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How does COVID-19 affect r*?

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Abstract

This memo discusses the potential effects of COVID-19 on the general trend of interest rates through the lens of global movements in the natural real interest rate, r*, in the medium to long run. While government spending and public debt issuance are likely to cause a rise in r*, r* may also decline due to precautionary behaviour, which could cause a rise in the private desire to save and a drop in the desire to invest. The net effect is uncertain.

Introduction

This memo discusses the potential consequences of the COVID-19 crisis for the level of interest rates through the lens of the natural real interest rate, r*. We analyse changes in r*, as it constitutes a path for interest rates in the medium to long run, thereby providing a guide on whether to expect changes in the general trend of interest rates as a consequence of COVID-19.

Since the 1990s, r* has been on a downward trend across countries, including Denmark. The main drivers have been persistent developments in productivity growth and demography, suggesting that r* will be low for many years to come and may fall even further.[1] In this memo, we discuss the *additional* effects of the COVID-19 crisis on r*. These are complex and ambiguous. The COVID-19 crisis may both dampen or amplify some of the structural drivers of r* in recent decades as well as giving rise to new trends that could influence the level of r*. In total, this leaves the aggregated effect of COVID-19 on r* uncertain.

We begin by introducing the concept of r* and intuition on how it could be affected by the COVID-19 crisis. We then discuss factors that drive r* in the medium to long run 3-10 years into the future, i.e. beyond the usual forecast horizon. These factors are persistent and influence the global equilibrium of desired saving and investment, but they are not permanent. They include:

- Global public spending and issuances of government debt.
- Global changes in desired saving, including precautionary behaviour during crises and changes in inequality.

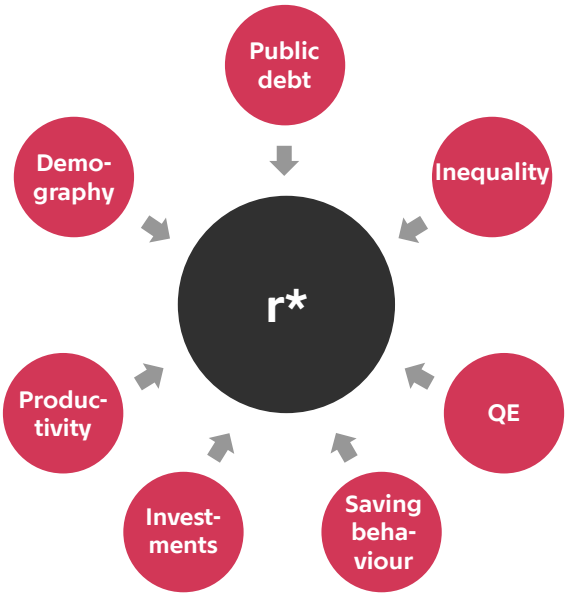
[1] See, e.g., Adolfsen and Pedersen (2019) and Brand et al. (2018).

- Global changes in desired investment.

We proceed to discuss whether the COVID-19 crisis could have permanent effects on r*, i.e. in the very long run beyond the 10-year time horizon where changes in r* are purely driven by structural factors, i.e. international productivity trends and demography.

We are not providing a quantitative estimate of the final effects of COVID-19 on r*, as these are very complex and impossible to predict. Instead, we provide a qualitative discussion and judgements of potential channels through which r* might be affected, including all those illustrated in figure 1.

Effects from covid-19 on r* are complex Figure 1

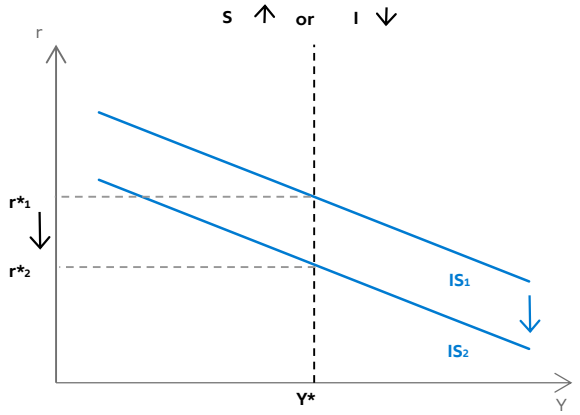


Introducing r*

The equilibrium or natural real interest rate, referred to as r* in the literature, is a theoretical and unobserved concept. It was originally introduced by Wicksell (1898) as the rate of interest generating equilibrium on the market for real capital. Since then, Wicksell's definition of r* has been modified in several dimensions to fit the designs of different economic models both with the purpose of estimating r* and to analyse monetary policy in different theoretical settings.[2]

For simplicity, in this discussion, we stick to the original interpretation of r* and define it as the rate of interest that balances desired saving and investment in an economy where output equals potential output and prices are stable. Under this definition, r* is solely determined by factors that influence the demand and supply of savings and investments in the medium to long run.[3]

r* balances desired saving and investment at potential output Figure 2



Note: Stylised illustration of the mechanisms generating r* in a simple IS diagram. "S" denotes aggregate desired saving, "I" denotes aggregate desired investments, "r" denotes the real rate of interest and "Y" denotes total output. "Y*" is potential output.

In figure 2, the intuition on how r* is determined from desired saving and investment is illustrated in a simple IS diagram. When desired saving (investment)

2 See Annex 2 for a list of the prominent definitions of r* in the macroeconomic literature.

3 In general, we abstract from factors that only influence r* in the short run but may be important in some model settings, e.g. DSGE models. In Annex 1, we provide an empirical estimate of the short-run effect of the COVID-19 crisis on r* for the Danish economy, using the model which was also used in Adolfsen and Pedersen (2019). This simulation is based on the Danmarks Nationalbank forecast for the Danish economy until the end of 2022. The model is better suited for estimating historical developments in the Danish r* than predicting future developments, as a simulation based on the model is unable to capture potential changes in global saving and investment behaviour in the medium to long run. Thus, we abstract from discussing the simulation further in the main text of this memo.

tends to increase (decrease), r* drops to a level consistent with output staying at the potential level.

There is a distinction between *desired* and *realised* saving and investment. *Desired* saving and investment are planned ex ante. By definition, *realised* saving and *realised* investment will always balance in a closed economic system, while *desired* saving and investment balance in equilibrium, i.e. after changes to the interest rate have occurred. What ensures this equilibrium are changes in the real interest rate, which in the medium to long run is equivalent to r*.

In the very long run, r* is solely determined by factors that drive long-run growth in the economy, as r* represents the marginal return on capital. This means that permanent changes in r* are driven by changes in productivity growth and labour input.

We focus on global changes in factors driving r*. For example, in the medium to long run, we discuss changes in the international equilibrium of desired saving and investment. The global economy is a closed system where saving and investment balance by definition and thus, the global r* secures equilibrium between desired saving and investment at the global level.[4]

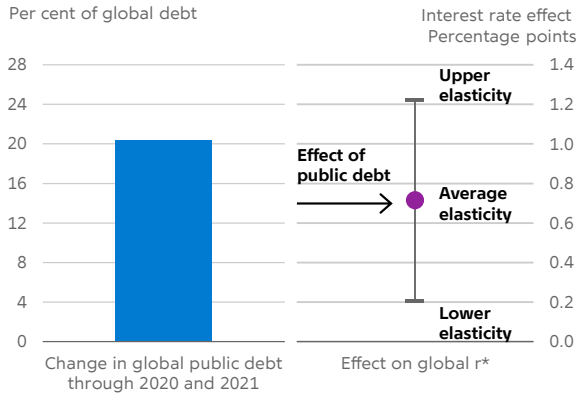
Government debt issuances might put upward pressure on r*

A key consequence of the COVID-19 crisis is a sudden and large global increase in government spending and debt following large public healthcare expenses and fiscal relief packages. In its latest public estimate of global public debt, the IMF estimates – with substantial uncertainty – a rise in global public debt through 2020 and 2021 of around 20 per cent of world GDP, while it was fairly unchanged in the estimates provided by the IMF before the COVID-19 outbreak.[5]

Historical elasticities between changes in government debt to GDP and r* suggest that the anticipated increases in government debt in 2020-21 will raise r* by around 0.7 per cent, cf. figure 3. Whether this effect materialises is very uncertain, and when following our definition of r* as a medium- to long-run concept, it ultimately depends on government budgets and debt being persistently affected by the pandemic, i.e. beyond the time horizon currently covered by the IMF forecast.

A rise in government debt is likely to lift r*

Figure 3



Note: Estimated effect of the increase in global debt in 2020 and 2021 on global r* anticipated by the IMF. The purple dot represents the estimated effect based on an elasticity of 0.035 per cent between public debt and long-term real interest rates, which is the average of elasticities in a list of studies presented in Rachel and Summers (2019). Moreover, effects given the highest and lowest elasticities in the same list of studies are presented.
Source: Rachel and Summers (2019), IMF and own calculations.

Fiscal policies affect r* through multiple channels

Moreover, the effects of changes in global fiscal policies on r* may work through two channels. These effects cannot be separated when estimating the effect of fiscal policy on r*.

First, an increase in government spending corresponds to a drop in public saving in the global

[4] In general, the Danish r* follows trends in international r*s with only short-run deviations, see Adolfsen and Pedersen (2019). See also Jordà and Taylor (2019) for an introduction to the concept of a global r*.

[5] See IMF World Economic Outlook Update June 2020 and IMF Fiscal Monitor April 2019.

economy and therefore a drop in global desired savings. Public deficits may be elevated for a period beyond the short-term horizon depending on the global development of the pandemic, repercussions on healthcare systems and the speed of economic recovery. This will tend to raise r*.[6]

Second, an increase in public spending raises government debt issuance. To the extent that government debt is considered a safe asset, this increases the overall supply of safe assets and therefore puts upward pressure on risk-free interest rates. Risk-free interest rates usually serve as a benchmark, which influences the general interest rate level of the economy and is therefore relevant for the level of r*.

It is important to note that a large and relatively fixed share of global savings can be expected to be invested in safe assets. This financial investment behaviour provides an intuitive link between a change in the supply of safe assets and the determination of r* through the saving and investment nexus. The rigidity in financial investment behaviour is related to preferences for safety among large global asset managers such as institutional investors, FX reserve managers and money market funds. According to the literature, preferences for safety among financial investors have generated an extra financial premium related to safety, which is solely determined by the demand and supply of safe assets.[7] For a given level of global savings, an increase in the supply of safe assets in light of COVID-19 expands the pool of financial investment opportunities for those who manage the savings. The consequence is an upward pressure on r*.

Effects of a larger supply of safe assets on r* are uncertain in the current economic setting

There is considerable uncertainty about the size of the effect of increased government spending and debt on r*. Besides the uncertainty over the time horizon of the pandemic and elevated public spending, uncertainty is mainly related to the effects of an increase in the supply of safe assets on r*. There are mainly two conditions, which complicate a comparison of public debt issuance under the current economic conditions relative to previous episodes.

First, in light of high initial ratios of public debt in many countries, the credit risk on public debt might rise drastically, even for advanced economies.[8] If the perceived safety status of sovereign bonds declines in many countries, it might essentially limit the supply of what is considered to be safe assets among investors, leading to a lower supply of safe assets, a higher safety premium and higher risk-free interest rates. Thus, high initial ratios of public debt may amplify the effects of public debt issuance on r*.

On the other hand, through large and open-ended QE programmes, central banks act as a backstop to the potential rise in risk on government bonds. As long as real economic effects of QE programmes are assessed to be temporary and limited to the business cycle duration, they do not affect r*. However, the presence of a "buyer-of-last-resort" in the bond market might have persistent effects on risk-free interest rates and thereby r*. Essentially, some claims on sovereigns may remain in the safe asset category due to the significant presence of central banks in the bond market. Thus, QE programmes may dampen the potentially amplified effects of public debt

6 A simple approach to assessing the impact of increases in public spending is to think in terms of a drop in total savings in figure 1. However, according to macroeconomic theory, households can be expected to save in response to higher public debt, as they know that the extra debt needs to be repaid in the future, either in terms of higher taxes or lower public consumption or a combination of the two. Therefore, they will save now in order to smooth consumption; the so-called Ricardian equivalence. The theoretical result is based on quite strong assumptions, see Barro (1974). Whether public spending during the COVID-19 crisis has an effect on aggregate savings in the global economy depends on who will end up receiving the liquidity from the governments as well as the marginal propensity to save out of the permanent income of the receivers.

7 See Krishnamurthy and Vissing-Jørgensen (2012), Del Negro et al. (2019) or Caballero et al. (2010).

8 It is doubtful whether estimates of elasticities between public debt and risk-free interest rates based on historical data can be used under the current circumstances. Corsetti et al. (2012) present an exponential relationship between sovereign risk premiums and anticipated developments in public debt ratios; all else being equal, when public debt levels are low, additional public debt can be issued at almost the same price as for existing debt, but when public debt levels reach a certain threshold, this relationship breaks down and additional issuances can become very expensive.

issuance on r* in light of the high initial public debt levels.[9]

Negative effects of changes in desired private saving on r*

The decline in international interest rates has largely been attributed to an increase in the global private demand for saving since the 1990s. Among the hypotheses linking the low level of interest rates to private saving is the idea of a "global saving glut" driven by large current account surpluses in mainly emerging market economies.[10]

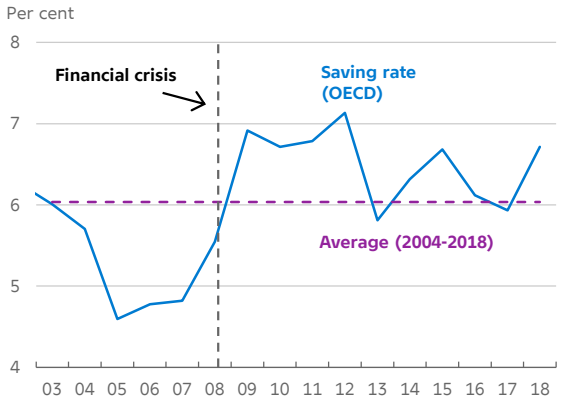
The literature has proposed several other factors as drivers of global private saving, many of which are structural. Among the most slow-moving factors are demographic changes, which we discuss later in this memo. In this section, we focus on factors that might become more prominent in response to the COVID-19 crisis. These include precautionary saving and changes in inequality. Besides persistently putting upward pressure on the global saving rate in recent decades, these factors have also been found to have driven a substantial part of the rising demand for risk-free assets globally. We argue that the COVID-19-crisis is likely to increase precautionary saving and global inequality, which imply a downward pressure on r*.

Economic crises tend to raise desired saving

History has shown that large recessions are typically followed by increases in private savings. Examples of such episodes were seen in the US during the recoveries from the Great Depression in the 1930s as well as the recent financial crisis where empirical analyses suggest that a substantial part of the increases in private savings can be explained by precautionary behaviour among households.[11] A result in the literature is also that precautionary behaviour has contributed to declines in the global r* following previous pandemics based on data since the 14th century.[12]

Moreover, after the financial crisis there was a large need for financial consolidation among households and firms, which prompted them to increase savings.[13] A mitigating factor in this crisis is that saving rates in the private sector in advanced economies were already at a high level when entering the COVID-19 crisis relative to before the financial crisis, cf. figure 4. Therefore, the need for financial consolidation in the private sectors across economies is likely to be lower in the current crisis relative to previous economic recoveries.

Saving rates were higher before COVID-19 than before the financial crisis Figure 4



Note: The saving rate is calculated as an average of household net saving rates in per cent of disposable income in OECD member countries weighted by households' disposable income in each country converted into US dollars. Colombia, Czech Republic, Iceland, Israel, Korea, Switzerland and Turkey are excluded, while Lithuania is excluded in 2003 due to missing data.
Source: Macrobond and own calculations.

A change in the income and wealth distribution can affect global savings

A possible contributing factor to the rise in private savings in recent decades is increasing inequality, as an ever larger share of global financial wealth and income is concentrated among the rich.

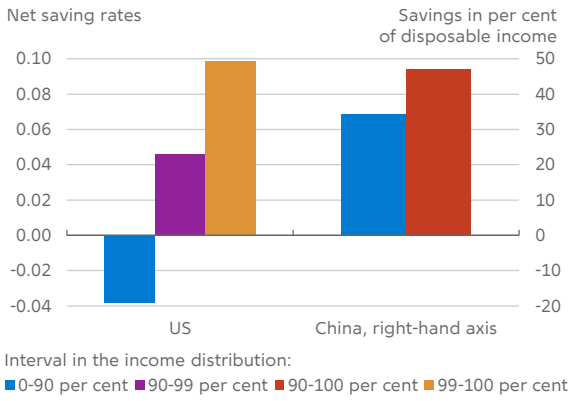
[9] The effects of QE on the safe asset premium are very complex. For example, it can also be argued that central banks limit the supply of safe assets when conducting large asset purchases.
[10] See Bernanke (2005).
[11] See Romer (1990) and Mody et al. (2012).
[12] See Jordà et al. (2020).
[13] See microdata-based evidence for Denmark in Hviid and Kuchler (2017).

Rising inequality has been seen in the US, in particular, but also in other countries. Households in the top of the income distribution tend to save a larger part of their income according to estimates for the US and China, cf. figure 5. Therefore, a higher concentration of income and wealth implies a higher marginal propensity to save out of permanent income, implying downward pressures on r*.[14]

In the beginning of a typical economic crisis, shocks to income especially affect households in the bottom of the income distribution, while negative shocks to asset prices affect wealthy households relatively more.[15] This implies higher income inequality and lower wealth inequality. However, while the top of the wealth distribution is typically able to rebound relatively quickly from a negative wealth shock, the bottom of the income distribution is likely to be less able to absorb the negative income shock.[16]

Moreover, international stock markets have already rebounded relatively quickly after the large drops in stock prices at the beginning of the crisis meaning that, so far, the top of the wealth distribution has been relatively spared from the economic consequences of COVID-19. Thus, when focusing on the medium to long run, inequality is likely to increase in light of the COVID-19 crisis, all else being equal. In isolation, the anticipated effect of a rise in inequality in the medium to long run is a higher saving rate and a lower r*.

Saving rates are higher in the top of the income distribution Figure 5



Note: US: Net savings are defined as after-tax income minus personal consumption, scaled by national income. An average of 2008-2015 is shown.
China: Saving rates from 2013.
Source: Mian et al. (2020) and Zhang et al. (2018).

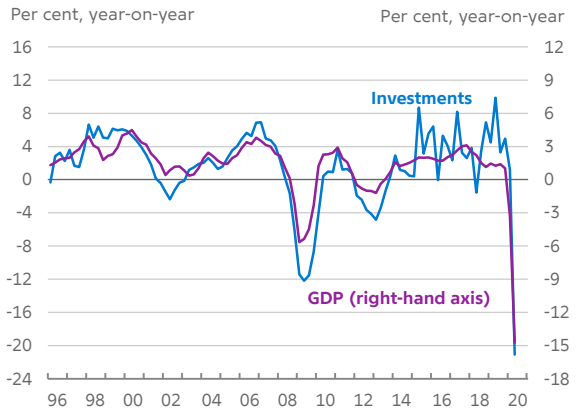
Lower investment growth may cause downward pressure on r*

We now turn to analysing the other side of the saving-investment equilibrium by considering the likely impact of COVID-19 on real investments. For a given level of ex ante desired saving, if global desired demand for investments fall, r* needs to fall to ensure a balance between saving and investment, and vice versa.

Historically, there has been a close relationship between growth and investments, and investments declined dramatically during the lockdowns of economies in the spring, see figure 6. The path of desired investment depends on how quickly the global economy will recover from the COVID-19 crisis and the uncertainty about the economic outlook. Moreover, the nature of the crisis may also lay the groundwork for investments in technology and new production chains as well as public investments. Therefore, although the short-run effect of the COVID-19 outbreak seems to be a reduction in desired investment, the effect on investment demand in the medium to long run is ambiguous.

14 Mian et al. (2020).
15 See Hanspal et al. (2020).
16 See Nassif-Pires et al. (2020).

Close historical relationship between growth in investments and GDP for the euro area Figure 6



Note: Yearly growth rates in GDP and total investments. Chained values are seasonally adjusted.
Source: Eurostat and own calculations.

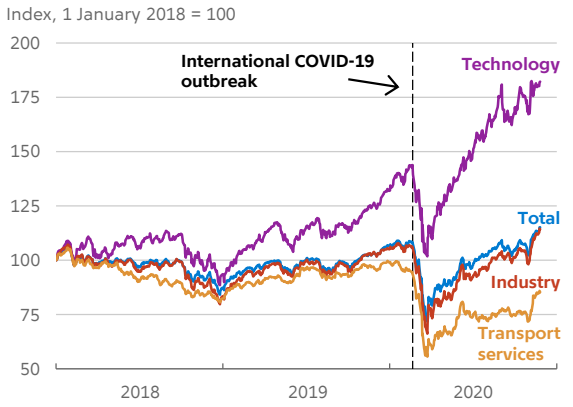
Uncertainty is likely to put downward pressure on private desired investment

Uncertainty is elevated, and it is likely to stay so until more is known about COVID-19, its impact on society and the prospects for public restrictions on activity. Uncertainty was a key driver of reductions in investments during the financial crisis.[17] Whether and how economic uncertainty continues to affect investments in the medium to long run depends on the outlook for the pandemic, the depth of the economic crisis and the speed of recovery.

Needed reallocation of capital might stimulate private investment

The shock from COVID-19 and the associated changes in lifestyle and work arrangements require a reallocation of capital from old to new technologies. The development in global stock prices since the international outbreak of COVID-19 indicates a belief in an acceleration of the ongoing technological transformation of the global economy among financial investors, see figure 7. An acceleration of the technological transformation is likely to spur investment. Besides investments in technology, COVID-19 could also lead to investments in new and more domestically based production chains, as industries have shown to be vulnerable to disruptions of global value chains.

The divergence between technology stocks and other stocks has accelerated Figure 7



Note: Global stock prices across industries.
Source: Refinitiv Datastream.

Public investments could lift total investments

The crisis could also be a potential trigger of public investments implemented to stimulate the economy in response to the economic crisis. Besides stimulating the economy, governments might find it necessary to invest heavily in the healthcare sector in order to prepare for potential future pandemics. Moreover, governments may exploit the opportunity to invest in future productivity growth. In the EU, a recovery fund has been set up with a significant share earmarked for public investments in, e.g., digitalisation, infrastructure and the green transition.

Changes in productivity and demography from COVID-19

We now turn our attention to more slow-moving factors and the very long-term horizon. On this horizon, r* is solely determined by factors affecting the long-run growth rate of the economy, namely labour input and productivity. r* follows productivity growth, as the real interest rate reflects the marginal

[17] See Banbura et al. (2018).

return on capital. Moreover, a smaller (larger) labour force relative to the stock of capital reduces (raises) the marginal return on capital implying a lower (higher) r*.

Permanent effects of changes in productivity growth and demography on r* are very uncertain. While productivity growth could fall following a drop in investment, an accelerated restructuring of the economy could also lead to higher productivity growth. Moreover, potential demographic changes following COVID-19 caused by, e.g., changes in fertility could eventually cause downward pressure on r*.

A COVID-19-induced change in investments could affect productivity growth

A potential change in investment behaviour following COVID-19 might have implications for productivity growth and r* beyond the medium run. First, if precautionary behaviour lead to a fall in investments, it could imply lower productivity growth from hysteresis effects.[18] This would ultimately lead to a long-run fall in r*.

On the other hand, an acceleration of structural changes, such as investments in digitalisation, might imply higher productivity growth. In isolation, this would lift r*. But structural economic changes could also result in mismatches on labour markets as well as losses of human capital in corporations. These effects may also lead to hysteresis effects and hamper productivity growth, if they turn out to be persistent, and they would reduce r*, among other things.[19] Whether hysteresis effects arise in labour markets depends very much on labour market flexibility.

Moreover, changes in production chains could exert downward pressure on r*, if reallocation from production abroad towards domestic production materialises and reduces productivity growth.

Lower population growth could follow from COVID-19

An essential effect of historical pandemics on r* has been a reduction of the labour force and r* following from a rise in mortality.[20] The demographic effect of a reduction in the labour force on long-run r* works through two channels. First, a smaller labour force reduces the marginal return on capital. Second, people in the working age tend to save more than people outside the labour force and, therefore, such changes in the demographic composition lead to a persistent decline in savings. These channels affect the long-run r* ambiguously.[21]

The historical demographic effect of previous pandemics is less likely to affect r* in similar ways following the COVID-19 pandemic, as mortality is heavily concentrated among elderly people outside the labour force.[22]

The long-run r* may also be negatively affected by a change in the fertility rate. Based on empirical investigations, some demographic studies find that economic crises and uncertainty are associated with some drops in the fertility rate.[23] Eventually, this would imply a lower r*, because a future reduction of the labour force lowers the marginal return on capital. Demographic changes after the baby boom following World War II have been shown to be significant drivers of the declining trend in r* in recent decades.[24]

18 See Dixit (1992).
19 See Bess et al. (2020) for a discussion of the effects of COVID-19 on structural growth in Denmark.
20 See Jordà et al. (2020).
21 A third effect of demographics on r* besides that of the marginal return on capital and the composition of savers and dissavers in the population is life expectancy, as prolonged life expectancy has lifted the incentive to save for retirement in recent decades. However, if COVID-19 remains a relatively short-lived phenomenon, it should not affect life expectancy going forward. Therefore, we abstract from this channel in the discussion.
22 See Dowd et al. (2020).
23 See Sobotka et al. (2011).
24 See, e.g., Gagnon et al. (2016).

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Annex 1: The impact of COVID-19 on Danish r* – an immediate fall in r* and a slow reversal

In the main text, the analysis has been a qualitative discussion centred on a saving-investment framework with a global perspective. While being simple and insightful, especially with regard to global developments in the middle to long run, the framework is less suited to analysing short-run domestic effects. We therefore combine Danmarks Nationalbank's forecast for the Danish economy from September 2020[25] and Danmarks Nationalbank's model for estimating r*, see Pedersen (2015). This can provide an empirical estimate of Danish r* in the near-term future.[26]

The model in Pedersen (2015) is a model of r* on the medium to long run and resides within the family of models of Laubach and Williams (2003). It is a semi-structural model and r* is influenced both by shocks in the business-cycle frequency and more slow-moving long-run structural forces, see also Annex B. The model can be regarded as a hybrid between a long-run growth model and a simple macroeconomic model for the business cycle. The latter gives rise to short-run deviations from the long-run condition between r* and the long-run growth rate in the economy through shocks in business-cycle frequencies. In the long-run growth model, r* is determined by the sum of the long-run growth rate in output and an error term. In the small macroeconomic model, the real rate gap, defined as the difference between the actual real rate and r*, is determined primarily through two relations. One is a relation between inflation and the output gap, a Phillips curve, the other is a relation between the output gap and the real rate gap, an IS relation. The model is able to filter out the unobserved variables through the theoretical model and statistical methods.

Danmarks Nationalbank's r* model shows an initial fall in r* and a reversal in tandem with improvements in activity

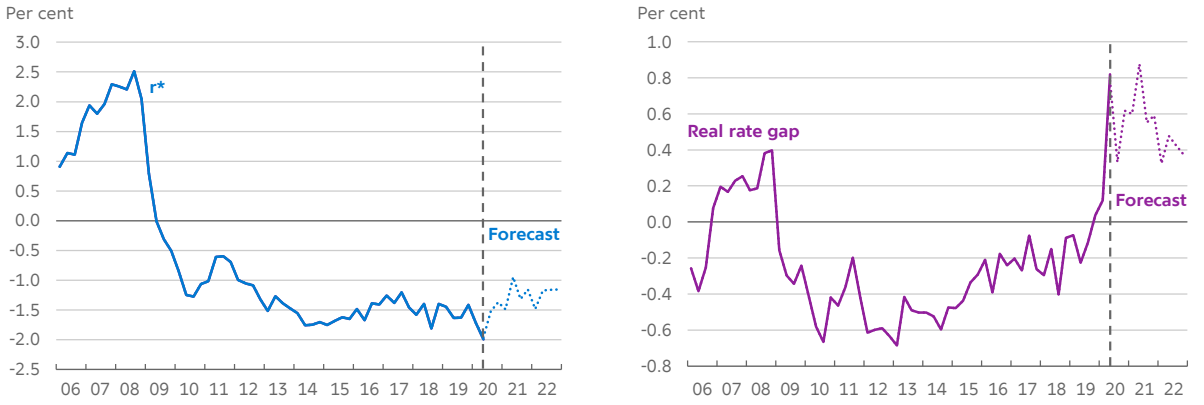
The model is estimated using historical data up until Q2 2020. The model is subsequently used to provide an estimate of r* when the model has observed data up until Q4 2022. The out-of-sample data is based on Danmarks Nationalbank's forecast from September 2020 involving the following. First, the steep decline in real activity seen during the beginning of 2020 is followed by a rebound and subsequent partial closing of the output gap. In the model, this implies that the output gap narrows, and it is not closed at the end of the sample. Second, inflation in the forecast is subdued, while the short rate is assumed to stay almost constant throughout the sample. The real exchange rate is kept constant at its levels from Q2 2020.

The implication for r* and the real rate gap, defined as the difference between the actual real rate and r*, is shown in figure 8. The model points to an initial fall in r* of around half a percentage point. This fall is reversed in tandem with the projected rebound in GDP. At the end of the forecasting period, r* is between -1 and -1.5 percentage points. The estimated drop in r* is driven by a significant decrease in the output gap. Intuitively, this is equivalent to a downward shift in the IS curve due to the fall in aggregate demand in figure 2. The subsequent rebound increases r* through the same channels. When feeding the model with a fall in the output gap, the model-based interpretation is that the distance between the actual real interest rate and r* is larger than previously. For a given level of the real interest rate, this implies a lower r*.

25 See Danmarks Nationalbank (2020).
26 It must be stressed that what is shown is not a model-based forecast of r*. The model has unit roots meaning that the best forecast of the future today is the value of the variables today.

COVID-19 can lead to a higher Danish r* in the short to medium term

Figure 8



Notes.: The figure to the left shows Danish r* estimated in Danmarks Nationalbank's model for r*, see Pedersen (2015). The forecast of r* is based on the assumptions stated in Danmarks Nationalbank's 2020 projections and the constant real effective exchange rate.
Source: Own calculations.

However, taken together subdued inflation and a close to constant nominal rate lead to a fall in expected inflation and an increase in the actual real rate going forward. This pushes up the actual real rate and thus widens the real rate gap for a given r*, see the figure to the right. This explains why r* does not fall by much; the real rate gap widens both through an increase in the actual real rate and a fall in r*.

It should be noted that the model is well suited for estimating historical movements in r*, but its simplicity also means that the model does not fully capture the complexity of the effects of COVID-19 on the Danish and international economy. This is especially the case for changes in potential output, which require more data to estimate with a high degree of precision. In other words, the model, like most models, suffers from the end-point problem, a problem which is more severe in the current situation with unprecedented fluctuations in output.

Annex 2: Definition of r* in the macroeconomic literature

Different definitions and maturities across different types of economic models

The natural rate of interest, or r*, is an unobservable theoretical variable. r* was originally introduced by Knut Wicksell in 1898 as the rate of interest generating equilibrium on the market for real capital.[27] In modern macroeconomics this definition has evolved, though still clinging to Wicksell's original definition. It has now become customary to define r* as the real rate of interest that brings output into line with its potential or natural level and thus closes the output gap and brings inflation on target. But this definition leaves a lot of questions on the table: What is meant by "potential output"? How fast can inflation be expected to reach target? And what drives movements in r*?

Consequently, r* must be discussed within a theory or a model setup. While these different setups differ along many dimensions, for this discussion the most important is the time horizon in the model. That is, one has to ask whether the theoretical setup is a business-cycle model, a long-run growth model or something in between. And while r* typically is a one-period rate in these theoretical frameworks, how long is such a period; one quarter, 3 years or more?

One very important aspect to keep in mind is also what drives movements in r* in the theoretical framework. In all models, this is discussed in terms of shocks, and before various definitions of r* are presented, it can be useful to be specific about what is meant by the type of shocks. A *cyclical* shock is a shock which affects the economy on the business-cycle frequency, typically 1-3 years. Prominent examples include changes in interest rates and the desire for consumption today compared to in the future.[28] Further, within the set of cyclical shocks it can be useful to distinguish between real shocks and nominal shocks. Nominal shocks can be defined as shocks to nominal variables, like the monetary policy rate, shocks to price and wage markups and the money supply. Real shocks can loosely be defined as the rest.

By *permanent* shocks is meant shocks that determine the long-term development of the economy; i.e. long-run productivity, labour supply and capital formation, but can also as a result of, e.g., inertia and forward-looking behaviour give rise to deviations from trend growth in the short term.

Permanent shocks are sometimes also denoted structural shocks. But this nomenclature is a bit unfortunate, as it can lead to confusion between shocks which affect the economy in the long run, as discussed above, and shocks in structural models. A *structural* shock in such a model is a shock that is uncorrelated with other shocks and that can be given an economically unambiguous interpretation. Hence, within this terminology structural shocks can be both cyclical and permanent shocks and both real and nominal shocks.

With this in mind, the following definitions of r* are presented.

1. *Business-cycle models:* r* is the real interest rate prevailing in a counterfactual economy with no price rigidities. r* stabilises output gaps defined in relation to output under flexible prices. The time span is short, typically a quarter, and r* is a quarterly rate. Output and inflation thus need to be brought to their targets within a quarter. r* is consequently influenced by *all* shocks within the model, including shocks to business-cycle frequency, e.g. consumption shocks, fiscal policy shocks and temporary productivity shocks, but *not nominal* shocks, including monetary policy shocks. Business-cycle models can also include permanent shocks, which affect the long-term growth rates of the economy. These shocks also affect r*. Estimates of r* within this framework are typically volatile and r* can easily fall markedly within over a quarter. Short-term interest rates are typically used to estimate r* in

[27] See Wicksell (1898).
[28] Shocks on business-cycle frequencies can transform temporary shocks into permanent shocks through hysteresis.

these models. Models count DSGE, see also Woodford (2003) for a thorough review of the theory and Barsky et al. (2014) for an example using an estimated model.

2. *Semi-structural models:* r* is the real interest rate in the medium-long run and therefore a level of the real interest rate beyond the business cycle, i.e. 3-5 years. r* stabilises output according to potential output, and it is influenced by cyclical shocks as well as longer-run changes in growth and saving-investment behaviour, i.e. permanent shocks. Short-term interest rates are typically used to estimate r* in these models. Models count the Laubach-Williams model and the r* model of Danmarks Nationalbank. As the models by their very nature are not structural, the shocks are not structural but residuals and hence cannot be given a precise economic interpretation. One prominent example is the so-called Z factor in the mentioned examples. This factor is a residual in the relation between r* and the economy's long-run growth rate. The factor thus captures all differences between the long-run growth rate and r*, but the model cannot tell the user from where this discrepancy originates.
3. *Long-run growth models:* r* is consistent with the marginal return on capital and r* equals the actual real interest rate in these models. One step in time represents several years. r* is not influenced by cyclical shocks, as there is no variation in output on business-cycle frequencies. r* only depends on changes in productivity and demography and other factors which influence the input of labour in the long run. Estimates of r* within this framework are typically smooth and slow-moving. Interest rates on long-term safe assets (e.g. 10-year government bonds) are typically used to estimate r* in these models. Models count OLG models and DREAM, see also Gagnon et al. (2016) or Carvalho (2016).

y* versus r*

Potential output, or y*, is a more familiar concept for macroeconomists than r*. It can therefore be useful to compare different definitions of potential output with definitions of r*, also because there is a close relationship between the two concepts.

Natural output is discussed within structural macroeconomic models on the business-cycle frequency. It is defined as the level of activity in a counterfactual economy without nominal rigidities. Estimates of natural output can be volatile, as *all shocks* which hit the actual economy also affect the natural economy. The motivation behind the focus of the measure of the output gap is that this measure of the output gap determines the inflationary pressures in the economy. Stabilisation of inflation typically demands that output is close to natural output. r* plays a key role in closing the output gap and thus the inflation gap. In fact, in a simple setting, the output gap is only determined by expected future deviations between the actual real rate and r*. See also Woodford (2003).

A common way to think about *potential output* is within the family of unobserved component models, like Nationalbanken's model for estimating y*. Typically, these estimates are done within semi-structural models. While shocks to the business-cycle frequency might play a role, longer-run changes in growth are typically thought to be the main drivers of potential output within this setting. Models within this framework can be compared to the r* models in Laubach and Williams (2003) and Pedersen (2015). In fact, the output gap estimated in Pedersen (2015) resembles closely the output gap estimated using Nationalbanken's model for y*.

Structural output indicates the level of activity which output would converge to when all temporary shocks have died out. Estimates of structural GDP are typically smooth and slow-moving, and they are usually thought of as being driven primarily by productivity and inputs of capital and labour. MONA and DREAM are Danish examples of models which have been used to estimate structural GDP for Denmark. Estimates of r* based on long-run growth models reside within this family of models.

LOW ↓FOR LONG

Low for long

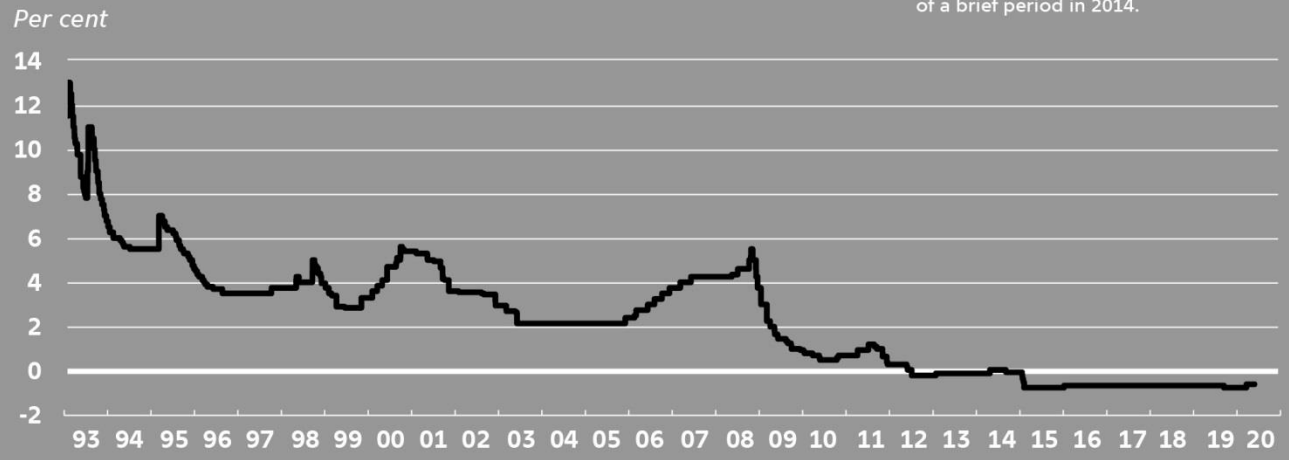
Denmark was the first country to introduce negative monetary policy rates in 2012. Since then, Switzerland, Sweden, Japan and the euro area have followed suit.

Very low and in some cases negative interest rates have characterised the past decade across the advanced economies. There are several reasons why interest rates have fallen to the current low levels. Low interest rates reflect the fact that inflation has been subdued in many countries, but structural changes in household and corporate savings and investment behaviour are also part of the explanation.

These developments have brought monetary policy and the economy into uncharted waters, which is why Danmarks Nationalbank will be issuing a series of publications on the topic of which this Economic Memo is one.

Danmarks Nationalbank's interest rate

Danmarks Nationalbank's key interest rate has been negative since the summer of 2012, with the exception of a brief period in 2014.



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