt}$) | (0.10) | (0.10) | (0.11) | (0.26) | (0.06) | (0.21) | (0.17) |
| Economic growth | 0.04 | 0.04** | 0.03** | 0.03 | 0.01 | -0.05*** | -0.03 |
| ($x_{it}$) | (0.02) | (0.02) | (0.01) | (0.03) | (0.01) | (0.02) | (0.04) |
| Country FE | yes | yes | yes | yes | yes | yes | yes |
| Year FE | no | yes | yes | yes | yes | yes | yes |
| Obs. | 1,874 | 1,874 | 763 | 1,111 | 720 | 240 | 824 |
| $R^2$ | 0.28 | 0.69 | 0.82 | 0.64 | 0.83 | 0.70 | 0.70 |
| Adj. $R^2$ | 0.28 | 0.65 | 0.79 | 0.60 | 0.80 | 0.64 | 0.67 |
| $\alpha_j$-insign. ($F$-stat) | 5.5*** | 12.7*** | 5.0*** | 19.0** | 10.6*** | 18.0*** | 20.8*** |
| $\alpha_t$-insign. ($F$-stat) | | 11.5*** | 22.4*** | 9.2** | 18.8*** | 9.2*** | 12.6*** |
| Population growth from the birth surplus and net migration | | | | | | | |
| Population growth | -0.13 | 0.58*** | 1.41*** | 1.79*** | 0.38** | 1.81* | 0.76** |
| (from birth surplus $\ddot{n}_{jt}$) | (0.19) | (0.19) | (0.36) | (0.45) | (0.17) | (0.94) | (0.36) |
| Population growth | -0.20 | -0.14 | 0.14 | -0.41 | 0.08 | -0.87*** | -0.54*** |
| (from net migration $\hat{n}_{jt}$) | (0.13) | (0.13) | (0.10) | (0.28) | (0.06) | (0.22) | (0.21) |
| Economic growth | 0.05* | 0.05** | 0.04** | 0.04 | 0.01 | -0.04** | -0.03 |
| ($x_{it}$) | (0.03) | (0.02) | (0.02) | (0.03) | (0.01) | (0.02) | (0.04) |
| Country FE | yes | yes | yes | yes | yes | yes | yes |
| Year FE | no | yes | yes | yes | yes | yes | yes |
| Obs. | 1,736 | 1,736 | 626 | 1,110 | 583 | 239 | 824 |
| $R^2$ | 0.28 | 0.68 | 0.83 | 0.65 | 0.83 | 0.71 | 0.71 |
| Adj. $R^2$ | 0.28 | 0.64 | 0.79 | 0.61 | 0.79 | 0.66 | 0.67 |
| $\alpha_j$-insign. ($F$-stat) | 6.9*** | 10.2*** | 5.5*** | 19.4*** | 9.7*** | 15.2*** | 19.2*** |
| $\alpha_t$-insign. ($F$-stat) | | 10.5*** | 18.0*** | 9.9*** | 15.1*** | 6.5*** | 12.4*** |

Notes: This table reports estimates of Equation (3) with real interest rates, i.e. $i_{jt} - \pi^e_{jt}$, as the dependent variable. The regressions include dummy variables indicating fixed exchange rate regimes, the occurrence of a world war, a systemic financial crisis, and the installation of the gold standard, the Bretton Woods system, or inflation targeting in country $j$ during year $t$. To measure interest rates $i_{jt}$, long-term bond yields are used. Recursive projections of an autoregressive model of inflation estimated over a rolling twenty-year window and averaged over the future 5 years are used to calculate $\pi^e_{jt}$. Coefficient estimation is by panel data estimators with fixed effects. Robust standard errors to heteroscedasticity and serial correlation are reported in parentheses (based on country clusters). Significant coefficients are indicated by * at the 10% level; ** at the 5% level, and *** at the 1% level. The diagnostic statistics appear in the lower part of each panel. Obs. denotes the number of observations. $\alpha_{(.)}$-insignificant refers to the F-test (based on HAC standard errors) on redundant fixed effects. Owing to the two-way nature of the panel data, this can pertain to the country-specific and the year-specific fixed effects. Diagnostic statistics that reject the null-hypothesis at the 10% level are marked by *, at the 5% level by **, and at the 1% level by ***.

## 5.2 Dependency ratio

Another demographic variable exhibiting secular trends is the dependency ratio as defined in Table 4 of Appendix A. This subsection extends our analysis in this regard by including the dependency ratio into our baseline specifications. The corresponding results in Table 2 show that the dependency ratio enters with an insignificant coefficient in the top and bottom panels of Column 1.

High dependency ratios can, in principle, arise from relatively large population cohorts of the young and/or the old. During the nineteenth century, the number of persons aged below 20 outnumbered those of the working-age population in some countries. Nowadays, a ratio of one young person to three persons of working age is quite common. Conversely, across the developed world, fractions of 1 old to 10 persons of working age were normal until the middle of the twentieth century. Since then, this has changed to around 3 to 10 (Luca and Bloom, 2016, p.10). To disentangle these countervailing developments, the young-age and the old-age dependency ratio (as defined in Table 4 of Appendix A) are separately and jointly introduced in Columns 2 to 4 of Table 2. The corresponding results suggest that a relatively young population tends to increase the real interest rate, although this effect is nonsignificant in the bottom panel of Table 2. Conversely, across all the specifications, a high old-age dependency ratio tends to be associated with significantly lower real interest rates. Obviously, these negative coefficients concur with the widely observed decline in real interest rates during the most recent decades. However, across all these specifications, the birth-surplus effect remains positive and significant.

## 5.3 Further robustness checks

Our baseline results are also robust to the following changes. First, as mentioned in Section 3, the measurement of inflation expectations poses a key challenge to determining the long-term real interest rate. Therefore, Column 5 of Table 2 employs a one-sided moving average over the next *ten* years of expected inflation to calculate $\pi^e_{jt}$ in (3). Second, similar to Hamilton *et al.* (2015) and Lunsford and West (2019), Column 6 employs the short-term interest rate for $i_{jt}$ to estimate (3). This approach greatly simplifies the calculation of expected inflation $\pi^e_{jt}$, which can now be derived from the projection of the above-mentioned AR(1) for the current year to match the maturity of less than one year. Third, additional explanatory variables, such as life expectations, total factor productivity, and inequality are considered in Column 7.[13] The inclusion of these additional variables is associated with a substantial reduction in the number of joint observations. However, the main result that the birth surplus has a significantly positive effect on the real interest rate development remains through all these robustness checks.[14]

## 5.4 Economic significance

Across the various specifications of Tables 1 and 2, the coefficient estimates pertaining to the birth surplus are almost always in the range between 0.5 and 1.5. These estimates would imply that the reduction in the birth surplus of approximately one to two percentage points observed during the last decades (see Fig. 2) has been associated with a decline in the long-term real interest rate of approximately one to two percentage points. These estimated declines due to the demographic transition generally coincides with the corresponding simulated values reported by Gagnon *et al.* (2016) for the United States and Papetti (2021) for the euro area.

[13] See Borio *et al.* (2017, pp.8ff.) for an economic motivation of these explanatory variables.

[14] Fuhrer and Herger (2021) contain some further robustness checks that essentially confirm the main finding of this paper. These additional robustness checks include taking a *centered* moving average over the past and future five years of expected inflation to calculate $\pi^e_{jt}$, employing coefficient standard deviations allowing for seemingly unrelated regressions relationships (SURs) across countries $j$ and time $t$, and re-estimating the results with data averages per decade.

Table 2: Further results: Population effects on real interest rates

| | With the dependency ratio | | | | $\pi^e_{j,t+10}$ | Short-t. $i_{jt}$ | Large mod. |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **Total population growth** | | | | | | | |
| Population growth | 0.09 | 0.07 | 0.07 | 0.01 | 0.14 | 0.17 | -0.07 |
| (total $\tilde{n}_{jt}$) | (0.16) | (0.17) | (0.16) | (0.17) | (0.10) | (0.14) | (0.30) |
| Dependency ratio | 1.24 | | | | | | 6.60*** |
| (young and old) | (0.97) | | | | | | (1.44) |
| Young-age | | 2.56** | | 3.48*** | | | |
| dependency ratio | | (1.10) | | (1.12) | | | |
| Old-age | | | -14.6*** | -17.0*** | | | |
| dependency ratio | | | (3.66) | (3.73) | | | |
| Economic growth | 0.05** | 0.05** | 0.05** | 0.05** | 0.04*** | 0.01 | 0.06* |
| ($x_{it}$) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) | (0.03) | (0.03) |
| Life expectancy | | | | | | | 0.29*** |
| | | | | | | | (0.08) |
| TFP | | | | | | | 0.27*** |
| | | | | | | | (0.08) |
| Inequality | | | | | | | 0.04 |
| | | | | | | | (0.04) |
| Obs. | 1,584 | 1,584 | 1,584 | 1,584 | 1,784 | 1,811 | 763 |
| $R^2$ | 0.67 | 0.67 | 0.67 | 0.67 | 0.72 | 0.69 | 0.72 |
| Adj. $R^2$ | 0.62 | 0.62 | 0.63 | 0.63 | 0.68 | 0.64 | 0.66 |
| $\alpha_j$-insign. ($F$-stat) | 11.6*** | 11.0*** | 12.7*** | 12.6*** | 13.0*** | 13.5*** | 19.3*** |
| $\alpha_t$-insign. ($F$-stat) | 9.3*** | 9.6*** | 9.7*** | 9.7*** | 12.3*** | 9.9*** | 6.5*** |
| **Population growth from birth surplus and net migration** | | | | | | | |
| Population growth | 1.26*** | 1.11** | 1.16*** | 0.90* | 0.38** | 0.85** | 1.04** |
| (birth surplus $\ddot{n}_{jt}$) | (0.43) | (0.47) | (0.31) | (0.48) | (0.17) | (0.42) | (0.53) |
| Population growth | -0.33* | -0.32* | -0.33* | -0.31* | 0.01 | -0.13 | -0.41 |
| (net migration $\hat{n}_{jt}$) | (0.18) | (0.18) | (0.18) | (0.18) | (0.13) | (0.12) | (0.35) |
| Dependency ratio | -0.17 | | | | | | 4.09** |
| (young and old) | (1.53) | | | | | | (1.75) |
| Young-age | | 1.17 | | 2.20 | | | |
| dependency ratio | | (1.83) | | (1.88) | | | |
| Old-age | | | -12.4*** | -13.8** | | | |
| dependency ratio | | | (3.59) | (3.70) | | | |
| Economic growth | 0.06*** | 0.06** | 0.06*** | 0.06** | 0.05** | 0.01 | 0.06* |
| ($x_{it}$) | (0.02) | (0.03) | (0.02) | (0.03) | (0.02) | (0.03) | (0.03) |
| Life expectancy | | | | | | | 0.23*** |
| | | | | | | | (0.09) |
| TFP | | | | | | | 0.25*** |
| | | | | | | | (0.08) |
| Inequality | | | | | | | 0.04 |
| | | | | | | | (0.04) |
| Obs. | 1,526 | 1,526 | 1,526 | 1,526 | 1,651 | 1,733 | 762 |
| $R^2$ | 0.67 | 0.67 | 0.68 | 0.68 | 0.71 | 0.69 | 0.72 |
| Adj. $R^2$ | 0.62 | 0.63 | 0.63 | 0.63 | 0.67 | 0.64 | 0.67 |
| $\alpha_j$-insign. ($F$-stat) | 11.7*** | 11.5*** | 12.5*** | 12.5*** | 10.6*** | 10.0*** | 17.0*** |
| $\alpha_t$-insign. ($F$-stat) | 9.3*** | 9.4*** | 9.6*** | 9.5*** | 11.2*** | 9.7*** | 6.6*** |

Notes: This table reports estimates of (3) with real interest rates, i.e. $i_{jt} - \pi^e_{jt}$, as the dependent variable. All regressions include dummy variables indicating the occurrence of a world war, a systemic financial crisis, a fixed exchange rate, or the installation of the gold standard, the Bretton Woods system, or inflation targeting in country $j$ during year $t$. For a detailed description of the estimation and definition of the diagnostic statistics, see the notes of Table 1. The detailed definition and sources of the additional variables can be found in Table 4 of Appendix A.

# 6 Summary and conclusion

Although the effects of population growth on real interest rate levels are well founded in macroeconomic theories, such as the overlapping generations model, the corresponding empirical results have been rather elusive. Within a sample comprising the historical development of interest rates, inflation, population growth, and per capita economic growth for 12 countries with developed financial markets since the year 1820, panel data regressions uncover a positive relationship between the natural rate of population growth and long-term real interest rates. Furthermore, considering the birth surplus as a component of population growth, the corresponding relationship is quite robust and statistically significant. Hence, consistent with standard macroeconomic theory, our results suggest that demographic variables indeed affect the real interest rate.

Our results help reconcile standard macroeconomic models with the empirical literature. However, although our empirical findings could also help explain the currently low interest rate levels by the secular decline of the birth rate, which has in some countries fallen even below the mortality rate, and ageing societies in many developed countries during the recent decade, the long-term nature of these relationships should be kept in mind. Non-demographic factors, such as credit cycles, monetary policy, increased wealth, or productivity growth, could still profoundly affect both nominal and real interest rate developments during the next couple of years and possibly even decades.

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# A Description and sources of the data

Table 3: Description of the data set

The data have an annual frequency.

| Variable | Unit | Description |
|---|---|---|
| Nominal interest rate $i_{jt}$ | per cent | Nominal interest rate measured in terms of the yield (annual averages) on long-term government bonds with a 10 year maturity or closest proxy. The main source is Homer (1977) before 1960, and thereafter the OECD statistics (long-term interest rates). Country details are: Australia: 1870-1929, long-term interest rate, Jorda-Schularick-Taylor macrohistory database (http://www.macrohistory.net/data/). 1930-1970, long-term government bond yields, Homer (1977, Tab. 77). Since 1970, OECD. Belgium: 1831-1918, yield on 2.5% rentes, Homer (1977, Tab. 30, 64). 1919-1944, yield on 3% rentes , Homer (1977, Tab. 64). 1945-1959, yield on 4% rentes, Homer (1977, Tab. 64). Since 1960, OECD. Canada: 1870-1899, long-term interest rate, Jorda-Schularick-Taylor macrohistory database. 1900-1919, Province of Ontario bond yields, Homer (1977, Tab. 70). 1920-1959, long-term government bond yields, Homer (1977, Tab. 70). Since 1960, OECD. Denmark: 1870-1929 and 1976-2000, long-term interest rate, Jorda-Schularick-Taylor macrohistory database. 1930-1975, long-term government bond yield, Homer (1977, Tab. 76). Since 2001, OECD. Finland: 1870-1987, long-term interest rate, Jorda-Schularick-Taylor macrohistory database. Since 1988, OECD. France: 1825-1899. Average yield on 3% rentes, Homer (1977, Tab. 25). 1900-1959, yield on perpetual 3% yields, Homer (1977, Tab. 60). Since 1960, OECD. Netherlands: 1820-1959, 2.5% perpetual bond yield, Homer (1977, Tab. 28, 62). Since 1960, OECD. Norway: 1820-1984, long-term government bonds yields quoted in various financial markets, Norges Bank, Historical Monetary Statistics for Norway – Part II. Since 1985, OECD. Sweden: 1856-1993, yields on long-term government securities, Sveriges Riksbank, Historical Statistics of Sweden, Tab. II.A6.3. Since 1994, OECD. Switzerland: 1831-1898, interest rate on saving account of various banks, Swiss National Bank historical time series, Tab. 4.3a. 1899-1954, yield on five-year federal government bond, SNB historical time series, Tab. 3.1. Since 1955, OECD. United Kingdom: 1820-1960, average yield on consols, Homer (1977, Tab. 19, 57). Since 1960, OECD. USA: 1820-1829, annual average yield U.S. 3s of 1790 (Homer, 1977, Tab.40). 1830-1859, current yield on Boston City 5s, Homer (1977, Tab. 41). 1860-1879, current yield on U.S. 6s of 1861-1881, Homer (1977, Tab. 42). 1880-1899, current yield on US Refunding 4s of 1907, Homer (1977, Tab. 43). 1900-1920, High Grade Municipal Bonds, Homer (1977, Tab. 45). 1921-1960, long-term government bond yield, Homer (1977, Tab. 48,50). Since 1960, OECD. |
| Inflation $\pi_{jt}$ | per cent | Inflation in terms of the annual change of the consumer-price index (CPI). The main source is Mitchell (1992, 1995, 1998) before 1960, and thereafter the OECD statistics (inflation (CPI)). Country details are: Australia: 1862-1959, Mitchell (1995, Tab. H2). Since 1960, OECD. Belgium: 1836-1959, Mitchell (1992, Tab. H2). Since 1960, OECD. Canada: 1871-1910, CPI change, Jorda-Schularick-Taylor macrohistory database (http://www.macrohistory.net/data/). 1911-1959, Mitchell (1998, Tab. H2). Since 1960, OECD. Denmark: 1816-1966, Mitchell (1992, Tab. H2). Since 1967, OECD. Finland: 1871-1914, Jorda-Schularick-Taylor macrohistory database. 1915-1959, Mitchell (1992, Tab. H2). Since 1960, OECD. France: 1841-1959, Mitchell (1992, Tab. H2). Since 1960, OECD. Netherlands: 1870-1880, Jorda-Schularick-Taylor macrohistory database. 1881-1960, Mitchell (1992, Tab. H2). Since 1961, OECD. Norway: 1800-1902, Norges Bank Historical Statistics. 1902-1959, Mitchell (1992, Tab. H2). Since 1960, OECD. Sweden: 1800-1959, Mitchell (1992, Tab. H2). Since 1960, OECD. Switzerland: 1806-1890, CPI change, Swiss economic and social history database (Tab. H39). 1891-1959, Mitchell (1992, Tab. H2). Since 1960, OECD. United Kingdom: 1800-1959, Mitchell (1992, Tab. H2). Since 1960, OECD. USA: 1801-1959, Mitchell (1998, Tab. H2). Since 1960, OECD. |
| Population growth $\tilde{n}_{jt}$ | per cent | Growth of the residential population calculated from the population size of the Maddison project database (vers. 2018). The sample is 1820-2018 except for: Canada: 1871-2018. France: The years 1870, 1871, and 1919 are dropped due to the loss and the recovery of parts of Alsace-Lorraine. United Kingdom: The year 1921 is dropped due to the independence of the Republic of Ireland. |
| Birth surplus $\ddot{n}_{jt}$ | per cent | Birth surplus (positive/negative) in terms of the difference between the crude birth rate and the crude mortality rate. This is also called the "rate of natural population growth". Sample: Australia: 1851-2019. Belgium: 1830-2019. Canada: 1900-2019. Denmark: 1820-2019 (without 1862). Finland: 1820-2019. France: 1820-2019. Netherlands: 1840-2019 (without 1921). Norway: 1820-2019 (without 1851). Sweden: 1820-2019. Switzerland: 1870-2019. United Kingdom: 1821, 1826, 1831, 1836, 1838-2018. USA: 1870, 1880, 1890, 1900, 1909-2017. |
| Net migration $\hat{n}_{jt}$ | per cent | Net migration is given by the difference between total population growth ($\tilde{n}_{jt}$) and the birth surplus ($\ddot{n}_{jt}$), that is $\hat{n}_{jt} = \tilde{n}_{jt} - \ddot{n}_{jt}$. The sample follows from the definitions of $\tilde{n}_{jt}$ and $\ddot{n}_{jt}$. |
| Economic growth $x_{jt}$ | per cent | Real economic growth in terms of annual change of real GDP per capita. The sample is 1821-2018 except for: Belgium: 1847-2016. Canada: 1871-2016. Finland: 1861-2016. Norway: 1831-2016. Switzerland: 1852-2016. The data are taken from the Maddison project database (vers. 2018) with a US$ 2011 benchmark. |

Table 4: Description of the data set

Dummy variables used as control variables (see notes to Tables 1 and 2)

| Variable | Unit | Description |
|---|---|---|
| World War | nom. | Variable indicating that country $j$ is involved in World War I or World War II during year $t$. The corresponding years are: Australia: 1914-1918, 1939-1945. Belgium: 1914-1918, 1939-1945. Canada: 1914-1918, 1939-1945. Denmark: 1940-1945. Finland: 1939-1945. France: 1914-1918, 1939-1945. Netherlands: 1940-1945. Norway: 1940-1945. United Kingdom: 1914-1918, 1939-1945. USA: 1917-1918, 1941-1945. |
| Crisis | nom. | Systemic financial crisis in country $j$ during year $t$. The corresponding years are: Australia: 1893, 1989. Belgium: 1856, 1870, 1885, 1925, 1931, 1939, 2008. Canada: 1907. Denmark: 1857, 1877, 1885, 1908, 1931, 1987, 2008. Finland: 1848, 1857, 1877, 1900, 1921, 1931, 1991. France: 1838, 1848, 1857, 1864, 1882, 1889, 1930, 2008. Netherlands: 1848, 1857, 1893, 1907, 1921, 1939, 2008. Norway: 1848, 1857, 1899, 1822, 1931, 1988. Sweden: 1848, 1857, 1878, 1907,1922, 1931, 1991, 2008 . Switzerland: 1848, 1857, 1870, 1910. 1931, 1991, 2008. United Kingdom: 1825, 1836, 1847, 1857, 1866, 1890, 1974, 1991, 2007. USA: 1837, 1848, 1873, 1893, 1907, 1929, 1984, 2007. Sources: Kindleberger and Aliber (2011, pp.302ff.) before 1870, and thereafter Jorda-Schularick-Taylor macrohistory database (http://www.macrohistory.net/data/). |
| Monetary regime | nom. | Variable indicating that country $j$ adhered to the gold standard (GS), the Bretton Woods System (BW), or inflation targeting (IT) during year $t$. The corresponding years are: Australia: GS: 1852-1915, BW: 1946-1971. Belgium: GS: 1878-1914, BW: 1946-1971, IT: 1999-2019. Canada: GS: 1854-1914, BW: 1946-1971, IT: 1991-2019. Denmark: GS: 1872-1914, BW: 1946-1971, IT: 1998-2019. Finland: GS: 1877-1914, BW: 1946-1971, IT: 1999-2019. France: GS: 1878-1914, BW: 1946-1971, IT: 1999-2019. Netherlands: GS: 1875-1914, BW: 1946-1971, IT: 1999-2019. Norway: GS: 1875-1914, BW: 1946-1971, IT: 2001-2019. Sweden: GS: 1873-1914, BW: 1951-1971, IT: 1993-2019. Switzerland: GS: 1878-1914, BW: 1946-1971, IT: 2000-2019. United Kingdom: GS: 1820-1914, BW: 1946-1971, IT: 1992-2019. USA: GS: 1879-1914, BW: 1946-1971, IT: 1983-2019. Sources: Bordo *et al.* (2017, p.27), Benati (2008, pp.1051ff.). |
| Peg | nom. | Fixed exchange rate in country $j$ during year $t$. The corresponding years are: Australia: 1852-1913, 1925-1929, 1940-1982. Belgium: 1878-1913, 1927-1934, 1940-1944, 1954-2019. Canada: 1854-1913, 1927-1928, 1947-2001. Denmark: 1873-1913, 1927-1931, 1940-1950, 1952-2019. Finland: 1877-1913, 1926-1931, 1940-1944, 1948-1950, 1958-2019. France: 1878-1913, 1928-1936, 1940-1945, 1957-2019. Netherlands: 1875-1913, 1925-1936, 1940-1944, 1951-2019. Norway: 1873-1913, 1928-1931, 1940-1944, 1957-1974. Sweden: 1873-1913, 1924-1931, 1952-1991, 1999-2008. Switzerland: 1879-1913, 1925-1936, 1940-1941, 1947-1972, 2012-2014. United Kingdom: 1820-1913, 1925-1931, 1949-1971, 1991-1992. USA: 1879-1932, 1940-1971. Sources: Bordo *et al.* (2017, p.27) before 1870, and thereafter Jorda-Schularick-Taylor macrohistory database (http://www.macrohistory.net/data/). |

Data used for the non-baseline results

| Variable | Unit | Description |
|---|---|---|
| Nominal interest rate $i_{jt}$ (short-term) | per cent | Nominal interest rate typically measured in terms of the three-months discount or money market rate (annual average). The main source is Homer (1977) before 1960, and thereafter the OECD statistics (short-term interest rates). Country details are: Australia: 1870 -1936, short-term interest rate, Jorda-Schularick-Taylor macrohistory database (http://www.macrohistory.net/data/). 1937-1960, short-term government bond yields, Homer (1977, Tab. 77). Since 1968, OECD. Belgium: 1848-1959, discount rate, Homer (1977, Tab. 31, 65). Since 1960, OECD. Canada: 1935-1959, discount rate, Homer (1977, Tab. 70). Since 1960, OECD. Denmark: 1875-1929 and 1976-1986, short-term interest rate, Jorda-Schularick-Taylor macrohistory database. 1930-1975, official discount rate, Homer (1977, Tab. 76). Since 1997, OECD. Finland: 1870 -1987, short-term interest rate, Jorda-Schularick-Taylor macrohistory database. Since 1987, OECD. France: 1863-1969, discount rate, Homer (1977, Tab. 27, 61). Since 1970, OECD. Netherlands: 1820-1975, discount rate, Homer (1977, Tab. 29, 63). 1976-1981, money market rate (Q1), IFS of IMF. Since 1982, OECD. Norway: 1820-1978, marginal liquidity rate, Norges Bank, Historical Monetary Statistics for Norway – Part II. Since 1979, OECD. Sweden: 1854-1975, discount rate, Homer (1977, Tab. 35, 69). 1976-1981, yields on short-term government securities, Historical Statistics of Sweden, Table II.A6.3. Since 1982, OECD. Switzerland: 1837-1973, discount rate, Homer (1977, Tab. 34, 68). Since 1974, OECD. United Kingdom: 1820-1975, discount rate, Homer (1977, Tab. 23, 59). 1976-1985, short-term interest rate Measuring Worth (www.measuringworth.com). Since 1986, OECD. USA: 1857-1964, call money rate, Homer (1977, Tab. 44, 51). Since 1965, OECD. |
| Life expectancy | years | Life expectancy at birth. Source: www.mortality.org. The data refer to the total (male and female) population. Sample: Australia: 1921-2018. Belgium: 1841-1913, 1919-2018. Canada: 1851-2016. Denmark: 1835-2018. Finland: 1878-2018. France: 1820-2018. Netherlands: 1850-2018. Norway: 1846-2018. Sweden: 1820-2018. Switzerland: 1876-2018. United Kingdom: 1922-2018. USA: 1933-2017. |
| Dependency ratio | ratio | Size of the population aged 19 or below or 65 or above as a fraction of the working-age population between 20 and 65. This definition follows Borio *et al.* (2017, p.9). Sample: Australia: 1881-2018. Belgium: 1841-1914, 1919-2018. Canada: 1851-2018. Denmark: 1835-1863, 1921-2018. Finland: 1850-2018. France: 1820-1870, 1919-2018. Netherlands: 1840-2018. Norway: 1846-2018. Sweden: 1820-2018. Switzerland: 1860-2018. United Kingdom: 1921-2018. USA: 1890-2018. The main source are the population tables in www.mortality.org. Some earlier data have been compiled from Table A2 of Mitchell (1992, 1995, 1998). |
| Total factor productivity | index | Total factor productivity (TFP). The data cover the years 1890-2018 for all countries in the sample. Source: Long-term productivity database (www.longtermproductivity.com). See also Bergeuad *et al.* (2016). |
| Inequality | ratio | Share of top 1 per cent in gross income (tax units, excluding capital gains). Sample: Australia: 1921-2013. Belgium: na. Canada: 1920-2011. Denmark: na. Finland: 1920-2009. France: 1900, 1910, 1915-2013. Netherlands: 1914-2012 (with missing obs.). Norway: 1900-1903, 1906, 1910, 1913, 1929, 1938, 1948-2011. Sweden: 1903-2010 (with missing obs.). Switzerland: 1933-2010 (with missing obs.). United Kingdom: 1918-1919, 1937, 1949, 1951-2012. USA: 1913-2015. Source: Chartbook of Economic Inequality (www.chartbookofeconomicinequality.com). |

# B Reviewer's Appendix (not for publication)

## B.1 Panel VAR results (not for publication)

Table 5: Population effects on real interest rates and economic growth in a panel VAR

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Dependent variable: | Real interest rate ($i_{jt} - \pi^e_{jt}$) | Economic growth ($x_{jt}$) | Real interest rate ($i_{jt} - \pi^e_{jt}$) | Economic growth ($x_{jt}$) | Net migration $\hat{n}_{jt}$ |
| Population growth (total $\tilde{n}_{jt}$) | 0.15*** | 0.21 | | | |
| | (0.03) | (0.14) | | | |
| Population growth (birth surplus $\ddot{n}_{jt}$) | | | 0.10* | 0.30 | -0.04* |
| | | | (0.06) | (0.24) | (0.02) |
| Obs. | 1,819 | 1,819 | 1,661 | 1,661 | 1,661 |
| $R^2$ | 0.89 | 0.05 | 0.89 | 0.08 | 0.53 |

Notes: This table reports estimates of a panel VAR with real interest rates, e.g., $i_{jt} - \pi^e_{jt}$, and economic growth, $x_{jt}$ as endogenous variables and population growth—either crude $\tilde{n}_{jt}$ or separated according to birth surplus $\ddot{n}_{jt}$ and net migration $\hat{n}_{jt}$—as the exogenous variable. All regressions include exogenous country-specific fixed effects and dummy variables indicating fixed exchange rate regimes, the occurrence of a world war, a systemic financial crisis, and the installation of the gold standard, the Bretton Woods system, or inflation targeting in country $j$ during year $t$. Based on the minimum of the Schwarz Information Criterion (SIC), 2 lags are included. To save space, the table reports only the (exogenous) effect of population growth upon the endogenous variables. Coefficient standard errors are reported in parentheses. Significant coefficients are indicated by * at the 10% level; ** at the 5% level, and *** at the 1% level.

## B.2 Additional results (not for publication)

Table 6: Results without year-specific fixed effects, split around 1950, separate birth and mortality rate, and the 1971-1007 period

| Sample: | Without time fixed effects | Pre 1950 | Post 1950 | Birth and Mortality Rate | 1971-2007 |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Total population growth | | | | | |
| Population growth | -0.25*** | 0.27** | -0.27 | | -0.71*** |
| (total $\tilde{n}_{jt}$) | (0.08) | (0.12) | (0.17) | | (0.28) |
| Economic growth | 0.01 | 0.04** | -0.07 | | -0.21*** |
| ($x_{it}$) | (0.02) | (0.02) | (0.05) | | (0.05) |
| Country FE | yes | yes | yes | | yes |
| Year FE | no | yes | yes | | yes |
| Obs. | 1,308 | 1,094 | 780 | | 444 |
| $R^2$ | 0.18 | 0.77 | 0.68 | | 0.73 |
| Adj. $R^2$ | 0.17 | 0.73 | 0.74 | | 0.70 |
| $\alpha_j$-insign. ($F$-stat) | 16.2*** | 7.9*** | 24.8*** | | 22.1*** |
| $\alpha_t$-insign. ($F$-stat) | | 16.4*** | 11.9*** | | 18.8 |
| Hausman test ($\chi^2$-stat) | 51.3*** | | | | |
| Population growth from the birth surplus and net migration | | | | | |
| Population growth | 0.51* | 0.57* | 0.61* | | -1.04 |
| (from birth surplus $\ddot{n}_{jt}$) | (0.28) | (0.34) | (0.35) | | (0.76) |
| Birth rate | | | | -0.01 | |
| | | | | (0.02) | |
| Mortality rate | | | | -0.17*** | |
| | | | | (0.04) | |
| Population growth | -1.00*** | 0.21 | -0.63** | -0.04 | -0.64** |
| (from net migration $\hat{n}_{jt}$) | (0.20) | (0.14) | (0.21) | (0.13) | (0.30) |
| Economic growth | -0.05* | 0.05*** | -0.06 | 0.05** | -0.21*** |
| ($x_{it}$) | (0.03) | (0.02) | (0.05) | (0.02) | (0.05) |
| Country FE | yes | yes | yes | yes | yes |
| Year FE | no | yes | yes | yes | yes |
| Obs. | 924 | 956 | 780 | 1,736 | 444 |
| $R^2$ | 0.26 | 0.76 | 0.68 | 0.69 | 0.73 |
| Adj. $R^2$ | 0.24 | 0.72 | 0.65 | 0.64 | 0.70 |
| $\alpha_j$-insign. ($F$-stat) | 19.2*** | 5.4*** | 22.9*** | 11.5*** | 21.9*** |
| $\alpha_t$-insign. ($F$-stat) | | 10.4*** | 12.0*** | 12.6*** | 17.1*** |
| Hausman test ($\chi^2$-stat) | 38.7*** | | | | |

Notes: This table reports estimates of Equation (3) with real interest rates, i.e. $i_{jt} - \pi^e_{jt}$, as the dependent variable. All regressions include dummy variables indicating fixed exchange rate regimes, the occurrence of a world war, and a systemic financial crisis in country $j$ during year $t$. To measure interest rates $i_{jt}$, long-term bond yields are used. Recursive projections of an autoregressive model of inflation estimated over a rolling twenty-year window and averaged over the future 5 years are used to calculate $\pi^e_{jt}$. Coefficient estimation is by panel data estimators with fixed effects. Robust standard errors to heteroscedasticity and serial correlation are reported in parentheses (based on country clusters). Significant coefficients are indicated by * at the 10% level; ** at the 5% level, and *** at the 1% level. The diagnostic statistics appear in the lower part of each panel. Obs. denotes the number of observations. $\alpha_{(.)}$-insignificant refers to the F-test (based on HAC standard errors) on redundant fixed effects. Owing to the two-way nature of the panel data, this can pertain to the country-specific and the year-specific fixed effects. The Hausman test (based on ordinary standard errors) indicates whether or not the random effects are correlated with the regressors. Diagnostic statistics that reject the null-hypothesis at the 10% level are marked by *, at the 5% level by **, and at the 1% level by ***.

Figure 2: Real interest rates, per-capita economic growth, and dependency ratio (1820-2019) (not for publication)