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How does climate change affect the long-run real interest rate?[1]

Emma Bylund and Magnus Jonsson
The authors work in the Riksbank's Monetary Policy Department.

"Central banks would benefit from enhanced assessments of the potential impact on the natural interest rate [from climate change] since that could reveal that policy space is more limited than previously thought, which has implications for the conduct of monetary policy."
(NGFS (2020))

We study the potential impact of climate change on the long-run real interest rate. Our starting-point is that climate change weakens growth prospects, increases uncertainty over economic developments and elevates the risk of disasters. According to economic theory, these developments could imply a lower long-run real interest rate and, under certain conditions, it could be significantly lower. From a policy perspective, this may make it more difficult for central banks to achieve price and financial stability.

Climate change presents new and difficult challenges for society. For example, to comply with the Paris Agreement – which aims to limit the global temperature rise to 1.5–2 degrees Celsius above preindustrial levels – powerful political measures are necessary to reduce global carbon emissions. The most cost-effective measure to achieve this, according to economic theory, is a global carbon tax.[2]

In recent years, central banks have started to emphasise the impact of global warming on the economy.[3] It is primarily a question of how the economic consequences of climate change affect the ability to fulfil the price and financial stability objectives, but also to what extent the transition to a less fossil-based economy can be supported.[4]

From a monetary policy perspective, it is important to recognise the impact of climate change on:

- Inflation and inflation expectations
- Output and employment in the short- and long-run
- The long-run real interest rate

In this context, the long-run real interest rate is of particular significance. In the longer run – when the business cycles have subsided – the inflation target, π^{target}, must equal the difference between the average policy rate, R, and the long-run real interest rate, r^*, that is,

$$\boldsymbol{\pi^{target} = R - r^*}.$$

It is commonly believed that monetary policy cannot affect the long-run real interest rate. This means that in order to fulfil the inflation target, the average policy rate must be adjusted in line with the changes in the long-run real interest rate.

The policy rates have been low in many countries for some time, due in part to a downward trend in the long-run real interest rate, see Figure 1. This decline has several causes, including lower long-run growth prospects, various demographic changes, a high

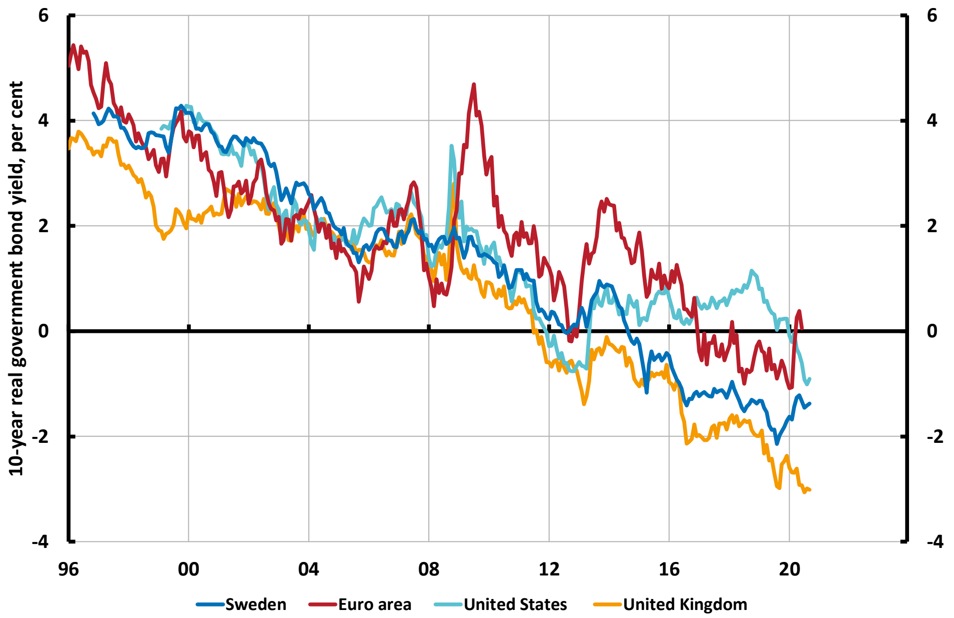
[1] We would like to thank Mikael Apel, Anna Breman, Jesper Hansson, Marianne Nessén, Marianne Sterner and Anders Vredin for valuable comments. The opinions expressed in Economic Commentaries are the authors' personal opinions and cannot be regarded as an expression of the Riksbank's view on the questions concerned.
[2] See Olovsson (2020).
[3] See, for instance, Andersson et al. (2020), Brainard (2019), Breman (2020) and NGFS (2020).
[4] For example, the Riksbank recently introduced a sustainability perspective in the management of the foreign exchange reserves, see Flodén (2019).

level of saving in Asian emerging market economies and a greater demand for safe assets.[5]

In this Commentary, we study the potential impact of climate change on the long-run real interest rate. Our starting-point is that climate change weakens growth prospects, increases uncertainty over economic developments and elevates the risk of disasters. We show that these developments could lead to a lower long-run real interest rate and, under certain conditions, it could be significantly lower.

We limit the analysis to the impact on the long-run (steady state) real interest rate. The transition of the economy to the new long-run equilibrium is therefore not accounted for. Such analysis is important, but also more complicated and would involve many more factors, for example, political decisions on the national and global level, the capital stock, labour supply, etc.[6] Our aim is merely to provide a theoretical framework that illustrates the factors that may affect the real interest rate in the long-run and using a number of illustrative calculations to show how important these factors can be quantitatively.

Figure 1. Downward trend in global real interest rates



Sources: National central banks and the Riksbank

Effects of climate change on the economy

Climate change poses various types of risk for the economy. These can be divided into three categories. The first category is **physical risk**. This may be extreme weather events such as drought, flooding, hurricanes, heatwaves, as well as more gradual effects, such as rising sea-levels or changes in ecosystems. The second category is **transition risk**, that is, the risk associated with the transition to a less fossil-based economy. This can be political decisions to raise taxes on carbon emissions, higher prices for emission rights or changed patterns of consumption. But it may also be decisions that make it more difficult to extract fossil-based resources such as coal, gas and oil. The third category is the **risk of irreversible threshold effects**. These effects occur at a certain point in time when climate change has gone so far that it can no longer be reversed and instead accelerates further change in a self-generating process. This can be the melting polar ice caps in the Arctic, the thawing permafrost in Siberia

[5] See Lundvall (2020).
[6] See NGFS (2020) for a discussion of these factors.

or the decimation of the Amazon rainforest. Threshold effects are examples of fundamental uncertainties – science cannot say if and when a certain event will occur, but neither can it rule out the possibility of the event occurring – with potentially disastrous consequences.

The impact of physical risk, transition risk and the risk of irreversible threshold effects on the economy is discussed in a report from the **Network for Greening the Financial System (NGFS)**.[7] The report emphasises the complexity of climate change and that the economic effects are uncertain and difficult to predict, not least due to the fact that the development depends to a large extent on political decisions on both the national and global level. Nevertheless, the report points out several effects of climate change that could impact the economy in different, sometimes contradictory, ways.

Economic growth prospects can be an important determinant of the long-run real interest rate. According to the NGFS report, several factors indicate that climate change may lead to **weaker growth prospects**. This is in line with other studies, including a new study from the IMF that also predicts lower growth rates, especially in poorer regions with a warmer climate.[8] However, political decisions play an important role for the economy's growth potential. This means that with an effective climate policy – involving, for example, global carbon taxes, emission rights trading, introduction of carbon tariffs, public investment in new technology that facilitates the transition to a less fossil-based economy – growth could instead be higher.

Two other important factors for the determination of the long-run real interest rate are risk and uncertainty. These factors are often not mentioned among the main causes of the decline in the real interest rates as illustrated in Figure 1, but can nevertheless be important going forward. In all likelihood, climate change will imply **greater uncertainty over economic developments**, which is emphasised in the NGFS report.

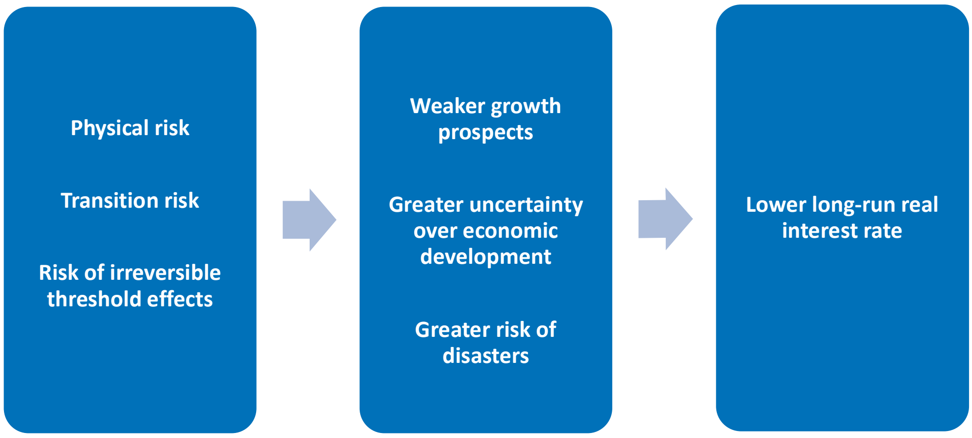
Greater risk of disasters of different kinds appears to be an inevitable consequence of climate change. We can already see that natural disasters and extreme weather events are becoming more common with negative consequences for the economy: Hurricane Maria that devastated Puerto Rico in 2017 and killed a large number of people, the intensive forest fires on the Australian continent at the beginning of 2020 and the unusually hot and dry summer in Sweden in 2018 are just a few examples. Other phenomena that may increase the risk of major natural disasters in the future have been pointed out by the Swedish Society for Nature Conservation:[9]

- A reduction in the Arctic sea ice of about 13 per cent per decade since 1979
- A rise in the average sea level of about 20 centimetres
- Heatwaves in the Mediterranean region and the Middle East
- Flooding and rainstorms in the Andes and the Himalayas.
- Drought and acute water shortages on the Horn of Africa and in South Africa
- Large-scale degradation of coral reefs around the world due to coral bleaching

Figure 2 summarises how climate change in terms of physical risk, transition risk and the risk of threshold effects could weaken growth prospects, increase uncertainty over economic developments and elevate the risk of disasters, which in turn could affect the long-run real interest rate.

[7] See NGFS (2020).
[8] See Kahn et al. (2019).
[9] See the Swedish Society for Nature Conservation "Den globala uppvärmningens konsekvenser [The consequences of global warming]", in Swedish only, https://www.naturskyddsforeningen.se/vad-vi-gor/klimat/konsekvenser-global-uppvarmning.

Figure 2. How climate change could affect various economic factors, which in turn could affect the long-run real interest rate



Source: Authors' own illustration

Weaker growth prospects

The long-run real interest rate is affected by economic growth prospects through this relationship,[10]

$$r^* = \delta + \gamma\mu,$$

where δ is the discount rate at which households value current consumption versus future consumption, μ is the long-run economic growth rate and $1/\gamma$ is the intertemporal elasticity of substitution, that is, the households' willingness to substitute current consumption against future consumption in response to a change in the real interest rate.

A positive discount rate implies that households are "impatient" and value current consumption higher than future consumption. The more impatient households are, the less they save, and the higher becomes the real interest rate. However, we see no strong reason why climate change should affect the discount rate in either direction. We therefore disregard this factor and set $\delta = 0$ in our calculations.[11]

In a growing economy, future consumption is greater than current consumption, which increases the demand for credit and drives up the real interest rate. If, on the other hand, growth prospects deteriorate, this demand falls and the real interest rate decreases. How much it decreases depends on the intertemporal elasticity of substitution. If the elasticity is small, that is, γ is high, minor changes in growth prospects may have major effects on the long-run real interest rate.

Figure 3 shows how the long-run real interest rate is affected when growth prospects are halved from 2 to 1 per cent. The figure also shows how the intertemporal elasticity of substitution affects the results. The value of this parameter is difficult to measure. In many studies, it is set to one, which is also our benchmark value, but we also consider values where it is less and above one.

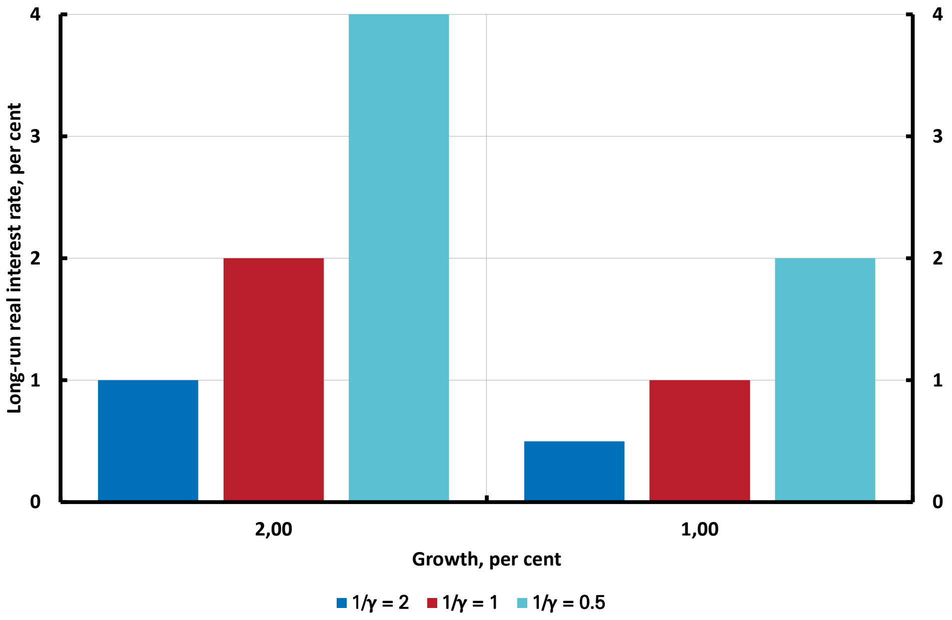
If growth prospects are halved, the long-run real interest rate decreases by between 0.5 and 2 percentage points, depending on the intertemporal elasticity of substitution. Weaker

[10] See Jonsson (2002) for a description of the assumptions under which this relationship applies. In this study, we set the households' weight on consumption relative to leisure in the utility function to one and the capital tax to zero. This relationship disregards risk and uncertainty. These factors are accounted for in the next sections.

[11] We also disregard population growth, which can be a factor in this relationship under certain assumptions.

growth prospects could in other words have relatively large effects on the long-run real interest rate, in particular when the elasticity is low.

Figure 3. Weaker growth prospects can have large effects on the long-run real interest rate



Note. The parameter $\delta = 0$. The figure shows how the factor $\gamma\mu$ affects the long-run real interest rate for two different values of the growth rate and three different values of the intertemporal elasticity of substitution.

Source: Own calculations

Greater uncertainty over economic developments

In economic decision-making, uncertainty is often an important factor. This is also the case for the households' consumption and saving decisions and thus for the long-run real interest rate.

Uncertainty reduces the long-run real interest rate

When accounting for uncertainty, the relationship for the determination of the long-run real interest rate is modified in the following way,[12]

$$r^* = \delta + \gamma\mu - \frac{\gamma^2}{2}\sigma^2.$$

A new variable is added to the relationship, σ^2, measuring uncertainty or formally the variance of consumption growth. This means that the parameter γ has two functions in this case: As before, $1/\gamma$ is a measure of the intertemporal elasticity of substitution, but γ is now also a measure of the households' risk aversion, that is, their attitude to risk and uncertainty.

When economic developments are uncertain, the households want to save some of the income to have a buffer if the economy would deteriorate – known as precautionary savings. This drives down the long-run real interest rate. By how much depends on the households' risk

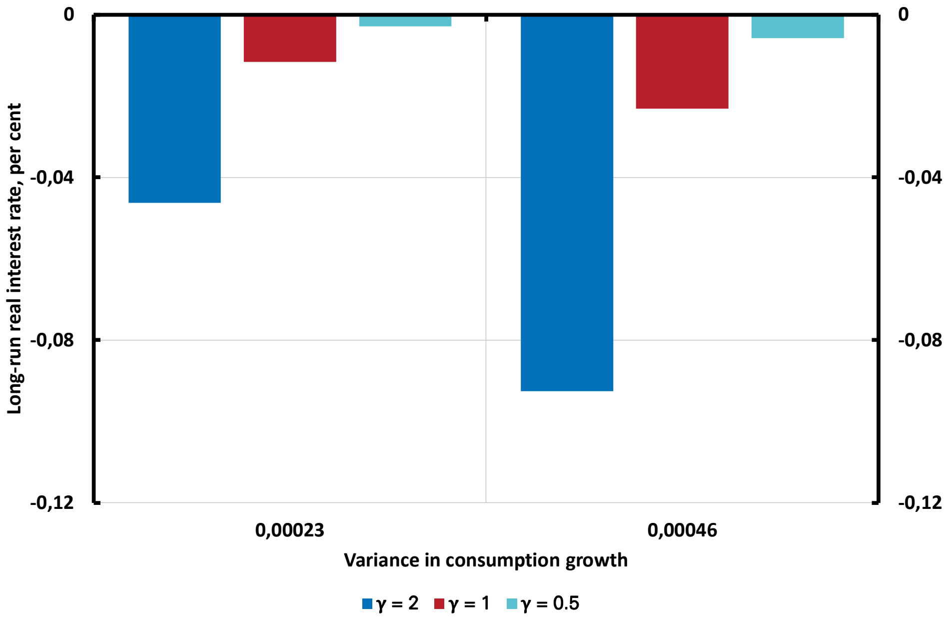
[12] See Campbell and Cochrane (1999).

aversion. The more households dislike uncertainty, the more they save, and the larger is the reduction in the long-run real interest rate.

To calculate the quantitative effects of uncertainty, we need a benchmark value for the variance of consumption growth. For this purpose, we use the variance in the Swedish data, that is, 0.00023.[13] Figure 4 shows how a doubling of the variance, for three different values of the risk aversion, would affect the long-run real interest rate. To isolate the effect of uncertainty, we set the growth rate $\mu = 0$ in this and the following calculations.[14]

A doubling of the variance has relatively minor effects on the long-run real interest rate. If the risk aversion is one, the long-run real interest rate decreases by a mere 0.01 percentage points. If the risk aversion increases to two, the decrease is somewhat greater, around 0.05 percentage points. This suggests that uncertainty has relatively minor effects on the long-run real interest rate.

Figure 4. Minor effects of greater uncertainty on the long-run real interest rate



Note. The parameters $\delta = \mu = 0$. The figure shows how the factor $-\frac{\gamma^2}{2}\sigma^2$ affects the long-run real interest rate for two different values of the variance and three different values of the risk aversion.

Source: Own calculations

However, the specification of the households' utility function is important when evaluating the quantitative effects of uncertainty on the long-run real interest rate. Utility functions are not observable objects and are therefore difficult to specify, in particular on the society level. It is difficult to know which terms that should be included in the function and which functional form that best describes the utility. In simpler models, usually only today's consumption is included, which has also been the case in the relationships that we have discussed so far. This simplification may be useful under certain conditions, but we know from various studies that individuals also receive utility from other factors. For instance, habit formation in consumption can be an important factor and may therefore play a role for the household's consumption and saving decisions.

[13] The variance is calculated for the period 1995 quarter 1 – when the inflation target regime was formally introduced – to 2020 quarter 1.

[14] This means that we disregard the fact that a higher risk aversion implies a lower intertemporal elasticity of substitution. If γ increases, there is a negative effect on the long-run real interest rate from the uncertainty factor but also a positive effect from the growth factor. For reasonable growth and variance values, the quantitative effect from the growth factor is greater than from the uncertainty factor. In other words, an increase in risk aversion leads to a higher long-run real interest rate. The purpose of this calculation is to only show how the uncertainty factor affects the long-run real interest rate.

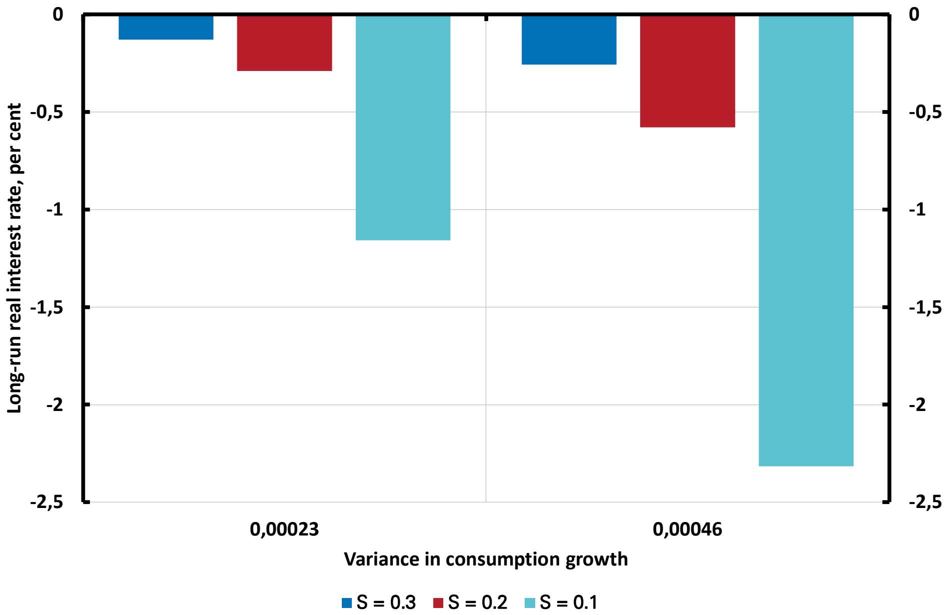
In an influential article from 1999, John Campbell and John Cochrane specified a utility function where both today's consumption as well as habit formation in consumption were included.[15] The relationship that determines the long-run real interest rate is then modified in the following way,

$$r^* = \delta + \gamma\mu - \frac{1}{2}\left(\frac{\gamma}{S}\right)^2 \sigma^2.$$

A new term, S, is added to the relationship, which shows the difference between the economy's average consumption level and the habit formation level. In this context, the habit level can be interpreted as the subsistence level of the economy. Households do not want to end up below this level under any circumstances. When they are close to the subsistence level – if S is close to zero – risk aversion is high and they want to increase savings. If they instead are further away from the subsistence level, the risk aversion is lower, and if $S = 1$, the risk aversion is as in the previous section.[16]

Figure 5 shows that when habit formation is part of the utility function, the effect of uncertainty on the long-run real interest rate becomes larger.[17] If the variance is doubled, the long-run real interest rate decreases by 0.1 to 1.1 percentage points, depending on the level of S.

Figure 5. Uncertainty can have major effects on the long-run real interest rate when habit formation is included in the utility function



Note. The parameters $\delta = \mu = 0$ and $\gamma = 1$. The figure shows how the factor $-\frac{1}{2}\left(\frac{\gamma}{S}\right)^2 \sigma^2$ affects the long-run real interest rate for two different values of the variance and three different values of S.

Source: Own calculations

[15] See Campbell and Cochrane (1999). See also Benmir et al. (2020).

[16] Households' risk aversion is now given by γ/S. This means that a reduction in S leads to a higher risk aversion, but no decrease in the intertemporal elasticity of substitution, i.e., risk aversion and the elasticity of substitution are independent of each other. Higher risk aversion thus leads unequivocally to a decrease in the long-run real interest rate.

[17] We show results for three cases: $S = 0.3, 0.2$, and 0.1, where $\gamma = 1$ in all three cases. This means that risk aversion, given by γ/S, is 3.3, 5 and 10, respectively. In the article by John Campbell and John Cochrane, $S = 0.06$. This implies that risk aversion is almost 17.

Expectations of future uncertainty can also reduce the long-run real interest rate

The example with habit formation in the utility function shows that the specification of the utility function is important for the quantitative effect of uncertainty on the long-run real interest rate. Another, technically more complicated, example of this is Epstein and Zin's specification of the utility function.[18] Their specification – non-separable utility between time periods – has important implications for the households' consumption and saving decisions. First, the intertemporal elasticity of substitution is independent of risk aversion, as was the case with habit formation. Second, *expected future variance in long-run consumption growth* may, under certain conditions, affect the long-run real interest rate.[19]

Households' expectations of future uncertainty may therefore be an additional factor that could increase precautionary savings and reduce the long-run real interest rate. In a discussion of the effects of climate change on the long-term real interest rate, this uncertainty factor could be important since the risks from climate change are in many cases further ahead in time.

Greater risk of disasters

Climate change increases the strength and frequency of different types of natural disasters. If we consider this, the relationship for the long-run real interest rate is, under certain conditions, modified in the following way,[20]

$$\boldsymbol{r^* = \delta + \mu - pb/(1 - b)},$$

where p denotes the probability of a disaster and b the magnitude of the disaster in terms of reduced output. In this context, disasters can be natural disasters of different kinds, but also economic events like the depression of the 1930s or financial crises, war or epidemics. Just like uncertainty over economic developments, the risk of disasters increase precautionary savings, which reduces the long-run real interest rate. By definition, disasters cause major falls in output. This means that even a minor risk can have a major impact on the long-run real interest rate.

However, applying this relationship is not straightforward since it is difficult to identify the probability of a disaster from data. As a benchmark value, we use an estimate of this probability from a study by Robert Barro.[21] In this study, he estimates what the probability of a disaster has been during the twentieth century in the world's major economies. He define the size of a disaster as a decline in GDP of at least 15 per cent. With this definition, the probability of a disaster is 1.7 per cent. The largest declines occurred in Germany and Greece during the Second World War, where GDP fell by 64 per cent. The size of a disaster thus varies from a decline in GDP of 15 per cent to 64 per cent.

Figure 6 shows by how much the long-run real interest rate decreases when the probability of a disaster is doubled from 1.7 to 3.4 per cent, and the decline in GDP is 32 per cent, that is, half of the maximum decline in GDP from Robert Barro's study. If the probability of a disaster doubles, the long-run real interest rate decreases by around 0.8 percentage points.

Figure 7 shows how the size of the disaster affects the long-run real interest rate, given a disaster probability of 1.7 per cent. An approximate doubling of the decline in GDP from 15 to 32 per cent causes a fall in the long-run real interest rate by about half a percentage point. An

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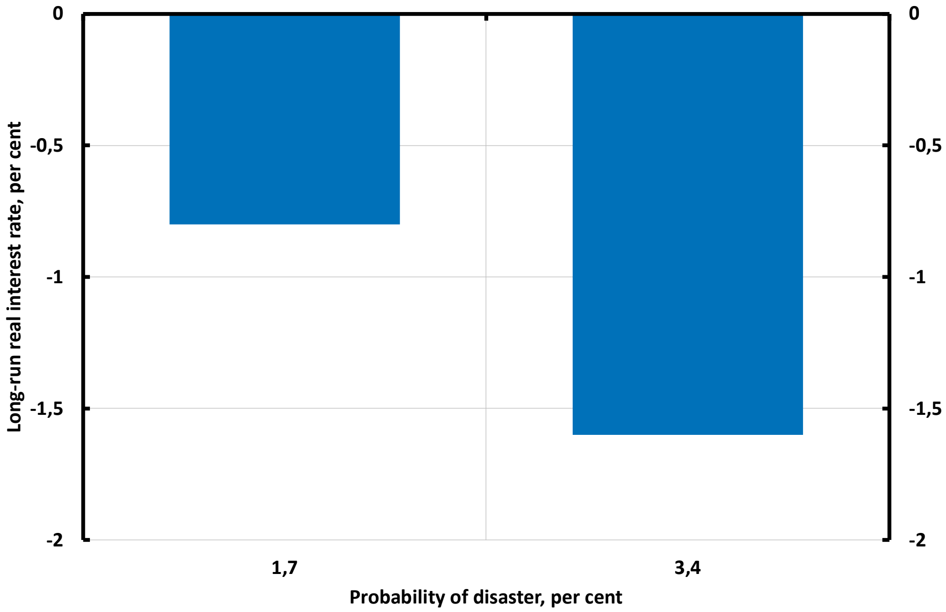
[18] See Epstein and Zin (1989).
[19] See Bansal and Yaron (2004).
[20] See Barro et al. (2017).
[21] See Barro (2006).

additional doubling of the decline, from 32 to 64 per cent, causes a fall of 2.2 percentage points. Hence, the size of the disaster has a non-linear impact on the long-run real interest rate, that is, the long-run real interest rate decreases at an increasingly rapid rate as the size of the disaster grows.

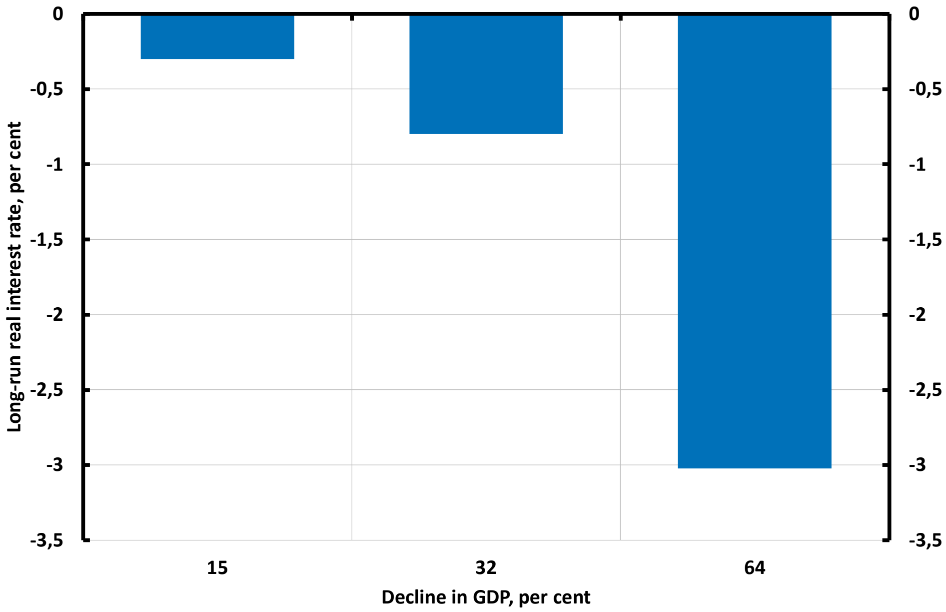
Figure 6. Greater risk of disasters can have significant effects on the long-run real interest rate



Note. The parameters $\delta = \mu = 0$. The figure shows how the factor $-pb/(1-b)$ affects the long-run real interest rate for two different values of the probability of a disaster and $b = 32$ per cent in both cases.

Source: Own calculations

Figure 7. Major disasters have non-linear impacts on the long-run real interest rate



Note. The parameters $\delta = \mu = 0$. The figure shows how the factor $-pb/(1-b)$ affects the long-run real interest rate for three different values of the probability of a disaster and $p = 1{,}7$ per cent in the three cases.

Source: Own calculations

Concluding comments

We have shown that the effects of climate change – such as weaker growth prospects, greater uncertainty over economic developments and greater risk of disasters – could reduce the long-run real interest rate, and under certain conditions the reduction could be significant. The long-run real interest rate is currently low in many countries. If it should become excessively low, it may make it more difficult for central banks to achieve price and financial stability.

To fulfil the inflation target, the central bank's average policy rate must be adjusted in line with the changes in the long-run real interest rate. An excessively low long-run real interest rate could imply:

- The policy rate hitting the lower bound more often and monetary policy therefore becoming more dependent of extensive bond purchases, forward guidance or interventions in the foreign exchange market.
- Fiscal policy getting a more important role than previously in stabilising the economy.
- A reform of the monetary policy framework. International discussions are already ongoing regarding how inflation target policy can be better adapted to the low policy rate environment that we have seen since the global financial crisis of 2008–2009. For example, the Federal Reserve has recently introduced what is known as average inflation target policy.[22]

Risks in the financial system may increase:

- The trends of rising housing prices and increased indebtedness among households and companies could be amplified. Fund managers, insurance companies and pension funds may find it more difficult to achieve their required rates of return and therefore choose to take greater risks, which may lead to greater financial imbalances. In this context, a well-functioning macroprudential policy is even more important.[23]
- Financial stability and price stability are closely interlinked. This means that it could become more important to coordinate monetary policy decisions and decisions on macroprudential policy measures to effectively reduce the risks in the financial system and at the same time achieve price stability.[24]

Finally, we know that climate change most likely causes more uncertainty. According to Brainard's "precautionary principle", central banks should act more cautiously and rely more on historical relationships when uncertainty on the long-run real interest rate increases.[25] This precautionary principle is not always applicable, however. If the policy rate is near its lower bound, it may be wise to act more rapidly and more powerfully than what has previously been considered normal.[26] In other words, there is no simple rule – that is always applicable – for how central banks should act when uncertainty increases. Neither is there a simple rule for how central banks should take the effects of climate change on the economy into account. This is a learning process that has just begun – where more research and knowledge are necessary ingredients.

[22] See Federal Reserve (2020).
[23] See Ingves (2017).
[24] See Bryant et al. (2012) and Jonsson and Moran (2014).
[25] See Brainard (1967).
[26] See Ingves (2019).

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