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SNB Economic Studies
14/2025

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ISSN 1661-1438 (online version)

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* We thank Christian Grisse, Carlos Lenz, Marc-Antoine Ramelet, Yannic Stucki, Petra Tschudin, Christoph Winter and Attilio Zanetti for their helpful comments and interesting discussions. We are grateful to Jonas Heim, Matthias Lukosch, Simon Racheter and Lisa Wenger for their excellent research assistance. 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 (SNB). The SNB takes no responsibility for any errors or omissions in, or for the correctness of, the information contained in this paper. All remaining errors are ours.

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Contents

Abstract

Obtaining reliable estimates of the natural rate of interest, r*, and understanding its drivers is key for assessing long-run trends in real interest rates. In turn, this plays a role in assessing the stance of monetary policy. Against this backdrop, we discuss the evolution of real interest rates in Switzerland and present a portfolio of models used by the Swiss National Bank (SNB) to estimate r* as well as investigate its drivers. Moreover, we discuss the implications of the r* estimates for monetary policy. We find that, consistent with the evolution of real interest rates globally and in Switzerland, all model estimates point to a significant decline in r* since the mid-1980s. Also, r* is lower in Switzerland than abroad. Potential output growth as well as global factors related to the demand for and supply of safe and liquid assets (i.e., the convenience yield) and to demographics (as reflected in the discount factor) appear to be important drivers of the downward trend in r*. However, generally speaking, r* estimates are subject to sizeable model and statistical uncertainty. Concerning policy implications for Switzerland, we argue that while estimates of r* provide an important piece of information for monetary policy, other factors, such as the exchange rate, are also key determinants of monetary conditions for a small open economy such as Switzerland.

JEL Codes: E52, E43

Keywords: Natural rate of interest, demographics, productivity growth, monetary policy

1. Introduction

The COVID-19 pandemic-induced inflationary shock led central banks around the globe to tighten monetary policy. The resulting sharp and synchronised increase in policy rates lifted real interest rates from their historic lows, which they had reached after a decade-long decline.[1] This raises the question as to whether the previous downward trend has been broken or whether real rates could return to their prepandemic lows.

A central factor in this debate is the level of the so-called natural rate of interest, r*. The natural rate is the short-term real interest rate that would prevail after all business cycle shocks have dissipated, output is at potential, savings equal investments, and inflation is stable.[2] Given this definition, in this paper, we focus on a medium- to long-run concept of r*, which is a slow-moving variable. The actual real rates fluctuate around this long-run equilibrium level. As a result, understanding the drivers of r* will help understand the trends of real interest rates.

The concept of r* used in this paper contrasts with a "short-run r*" in the spirit of, for example, Woodford (2003). There, the natural rate corresponds to the short-term real rate that would prevail in the absence of nominal rigidities and that would imply

1 Some studies even find a century-long decline of real interest rates; see Rogoff, Rossi and Schmelzing (2024).

2 While Switzerland is an open economy, so that savings do not necessarily equal investments at the country level, that relationship has to hold at the global level and corresponding forces related to the propensity to save and invest will also have an impact on the Swiss economy. See the discussion in Sections 2.2, 2.3 and 3.2.

stable inflation at every point in time. As a result, that measure of r* can fluctuate substantially from one period to another depending on the realisation of shocks.

Against this backdrop, we discuss the evolution of real interest rates in Switzerland—also in relation to global developments—and present a portfolio of models used by the Swiss National Bank (SNB) to estimate r*.[3] The corresponding estimates for Switzerland are shown, and we investigate their economic drivers. Moreover, we discuss the implications of the r* estimates for monetary policy.

Our main findings are as follows: First, consistent with the evolution of real interest rates globally and in Switzerland, all model estimates point to a significant decline in r* since the mid-1980s of approximately 2 percentage points, where r* is lower in Switzerland than abroad. These estimates are subject to sizeable model and statistical uncertainty. Second, potential output growth as well as global factors related to the convenience yield on safe and liquid assets and to the discount factor of economic agents appear to be important drivers of the downward trend in r*.[4] Third, with the decline in r*, the risk that the effective lower bound (ELB) for the policy rate becomes binding has increased.

Concerning policy implications, we argue that while estimates of r* provide an important piece of information for monetary policy, other factors, such as the exchange rate, are also key determinants of monetary conditions in a small open economy such as Switzerland.

The remainder of the paper is organised as follows. Section 2 discusses the measurement, evolution and potential drivers of real interest rates, both globally and in Switzerland. Section 3 describes the models used at the SNB to estimate r*, followed by the corresponding estimation results presented in Section 4. The implications for monetary policy, with a focus on the Swiss case, are discussed in Section 5. Finally, Section 6 concludes.

2. Real interest rates: measurement, developments and drivers

In most advanced economies, real interest rates have declined over the last few decades. Switzerland is no exception to that. In this chapter, we first discuss issues related to the measurement of real interest rates, then document the decline in nominal and real interest rates across countries and discuss drivers of this decline by distinguishing between global factors and those specific to Switzerland. Finally, we venture an outlook for the drivers of real interest rates.

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3 For a discussion of how r* estimates are used at the SNB to inform monetary policy decisions, see Jordan (2024).

4 The convenience yield is the yield reduction accepted by investors for the extra benefits from holding safe and liquid assets compared to other less safe or less liquid assets. The discount factor of economic agents is a key component of real interest rates. It reflects agents' time preference, i.e., the preference of consumption today relative to consumption tomorrow, and determines how future cash flows are valued today.

2.1 Measurement

In principle, real interest rates are derived by subtracting a measure of (expected) inflation from nominal rates. However, there is no standard approach to implement this in practice. We would like to highlight four major challenges concerning the measurement of real interest rates. First, one needs to distinguish between ex post and ex ante real interest rates. Ex post interest rates are calculated on the basis of interest rates for a specific time horizon h and realised inflation over the same horizon. While this measure can be easily calculated using observed data, it is only observed with a delay of h periods. Furthermore, decisions of economic agents are not based on ex post real rates—which are not available at the time these decisions are made—but instead incorporate ex ante expectations about inflation. Accurately measuring inflation expectations is a significant challenge, as estimates are inherently uncertain and can vary on the basis of the approach and data source used.

Second, there is no unique duration, and at each point in time, there is a term structure of real interest rates. Short-term real interest rates may differ from long-term rates, and the drivers of real short-term rates may differ from those of long-term rates. In principle, real rates of all maturities are relevant for economic decisions and hence for economic activity and inflation.

Third, it is a priori not clear which deflator should be used. Nominal interest rates can be deflated using consumer prices, producer prices or the GDP deflator. The most widely used deflator is based on consumer prices. Consumer price measurement is most advanced and best harmonised across countries; moreover, inflation expectations based on surveys or derived from financial market data are usually based on consumer prices. These expectation measures are important when taking an ex ante view of real interest rates.

Fourth, there is no unique choice of the underlying for the calculation of yields. However, government bonds are a natural benchmark, particularly for longer-term investments, because they are liquid debt instruments and do not contain risk premia as high as those of corporate bonds. An alternative benchmark is interest rates on an overnight index swap (OIS).

Given these possible choices for measuring real interest rates, this section considers ex ante 10-year real government yields computed using model-based CPI inflation expectations. To construct these inflation expectations for ten advanced economies and Switzerland, we follow the Kalman filter approach of Grishchenko, Mouabbi and Renne (2019) and Bacchetta, Benhima and Renne (2022), which allows for the estimation of expectations consistent with survey measures at different horizons.[5] In particular, we employ Consensus Economics' inflation expectations for annual inflation over the next one to four years, as well as for the average inflation expectation over the five-year period starting in five years.

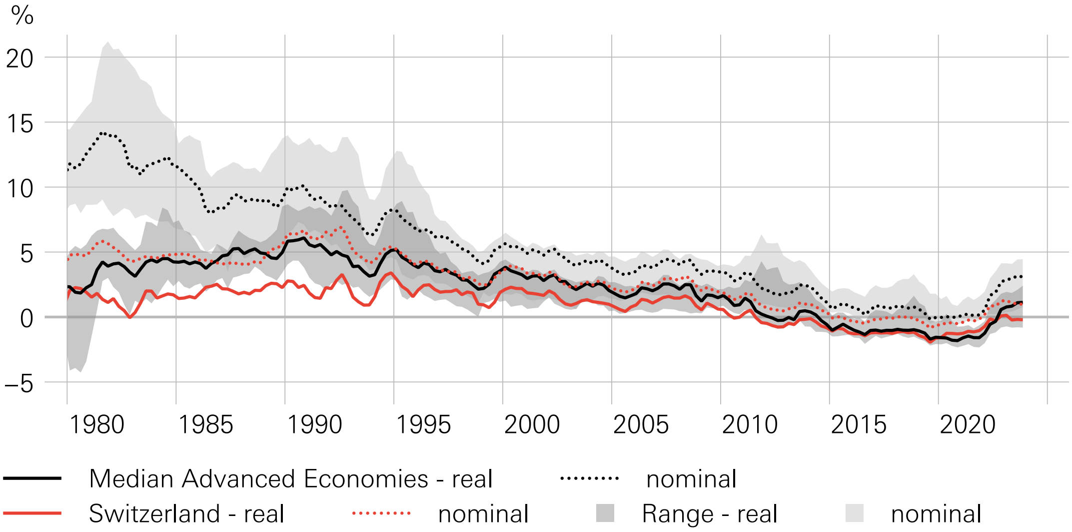
5 Details of the approach can be found in Appendix A.1.

2.2 Developments

Chart 1 shows the evolution of long-term real and nominal interest rates since 1980, comparing Switzerland to ten other advanced economies. Both real and nominal rates have markedly decreased, particularly since the 1990s. Interest rates across countries have converged visibly since the 1990s. In particular, nominal rates have aligned since the mid-1990s, primarily due to falling inflation in light of a more explicit commitment to price stability by central banks since then. Real rates have also converged. Bacchetta et al. (2022) find evidence for a global factor, which accounts for an increasing share of the cross-country variation in real rates over time. This is consistent with Del Negro, Giannone, Giannoni and Tambalotti (2019), who show that advanced economies share the same global trend in real interest rates. The most prominent drivers of this development are discussed in the next subsection.[6]

CHART 1: NOMINAL AND REAL INTEREST RATES

10Y government bond yields



Source(s): LSEG Datastream, SFO, SNB, own calculations

Note: The 10Y real interest rate is calculated as the difference between the 10Y government bond yield and a measure of 10Y inflation expectations based on the model proposed in Bacchetta et al. (2022). Advanced economies reported here include BEL, CAN, DEU, FRA, GBR, ITA, JPN, NLD, SWE and USA. The black solid and dotted lines represent the medians and the shaded areas represent the ranges over all other advanced economies.

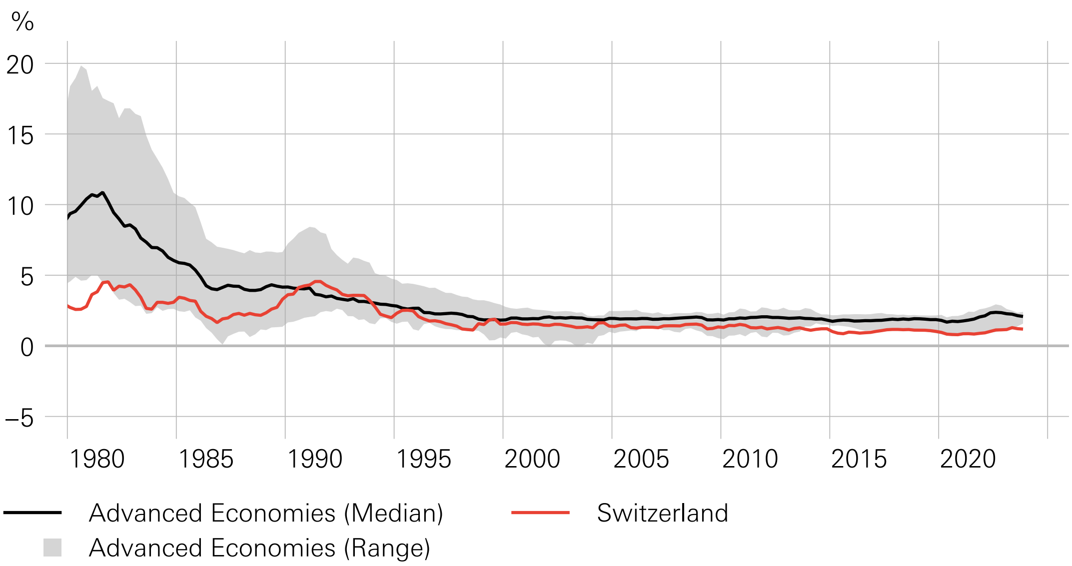
In Switzerland, nominal and real interest rates have also declined over the last several decades. Nominal long-term interest rates fluctuated around 5% in the 1980s and early 1990s before declining to approximately 0% after 2015. Real rates fluctuated around 2% before the great financial crisis (GFC) and started to decline thereafter. In 2015, they turned negative.

6 Convenience yields as a driver of the (relative) development of global interest rates will be discussed in detail in Section 2.3.3. Section 3.2 examines the global trend component of Switzerland's real interest rate.

It should be noted that the decline in Swiss interest rates is less pronounced than in the other advanced economies. While in the 1980s and early 1990s, real and nominal interest rates in Switzerland were considerably below the corresponding global rates, this discrepancy has subsequently narrowed for nominal rates and has vanished for real rates since the GFC. The narrowing of nominal yields can be attributed to a large extent to the fact that inflation expectations in other advanced economies have decreased and approached those in Switzerland (see Chart 2).

We now turn to a discussion of the drivers of the decline in real interest rates over the last four decades, placing special emphasis on the relative drivers of Swiss yields.

CHART 2: 10Y INFLATION EXPECTATIONS



Source(s): LSEG Datastream, SFO, SNB

Note: Computation of inflation expectations based on the model proposed in Bacchetta et al. (2022). The median over that of BEL, CAN, DEU, FRA, GBR, ITA, JPN, NLD, SWE and USA. The shaded areas represent the ranges over all other advanced economies.

2.3 Drivers

A key reason for the significant decline in nominal interest rates over the last four decades is most likely the decline in inflation expectations, as already indicated. However, why real interest rates have also fallen significantly is subject to debate and depends on the point of view.[7] There are two competing explanations.

First, *the real economy explanation* argues that the fall in real interest rates is due to a decline in the natural rate of interest, or r*. As indicated above, this is the rate at which both the goods and labour markets are in equilibrium and price stability prevails (Laubach and Williams, 2003). If this explanation were to be correct, the decrease in real interest rates would influence (or even just reflect) savings and investment decisions as well as asset price valuations but would not generate misallocations in the real economy or on the capital market.

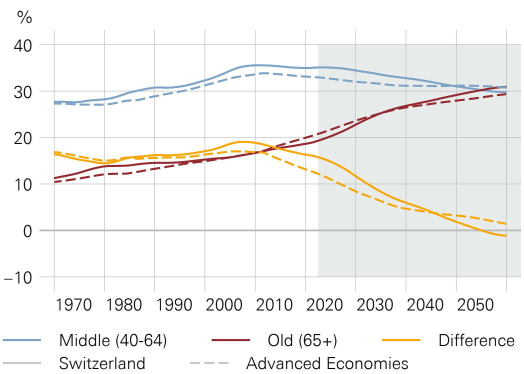
7 See Föllmi, Isaak, Jäger, Schmidt and Seiler (2021) for a detailed discussion of the different viewpoints in the discussion of the drivers of real interest rates.

Second, *the monetary explanation* argues that interest rates have fallen due to an excessively loose monetary policy since the GFC (Borio, Disyatat, Juselius and Rungcharoenkitkul, 2019). Furthermore, in contrast to the real economy explanation, it is argued that persistently low interest rates can induce distortions in the real economy or on the capital market.

The analysis carried out in this paper does not enable us to formulate a viewpoint in this debate. However, a few observations are in order. On the one hand, supporting the real economy explanation, weak consumer price inflation in the decade preceding the COVID-19 pandemic suggests that monetary policy has not been overly expansionary and that the decline in real interest rates instead reflects a decline in r*. Proponents of the monetary explanation, on the other hand, argue that interest rates can stay below the natural rate for long periods without causing significant inflation, for example, if high private debt levels weigh on consumer spending. Moreover, empirical work by Juselius, Borio, Disyatat and Drehmann (2017) suggests that monetary policy affects the credit cycle, while strong responses of monetary policy to credit crunches and sluggish responses to credit gluts lead to an average negative impact of monetary policy on real interest rates over time. Overall, however, the empirical literature tends to lean towards the real economy explanation, suggesting that the long-term decline in real interest rates reflects structural changes in the economy and hence a decline in r*, rather than excessively loose monetary policy (Holston, Laubach and Williams, 2017; Del Negro, Giannone, Giannoni and Tambalotti, 2017).

CHART 3: DEMOGRAPHICS

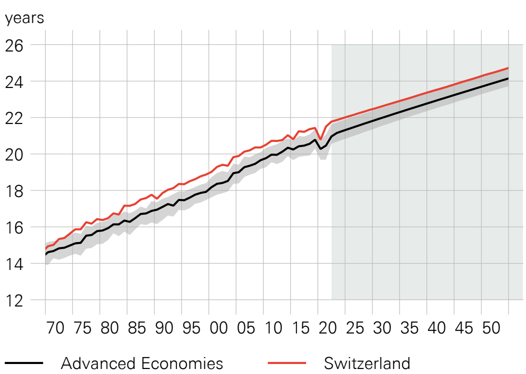
POPULATION SHARES



Source(s): UN, World Population Prospects 2022

Note: Average over 16 AEs (AUS, BEL, CAN, DEU, DNK, ESP, FIN, FRA, GBR, ITA, JPN, NLD, NOR, PRT, SWE, USA).

CONDITIONAL LIFE EXPECTANCY AT THE AGE OF 65



Source(s): UN, World Population Prospects 2022

Note: Average over 16 AEs (AUS, BEL, CAN, DEU, DNK, ESP, FIN, FRA, GBR, ITA, JPN, NLD, NOR, PRT, SWE, USA). The shaded areas represent the interquartile ranges.

The key question from an economic perspective is to what extent the natural interest rate has actually fallen in recent decades. We shed light on this by discussing in more detail the most prominent structural drivers mentioned in the literature: demographics (Section 2.3.1), productivity growth (Section 2.3.2) and financial drivers such as convenience yields and risk premia (Section 2.3.3).[8]

2.3.1 Demographics

Demographic developments such as increases in life expectancy and declining fertility rates have affected the age composition of the population in most advanced economies. We highlight two corresponding channels that could affect real interest rates in distinct ways.[9]

First, the share of high-saving middle-aged cohorts has increased relative to the share of high-spending old-aged cohorts. The difference between the shares of these cohorts is a good indicator of the aggregate savings of the economy. The left panel of Chart 3 displays the population shares of middle-aged (between 40 and 64 years) and old-aged (65 years and older) cohorts, comparing Switzerland to the average of 16 advanced economies. The relative importance of the high-saving middle-aged cohort increased between 1980 and 2010, leading to higher aggregate savings, which likely exerted *downward pressure on real interest rates*. Since 2010, the share of middle-aged individuals has stagnated, whereas the share of old-aged individuals has accelerated. Consequently, the relative importance of savers relative to spenders has been declining over the last decade, leading to lower aggregate savings, which are likely to exert upward pressure on real interest rates. In the ageing societies of advanced economies, this development is not expected to revert any time soon, representing *an upside risk for real interest rates* going forward.

Second, the increase in life expectancy has a direct effect on real interest rates through the increase in time spent in retirement (for a given retirement age, i.e., absent pension reforms aiming for a later retirement). A longer retirement period calls for greater savings at retirement to maintain living standards. Rising life expectancy should therefore lead to a greater propensity to save throughout working age, which should *lower the real interest rate*. The right panel of Chart 3 displays the conditional life expectancy at the age of 65 years in Switzerland and in an average of 16 advanced economies. The conditional life expectancy has increased over the last fifty years, and this trend is expected to continue for the foreseeable future.

Overall, the impact of demographic developments on real interest rates is mixed. While the relative evolution of the relevant population cohorts (high-saving middle-aged vs. high-spending old-aged) had mixed effects on real interest rates over the past 40 years, increasing life expectancy is likely to have supported aggregate savings and thus likely weighed on real interest rates.

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8 Lunsford and West (2019) conduct a comprehensive study of long-run correlations between real long-term government bond yields and potential drivers for the US. They find statistically and economically important long-run correlations of yields with aggregate labour hours and demographic variables. Furthermore, TFP growth has been proven to be an important ingredient for modelling trends in long-term yields.

9 See also Bean, Broda, Itō and Kroszner (2015, pp. 24ff).

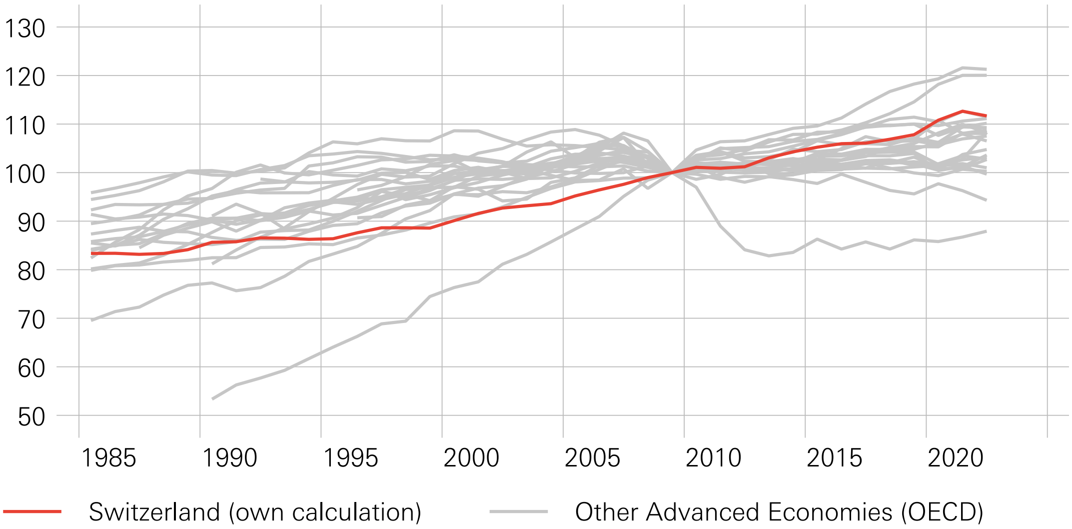
2.3.2 Productivity growth

Declining productivity growth as a key driver of potential output growth is another candidate for explaining falling real interest rates.[10] First, lower expected future productivity growth leads to lower expected future household income, which in turn induces agents to currently save more to smooth consumption over the life cycle. Second, lower productivity growth means that investment in physical capital is less profitable, which reduces the demand for investment.

Chart 4 displays multifactor productivity[11] for Switzerland and a range of other advanced economies.[12] While individual advanced economies exhibit different trajectories, the overall picture is quite clear: while enjoying decent productivity growth in the years before the GFC, productivity growth has been anaemic since the GFC. Switzerland is a bit of an outlier in this regard, as it enjoyed somewhat more growth in the post-GFC period.

CHART 4: MULTIFACTOR PRODUCTIVITY

Index, 2009 = 100



Source(s): OECD, own calculation

10 See Bean et al. (2015, pp. 35f).

11 The term 'multifactor productivity' (MFP) is often considered equivalent to the more frequently used term 'total factor productivity'. However, in this section, we opt for 'multifactor productivity' as we are reporting productivity data from the OECD, which specifically labels it as such. MFP is calculated as a residual, i.e., that part of GDP which cannot be explained by the combined production factors capital and labour.

12 Our own calculation of multifactor productivity in Switzerland is based on a production function featuring hours worked and a measure of the capital stock weighted by capacity utilisation. Details on the OECD production function can be found in OECD (2024).

2.3.3 Financial drivers: convenience yields and risk premia

Chart 1 suggests that nominal and real yields have converged over recent decades. Bacchetta et al. (2022) document a growing international comovement of interest rates, both in nominal and real terms, over the last 50 years. According to Del Negro et al. (2019), the convergence of real interest rates may reflect an increasing integration of international financial markets. This integration made downward pressure on interest rates a global phenomenon that also affected Switzerland. The literature discusses two main channels in this context.

First, the supply of safe and liquid assets—in particular, US government bonds but also bonds of other low-growth advanced economies—has not kept up with rising demand for these assets, which was driven by high-growth emerging economies, general population ageing (Caballero, Farhi and Gourinchas, 2017), and unconventional monetary policies such as quantitative easing and foreign reserve accumulation.[13] Overall, increasing demand amid a moderate supply of safe assets is likely to have driven up their prices, thereby lowering their return (Caballero et al., 2017; Del Negro et al., 2017). As those developments have not been observed for less safe and less liquid assets, the convenience yields, which capture the perceived quality of safe assets and thus the return investors are willing to forego holding them, have increased.

The second channel is related to heightened perceptions of economic and financial instability, particularly since the aftermath of the GFC. Risk premia, which compensate investors for the uncertainty and potential losses associated with holding riskier assets, have generally increased. The convenience yield on safe assets, by contrast, tends to increase during episodes of global stress and deleveraging, driving down the yield on safe assets (Gourinchas, Rey and Sauzet, 2022). Some papers argue—using different decomposition methods—that the increase in the risk premium is substantial (Caballero et al., 2017; Farhi and Gourio, 2018; Marx, Mojon and Velde, 2019) and largely explains the increasing wedge between the return on capital and the real yield on government bonds. In contrast, Eggertsson, Mehrotra and Robbins (2019) argue that in the United States, the increase in profits can explain most of the observed increase in the wedge.

2.4 Outlook

Over the past two years, real interest rates have risen back to levels slightly above zero (Chart 1). This mainly reflects the tightening of monetary policy in many countries but also raises the question of whether real interest rates will remain higher once the tightening cycle is completed and corresponding effects have faded. Indeed, the outlook for the structural drivers of real interest rates is mixed. Factors such as low potential growth and increasing life expectancy, which it seems plausible to assume are here to stay, suggest that real interest rates may remain low. However, there are other factors that could lead to a persistent rise. These include lower savings due to a growing proportion of the inactive population (Goodhart and Pradhan, 2020), large fiscal deficits (see Campos, Fernández-Villaverde, Nuño and Paz, 2024, for a formalisation

13 Regarding the financial integration of emerging market economies, Coeurdacier, Guibaud and Jin (2015) conclude that financial integration has led to a substantial drop in the world real interest rate. In contrast, Rachel and Smith (2017) find that its impact is rather small.

of the effect of the debt level on the natural real rate), a productivity boost from new technologies (Baily, Brynjolfsson and Korinek, 2023) and substantial investment in the green transition (Mongelli, Pointner and van den End, 2022). It is still too early to judge whether a reversal of the global downward trend in real interest rates is already taking place (IMF, 2023).

3. A portfolio of models used to estimate r*

Owing to the inherent uncertainty in estimating the unobserved natural rate r*, the SNB uses a portfolio of models covering different macroeconomic modelling frameworks and estimation approaches proposed in the literature. The models can be roughly divided as follows: a purely empirical financial market-based indicator and a range of macroeconomic models that differ in the degree of economic structure they impose. Each model offers its own particular vision of the natural rate r*. The technical details of these models can be found in Appendix A.2.

3.1 An indicator based on financial market data

A straightforward and widely employed approach to estimate r* is to extract market expectations about future short-term real interest rates from financial market prices. The underlying assumption is that the real interest rate should return to r* over time as the effects of shocks dissipate. This is why market expectations several years into the future are used in this approach.

To compute an expected short-term real interest rate for a time period in the future, forward nominal interest rates and forward inflation rates are employed. Forward nominal rates are the interest rates expected for future periods implicit in today's longer-term interest rates. Similarly, forward inflation rates, as measured by inflation-linked financial instruments, reflect market participants' inflation expectations for future periods. Deflating the forward nominal interest rate with such a measure of inflation expectations over the same period and accounting for the existence of a real term premium provides a measure of market expectations of the average future short-term real interest rate that can be interpreted as a measure of r*.

One advantage of estimating r* using financial market prices is that these estimates are, in principle, available on a daily basis. However, this approach also has certain disadvantages. Removing the term premium is subject to significant uncertainty, as its estimates are sensitive to model assumptions.[14] Moreover, in the case of Switzerland, no inflation-linked financial instruments are available, which further complicates the

14 Overnight index swaps (OIS) reflect the market-based expected policy rate over the life of the contract plus a premium charged to investors for uncertainty about the expected policy rate and possibly other risks. Inflation-linked financial instruments, in turn, reflect the average expected inflation over the life of the contract and, potentially, a risk premium that compensates for uncertainty about future inflation expectations. Since the OIS term premium and the risk premium of the inflation-linked instrument are not observable, they have to be estimated. Examples of methods to decompose longer-term interest rates into term premia and expected average short-term rates are presented by Kim and Wright (2005) or Adrian, Crump and Moench (2013). For an extensive overview of methods to estimate the inflation risk premium, see Bekaert and Wang (2010).

estimation of a financial market-based r*. Thus, we infer the expected real interest rate over a period of five years starting in five years (real 5y5y rate) on the basis of the nominal 5y5y OIS rate and a model-based measure of inflation expectations over the same horizon. The latter is derived following Grishchenko et al. (2019) and is already employed in Subsection 2.1 to deflate nominal 10-year government yields. The authors model inflation expectations in a dynamic factor model of inflation that incorporates survey-based inflation expectations to allow for survey-consistent inflation expectations at any horizon. Note that the 5y5y real rate—calculated as the 5y5y OIS rate minus our measure of 5y5y inflation expectations—still includes a term premium. We do not adjust for the term premium, however, as the estimates of this unobserved component are associated with considerable uncertainty. Furthermore, the level and volatility of this component vary from model to model, which would ultimately imply quite different estimates of r*.

3.2 Trends in real interest rates from a multicountry perspective (DGGT)

An alternative method for estimating r* is to focus on the long-term trend of real interest rates. As Del Negro et al. (2019) show, real interest rates have a strong global trend component. Therefore, taking a multicountry perspective in the estimation of these trends is appropriate.

Following Del Negro et al. (2019), we apply a vector autoregressive (VAR) model with unobserved common trends to estimate the long-run trends in real interest rates for the global economy and for individual countries (labelled DGGT). Economic theory is employed to model these trends. In particular, the model uses a set of Euler equations to describe how the global investors' decisions about when to consume are influenced by expected returns and their preferences for consumption. The models' Euler equations also incorporate the concept of convenience yields, i.e., the yield reduction accepted by investors for the extra benefits from holding certain assets compared with others. Because different countries have varying convenience yields, this leads to deviations from the traditional interest rate parity conditions, which usually dictate that interest rates should equalise across countries when adjusted for exchange rates.

The model assumes that, in the long run, the growth rate of the real exchange rate is stationary and that there are no opportunities for international arbitrage (profiting from price differences in different markets). This assumption implies that, in long-term equilibrium, the factor used to discount future payoffs to their present value is consistent across all countries. Consequently, the stochastic discount factor (which determines how future cash flows are valued today) is the same for all countries in long-term equilibrium. This results in a common component in real interest rate trends globally, referred to as the trend in the global short-term real interest rate.

Our procedure differs from that of Del Negro et al. (2019) in that we add Switzerland to the seven countries considered by these authors (the US, Japan, Germany, the UK, France, Italy and Canada). Furthermore, to obtain updates at a policy-relevant frequency, we estimate the model using quarterly data from 1978Q1 to 2024Q2, whereas the estimates of Del Negro et al. (2019) are based on annual data for the period 1870 to 2016. The analysis provides results on trends in the real interest rate for the global

economy and for individual countries, including Switzerland. These trends are interpreted as approximations of the long-run movements of r*.
We also use an extended version of the model (labelled DGGT+ hereafter) that produces various additional insights. Adding yields on corporate bonds and consumption growth to the model and maintaining the no-arbitrage assumption allows us to decompose the world real interest rate trend into contributions from global consumption growth and the global convenience yield for safety and liquidity and a residual potentially reflecting demographic shifts.

3.3 A modified version of the Laubach-Williams (LW) model

The semistructural Laubach-Williams model (Laubach and Williams, 2003; Holsten et al., 2017) has become the standard approach for empirical research on r* in many countries.[15] Consequently, we also include the Laubach-Williams methodology in our model portfolio.

In the Laubach-Williams (LW) framework, r* is the short-term real interest rate, which is consistent with a closed output gap and stable inflation. The model postulates a standard IS equation that describes the relationship between the output gap (the percentage deviation of real GDP from potential output, i.e., the unobserved full-capacity level of output) and the real rate gap (the difference between the real interest rate and r*), as well as a Phillips curve relating current inflation to the output gap and inflation dynamics. The natural rate r* is estimated as a latent variable. Using the Kalman filter, the model extracts estimates of several unobserved variables—including r* and the level and trend of potential output—from observed data on real GDP, inflation and the short-term interest rate.

As part of our model portfolio, we use a modified version of the LW model. Our version differs from those of Laubach and Williams (2003) and Holsten et al. (2017) in two ways. First, instead of considering an exogenously determined short-term real interest rate, we add a Taylor-type interest rate rule with interest rate smoothing, as is standard in many macroeconomic models. With this extension, we follow Brand and Mazelis (2019), who argue that adding a Taylor rule allows to capture the typical response of monetary policy to expected inflation and output while identifying the output gap and potential output growth, respectively, in a way that is model-consistent with r*. Second, the model is estimated using Bayesian methods rather than maximum likelihood techniques as applied by Laubach and Williams (2003) and Holsten et al. (2017). The use of Bayesian methods makes the estimates more stable, while appropriate priors help reduce estimation uncertainty.[16]

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15 For example, Grigoli, Platzer and Tietz (2023) apply the Laubach-Williams methodology to a set of advanced economies (including Switzerland) over a sample starting at the end of the 19th century. For some background on the genesis of the Laubach-Williams model, see Williams (2023).

16 A similar approach is taken by Bulíř and Vlček (2024). They also extend the LW framework to explicitly take into account open-economy aspects as well as appreciation or depreciation trends in the exchange rate. Their results for Switzerland are qualitatively but also quantitatively quite close to our LW-type model (see Figure A.3 Switzerland on page 30 of their paper).

3.4 New Open Economy Macroeconomics (NOEM) model with a time-varying steady state

Finally, our portfolio of models used to estimate r* includes a dynamic stochastic general equilibrium (DSGE)-based approach. Compared with the models referred to thus far, DSGE models place more emphasis on structural analysis and economic theory. This approach has many advantages. However, standard DSGE models typically focus on modelling fluctuations in macroeconomic variables at business cycle frequencies around constant steady-state values. Therefore, they have nothing to say about potential low-frequency movements of steady-state values for variables such as the equilibrium real interest rate r*.

We estimate the natural rate r* with an augmented DSGE model that allows for a time-varying endogenous steady state. This model builds on the now standard open economy macroeconomics framework, initially developed by Galí and Monacelli (2005) and Justiniano and Preston (2010) and further adapted for Switzerland by Rudolf and Zurlinden (2014). The time-varying steady state is integrated into the open economy framework by employing a VAR approach with unobserved common trends, in line with the methodology proposed by Del Negro et al. (2019). This model approach differs from the DGGT approach in that it is based on significantly more structure that describes the business cycle relationships. These additional restrictions result in an alternative decomposition of the real interest rate into its trend and cyclical component. The resulting model provides estimates of long-run movements in potential output growth, the nominal exchange rate, the short-term nominal interest rate and the inflation rate. The difference between the steady-state short-term nominal interest rate and the steady-state inflation rate can be interpreted as a measure of the natural rate r*.[17]

4. Results

Chart 5 shows estimates of the Swiss natural rate, or r*, from the models described above for a sample from 1985 to 2023.[18] All model estimates point to a significant decline in r* since the mid-1980s. This finding is illustrated in Table 1, which shows the 5-year averages of the model estimates for the periods 1985 to 1989 and 2019 to 2023 and the difference between the two averages. The estimates suggest that r* in Switzerland was approximately 1.3-2.9% in the second half of the 1980s. It fell particularly after the global financial crisis until the outbreak of the COVID-19 pandemic and then roughly stabilised at a value of approximately 0%. The agreement between the models since the global financial crisis until the pandemic is particularly striking, with all the models suggesting a significant decline in r*. Overall, the models show a decline in the natural rate of between 1.3 and 3.1 percentage points since the mid-1980s (fourth column in Table 1).

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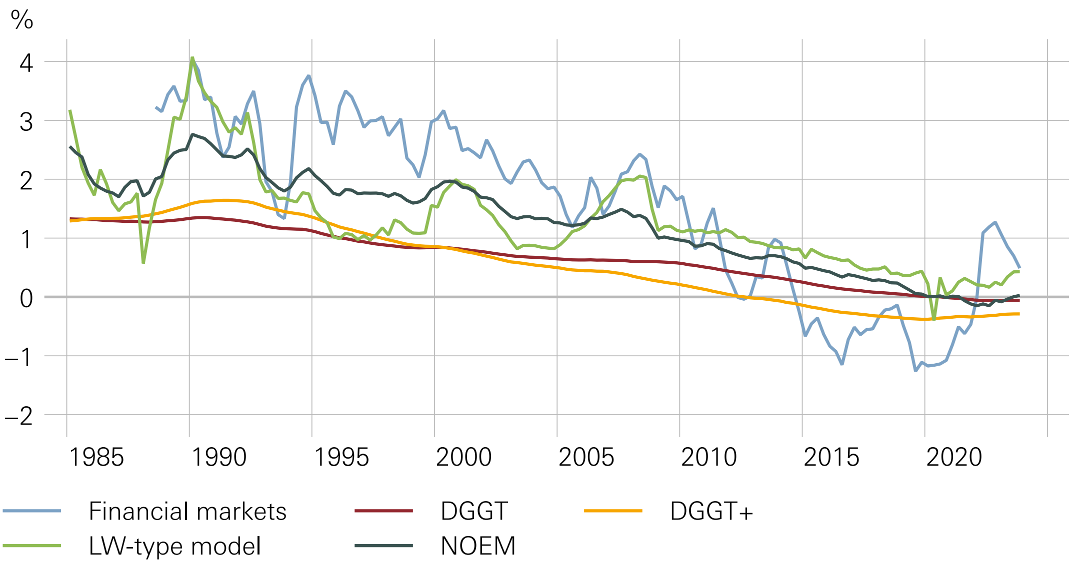
17 DSGE models in both their standard and augmented versions can also be used to derive a short-term r*, the concept briefly discussed in the introduction of this paper.

18 Recent estimates for other countries or currency areas can be found, for example, in Brand, Lisack and Mazelis (2025) for the euro area and Nakano, Sugioka and Yamamoto (2024) for Japan.

CHART 5: MODEL ESTIMATES OF r* FOR SWITZERLAND



Source(s): Bloomberg, BIS, Consensus Economics, IMF, LSEG Datastream, SFSO, SNB, own calculations

As the models differ considerably in their approaches to determine the equilibrium real interest rate r*, these model estimates also reflect sizable model uncertainty. Moreover, the individual estimates of r* are data dependent, i.e., they depend on the variables included in the model and on the estimation sample. In particular, as more data becomes available over time, the r* estimates are revised. These challenges due to data dependency are referred to as statistical uncertainty.[19] Even abstracting from statistical uncertainty, the difference between the highest and lowest estimates in Chart 5 is approximately 1-2 percentage points on average from 1985 to the present, indicating considerable model uncertainty in the estimation of r*.[20]

Since the pandemic, some models, particularly the indicator based on financial market data and the structural models, such as the NOEM and LW-type model, estimate an increase in r*.[21] However, given the high degree of uncertainty associated with these estimates, it is too early to call an end to the downward trend in r* in Switzerland.

Given the large uncertainty in estimating r*, a sound understanding of the various structural drivers in the individual models helps in judging the plausibility of these estimates. How do the different models explain the decline in the Swiss r* since the mid-1980s? As outlined in Section 3, the models include a variety of data that capture, to varying degrees, the evolution of the main determinants of aggregate savings relative to investment and hence of r*. These include global and domestic potential growth, as well as different interest rate measures that reflect how savings and investment

19 Brand, Bielecki and Penalver (2018), for example, discuss the uncertainty in estimating r* for the euro area.

20 Chart 5 shows only part of the total model uncertainty, as we restrict the analysis to a set of models to make it feasible.

21 Benigno, Hofmann, Nuno and Sandri (2024) use five structural and financial market models to estimate r* for the US and the euro area. They find evidence that r* may have increased since the pandemic but emphasise the large uncertainty surrounding r* estimates in general and in the current situation, in particular.

dynamics are influenced by demographic developments, fiscal policy, geopolitical stability, financial market conditions and other factors. Chart 6 shows a decomposition of the main drivers of r* for each model. Some key observations emerge from the chart.

TABLE 1: Comparison of the r* model estimates between the 1980s and the recent past

r* in percent	1985Q1-1989Q4	2019Q1-2023Q4	Difference
Financial market[22]	2.9	-0.2	-3.1
DGGT	1.3	0	-1.3
DGGT+	1.4	-0.3	-1.7
LW-type model	2.1	0.3	-1.8
NOEM	2.1	0	-2.1

First, the indicator based on financial market data confirms that nominal interest rates in Switzerland have decreased faster than inflation expectations, especially after the GFC, leading to a decline in r*. This downward trend has reversed since the pandemic, as noted by Benigno et al. (2024). However, to a certain extent, the observed increase in the financial market measure probably results from an increase in the term premium and is therefore not entirely attributable to an increase in r*.[23]

Second, the models suggest that a predominant part of the downward trend in r* is explained by global factors. This is visible in the DGGT, DGGT+ and NOEM decompositions. All three show that the global component (the grey shaded areas and sum of the blue, green and yellow areas in DGGT+) is a key driver of the Swiss r* estimate. This is consistent with Del Negro et al. (2019), who show that advanced economies share the same global trend in real interest rates. Many other studies in the literature confirm the importance of global factors for the evolution of r* across countries (e.g., IMF, 2023; Cesa-Bianchi, Harrison and Sajedi, 2023). Moreover, Obstfeld (2021) emphasises that in a world of integrated capital markets, r* is globally determined.

Another observation can be made in the same graphs. The three aforementioned models indicate that r* is lower in Switzerland than abroad. The domestic component, the red shaded area, is negative throughout the estimation sample. However, the domestic component in the DGGT+ and NOEM models becomes less negative over time, leading to the conclusion that the downward trend in r* in Switzerland has been somewhat less pronounced than the global trend. This finding was also reported by Bacchetta et al. (2022).

The third observation in Chart 6 concerns the role of potential growth in the evolution of r* in Switzerland. In the DGGT+ and LW-type models, potential output or consumption growth (light blue shaded areas) is a key driver for the evolution of r*.[24]

22 Due to data availability, we only have a r* estimate of the financial market measure since 1988Q3. Therefore, the second column shows the 5-year average from 1990 to 1994.

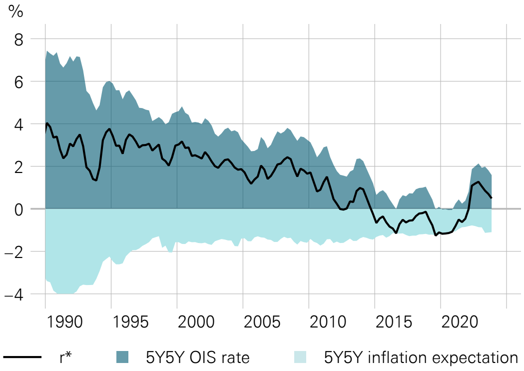
23 As previously outlined in Section 3.1, the financial market measure of r* illustrated in Chart 5 is not adjusted for the term premium.

24 Potential output growth or income growth is a key determinant of consumption growth and thereby closely related. Moreover, in these types of models the stochastic discount rate is a key determinant of r* and the stochastic discount rate evaluates future income streams based on the expected consumption at the time.

Comparing the difference between the periods 1985 to 1989 and 2019 to 2023, these models suggest that between 0.8 and 1.5 percentage points of the decline in Swiss r* can be attributed to lower potential growth.

CHART 6: DECOMPOSITIONS OF THE r* ESTIMATES INTO THE MAIN DRIVERS

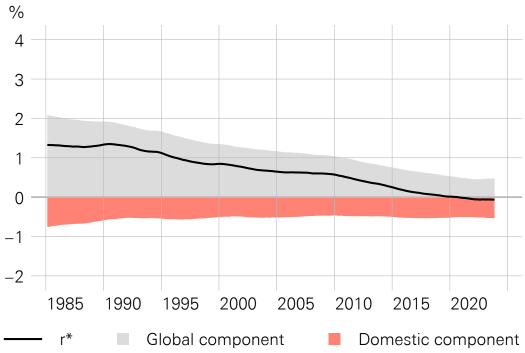
FINANCIAL MARKET MEASURE OF r*



Source(s): Bloomberg, Consensus Economics, SFSO, own calculations

DGGT

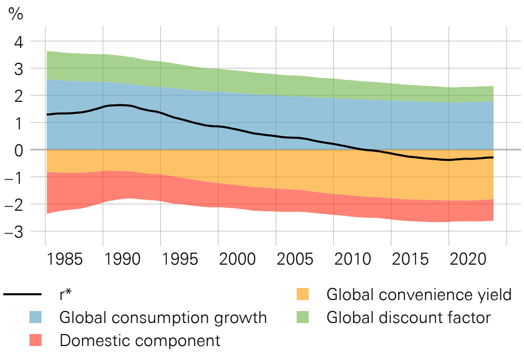
Baseline VAR with common trends (Del Negro et al., 2019)



Source(s): BIS, IMF, LSEG Datastream, SFSO, SNB, own calculations

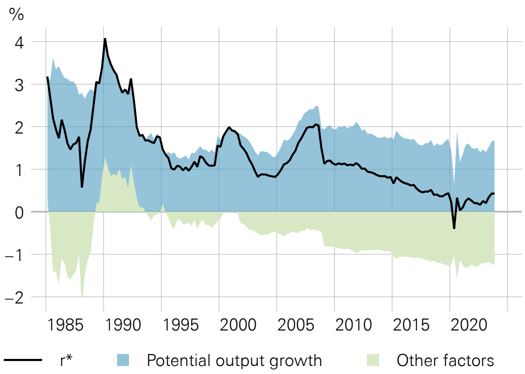
DGGT+

Extended VAR with common trends (Del Negro et al., 2019)



Source(s): BIS, IMF, LSEG Datastream, SFSO, SNB, own calculations

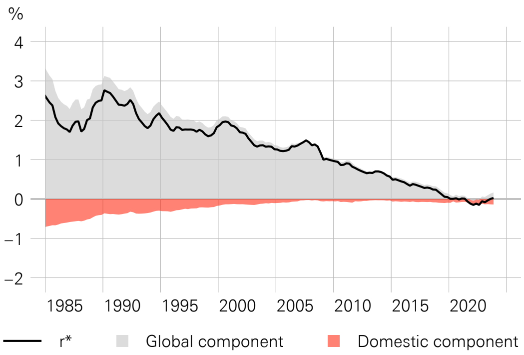
LW-TYPE MODEL



Source(s): LSEG Datastream, SFSO, own calculations

NOEM

Open Economy Model with time-varying steady state



Source(s): LSEG Datastream, SFSO, SNB, own calculations

In the decomposition of the DGGT+ model, one can also see the contribution of the global convenience yield (yellow shaded area). The convenience yield has increased substantially since 1985, thereby exerting significant downward pressure on r*. The increase in the global convenience yield may indicate a growing global demand for safe and liquid assets by investors relative to supply. The DGGT+ model suggests that the convenience yield contributes approximately 1 pp to the decline in r*.

Finally, the global discount factor component in the DGGT+ model (green shaded area), the nonconsumption-related part of the stochastic discount rate, also seems to have contributed to the declining trend in r*. As demographic factors, which are discussed in Subsection 2.3.1, should be reflected mainly in the stochastic discount factor, this result is an indication of the downward pressure of demographic factors on r*. This component explains approximately 0.5 pp of the decline in r* in the DGGT+ model between the mid-1980s and today.

5. Relevance for monetary policy in Switzerland

A shift in r* has two direct implications for the conduct of monetary policy. First, ceteris paribus, it affects the assessment of monetary conditions. Second, it implies that the constraint of the ELB becomes more or less relevant for monetary policy.

Starting with the first implication, despite its uncertainty, r* is a relevant element in the assessment of monetary conditions. However, any central bank also takes into account factors related to the state of the economy, as reflected in a broad set of indicators like the inflation rate relative to the target (range), the output gap or the real exchange rate.[25] This is especially relevant for a small open economy such as Switzerland.

To obtain an estimate of r*, the SNB uses the portfolio of r* models described in Section 3. The portfolio approach is appropriate because of the high uncertainty in estimating the latent variable r*, as discussed in Section 4. In Chart 7, we apply the median, a robust statistical measure, to the range of r* estimates and display it together with the Min/Max range. The portfolio approach can help filter out some of the unsystematic variation that a few outlier estimates might cause.[26]

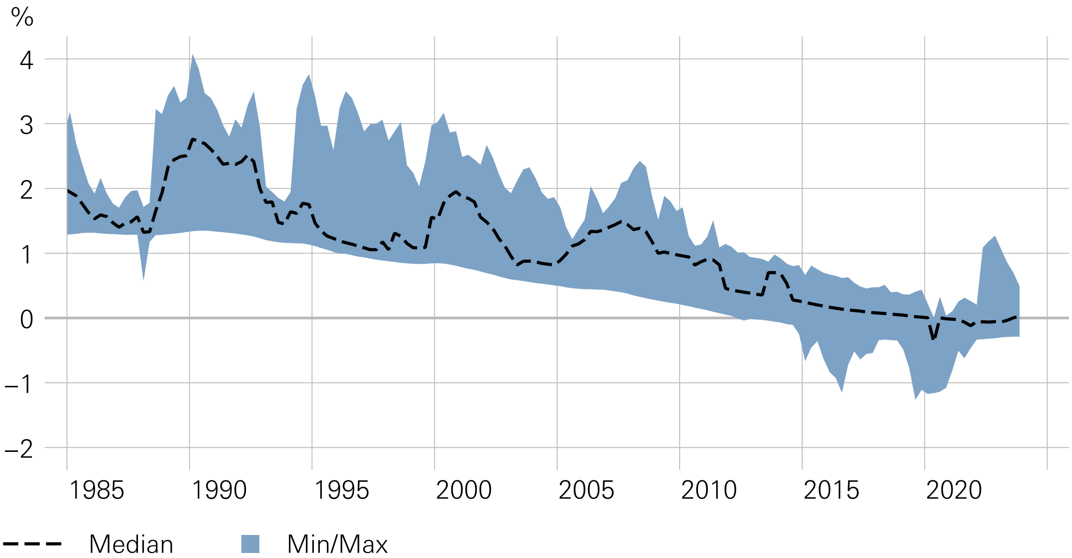
The median, as indicated in Chart 7, shows a substantial decline in r* of 1.5-2 pp since the mid-1980s. This decline implies that a given real interest rate level becomes less expansionary over time for a given state of the economy, particularly for a given inflation rate and output gap relative to their respective target value. Conversely, if r* were to rise, a given real interest rate level would—ceteris paribus—become more expansionary. Overall, it is therefore important for an assessment of the monetary policy stance to take longer-term changes in r* into account. Moreover, r* typically changes only gradually, so shifts in r* are of little relevance for the assessment of how monetary conditions change over short horizons, such as from one quarter to the next.

The second implication of a shift in r* is that the constraint of the ELB becomes more or less relevant for monetary policy. The ELB is defined as the nominal policy

25 For more on this point, see Williams (2024).

26 For more on how to arrive at policy-relevant r* estimates, see Jordan (2024).

CHART 7: STATISTICAL MEASURES OF THE r* ESTIMATES



Source(s): Bloomberg, BIS, Consensus Economics, IMF, LSEG Datastream, SFSO, SNB, own calculations

rate level that marks the natural limit for interest rate policy.[27] A further lowering of the policy rate would not be possible because consumers always have the option to hold noninterest-bearing cash instead of bank deposits and other financial instruments. Because this inhibits monetary policy transmission, there would be no additional positive effect on aggregate demand.[28] The location of the ELB is unknown. Moreover, the ELB likely differs across countries, reflecting differences in the institutional features of the financial system.

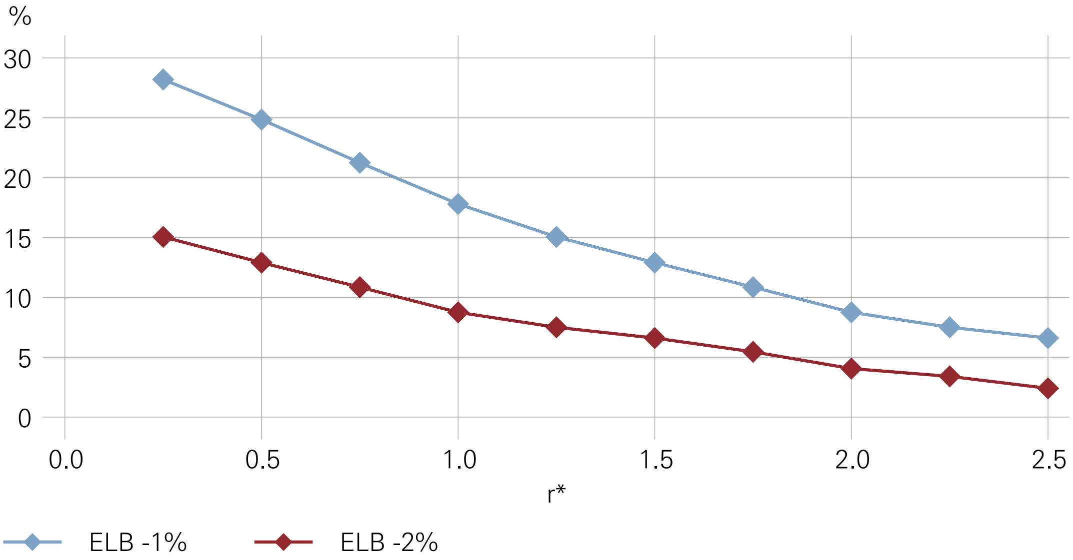
During periods where the ELB constraint is binding, interest rate policy is not able to respond optimally to negative demand disruptions. In the absence of other policy instruments, this results in a more negative output gap and lower inflation than would otherwise be the case. The ELB may therefore lead to a drop in inflation rates below the central bank's target (range) and to a decline in inflation expectations. This can further exacerbate the effects of the lower bound on the economy (Mertens and Williams, 2019).

To illustrate the potential direct consequences of a shift in r* for the conduct of monetary policy in Switzerland, we simulate probabilities of Swiss short-term interest rates hitting the ELB (Chart 8). Because the location of the ELB is unknown, we simulate ELB probabilities for two values of the ELB: –1% (blue line) and –2% (red line). This is the upper and lower bound of the interval estimated by Kolcunová and Havránek (2018) for the Czech Republic. The simulation is conducted using the NOEM described in Subsection 3.4. Starting from the model's steady state, we compute the

27 In reality, the ELB is probably less of a sharp divide between regimes; rather, there is likely a smooth transition between regimes.

28 Some studies even find negative effects when the policy rate is cut below a certain threshold owing to the shrinking profit margins of banks and therefore lower bank lending. This reversal rate is proposed by Abadi, Brunnermeier and Koby (2023).

CHART 8: ELB PROBABILITIES



Source(s): Bloomberg, LSEG Datastream, SFSO, SNB, own calculations

share of episodes in which the Swiss short-term interest rate hits the ELB by using estimated shocks for the Swiss economy from Q1 1995 until Q2 2024.[29]

Chart 8 shows the simulation results for r* values ranging from 0.25% to 2.5%. A comparison of the results reveals how much the ELB probability increases when moving from a world with a high r* of 2.5% to a world with a low r* of 0.25%. Under the assumption of an ELB of –2%, the ELB probability increases from 2% to 15%, and under the assumption of an ELB of –1%, the ELB probability increases from 7% to 28%. Furthermore, the relationship between r* and the ELB probability is nonlinear. A 1 pp decrease in r* increases the ELB probability more when r* is initially low than when r* is initially high. This nonlinearity arises because, in a low r* world, more combinations of deflationary shocks can push the economy towards the ELB, and it becomes more difficult for monetary policy to lift the economy out of the ELB.

Similar increases in ELB probabilities can also be found for other countries or currency areas. For example, Coenen, Montes-Galdón and Schmidt (2021) simulate ELB probabilities for the euro area assuming an ELB of –0.5%.[30] They find an increase in the ELB probability from 13% to 27% when r* falls from 2% to 0%. These probabilities are comparable to the results we find for Switzerland.

29 The sample period includes the period of the COVID-19 pandemic. We estimated the NOEM with data including and excluding the pandemic and compared the estimated parameters and shock processes. The persistence and variance of the Swiss and foreign productivity and demand shocks increase slightly in the model when the period of the pandemic is included. These higher shock variances make ELB episodes somewhat more likely in the simulations shown in Chart 8.

30 For estimates of ELB probabilities for the US, see Chung, Gagnon, Nakata, Paustian, Schlusche, Trevino, Vilan and Zheng (2019).

Owing to the higher expected ELB incidences in a low r* world, central banks around the world have used additional "unconventional" tools to steer the economy. Central banks in economies with large domestic bond markets have used mainly purchases of domestic government and corporate bonds to stimulate inflation by lowering long-term interest rates. Central banks in small open economies, including the SNB, have employed foreign exchange market interventions. This is consistent with the SNB monetary policy strategy, which states that, if necessary, the SNB may use additional monetary policy measures to influence the exchange rate or the interest rate level, in addition to steering the short-term interest rate.

6. Conclusion

Obtaining reliable estimates of the natural rate r* and understanding its drivers is key for assessing long-run trends in real interest rates. In turn, this plays a role in assessing the monetary policy stance. Against this backdrop, we discuss the evolution of real interest rates in Switzerland and present a portfolio of models used by the SNB to estimate r* while also investigating its drivers.

Consistent with the evolution of real interest rates globally and in Switzerland, model estimates point to a significant decline in r* since the mid-1980s, where r* is lower in Switzerland than abroad. Potential output growth as well as global factors related to the demand for and supply of safe and liquid assets (i.e., the convenience yield) and to demographics (as reflected in the discount factor) appear to be important drivers of the downward trend in r*. However, estimates are subject to significant model and statistical uncertainty.

Estimates of r* provide an important piece of information for monetary policy. However, any central bank also takes into account factors related to the state of the economy, as reflected in a broad set of indicators like the inflation rate relative to the target (range), the output gap or the real exchange rate. This is especially relevant for a small open economy such as Switzerland. As one would expect, simulations show that in an environment where r* is low, the risk increases such that the policy rate becomes constrained by the effective lower bound (ELB). Under such circumstances, other policy tools such as foreign exchange interventions can therefore play an important role in ensuring adequate monetary conditions.

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A. Appendix

A.1. State-space model of CPI inflation expectations

This chapter in the appendix describes the model of inflation expectations that generates survey-consistent 10-year CPI inflation expectations, which are used to deflate 10-year government bond yields for 11 countries in Section 2.1. Additionally, the model produces 5-year inflation expectations 5 years forward, which serve as deflator for the calculation of a r* indicator on the basis of financial market data, as presented in Section 3.1.

The approach to estimate inflation expectations is based on the methodology proposed by Grishchenko et al. (2019), who employ a state-space model and utilise an array of professional forecaster surveys to generate model-based inflation expectations. Moreover, Grishchenko et al. (2019) incorporate information regarding the time-varying uncertainty of professional forecasters' inflation expectations, which is quantified by the cross-sectional standard deviation of inflation expectations. By integrating time-varying uncertainty, the model can offer a detailed perspective on inflation expectations and account for shifts in forecasters' confidence.

A simplified version that ignores time-varying uncertainty was applied by Bacchetta et al. (2022) to estimate real-time inflation expectations for 17 countries simultaneously, with forecasting horizons of up to 10 years.

We follow Bacchetta et al. (2022) with two notable differences: First, we do not allow for correlations between inflation components across countries but instead estimate a model of inflation expectations separately for 11 countries, using CPI inflation data as well as survey information for each country. Second, we use Bayesian techniques to estimate some parameters, whereas Bacchetta et al. (2022) use maximum likelihood estimation. The use of prior knowledge through Bayesian estimation is crucial, as it helps us to disentangle the CPI inflation rate into two latent factors.

The model has the following form:

$$\pi_{j,t} = \pi^{T}_{j,t} + \pi^{C}_{j,t} + \varepsilon_{j,t}$$

$$\pi^{T}_{j,t} = \pi^{T}_{j,t-1} + \varepsilon^{T}_{j,t}$$

$$\pi^{C}_{j,t} = \rho\, \pi^{C}_{j,t-1} + \varepsilon^{C}_{j,t}$$

$$E_t \pi^{CE}_{j,t+h} = \pi^{T}_{j,t} + E_t \pi^{C}_{j,t+h} + \varepsilon^{CE}_{j,t+h},$$

where $\pi_{j,t}$ denotes country-j-specific consumer price inflation in quarter t (annual percentage change), while $\pi^{T}_{j,t}$ and $\pi^{C}_{j,t}$ denote the latent country-specific trend and cyclical component, respectively. We use inflation expectations from Consensus Economics (CE) to incorporate additional information about expected inflation available at t into the model. Specifically, we integrate the CE average inflation expectations over a horizon of h = 1, 2, 3, and 4 years as well as the average inflation rate expected in the five-year window starting in five years (5y5y). The measurement error, $\varepsilon^{CE}_{j,t+h}$, allows for discrepancies between the observed survey-based inflation expectations ($E_t\pi^{CE}_{j,t+h}$) and the model-implied inflation forecast ($E_t\pi_{j,t+h}$) over the same horizon:

$$E_t\pi_{j,t+h} = \pi^{T}_{j,t} + E_t\pi^{C}_{j,t+h}.$$

Bayesian techniques are employed for the estimation of the autoregressive parameter, ρ, as well as the standard deviations of all error terms, with the exception of the one pertaining to the error term of the low-frequency inflation component, $\varepsilon^{T}_{j,t}$.[1] The standard deviation of the innovations to the low-frequency component, $\varepsilon^{T}_{j,t}$, is calibrated to the average standard deviation of the 5y5y CE inflation expectations. Over the sample period, this calibration is in line with the idea that innovations in the long-run component have a small standard deviation. Survey respondents generally expect inflation to be at its long-run level over the five-year period starting in five years.

With the model described above, ex ante inflation forecasts are computed that agents could have formed at any point within the sample period. This is achieved by re-estimating the model on a quarterly basis using available data up to period *t*, which allows the accurate simulation of model-endogenous ex ante inflation expectations in period *t*+*h*.

A.2. Details on the various model-based approaches used to estimate r*

A.2.1. Trends in real interest rates from a multicountry perspective (DGGT and DGGT+)

The DGGT model's measurement equations, which separate the trend components from the observed interest rate and inflation data, are as follows:

$$i_{j,t} = \bar{r}^{w}_{t} + \bar{r}_{j,t} + \lambda^{\pi}_{j}\bar{\pi}^{w}_{t} + \bar{\pi}_{j,t} + \tilde{\imath}_{j,t}$$

$$i^{L}_{j,t} = \bar{r}^{w}_{t} + \bar{r}_{j,t} + \overline{ts}^{w}_{t} + \overline{ts}_{j,t} + \lambda^{\pi}_{j}\bar{\pi}^{w}_{t} + \bar{\pi}_{j,t} + \tilde{\imath}^{L}_{j,t}$$

$$\pi_{j,t} = \lambda^{\pi}_{j}\bar{\pi}^{w}_{t} + \bar{\pi}_{j,t} + \tilde{\pi}_{j,t},$$

[1] For all countries *j*, the prior for the persistence parameter ρ of the cyclical component, $\pi^{C}_{j,t}$, is calibrated to follow a beta distribution with mean 0.8 and a standard deviation of 0.2. The standard deviation of the error term of the cyclical inflation component is set equal to the standard deviation of CPI inflation of the respective country. In addition, the standard deviation of the various measurement errors in the model are all calibrated to 5 percent of the standard deviation of the country's CPI inflation.

where $i_{j,t}$ and $i_{j,t}^{L}$ denote nominal short-term and long-term interest rates on safe assets for country j, respectively, and $\pi_{j,t}$ denotes the country-specific consumer price inflation.

These observed quarterly data series are decomposed into trend components labelled with a bar ($\bar{}$) and cyclical components labelled with a tilde ($\tilde{}$). Note that the trends in real interest rates ($\bar{r}_t^{\,w} + \bar{r}_{\,j,t}$) and inflation ($\lambda_j^{\pi}\bar{\pi}_t^{w} + \bar{\pi}_{j,t}$) consist of a global and a country-specific component for each country. From long-term interest rates, in addition to the real interest rate and inflation components, trend components are identified for the term spread $\overline{ts}_t^{\,w} + \overline{ts}_{\,j,t}$, which is the premium for the maturity range between long-term and short-term nominal interest rates.

In the extended model (DGGT+), the yield on US Baa securities and per capita consumption growth in each country j are included as additional observable variables, i.e., the DGGT model is extended by the following two measurement equations:

$$i_{US,t}^{Baa} = \bar{g}_t^{\,w} + \bar{\beta}_t^{\,w} + \overline{ts}_t^{\,w} + \overline{ts}_{\,US,t} + \lambda_{US}^{\pi}\bar{\pi}_t^{w} + \bar{\pi}_{US,t} + \tilde{\imath}_{US,t}^{Baa}$$

$$\Delta c_{j,t} = \bar{g}_t^{\,w} + \bar{\gamma}_t^{\,w} + \bar{\gamma}_{\,j,t} + \widetilde{\Delta c}_{j,t},$$

where $\bar{\gamma}_t^{w}$ and $\bar{\gamma}_{\,j,t}$ denote additional trends in consumption unrelated to the stochastic discount factor. The extended model corresponds to the "Consumption Model" in Del Negro et al. (2019). The authors show that the convenience yield $\overline{cy}_t^{w}$ can be identified assuming that $\bar{\imath}_{US,t}^{Baa} - \bar{\imath}_{US,t}^{L} = \overline{cy}_t^{w} + \overline{cy}_t^{US}$, where $-\overline{cy}_t^{US} = \bar{r}_t^{US}$. The trend in global consumption growth $\bar{g}_t^{\,w}$, in turn, can be extracted from the trend real interest rate $\bar{r}_t^{\,w} = \bar{g}_t^{\,w} + \bar{\beta}_t^{\,w} - \overline{cy}_t^{w}$ and the trends in consumption growth in individual countries $\Delta\bar{c}_{j,t} = \bar{g}_t^{\,w} + \bar{\gamma}_t^{\,w} + \bar{\gamma}_{\,j,t}$.

A.2.2. A modified version of the Laubach-Williams model

The Laubach-Williams model we use here is a slightly modified version of the widely used Laubach-Williams model (Laubach and Williams, 2003, hereafter LW; and Holston et al., 2017, hereafter HLW). It provides estimates of the natural rate of interest (r*) for Switzerland, using a semistructural New-Keynesian-type setup.

More specifically, the model differs from the LW and HLW frameworks in two fundamental ways: (1) unlike LW and HLW, we incorporate a Taylor-type interest rate rule with nominal interest rate smoothing, aligning more closely with the spirit of the canonical three-equation New-Keynesian model; and (2) the model is estimated using Bayesian methods rather than maximum likelihood estimation.

The model consists of the following equations: a dynamic *IS equation*

$$\hat{y}_t = a_{\hat{y},1}\hat{y}_{t-1} + a_{\hat{y},2}\hat{y}_{t-2} + \frac{a_r}{2}\sum_{j=1}^{2}\hat{r}_{t-j} + \epsilon_{y,t},$$

where the output gap, i.e., the percentage difference between the log of real GDP and the log of potential output $\hat{y}_t \equiv 100(y_t - y_t^{*})$, depends on its lags and two lags of the real rate gap, $\hat{r}_t$, i.e., the difference between the real short-term interest rate,

r_t , and the natural rate, r_t^*. The AR(1) shock process $\epsilon_{y,t}$ captures transitory shocks to the output gap.
The *Phillips curve* links consumer price inflation to expected inflation and the output gap:

$$\pi_t = b_\pi \pi_t^* + \frac{1 - b_\pi}{3}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3}) + b_y \hat{y}_t + \epsilon_{\pi,t},$$

where π_t, π_{t-1}, π_{t-2}, and π_{t-3} denote the annualised quarter-on-quarter consumer price inflation rate and its lags, respectively. π_t^* is the target level of the rate of inflation, which is allowed to vary over time. The lagged inflation rates incorporate the concept of delayed price adjustment due to nominal frictions. The AR(1) shock process $\epsilon_{\pi,t}$ captures transitory cost-push shocks to inflation.

The interest rate follows a *Taylor rule* with estimated parameters and inertia:

$$\begin{aligned} i_t = \rho i_{t-1} + (1 - \rho)\big[\pi_t^* + r_t^* \\ + \rho_\pi([(\pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3})/4 - \pi_t^*]) + \rho_{\hat{y}} \hat{y}_t\big] \\ + \epsilon_{i,t}. \end{aligned}$$

The short-term nominal policy interest rate is driven by the target level of inflation, π_t^*, the natural rate r_t^*, an inflation gap, and the output gap $\hat{y}_t$.

The target inflation level, π_t^*, is allowed to temporarily deviate from the long run target $\pi^* = 1\%$, represented as

$$\pi_t^* = \pi^* + \epsilon_{\pi^*,t},$$

where $\epsilon_{\pi^*,t}$ follows an AR(1) shock process, capturing temporary deviations from the long-run target. The level of potential output follows a random walk:

$$y_t^* = y_{t-1}^* + g_t + \epsilon_{y^*,t},$$

where $\epsilon_{y^*,t}$ captures permanent shocks to the level of potential output, y_t^*, while the stochastic drift

$$g_t = g_{t-1} + \epsilon_{g,t}$$

features a permanent shock to the period-by-period growth rate of potential output, g_t. The natural rate of interest, r_t^*, is then given by

$$r_t^* = g_t + z_t,$$

which represents the sum of the trend growth rate and an additional, nongrowth determinant z_t that follows a random walk:

$$z_t = z_{t-1} + \epsilon_{z,t}.$$

A.2.3. New Open Economy Macroeconomics (NOEM) model with a time-varying steady state

In the NOEM, we estimate the natural rate of interest, r*, as the difference between the steady-state short-term nominal interest rate and the steady-state inflation rate. These steady-state values are allowed to change over time to reflect underlying low-frequency factors that influence r*. We adopt the identification approach of Del Negro et al. (2019) to separate the trend and cycle components of the main macroeconomic variables (see Appendix A.2.1.). In contrast to their VAR approach, we use the NOEM structure to model the business cycle components of the macroeconomic variables. This approach imposes more economic structure, which may more accurately identify the time-varying steady states and hence r*.

In this chapter of the appendix, we present the measurement equations relevant to the modelling of r*. These equations are almost identical to those in Appendix A.2.1., except for the cyclical component. Here, we use a hat ($\widehat{\ }$) to denote the cyclical component, i.e., the deviation of each macroeconomic variable from the NOEM steady state, whereas the cyclical component in Appendix A.2.1. is denoted by a tilde ($\widetilde{\ }$), which is modelled on the basis of a VAR approach.

$$i_{j,t} = \bar{r}_t^{\,w} + \bar{r}_{j,t} + \lambda_j^{\pi}\bar{\pi}_t^{w} + \bar{\pi}_{j,t} + \hat{i}_{j,t}$$

$$i_{j,t}^{L} = \bar{r}_t^{\,w} + \bar{r}_{j,t} + \overline{ts}_t^{\,w} + \overline{ts}_{j,t} + \lambda_j^{\pi}\bar{\pi}_t^{w} + \bar{\pi}_{j,t} + \hat{i}_{j,t}^{L}$$

$$\pi_{j,t} = \lambda_j^{\pi}\bar{\pi}_t^{w} + \bar{\pi}_{j,t} + \hat{\pi}_{j,t}.$$

r* in the NOEM is defined as the sum of the global and country-specific trends in the real short-term interest rate

$$r_{j,t}^{*} = \bar{r}_t^{w} + \bar{r}_{j,t}\ .$$

Note that in the NOEM, we consider Switzerland as the domestic economy. The foreign economy is defined as a convex combination of the euro area and the United States, with weights of 0.7 and 0.3, respectively. For details of the DSGE model structure and estimation, see Rudolf and Zurlinden (2014).

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