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How can a decline in R* be reversed?

Productivity, retirement age, and the green transition

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How can a decline in R* be reversed?

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The room for maneuver of monetary policy and the relevance of the zero lower bound of nominal interest rates are largely determined by the level of and the outlook for the natural rate of interest (R), i.e. the unobservable equilibrium interest rate that neither stimulates nor contracts the economy. Available estimates suggest that the rate has declined substantially over the last decades and even centuries. The literature on the potential drivers of this decline – both macroeconomic and financial – finds that demographic factors, real GDP trend growth, and total factor productivity have the most robust links with R*. Generally, the decline in R* was less pronounced in emerging market economies.*

We discuss three policies aimed at re-increasing R, which promise to amplify the distance to the zero lower bound and therefore increase monetary policy space: (1) One promising route is boosting productivity via increased diffusion and deployment of digitalization and AI, and potentially also through transitioning toward a more climate-friendly economy. (2) Reforming the pension system, specifically raising the retirement age, could have strong transitory and even longer-term positive effects on R*. (3) The comparative advantage of the Global South is clean energy. Capital flows from the Global North to the Global South to finance investments in renewable energy may offer immense potential for unlocking productivity gains due to cheaper energy, less uncertainty, and higher returns.*

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The room for maneuver of monetary policy and the relevance of the zero lower bound is largely determined by the level of and outlook for the natural interest rate (R*), i.e. the equilibrium real interest rate that neither stimulates nor contracts the economy. As a latent variable, it is not observable and therefore has to be estimated. Estimates from the literature find a falling R* for the last decades, possibly reaching or falling below zero, although more recent estimates suggest a modest (temporary?) increase, potentially linked to monetary policy. This has posed challenges for monetary policymakers, as the natural rate of interest is not only an important indicator of structural economic factors: A low R* imposes a binding constraint and reduces the space for monetary policy. This is because the nominal short-term policy rate, the main policy instrument, has an effective lower bound slightly below zero. This limits the ability of monetary policy to stimulate the economy unless unconventional policy instruments are applied that have limits of their own (see Holzmann, 2024b).

Understanding the trends of R* and their causes is thus key to evaluating the central bank's toolkit to fulfill its mandate and the options for future policy interventions. Research on the determinants of the natural rate of interest gives rise to hopes that R* could be influenced by conscious policy choices. In this paper, we discuss various promising structural policy routes to increasing R* from its current lows to avoid the zero lower bound from becoming binding again.

In section 1, we first review the evidence for a long-term downward trend in R* in advanced economies over the last decades and centuries and consider its various drivers. We then zoom into the more recent trend reversal and discuss its persistence. In section 2, we discuss three different policies that might influence the level of the natural interest rate, and how those could facilitate a lasting rise of R*. We focus on policies to foster total factor productivity growth, one of the main drivers of R*, by promoting digitalization, artificial intelligence, and the energy transition. Then we explore the scope of contribution to increasing R* by raising the effective retirement age. We finish by elaborating the potential effects on R* of measures to stimulate North-South capital flows to finance investments in renewable energy. Section 3 concludes.

1 Level and evolution of equilibrium real interest rates across the world

In this section, we report substantial evidence from the literature documenting the decline of R* in advanced economies over recent decades that may have slightly reversed recently. We review numerous potential drivers – both macroeconomic and financial – of the R* decline. Demographic factors, real GDP trend growth, and total factor productivity are found to be the most important drivers of the natural rate of interest. Generally, the decline in R* was less pronounced in emerging market economies. Estimating R* for China is especially challenging given the availability and quality of data, but demographic developments appear to be a key driver of R* there. Box 1 offers a brief excursion into how the short-run and long-run dynamics of the equilibrium real interest rate may diverge and discusses potential drivers of such divergences between short-run r* (driven by monetary or financial factors) and long-run R* (driven by structural factors).

Box 1

Monetary drivers of short-run r*

There is a distinction between short-run r and long-run R*, and several empirical estimates exist for each. While structural factors such as productivity and demographics, which are the focus of this paper, are related to long-run R*, they do not show a stable relationship with the conjectured short-run r* and observed real interest rates. In fact, the theoretical relationship between structural factors and the equilibrium rate of interest varies over time. In this box, we highlight monetary and financial factors[2] that may account for short-run deviations. Recent years have shown that common measures of r* can change rapidly without any shift in long-run drivers. We discuss the factors that may cause short-run r* to deviate from long-run R*. They predominantly relate to the balance between demand and supply of riskless assets.*

1. Increased demand for safe assets began with the capital market liberalization and globalization in the 1990s, which allowed global investors access to assets like US Treasury securities. Post-1998 Asian crisis reforms led to an expansion of official reserves in emerging countries, further intensifying demand for US Treasury securities, as the US Dollar remains the dominant global reserve currency.

2. Sovereign wealth funds from various economies have grown in size and significance, with safe assets like US Treasury securities forming a substantial part of their portfolios.

3. The global aging population has increased the demand for safe, liquid assets as baby boomers seek secure investments for retirement.

4. Post-2008 financial regulations have further increased demand for safe, liquid assets by requiring banks to hold more of these assets on their balance sheets.

5. Quantitative easing and tightening influence risk premiums, and this has an impact on r as it is the risk-free rate. Additionally, the scarcity of safe assets leads to price distortions, which may raise risk premiums on other assets, thereby reducing risky investments and hindering productivity growth.*

6. Firms can issue debt to expand their size and market power. Due to the high monopsonistic power of these firms, they can reduce wages, leading to increased consumption risk for households. Consequently, demand for debt can become downward sloping at certain levels of debt. Central bank asset purchases increase demand for debt at all interest rate levels, further enhancing firms' monopsonistic power and lowering the equilibrium interest rate.

7. The shift by major central banks to ample liquidity regimes has resulted in higher demand for safe, liquid assets. Central banks started to permanently hold safe, liquid assets such as government bonds, putting downward pressure on yields and r.*

8. In an interaction with the financial cycle, prolonged expansionary monetary policy could lower r over long horizons by fueling debt accumulation and financial imbalances. The latter can in turn lead to financial crises, which often have persistent, if not permanent, negative effects on economic growth.*

9. Low interest rates influence firm dynamics and productivity, affecting entry/exit decisions and growth of companies due to changes in profit expectations and market structure.

There are other possible factors that can cause the short-term r to deviate from the long-term R*, but a detailed discussion of these is beyond the scope of this paper.*

Sources (amongst others): Benigno et al. (2024), Bonam et al. (2018), Schnabel (2024), and Waller (2024).

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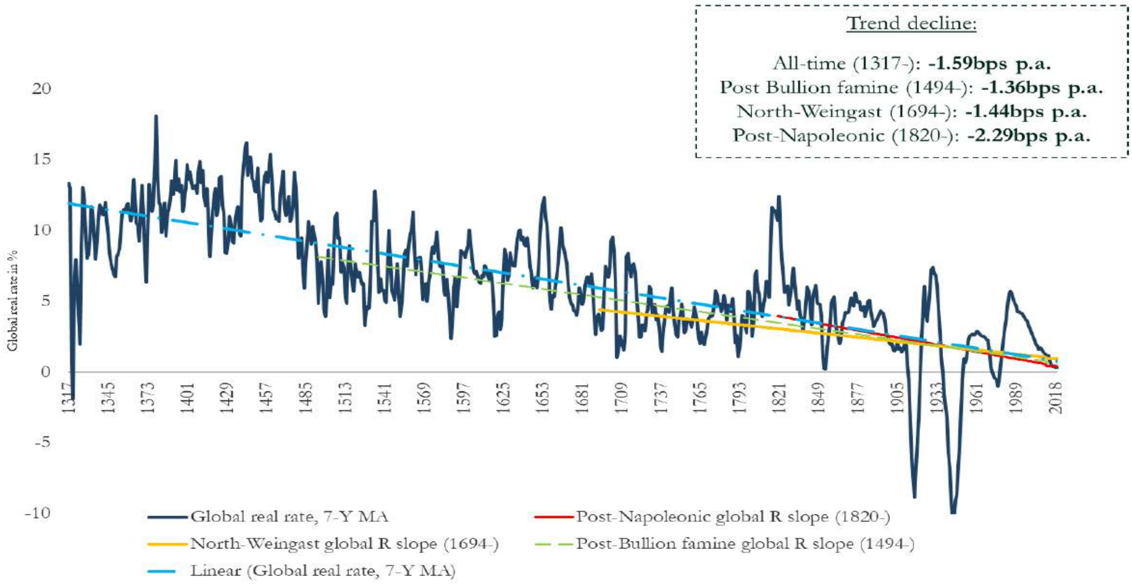
[2] Note that monetary and financial factors are not synonymous with the effects of monetary policy but should be understood separately, if not independently.

1.1 Secular decline of R* in advanced economies

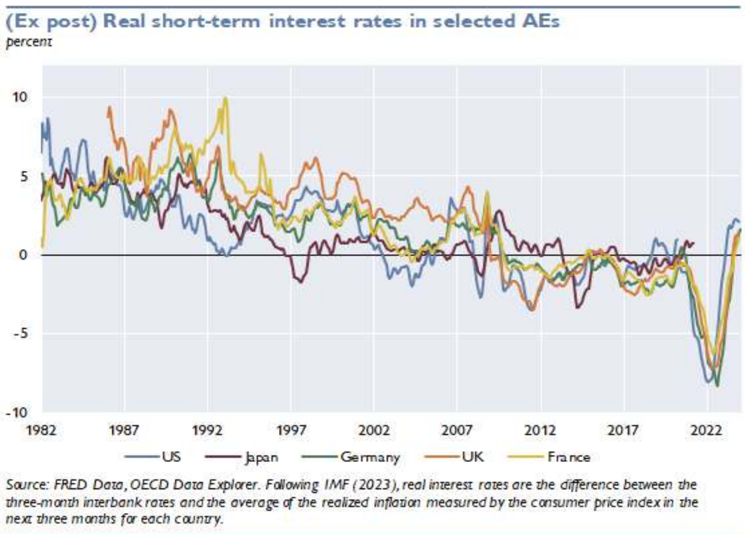
Over the last decades and even centuries, interest rates declined steadily. Given that the natural rate R* is unobservable, most studies on the long-term trend focus on observable real rates. Schmelzing (2020) compiled a data set of these rates over the last seven centuries, based on printed primary and secondary sources, covering almost 80% of advanced economies' GDP. Chart 1, taken from this paper, shows a persistent downward trend of real rates since the 14th century. The two marked downward spikes of the 20th century reflect the hyper-inflationary episodes following the two world wars. Rogoff et al. (2022) analyzed the same data set and found evidence for trend stationarity, which is not surprising in a large sample given that real interest rates are theoretically bound from below and above.

Chart 1: Headline global real rate, GDP-weighted, and trend declines 1317–2018



Source: Schmelzing (2020, figure IV, p. 14).

Chart 2: Real short-term interest rates



For the more recent history, we confirm this steady downward trend of real rates. Chart 2 shows a high extent of co-movement for a set of five advanced economies as well as, more recently, a convergence, indicating that global factors are at play. The 2008–09 global financial crisis temporarily accelerated the downward trend. After that, real interest rates reversed only slowly, before taking another severe hit with the onset of the COVID-19 pandemic. The latest observations reflect the hikes in key interest rates as a reaction to mounting inflation.

Given that the natural rate is an anchor for real rates, it is fair to assume that the former was declining as well. This is confirmed by numerous studies estimating R* over the last decades. For example, Holston et al. (2017) showed, based on the Laubach and Williams (2003) methodology[3], for the US, Canada, the euro area and the UK that the natural rate of interest declined over the last decades, with a marked drop during the global financial crisis. IMF (2023) used the Laubach-Williams model and other approaches and confirmed a global downward trend in R* as well as common movements across advanced economies. This suggests that global factors may have been at play.

1.2 Potential causes for the long-term decline in interest rates

Several explanations have been put forward for the longer-term decline in interest rates, as summarized by IMF (2023).

- **According to a first line of argument, the decline in the natural rate is linked to *macroeconomic developments*.** The weakening productivity growth (and hence GDP growth) over the last decades implied a decline in the opportunity cost of borrowing, thus pushing interest rates downward (see e.g. Cesa-Bianchi et al., 2022; Mankiw, 2022). While Rogoff et al. (2022) found no causal role of this factor for historical data of the last seven centuries, studies focusing on the last five decades emphasize its importance both for the decline in real rates and for the synchronized trend across advanced economies. For example, trend growth explains a major part of the decline in the natural rate in Canada, the US, and the UK over the last decades, according to Holston et al. (2017). In addition to these macroeconomic factors, *demographics* may have contributed as well (see e.g. Carvalho et al., 2016; Gagnon et al., 2021; Brand et al., 2018): As labor input decreases with an aging population, capital per worker rises, depressing the marginal product of capital and thus R*. Furthermore, higher life expectancy encourages savings in anticipation of a longer retirement period and medical expenses (see De Nardi et al., 2010), raising capital supply and depressing R*. This factor is dampened somewhat by the shift of the population toward relatively older individuals who dissave (see Backus et al., 2014). Furthermore, an older workforce is more likely to be less innovative. Fuhrer and Herger (2021) estimated the effect of population growth on R* based on panel data for 12 advanced countries stretching back to 1820 and found a sizeable positive and statistically significant effect of the birth surplus (as opposed to other reasons for population growth such as migration) on real interest rates.
- **The second line of argument refers to *financial drivers* and capital market movements.** With the opening of global capital markets and the emergence of new

[3] The semi-structural model of Laubach and Williams (2003) has become the econometric workhorse model for estimating R* at lower than business-cycle frequencies. Their approach relates observable variables, such as output, inflation, and the short-term interest rate, to unobservable state variables, one of which is R*, via textbook macroeconomic relationships like the IS or Philips curve.

players such as China, capital moved to fast-growing EMEs, driving interest rates in advanced economies up (see e.g. Galí and Monacelli, 2005; Obstfeld, 2021). However, subsequently, excess savings from countries with large current account surpluses such as China flowed back to advanced economies ("savings glut") considered as safe havens. This, as well as the increased preference for safe and liquid assets (convenience yield) drove up demand for those assets. With supply remaining limited, their price increased, thus lowering their return (see e.g. Bernanke, 2005; Del Negro et al., 2019; Krishnamurthy and Vissing-Jorgensen, 2012). With these two opposing trends, IMF (2023) concludes that the overall effect on natural rates was only moderate over the last decades.

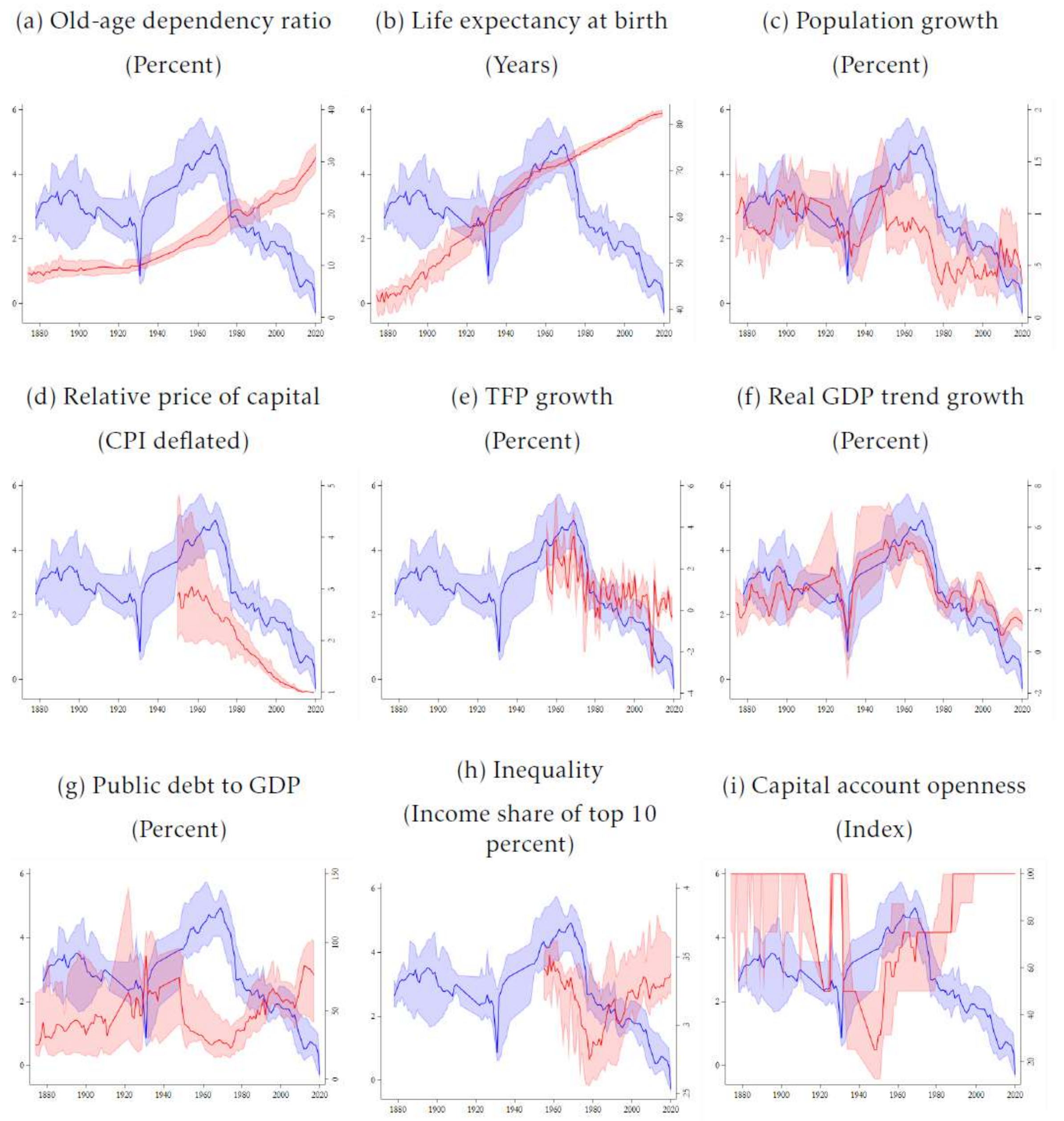
The association between public debt and R* is ambiguous. A higher debt may increase demand for savings and thus R* (see Rachel and Summers, 2019) or, in the case of reverse causality, lower rates and thus debt servicing costs may incentivize governments to target higher debt levels. However, an increase in the stock of debt also raises debt service costs. Mian et al. (2021a) showed that, by assuming non-homothetic consumption-saving behavior, this can lead to depressed (what they call *indebted*) demand, which puts downward pressure on R*. The strategy of lifting R* by increasing public debt levels has also been called into question by Garga (2020), for reasons other than sovereign default. She showed that in a non-Ricardian economy, households may increase savings to a point that depresses R* if the government debt level crosses a certain threshold.

To shed more light on the long-run determinants of R*, Grigoli et al. (2023) used again the Laubach and Williams (2003) methodology and a rich dataset covering 16 advanced countries for 1870–2019. They carried out correlation and regression analysis to study the association of their R* estimates with the following conjectured key determinants:

1. old-age dependency ratio,
2. life expectancy at birth,
3. population growth,
4. relative price of capital,
5. TFP growth,
6. real GDP trend growth,
7. public debt to GDP,
8. inequality,
9. capital account openness.

Chart 3 shows the estimated R* (blue line, median across countries) and the respective determinant of the sample median country observation of that year (red line), together with interquartile ranges.

Chart 3: Conjectured drivers of R* 1878–2019



Source: Grigoli et al. (2023, figure 6, p. 17).

In line with theoretical predictions, old-age dependency is negatively associated with R*, and population growth is positively associated (first row of chart 3). This association also holds when controlling for time and country trends in a regression analysis.[4] Furthermore, as expected, the decrease in R* over the last decades coincided with the decrease in the relative price of capital as well as total factor productivity and real GDP trend growth (second row). The link is particularly strong for real GDP trend growth. The ratio of public debt-

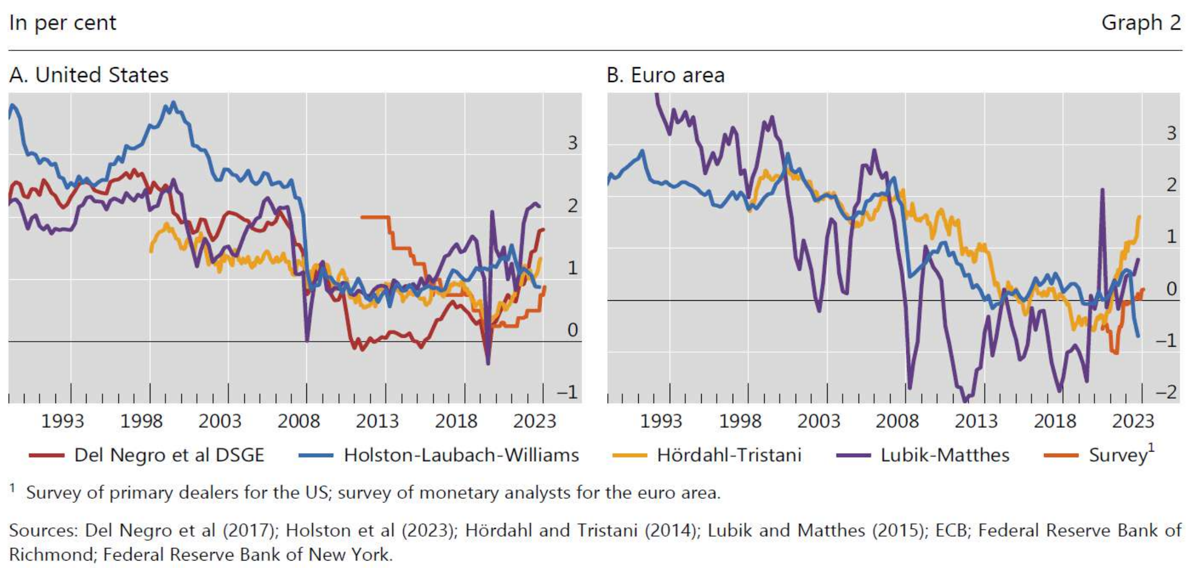
[4] For regression results see table 1 in Grigoli et al. (2023).

to-GDP (third row) shows a positive correlation until the second world war and then a negative one. The picture is also not clear-cut for inequality. Since saving rates are higher for high-income households, increasing income inequality should, in theory, reduce R* (see Mian et al., 2021b). Empirically, the neutral rates began to fall well before income inequality started to increase.[5] Finally, using the capital account openness index of Quinn (2003) as an empirical proxy, the authors find a mild negative but statistically insignificant effect (see chart 3).

1.3 How sustained is the recent trend reversal of the natural rate?

Zooming in on recent years, there is some indication of a trend reversal of R* (see also chart 2). Monetary tightening raised real interest rates in advanced economies recently, lifting them above the previous lows. Using different approaches from the literature (semi-structural, time series, DSGE, and term structure model) as well as results of a survey of monetary experts, Benigno et al. (2024) estimated the natural rate for the US and the euro area for the period since 1990 (see chart 4). They found that R* might have increased in advanced economies after the pandemic, reaching levels comparable to the global financial crisis in some cases. At the same time, however, the authors emphasize that estimates vary considerably and conclude that "[a]ssessments of the level and direction of R* are surrounded by very high uncertainty, making it a blurry guidepost for monetary policy, especially in the current context" (Benigno et al., 2024, p. 18).

Chart 4: Natural rate estimates



Source: Benigno et al. (2024, graph 2 on p. 22).

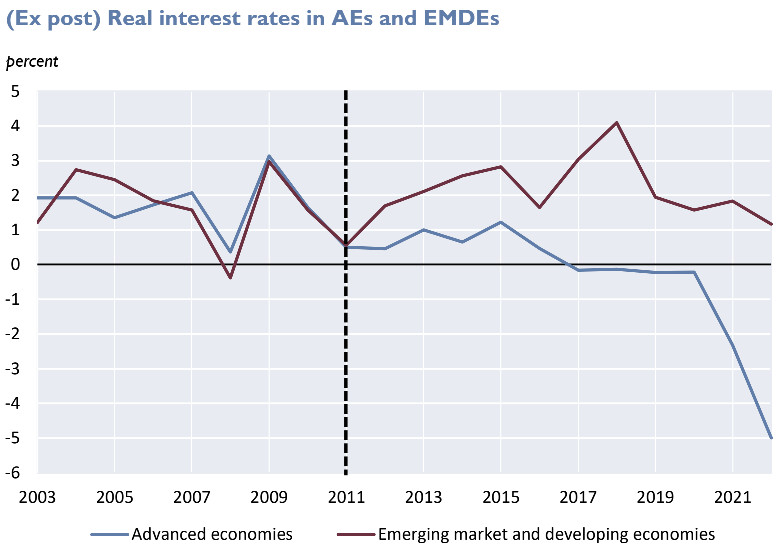
[5] However, for the US, Platzer and Peruffo (2022) found that rising income inequality is one of the most important drivers (–0.7 percentage points) of the decline in the neutral interest rate, together with demographic change (–0.7 percentage points) and productivity growth slowdown (–1 percentage point). Moreover, growing public debt is found as a major counteracting force (+0.3 percentage points). They focus on income inequality rather than wealth inequality since the impact of the former is better researched theoretically, and data are sparse for the latter.

It is much debated whether real and natural interest rates will revert to pre-pandemic levels or stabilize at a higher level. The first view would be supported by the argument that underlying (structural) forces, such as low potential growth, did not change and will bring down real interest rates again (see e.g. Obstfeld, 2023; IMF, 2023). On the other hand, high long-term bond yields suggest that investors believe in higher rates in the future. Also, the strong and resilient economic activity in the monetary tightening environment following the post-pandemic inflationary pressure in the US is seen as an indication that real policy rates that slow down the economy might be higher than previously expected.

1.4 Global country heterogeneities in real interest rate developments

Trends in emerging markets and developing economies (EMDEs) decoupled around 2011. IMF (2023) shows that the declining trend in real interest rates and the common movement across advanced economies (AEs) was shared by EMDEs in the 2000s. After 2011, however, real interest rates between AEs and EMDEs started to decouple (see chart 5 and chart 6 for China). While real interest rates continued to decline in AEs, they remained broadly at the level of the early 2000s in EMDEs.

Chart 5: Real interest rates in AEs and EMDEs



Source: IMF WEO (2023), chapter 2, data annex.

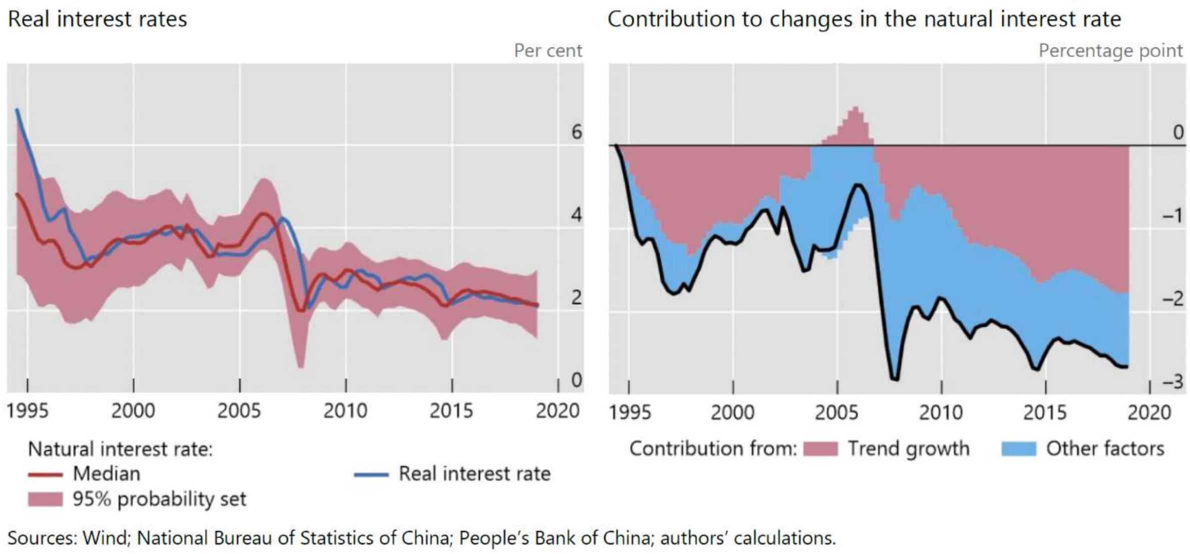
This decoupling may be due to market frictions and weak institutions. Obstfeld (2021) argues that market frictions cause a lack of capital mobility from AEs to EMDEs. Weak institutions and a lack of investor protection in potential recipient countries of investment may be another reason for real rate differentials between AEs and EMDEs. IMF (2023) adds that especially since the global financial crisis, EMDE debt might not have been perceived as stable, pushing down real interest rates in countries providing safe and liquid assets, especially in the US.

Chart 6: Real short-term interest rates in selected advanced economies and China

Estimating R* for China is especially challenging, given the availability and quality of data. Sun and Rees (2021) estimated the natural interest rate for China following the approach outlined by Laubach and Williams (2003). A key contribution of their work is the estimation of the output gap and other unobserved variables using multiple data sources (GDP, railway freight volumes, electricity usage, etc.). Their results indicate that R* varied between 3% and 5% between the late 1990s and 2010, declined thereafter and reached approximately 2% by end-2019 (chart 7, left-hand panel). The estimates of R* for China are thus higher than for most AEs. However, the declining trend found prior to the pandemic is similar to but less pronounced than the estimated curve for AEs.[6] Sun and Rees (2021) attribute about two-thirds of the R* decline to lower potential growth (chart 7, right-hand panel). The remaining part may be related to global factors.

[6] Such a declining trend in the natural rate for China is also found by Wang (2019), IMF (2023) and Fu and Wang (2024), although the magnitude of the estimated natural rates varies across the different studies.

Chart 7: Real interest rates and contributions to changes in R* for China



Source: Sun and Rees (2021, figure 2, p. 11). Note that the blue line in the left-hand panel shows model estimates of the real policy rate. Data end in Q4 2019, and they do not include the increase in (ex post) real rates in 2020 and the fluctuations thereafter, as displayed in chart 6.

Demographic developments are a key driver of R* in China. Fu and Wang (2024) assessed the effect of demographics and conclude that decreasing mortality rates have been the main driver of the decline in the natural rate in China since 2000. Similarly, IMF (2023) found a strong negative impact of demographic developments on estimates of R* in China. Looking ahead, Fu and Wang (2024) expect a slowdown in the decline of the natural interest rate over the next decade due to a brief period of young labor supply in China. Subsequently, they expect a continuation of the decline.

2 Increasing R* via structural policy reforms

Based on this evidence about the key drivers of the past R* decline, we discuss potential policy options to facilitate a rise in R*. A lasting increase in the natural rate would expand the scope of monetary policy because it would make the zero lower bound less relevant. In this chapter, we will discuss potential policies to raise R*…

(1) …via ***total factor productivity*** (TFP) and its key drivers, e.g. by promoting digitalization and artificial intelligence (AI), addressing climate change and harnessing the TFP potentials of the energy transition;
(2) …via the combined effects of an increase in ***labor supply*** due to an increase in the effective retirement age and the resulting reductions in the old-age dependency ratio and of government deficits; and
(3) …via capital account openness and ***financial flows*** (especially ***North-South***) to reduce any savings glut in the global North through financing investments, among others, in wind and solar energy in the global South.

2.1 Increasing R* via total factor productivity growth

Given the conjectured strong positive link between R* and economic growth, boosting TFP to increase R* seems especially promising. OECD/APO (2022) describes TFP as "a complex, multifaceted concept whose developments can be influenced by a wide range of policies and institutions". The OECD further classifies the drivers of productivity into three broader categories:

1. boost innovation and experimentation with new knowledge and technologies;
2. contribute to the diffusion of existing knowledge and technologies; or
3. facilitate the (re-)allocation of resources within or between sectors and firms.

The first category covers policies designed to increase investments in R&D, innovation, digitalization, or intangible assets. The main goal of measures addressing the second category is to support the diffusion of existing knowledge and technologies. To that end, educational policies providing the public with appropriate skills and qualifications must be elaborated, and public infrastructure that enables knowledge flow needs to be created. Lastly, translating the gains from new technology, product and process innovations into economic growth requires markets and institutions that permit innovative firms to expand their production factors, and market shares that do not impede market exit of less productive firms. Theoretically, in such an environment that is akin to Schumpeter's idea of creative destruction, the more freely resources can be reallocated between sectors and firms, the higher the potential TFP growth. Policies addressing this category cover regulations regarding product and factor market competition, business as well as labor entry and exit, globalization, and financial development.

There is a large literature on how to promote productivity growth and how well certain economic policies perform in achieving that. For instance, in its first productivity report, the Austrian Productivity Board (see Produktivitätsrat, 2023) offers a list of recommendations on how to increase productivity growth in Austria, including making greater efforts to reach the climate targets, fostering innovation and human capital, and reducing socio-economic inequalities. In the following, we will focus on some of the critical areas for boosting productivity growth that are discussed in Breitenfellner et al. (2022) and discuss them in turn:

1. Advancing the ***digital transformation*** is a major challenge since the euro area (on average) is still lagging behind the US in digitalization (Anghel et al., 2024).
2. Moreover, as first studies on ***generative artificial intelligence*** (AI) show very promising productivity potential, we put an emphasis on this new and hotly debated topic.
3. Finally, ***addressing climate change*** remains one of the most pressing challenges humanity faces. Transitioning toward a more climate-friendly economy will demand a well-orchestrated approach to mitigate enduring productivity costs (Bijnens et al., 2024).

2.1.1 Increasing TFP by promoting digitalization

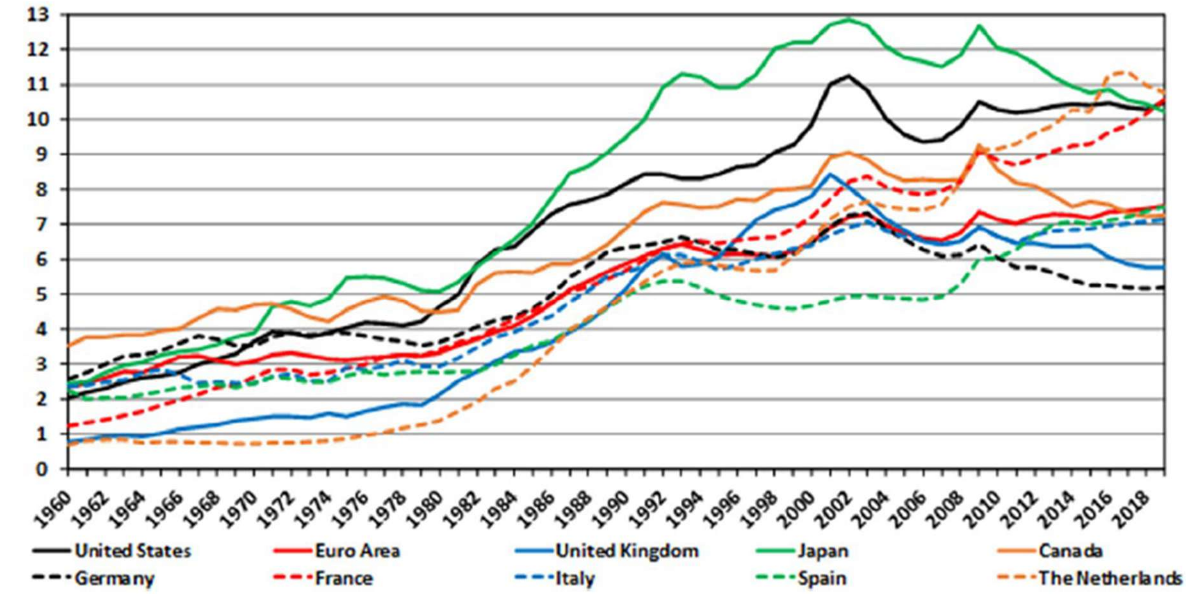
Digital technologies may improve productivity via various channels: They may be employed to automate or complement routine tasks, reduce interaction costs with suppliers/consumers (e.g. e-commerce) and generate new products or business processes, increasing the innovative potential of a firm. The positive links between the adoption of digital technologies and productivity growth are well documented in the literature (see reviews in Syverson, 2011; Gal et al., 2019). However, the causal effects are empirically hard to identify due to the complex interactions of digital technologies with complementing factors, their lagged impact on productivity (Brynjolfsson et al., 2021), and the potential reverse causality between digitalization and productivity.

The productivity effects of digitalization are very heterogeneous within and across firms. Evidence from a recent OECD analysis (Gal et al., 2019) of 1.5 million firms in 20 OECD countries suggests that digital adoption has the largest productivity impact in manufacturing firms and for routine-intensive activities. In addition to that, the analysis finds that firms that are already highly productive benefit the most, suggesting that digitalization may have contributed to the growing dispersion in productivity across firms. Anderton et al. (2023) conducted another in-depth analysis of 2.4 million European firms, arriving at similar results. While digitalization tends to have a positive average impact on firm productivity growth, this impact is very heterogeneous across firms. Anderton et al. (2023) found that the average firm in most sectors would not be able to reap the full benefit of digitalization. Among the firms lagging behind the productivity frontier of their industry, only the 30% most productive ones seem to benefit from investing in digital technologies. The less productive laggards would first need to optimize their production process by other means before investing in digitalization yields any benefits. These results suggest that so far digitalization has not been a gamechanger or "one-size-fits-all" strategy to improve productivity.

The euro area lags behind in digital adoption and diffusion. Another scenario analysis (Anghel et al., 2024, box 1), based on a multi-sector dynamic equilibrium model featuring production networks, shows that past digitalization accounted for about 70% of cumulative productivity growth between 1997–2018 in the US but only for 40–50% in Germany and France. As documented in the ECB Strategy Review (ECB, 2021), the euro area – on average – lags behind the US and other G7 economies in several measures of digital adoption, such as the European Commission's Digital Economy or Society Index, information and communication technology (ICT) capital intensity (chart 8), and the share of value added in digital sectors.[7] The weaker productivity impact of digitalization in the euro area may thus be the result of lower diffusion and adoption of digital technologies, i.e. less of Schumpeter's creative destruction.

[7] The average results mask great heterogeneity, with Finland, Sweden, Denmark, and the Netherlands being already highly digitized and Bulgaria, Greece, Romania, and Italy showing the lowest adoption rates.

Chart 8: ICT diffusion measured by the ICT capital stock in % of GDP in current prices 1960–2019



Source: Cette et al. (2022, figure 1, p. 168).

Exploiting the productivity potential of digitalization requires the right market incentives and firm capabilities. In recent OECD work, Andrews et al. (2018) studied the drivers of digital adoption for 25 industries in 25 European countries. The study found evidence that firm capabilities and market incentives were both important for adoption and complemented each other. Regarding firm capabilities, low managerial quality, a lack of ICT skills and poor matching of workers (skill mismatch) curbed digital adoption. On market incentives, the study emphasized the role of competitive pressure (i.e. via foreign competition), ease of resource reallocation (ease of scaling up in case of a successful implementation), availability of risk capital, and R&D support for the adoption of new technologies.

The evidence presented above suggests that digitalization has so far not provided a major productivity boost to the euro area, indicating a largely untapped productivity potential. Compared to the US, the euro area has on average seen weaker adoption and slower diffusion of ICT. This is well documented and could reflect a need to catch up in terms of ICT capabilities (complementing investments) and to improve market incentives. Policies should aim at upgrading managerial as well as ICT skills of employees, providing the physical, financial, and innovative infrastructure, promoting competition, and easing the reallocation of resources (OECD, 2019).

2.1.2 Potential TFP gains from generative artificial intelligence

As artificial intelligence (AI) is still at an early stage, it is difficult to make informed predictions on its effect on productivity. Generative artificial intelligence (GenAI) systems, such as large language models (LLMs) usually take a text prompt from a user and return data (text, graphics, music, code, etc.). These tools became known to the wider public with the release of ChatGPT in November 2022. First estimates show that around 80% of the US workforce could be impacted by GenAI in some way, with 19% having half or more of their tasks affected (Eloundou et al., 2023). Furthermore, the results show that higher-wage occupations generally comprise more tasks with high exposure to GenAI. Given this overall high exposure, GenAI may well exhibit the traits of a general-purpose technology, bearing significant economic, social and policy implications (Eloundou et al., 2023).

GenAI may increase the speed and output of certain tasks, especially for those with the lowest skills and productivity. Noy and Zhang (2023) showed that experienced and college-educated professionals could finish a writing task (press release, short report, analysis plan, etc.) nearly 40% faster when assisted by an AI. Furthermore, the quality, especially of the lower performing participants increased, reducing output inequality. Peng et al. (2023) found that professional programmers finished a standardized programming task more than 50% faster with AI assistance. Treatment effects were found to be higher for developers with less programming experience, older programmers, and those who programmed more hours per day. Choi and Schwarcz (2024) showed that AI assistance enhanced the performance in introductory law school exams for simpler multiple-choice question settings but not for complex essay questions. The impact was found to be highest for students with the lowest starting skill level, whereas the performance of top students declined. Furthermore, the test performance of the AI (alone) given optimal request input was above the average student with or without AI assistance. Choi and Schwarcz (2024) see this as evidence that it may be advantageous to outsource some tasks entirely to an AI.

The closed lab results are confirmed by studies in real-world settings. Brynjolfsson et al. (2023) analyzed the impact of a GenAI assistant in customer support. Their pseudo-experimental results point to significant increases of agents' productivity (customer issues resolved per hour) by 14%. The effects are higher for workers with lower skills and less work experience (+34%). On the other hand, agents with the highest skills and longest experience did not experience productivity gains. Brynjolfsson et al. (2023) argue that this may occur since the models are trained and adjusted for optimal output and thus likely emulate the behavior patterns of the most productive agents. Another study involving a real-world setting of AI but addressed at the more complex task of running a business is Otis et al. (2023). Based on a field experiment involving Kenyan small business entrepreneurs, they did not find that the AI assistant had a statistically significant impact on business performance. Especially lower skilled entrepreneurs sought AI advice on more challenging business tasks where AI was of limited help, as compared to the high performers. This could hint that AI assistance reaches its limits for more complex and interconnected tasks.

AI adoption is concentrated among larger and more productive firms. Firms adopting AI (in general) seem to differ substantially from non-adopters: AI adoption is concentrated among younger, larger, and more productive firms in the sectors of ICT and professional services (Acemoglu et al., 2022; Calvino and Fontanelli, 2023). In an analysis of advanced technology usage in US firms, Acemoglu et al. (2022) did not find that firms adopting AI had a significantly higher labor productivity than non-adopting firms, when controlling for age, size, and usage of other advanced technologies such as robotics or cloud computing. Similarly, Calvino and Fontanelli (2023) found for firm-level data of 11 OECD countries that while AI adopters were more productive on average, this seemed to be related to complementary assets like ICT skills, high-speed digital infrastructure, and the use of other digital technologies which are important for adoption.

Economy-wide productivity impacts of AI show a large variation that is driven by assumptions on the scope for automation. Acemoglu (2024) estimated the macroeconomic effects of GenAI employing estimates from the recent literature on the exposure of tasks to GenAI and potential time savings (as discussed above). He found that GenAI may increase annual US TFP growth by 0.05–0.07% over the next ten years. This estimate is much smaller than the annual US labor productivity growth effects of 0.3–2.9% reported in Briggs and Kodnani (2023) and McKinsey & Company (2023). The difference can to some extent be explained by the assumption on the share of tasks affected by AI. Acemoglu (2024) was more cautious and assumed that only around a quarter of all GenAI exposed tasks could feasibly and profitably be automated over the next ten years. Moving to the long run, however, AI productivity channels via the creation of new tasks and increased innovation (Babina et al., 2024; Baily et al., 2023) will gain relevance and add to the cost-saving effects. Note that Acemoglu's (2024) estimate is based on task exposure of GenAI only. Extending his calculation to include traditional AI, the impacts for the euro area could reach 0.3% per year (Bergeaud, 2024).

Overall, there seems to be a significant potential for boosting productivity by using generative AI assistants for certain tasks. Many of those tasks are in higher wage-occupations (i.e. programming). Looking ahead, some tasks will still best be carried out exclusively by humans, some by humans assisted with AI, and some exclusively by AI, but the frontier of tasks susceptible to AI is constantly moving. As the required infrastructure and skills to operate GenAI are readily available from the prior digitalization wave, its adoption could be faster than previous general-purpose technologies. This may explain why ChatGPT gained 100 million users in the first two months after its introduction. However, this trend captures mostly the private household user perspective. Tailoring GenAI to specific business applications within a firm will require new (managerial) skills, training, and technical and organizational infrastructure.

The productivity potential of GenAI as a general-purpose technology remains untapped as long as diffusion is limited to already high performing firms in a few knowledge-intensive sectors. Policies should be aimed at increasing adoption and stimulating diffusion. This could include both demand-side measures, such as raising awareness about new technologies and developing absorptive capacity, as well as supply-side policies, such as promoting competition, providing financing, improving knowledge production and sharing, and strengthening the digital infrastructure and skill base (Calvino and Fontanelli, 2023).

2.1.3 The ramifications of climate policies for productivity

The transition toward a carbon-neutral future involves the application of new technologies in energy generation, heating, transportation, and manufacturing. As national innovation systems adapt and focus more on these climate-related challenges, the changes in innovative activities are likely to affect the growth rate of productivity and thereby R*. One of the first economic approaches to assess the effects of climate change and related policies on output growth and productivity was the so-called "Porter hypothesis" (Porter, 1991), which conjectured that environmental regulations might enhance competitiveness, thereby increasing productivity. Porter started from the assertion that negative externalities caused by climate change led to a misallocation of resources and concluded that climate change mitigation regulations that help internalize these externalities should enhance welfare and productivity.

Testing the Porter hypothesis empirically yields mixed results at best. Cohen and Tubb (2018) ran a meta-analysis of 103 studies on the topic and found that most estimates were statistically insignificant. They also observed that a positive effect of environmental regulation was more likely at the country level than at the firm or sector level. Combining the OECD Environmental Policy Stringency indicator with firm-level information on nearly three million firms from six euro area countries, Benatti et al. (2023) found no empirical support for the Porter hypothesis. Since they used a local projection approach that allowed to estimate the impact up to five years ahead, they conceded that positive productivity effects might materialize later. Since early adopters of climate-neutral technologies incur higher costs than their competitors, their competitive position deteriorates at first. When in the longer run all firms must decarbonize, the head start of early adopters might indeed yield positive results. In a similar vein, Pisani-Ferry (2021) emphasized that green innovations and investments may improve potential output in the long run but divert resources from expenditures that drive economic growth in the short-run. Lilliestam et al. (2021) analyzed ten carbon pricing schemes with prices of more than USD 25 per tonne of CO2 and found no empirical evidence that carbon pricing supports technological change.

For climate policies to induce positive productivity effects, they must be executed in an orderly transition, i.e. governments introduce their climate policies immediately and gradually, which will keep climate-related risks at bay. This assumption might have been still plausible in the early 1990s, when Porter published his hypothesis. Disorderly transition scenarios entail higher risks, as climate policy responses are uncoordinated or delayed, e.g. carbon prices are introduced later and therefore the price increases must be steeper than in the orderly scenario, resulting in more disruptions. An example of delays which make the orderly transition less likely is the time needed for the approval of wind farms in Germany, as quoted by Gourdel et al. (2024). Persistently high emission levels will require more rapid and more stringent emission reductions in the future, according to NGFS (2023), thereby making disorderly transition scenarios more likely.

A disorderly transition might lead to sudden stops of carbon-intensive production activities, lead to stranded assets, and reduce the capital stock, thereby lowering productivity. Bijnens et al. (2024) found that the timing of climate policies was critical for their effect on productivity. They compared the effects of an orderly and a disorderly transition on labor productivity from 2020 until 2050 in the EU and found that frontloading climate policies like the carbon tax leads to relatively lower productivity in the first decade, whereas the massively delayed surge in the carbon price that is required under a disorderly transition has a more severe and lasting negative effect on productivity.

The development and the diffusion of green technologies depend on the level of carbon prices which internalize negative externalities of carbon emissions. Since the diffusion of carbon-intensive technologies has started earlier, these technologies and their complementary infrastructures are well established, thereby creating path dependencies that new green technologies cannot compete against. Carbon taxes would shift relative prices in favor of green technologies and should induce more green innovations. However, they are biased toward incremental innovations which are already almost marketable. Naqvi and Stockhammer (2018) use a stock-flow consistent model to track financial flows across sectors and assess the feedback effects of climate policies on the overall economy. They find that a continuously increasing carbon tax is necessary to shift innovation processes to increase productivity.

However, a carbon price alone is not a sufficient incentive to decarbonize in time since negative externalities are not the only market failures caused by climate change (Stern and Stiglitz, 2017). In a multi-model simulation exercise, Brand et al. (2023) showed that raising carbon prices up to EUR 140 per tonne of CO2 by 2030 would not reduce carbon emissions enough for the EU's own net zero targets to be reached, which is why other policy instruments are necessary. Modelling firms' decision on investing in green and carbon-intensive technologies, Acemoglu et al. (2012) found that temporary R&D subsidies could efficiently complement a carbon tax since relying only on the carbon price would require a very high tax rate that would cause unwarranted economic harm.

Popp et al. (2022) emphasize the importance of a comprehensive approach to the climate transition which relies not only on supporting technological innovations and investments in physical infrastructure, but also on improvements in human capital. Implementing and handling the new green technologies will require a set of new skills, and to avoid unnecessary disruptions, these skills should be developed in tandem with the technological progress. In addition to that, knowledge spillovers between firms or sectors are higher for green technologies. Dechezleprêtre et al. (2014) used the World Patent Statistical Database to analyze the spillovers emanating from green and other innovations. They found evidence that green patents generate knowledge spillovers which are 40% larger compared to other patents, as indicated by patent citations. It remains unclear whether the knowledge spillovers from green technologies enhance productivity or not since their objective is to produce output with less emissions, not necessarily to produce output with less input.

The effects of climate-related policies on productivity may differ between the aggregate level and the firm level. Bijnens et al. (2024) analyze the impact of a carbon tax on sectoral productivity and business dynamics. Since a carbon tax imposes additional costs on firms, the least productive firms in all sectors may be priced out of the market, thereby raising aggregate productivity. Energy-intensive firms are more affected by carbon taxes than labor-intensive firms. Since manufacturing firms are on average more energy-intensive than service firms and exhibit higher productivity growth rates, a shift in production from carbon-intensive manufacturing to services in reaction to a carbon tax should rather depress aggregate productivity growth.

Uncertainty about future costs of renewable energy and its impact on productivity remains high. Stern and Romani (2023) argue that within a few years, most tipping points for critical green technologies will have been reached, making them competitive and thus boosting productivity. Way et al. (2022) state that renewable energy costs have fallen sharply over the past decades. According to their probabilistic cost forecasting methods, the cost decline will continue to accelerate dramatically.[8] On the other hand, changing preferences toward less energy-intensive lifestyles (or even anti-consumerism) and shifting production from manufacturing toward the more sustainable service sector could in aggregate reduce productivity growth.

In the very long run, climate change mitigation policies should have positive effects on productivity as they reduce damage from climate change that would otherwise hamper growth prospects. This economic damage would not only reduce future output, but also induce a reallocation of investment funds from technology-improving R&D to repair and replacement investments, thereby lowering productivity growth in the future (Dietz and Stern, 2015). If effective climate policies reduce global warming and prevent climate damage, the outlook for productivity and hence for R* will be improved. Day et al. (2019) survey papers that have analyzed the impact of global warming on labor productivity, and they find substantial heat stress-related reductions in productivity for temperature increases above certain thresholds. Adapting to these effects of climate change would require investments in building infrastructure. Therefore, effective climate policies are in the long run a beneficial contribution to positive productivity growth. The latter will elevate R* in comparison to a scenario in which climate change can wreak havoc on the economy.

International trade can play a crucial role in the green transition by allowing the transition to be accomplished at lower cost and higher global productivity. Le Moigne et al. (2024) apply the traditional idea of comparative advantage, introduced by David Ricardo already at the beginning of the 19th century, to the green transition. According to this concept, international trade allows countries to specialize in the production of those goods that they can produce with relatively lower carbon emissions, just like global real incomes rise when countries specialize in industries where they have relatively high productivity. The authors

[8] Two empirical observations are the starting point: "Moore's Law" refers to the hypothesis that technological performance improves exponentially over time. "Wright's Law" quantifies the experience curve effect in the production of goods: Each time the cumulative volume doubles, the value-added cost decreases by a constant percentage (typically between 15 and 30%).

simulate the implications of a global tax on carbon emissions of USD 100 per tonne of CO2 equivalent and show that up to 40% of the resulting reduction in carbon emissions can be attributed to this "green sourcing" effect, i.e. the shift in economic activity toward greener countries. This has important implications for global productivity and thus R*. First, with green sourcing, a given emission reduction target can be achieved with a lower carbon tax, which has a less dampening effect on output. Second, by concentrating production in locations with low emissions, emissions can be reduced at lower cost in terms of forgone output. Compared to a baseline without the green sourcing effect, concentration of production in greener countries increases productivity in these countries and thus global productivity.

2.1.4 Crucial policy areas to support a productivity drive

The brief survey of the three structural policy areas conjectured to be the most relevant ones for higher productivity growth in Europe have highlighted that taking them on board is a necessary but not a sufficient condition of success. There are many other policy elements needed. Identifying all sufficient conditions goes beyond the scope of this paper, but there are three policy areas that stand out: Public support, capital markets, Ricardo, and Schumpeter.

Public support matters: There is strong agreement that basic research is a crucial element for success in moving the research frontier and fostering productivity growth. Across centuries, military research and its impact on science has been a main driver, as has basic civil research in many other fields fully or partially financed by public money (Mazzucato, 2013). The relative size of such public research investments seems to matter. This necessary condition is likely to continue to be met but may not be sufficient from a European point of view. While Europe may be close to the US as far as, say, AI publications are concerned, this does not translate into major private sector investments and results at industry level (Maslej et al., 2024). The latter are conjectured to require sufficient risk capital and supportive markets, i.e. a functioning capital market.

Capital markets matter: The translation of new ideas into marketable products needs an efficient capital market where risk capital is in sufficient supply and investors can bear the high risk of investing in innovations and development of AI-related applications. This is only possible when the investors' capital base is large and diverse, the capital market is deep, transparent, and well managed, and the institutional set-up is well structured, supervised, and tested. Only few capital markets in the world meet these conditions, and Europe is – so far – not among them. This calls for an effective Capital Market Union (CMU), and the call was recently strengthened by a number of political statements at EU level and semi-public publications. They all identify various key problems, but even if all the current desiderata were met, it would still not be sufficient for a relevant capital market – a capital market also requires capitalists (Holzmann, 2024a).

Ricardo matters: One of oldest concepts in economics, the concept of comparative advantages, remains valid. It offers real income gains without greater use of production factors, i.e. TFP. The creation of the European Union and its predecessors was aimed at achieving such real income/productivity gains, and the union is often considered to have been fully established with the creation of the single market and its four freedoms, i.e. free movement of goods, services, labor, and capital. It has been quite successful, but much more can and needs to be done. This is the message of the Letta Report (Letta, 2024) that offers avenues to complete the single market and outlines promising new elements around a fifth freedom to enhance research, innovation, and education in the single market.

Schumpeter matters: Schumpeter's (1911) pathbreaking consideration of economic/ productivity growth as a process of creative destruction in an economy is well alive and crucial for turning digitalization, AI, and green finance into drivers of productivity growth. The mere adaptation of a new technology alone is not sufficient. The effect needs to be seen pervasively at enterprise level, meaning that the whole production process needs to be rethought and restructured if the effect is to be visible in the enterprises' balance sheet and in macroeconomic accounts. Mere tinkering with products and processes will not be effective. Such a change, however, requires the new governance structures at owner and management level and the relevant processes to get the employees on board for the changes needed, and needs to allow for major adjustments at the enterprise level, if warranted. Having to leave the comfort zone several times in a lifetime is likely to be a Pareto-optimal transition, a goal that can be achieved if the mobility requirements are met.

Addressing the policy issues outlined above will require substantial investments. A quantification of the annual investments required for each of the policies proposed goes beyond the scope of this analysis. The European Commission recently published estimates on the additional annual investments required to achieving policies very similar to ours, as outlined in the Draghi report on the future of European competitiveness (see European Commission, 2024; p. 282). According to these estimates, the European Union requires additional annual investments of at least EUR 700 billion, or 4% of EU GDP (at 2023 levels), over the period 2025–2030 for financing the energy transition, becoming a leader in digital innovation, and boosting productivity through breakthrough innovations. Given the required financial market reforms to increase the EU's financing capacities accordingly, such a boost in investment may reduce the imbalance between savings and investments in Europe and thus also contribute to increasing R* in the EU and reduce the gap with the US.

Last but not least, there are important other drivers of the slowdown in R* that are not captured by the three policy options we propose. For instance, Brand et al. (2018) highlight the prominent role of financial factors other than the savings glut for the slowdown in R* of the euro area after the global financial crisis (GFC), such as credit conditions, deleveraging after the GFC, and scarcity of safe assets in the euro area. Another conjectured factor is the international reserve currency role of the US dollar (Del Negro et al., 2019). We chose the three specific policy options above as they promise to deliver additional societal benefits via increased welfare, sustainable development, and securing public finances. Nevertheless, these policies may hit bottlenecks related to other important (financial) drivers of R* and may thus require complementary measures to achieve their full potential to lift R*. How well each of the policy options is able to lift R* in isolation and whether they are effective only in synergy with the other options are perennial questions.

2.2 Raising R* via an increase in the effective retirement age

Demographics (high life expectancy and low reproduction rates) were identified above as key drivers of the past decline in R*. With lower labor input, the marginal product of capital declines and reduces the demand for loans. Furthermore, with increasing life expectancy and smaller young cohorts, the ratio between savings and dissavings changes. When there are more older workers, the demand for safe assets increases, putting further downward pressure on R* (see e.g. Samuelson, 1958; Auerbach and Kotlikoff, 1987; Carvalho et al., 2016; Eggertsson et al., 2019; Lane, 2019; Breitenfellner et al., 2022). Carvalho et al. (2016) found that aging accounts for about one-third of the decline in the real interest rate for a set of mainly European countries between 1990 and 2014.

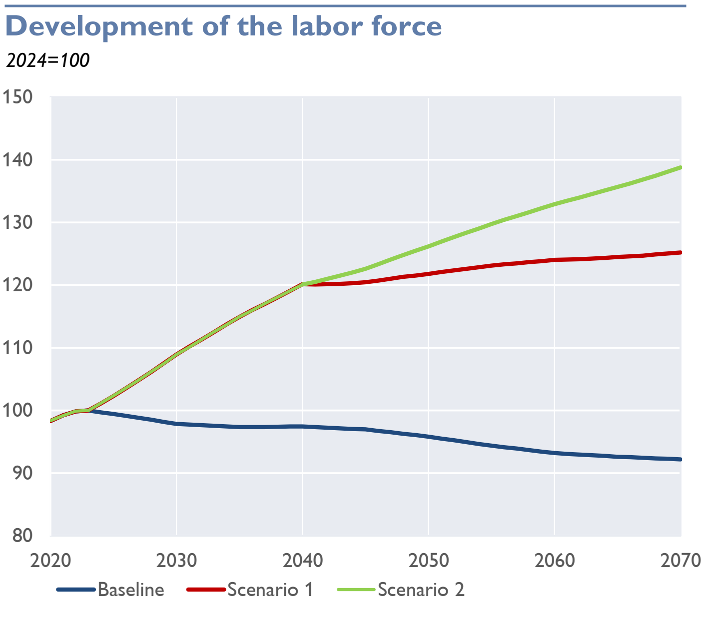
However, there may also be counteracting effects of aging on R*. Carvalho et al. (2016) argue that aging and the associated increase in the dependency ratio (retirees to contributors) might even drive up natural real interest rates because retirees have a lower saving rate than active persons. Goodhart and Pradhan (2017) expect that the downward trend of real interest rates will be reversed as baby boomer cohorts retire and begin dissaving (see also Goodhart and Pradhan, 2020). However, Lisack et al. (2017) reject these arguments and stress that it is the wealth of retirees that matters for real interest rates and that the dissaving effect of baby boomers is not strong enough. Furthermore, Auclert et al. (2021) observe that that even when the dissavings effect that Goodhart and Pradhan (2020) refer to materializes, this could be more than offset by a fall in investment.

We conjecture that raising the retirement age should positively affect R* both via higher labor supply and via debt stabilization. Increasing the effective retirement age may be necessary for two reasons: to account for the increases in life expectancy and to reduce deficits of public pension systems. A higher retirement age implies that individuals have to save less for retirement, which likely affects the savings-to-dissavings ratio in a way that raises real interest rates. A higher retirement age should (1) increase the incentives for individuals to engage in life-long learning for longer labor force participation, thereby increasing labor productivity to counteract possible negative effects of longer working lives on productivity (see the discussion below). (2) A higher retirement age increases the effective labor supply and thereby the natural interest rate à la Samuelson (1958) as direct driver of R*, and (3) reduces the effective old-age dependency ratio, thus lowering the fiscal deficit and debt by reducing the contribution of public pension systems to fiscal deficits and rising debt levels. Of course, changes in public deficits and debt may also have repercussions on real interest rates, as Auerbach in his discussion of Goodhart and Pradhan (2017) points out. In particular, when governments neither change contributions to public pensions nor cut benefits in the face of population aging, higher deficits might crowd out the effects of higher savings. Empirically, and in support of our conjecture, Grigoli et al. (2023) found indications that higher debt-to-GDP ratios negatively affect R* (see chart 3 above).

Empirical evidence confirms that an increase in the effective retirement age and a decrease in the dependency ratio have positive effects on R*. Most studies rely on model simulations. Lisack et al. (2017) developed a model for advanced country data and found that global demographic change (the secular increase in old-age dependency ratios) can explain three-quarters of the fall in global real interest rates since 1980. Their simulation showed that an increase in the retirement age by five years would increase the real interest rate relative to the baseline (albeit only modestly). Moreover, they found that a further decline in real interest rates – projected at the time of writing – was unaffected by the retirement phase of the baby boomers. Eggertson et al. (2019) calibrated a model for the US economy and found that the retirement phase of the baby boom generation was associated with a marked drop in real interest rates. They also simulated an increase in the retirement age: To fully offset the decline in real interest rates due to the demographic transition, policymakers would have to increase the retirement age by far more than currently planned. According to Bielecki et al. (2020), demographic change (mainly longer life expectancies) contributed about two-thirds of the secular decline in real interest rates since 1985 in Europe. They, too, showed in a simulation that raising the retirement age by three years significantly reduces the baseline decrease in real interest rates. However, the effect is rather small, which suggests that the increases in the retirement age must be sufficiently large.

How strong would the effect of an increase in the effective retirement age be for Austria? Chart 9 and table 1 show the results of two OeNB simulations.[9] In scenario 1, the effective retirement age increases linearly from 2024 (61 years) to 2040 (68.4 years) so that the financing gap of the pension system becomes zero in the final year. Scenario 2 assumes additionally that the retirement age increases further from 2040 onward, in line with the development of life expectancy at the age of 65, according to the assumptions in the EU Ageing Report (European Commission, 2021). In the baseline, the Austrian labor force would decline significantly until 2070. The simulation results indicate that eliminating the deficit in the public pension system by 2040 (scenario 1) leads to a steep increase in the labor force. Without additional measures, the labor force would level off thereafter. It would, however, grow strongly in scenario 2, where the retirement age is constantly adjusted to the increasing life expectancy. Labor force growth would be about 1% per year over the next two decades, which roughly equals the rate in the first two decades of this century, and slow down to about 0.5% after 2040. In line

Chart 9: Effects of increases in the retirement age on labor force in Austria



Source: Eurostat, OeNB.

[9] The simulations were carried out using the Austrian Fiscal Advisory Council's OLG model.

with these results, the effective old-age dependency ratio would decrease markedly until 2040 and continue to decrease slowly thereafter. Also, the annual deficit of the pension scheme would be gradually eliminated by 2040.

Table 1: Average annual labor force growth in Austria under different scenarios

Labor force growth under different scenarios

in percent

	Baseline	Scenario 2
2023–2030	−0.3	1.2
2031–2040	−0.0	0.9
2041–2050	−0.2	0.5
2051–2060	−0.2	0.5
2061–2070	−0.1	0.4
2023–2070	−0.2	0.7

Source: OeNB.

Once again, productivity comes into play. Demographic change may affect R* not only via a decreased labor supply, increased old-age dependency ratio and/or higher public debt but also indirectly via productivity. Depending on the direction and size of these productivity effects of aging, they may either dampen or amplify the total effect of a pension reform on R*.

The effects of demographic change on productivity are complex, and empirical studies come to different conclusions. For instance, Acemoglu and Restrepo (2017, 2022) found for a panel of OECD countries that there was no negative link between aging and productivity growth for the period from 1990 to 2015. They showed that countries exposed to more rapid demographic change also robotized more, which in sum yielded positive productivity dividends. Automatization and robotization efforts may act as an endogenous response of advanced economies to demographic change. For a confirmation of these arguments, see Eggertson et al. (2019). On the other hand, Maestas et al. (2023) exploited variation between US states and found significant negative effects from aging on GDP per capita. Around two-thirds of the effects were driven by labor productivity (GDP per hour worked) and one-third by slower employment growth (employment per capita). A study based on a policy-induced shift in work incentives for elderly Norwegians found a positive but insignificant effect of older workers (>62) on labor productivity. According to Hernæs et al. (2023), an older workforce has a significant positive effect on wages and a negative effect on new hiring. The causal effect of age on productivity varies by occupations, industries, and individuals, and may transform over time due to changes in the capital stock, technological innovation, improvements in health conditions, and changes in the relative supply of labor of different ages. Zélity (2023) modeled the impact of age diversity on aggregate productivity, assuming that experience and up-to-date education are complementary inputs in production. Because of skill-biased technological change, however, experience and education may not be equally productive, resulting in a hump-shaped relationship between age diversity and productivity that Zélity (2023) verified empirically. Holzmann (2013) adds the cohort perspective to the discussion: While for each individual, productivity may decline with age, each cohort is overall more productive than the previous, reflecting improved health status, life expectancy, and significantly higher cognitive skills of elderly people of the same age in younger cohorts.

Besides the direct effect on productivity via the labor input, two other channels of an aging population on productivity growth are worth mentioning. Empirical studies show that the innovative peak of inventors, measured by the number of patents filed and the quality of their citations, is around their 30s to 40s. Recent research based on more detailed data suggests that older inventors are less likely to patent disruptive research (Kaltenberg et al., 2023). An aging society thus has a more limited talent pool from which radical and disruptive innovations can emerge. In addition, aging implies a further decline in new business formation and thus slows down the process of creative destruction. Entrepreneurial ability depends on the one hand on creativity, risk taking, or out-of-the-box thinking, which decrease with age. On the other hand, it depends on business acumen and experience, which increase with age. The interaction of these two effects produces an empirical inverted U-shape between age and business formation rates that peaks at ages between 30 and 40. Liang et al. (2018) showed that a one standard deviation decline in a country's median age increases new business formation by 2.5 percentage points. The main channel is that relevant business experiences are gained in senior positions, which are held by older workers. In a society with an older workforce, younger workers are prevented from being promoted and acquiring the necessary skills to start a business at a younger age. To sum up, while there are mixed results regarding the direct effects of an older workforce on productivity, an older workforce is more likely to be less innovative and dynamic than a younger one.

2.3 Increasing R* via capital flows from Global North to Global South

An internationally coordinated green transition can act as a global productivity booster and thus contribute to efforts to increase R*. The idea is that the Global South has a cost advantage in producing clean energy but needs to overcome technological, financial, and regulatory constraints. Advanced economies can invest surplus capital and transfer digital and ICT knowledge and – most importantly – green technology, thereby boosting the clean energy export capacity of the Global South. Such an approach should not only offer comparative Ricardian benefits but also contribute to lower emission levels. To be sure, North-South capital transfers face significant implementation challenges. Capital flows from the Global North require strong institutions and political stability in the Global South to be effective, conditions that are rarely met, and changing these conditions also requires capital. Strategies to overcome these challenges must therefore be well-designed and holistic.

2.3.1 Historical determinants of capital flows from colonialization to the present

In the 19th and early 20th centuries, capital moved from North to South. Ohanian and Wright (2010) found that capital flows during the Gilded Age 1880–1913 went from low to high return countries, in line with standard theory.[10] The most prominent example was the British colonial investment in government institutions, railways and, to a lesser extent, resource extraction (Stone, 1999). The US, Canada, Argentina, Australia, and India absorbed well over half of British foreign investment in the period 1865–1914, mostly in government bonds and railway securities, while natural resource investment was concentrated in South African mines. German and French capital flows went to the Global South as well during the colonial period. One example is the Berlin–Baghdad railway built in the early 20th century and financed mainly by German banks. The French government focused on West Africa but had less capital to invest overseas than the British.

Esteves and Eichengreen (2019) point out that international capital mobility has followed a U-shaped pattern over time. Financial integration – as indicated by capital flows – was high before the Great Depression, low from the 1930s to the 1970s, and then increased again until recently, with also higher volatility. Esteves and Eichengreen (2019) seek to explain these shifts through a trilemma of policy tradeoffs between capital mobility, exchange rate stability, and monetary autonomy. Reinhart et al. (2016) emphasize the role of commodity price super-cycles and sovereign defaults in capital flow patterns over the past 200 years. Lucas (1990) observed a paradox whereby capital flows from poor countries to rich countries. Explanations could include low institutional quality (Alfaro et al., 2008) or the savings glut hypothesis (Bernanke, 2005): Following the Asian financial crisis in the late 1990s, emerging markets in Asia and elsewhere accumulated savings. This may have been due to a desire to accumulate foreign exchange reserves to avoid a recourse to the IMF, weak domestic investment, oil and commodity revenues, an export-led growth strategy, demographic change, and rising inequality. In the absence of domestic absorption, a glut of savings from emerging markets and developing economies flowed into the US in search for yield and/or safety. More recently, in the aftermath of the global financial crisis, some rebalancing has taken place, albeit at lower levels and with a different composition, as the euro area has become a major net lender.

2.3.2 The comparative advantage of the Global South in clean energy

The EU's net zero target requires a transition to clean energy by around 2045. Today, Europe's productivity still depends on imports of fossil fuels and raw materials, about 60% in the case of the EU. Even after 2045, there will still be a need for energy imports despite greater self-sufficiency and energy efficiency. The EU's dependence on energy imports is expected to fall to 20% in 2050 in the net zero scenarios, according to an in-depth analysis by the European Commission (2018) of the EU's long-term carbon strategy.[11] However, import dependency only declines to 27–38% by 2050 in the 80% reduction scenarios. Green hydrogen is still expensive

[10] However, this holds only when returns are measured in terms of consumption growth but not in terms of the marginal product of capital.

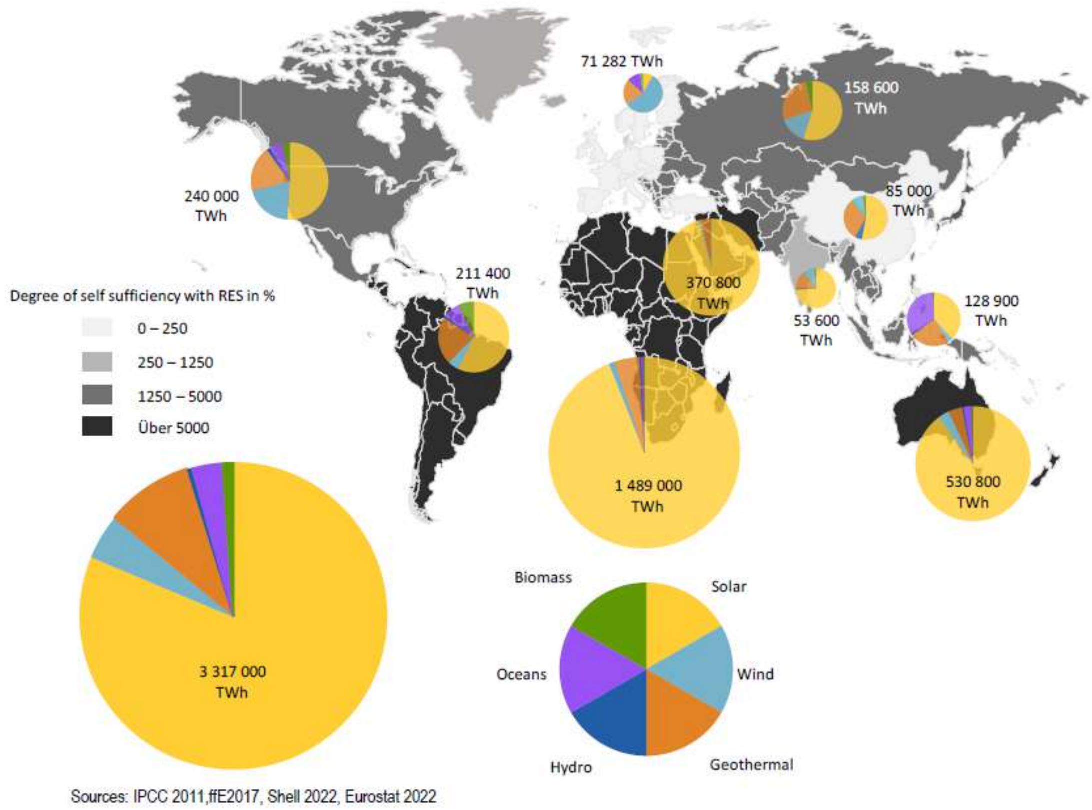
[11] 20% is also assumed in the industrial transition scenarios for Austria of NEFI (2022). Such scenarios depend on many assumptions, some of which have a high degree of uncertainty.

and price parity with gas is not expected to be reached before 2035 (Kienberger, 2022). In addition, the conversion of clean electricity into exportable hydrogen involves losses of around 30%, and a further 20% is lost in the production of hydrogen derivatives, such as methanol, methane or e-fuels (IRENA, 2022). Optimizing the global division of labor in energy production and consumption therefore requires joint efforts.

Fast-growing emerging market and developing economies (EMDEs) and the optimal location of renewable energy sources will change the patterns of the global economy. The Global South has a comparative advantage in clean energy, with up to three times more solar radiation (ESMAP, 2020). Specifically, half of the world's renewable energy potential lies in Africa, and supply is estimated to be 1,000 times greater than demand in this region (IRENA, 2020, see chart 10).[12] The global transition to net zero is likely to be more efficient if a substantial part of the clean energy needs of the Global North are met by imports. However, the Global North must provide the South with the relevant technologies. Productivity-enhancing green-tech transfer can take place through trade, FDI, or licensing.

[12] The chart is just a sketchy illustration of the wind and solar potential and may be missing some details. The share of wind in Latin America appears to be low, although it alone could meet two-thirds of the EU's primary energy needs. Most of the potential is in Chile and Argentina. In southern Chile alone, several thousand wind turbines are planned or under construction to produce green hydrogen.

Chart 10: Global distribution of renewable energy sources (RES)



Source: Kienberger (2022, slide 5).

2.3.3 How to redirect capital flows from North to South to raise productivity?

Supporting the green transition through a new international division of labor implies huge capital flows from North to South. The IMF (2023) follows the International Energy Agency's projections that the amount of climate finance needed in emerging and developing economies will have to increase to around USD 2 trillion per year by 2030. This is equivalent to 12% of total investment in these countries, four times higher than the current 3%. Given fiscal constraints in many high-income countries, these funds will need to be mobilized from both public and private sources. The IMF estimates that 80% of mitigation investment needs in EMDEs, including China, will have to come from the private sector, as public investment growth is expected to be limited.

EMDEs face significant challenges in attracting potential investors. Many have sub-investment grade credit ratings, resulting in high financing costs that reflect various real and perceived risks. But even investment-grade EMDEs face barriers to attracting private climate finance. The climate policies of large financial firms are not yet aligned with the Paris Agreement's emissions targets, despite the growth of environmental, social and governance (ESG) funds. Furthermore, recipient countries need to improve their absorptive capacity and ensure investment security. The G20 Eminent Persons Group on Global Financial Governance (G20, 2018) highlighted the need for reforms to catalyze private investment in low-income countries, including de-risking the investment environment through transparency, governance, and regulation; pioneering investment in fragile states, using instruments such as first-loss guarantees and co-investment; and pooling and diversifying risk by creating new asset classes for private investors. Given the political obstacles to making carbon pricing effective, a broad mix of policies is needed to improve the attractiveness of private climate-related investment. These measures include structural policies, financial sector policies, and additional international support. Some of these issues were taken up in a statement on a global climate finance framework issued jointly by 13 heads of state representing all constituencies at COP28 (2023).

North-South energy partnerships need to address the fears of "green imperialism" that may arise in recipient countries. One way of dealing with such sentiments is to provide clean energy first for local needs, and later for export. This strategy is also more efficient, given energy conversion and transmission losses. Several pilot projects are already underway that point the way to future North-South energy partnerships, such as the MENA Hydrogen Alliance ("Desertec 3.0"[13]), the German-Namibian partnership to export renewable energy in the form of ammonia, or the negotiations between Austria and Tunisia to export green hydrogen via pipelines to Central Europe.[14]

Overall, it seems efficient for the Global North to import a substantial part of its clean energy needs from the Global South. The Global South has a cost advantage but also a huge demand for energy and needs to overcome technological and financial constraints.[15] Advanced economies, in turn, can invest idle capital and transfer green technology to boost the South's development and clean energy export capacity. Ultimately, productivity can rise in both the receiving and the sending countries of financial flows due to relatively cheaper energy, less uncertainty (about development, migration, transition, etc.) and higher returns. Of course, the perspective that imported clean energy would eventually and effectively be cheaper than fossil energy depends on scaling up transformation, storage, and transport capacity. In conclusion, clean energy-related capital flows from the Global North to the Global South offer immense potential for unlocking productivity gains.

3 Conclusions

This article discusses policy options to reverse the past global downward trend of the natural rate of interest R* via structural reforms. This is of crucial relevance, as the level and trend of R* critically determine the room for maneuver of monetary policy and the relevance of the effective zero lower bound. The literature on the potential macroeconomic and financial drivers of the past

[13] https://dii-desertenergy.org/.
[14] https://www.earth4all.life/news/event-european-energy-partnership-austrian-chapter
[15] The Global South is also severely disadvantaged by climate change, even though their past contribution to global warming is negligible. The negative impact on productivity is much more pronounced in these countries because they are more exposed to heat (Day et al., 2019). Due to so-called currency risks, these countries also suffer from unfavorable financing conditions for investment in climate mitigation and adaptation.

R* decline finds the most robust links with demographic factors as well as real GDP trend growth and total factor productivity. We thus discuss five policy fields that have the potential to foster productivity growth and counter the negative impact of the aging society. Our main findings are the following:

(1) There seems to be a significant potential for boosting productivity via digitalization. Exploiting this potential requires the right market incentives and firm capabilities, especially since the euro area still lags behind in digital adoption and diffusion as well as in capital market depth to drive innovations and creative destruction to speed up adoption.

(2) Generative artificial intelligence is still at an early stage but may increase the speed and output of certain tasks, especially for those with the lowest skills and productivity. However, its full potential remains untapped as long as diffusion is limited to already high performing firms in a few knowledge-intensive sectors.

(3) A transition toward a more climate-friendly economy could enhance productivity in the long term but requires a well-orchestrated approach. A carbon tax is an essential but not sufficient instrument to decarbonize in time since negative externalities are not the only market failures implied by climate change.

(4) Raising the retirement age could dampen the effects of demographic shifts on R*, including pension deficits and lower public debt. Empirical evidence confirms that an increase in the effective retirement age and a decrease in the dependency ratio have positive effects on R*. The results regarding the direct effects of aging on productivity are mixed: An older workforce is conjectured to be less innovative, while the measured cognitive skills of elderly people in younger age cohorts have significantly increased.

(5) Finally, exploiting the comparative advantage of the Global South in clean energy can boost productivity – Ricardo's insights remain fully valid. Capital flows from the Global North to the Global South to finance investments in renewable energies offer immense potential to reduce any savings glut in the Global North or an investment drought in the Global South. They can also unlock productivity gains through relatively cheaper energy, less uncertainty, and higher returns. International efforts to help build infrastructure, train skills, and incentivize investment in the South can support the business opportunities of climate change and thus boost productivity.

Given the multiplicity of the determinants of R*, a comprehensive approach is required to gain more monetary policy scope by lifting R*. This includes well-coordinated measures in the fields of structural and climate policy to improve productivity. While the public sector has a key stake in these policy areas, the private sector needs to cover much of the investment demand for the green transition and provide the international capital transfers required to boost productivity at the global level. While structural reforms that boost productivity are crucial for economic growth and stability, it takes complementary financial reforms to ensure that these reforms also have a positive effect on R*.

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