The e-krona and the macroeconomy

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In this article, we discuss potential implications of an e-krona for the conduct of monetary policy and for macroeconomic developments in general. We argue that a universally accessible, non-interest-bearing e-krona supplied according to demand would establish a zero interest-rate floor for the policy rate and possibly all other interest rates in the economy. The effect of quantitative easing can thereby also be reduced. Furthermore, it is unlikely that the monetary policy transmission mechanism would be strengthened by an e-krona. We also note that international financial flows may increase and induce more exchange rate volatility. Finally, an e-krona could have long-run level effects on economic activity. The effects would be positive if an e-krona improves the efficiency and the resilience of the payment system and negative if an e-krona impinges on the supply of credit and financial stability.

1 Introduction

The Riksbank is currently conducting a review into whether to issue a digital complement to physical cash, the so-called e-krona.[1] In this article, we analyse possible consequences of an e-krona for the conduct of monetary policy and for macroeconomic developments in general.

The discussion regarding a digital central bank currency (CBDC) is new and a result of the ongoing digitalization of modern society. But from a theoretical point of view, the questions that arise when thinking about the possible consequences of CBDCs often turn out to be classic topics that have been investigated in macroeconomics in the past century or more. For example, issues such as the liquidity trap, the lower bound to monetary policy, inside versus outside money, and even monetary policy autonomy and the classic trilemma arise. This article sheds light on some of these matters. In some cases we arrive at firm results (conditional on our assumptions), in other cases we present only an overview of the issues involved. Many of our colleagues at other central banks have written about CBDCs and their possible consequences. The focus in this article is on monetary policy and macroeconomic issues that are important in a Swedish context.

The article is organized as follows. The next subsection describes the key properties of the type of e-krona analysed in this article. Section 2 studies the implications of such an e-krona for the effective lower bound of the monetary policy rate and other interest rates. Section 3 analyses how the transmission of monetary policy to the rest of the economy may be affected. Section 4 discusses other effects of an e-krona on the economy. Section 5 concludes. Appendix A contains the theoretical model that underlies the analysis in section 3.

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1 See the two reports on the e-krona review published so far, Sveriges Riksbank (2017) and (2018).

Key characteristics of the e-krona analysed in this article

There are several design choices for an e-krona, including whether it should be meant only for small payments, bear interest, be universally accessible and in unlimited quantities, and so on. However, the technical design, for instance whether or not it should use a distributed ledger technology, matters only to the degree that it affects an e-krona's functional features. We therefore abstract from technical issues.

The e-krona analysed in this article has the properties outlined in the Riksbank's first e-krona report (Sveriges Riksbank 2017):[2]

1. It is a direct claim on the Riksbank and specified in Swedish kronor.
2. It is universally accessible: by this we mean that it can be held by financial institutions, firms and members of the general public, both foreign and domestic residents, and without restrictions.
3. It is supplied according to demand: the Riksbank will supply as much e-krona as is demanded.

With these properties an e-krona will be similar to cash in the sense that it is universally accessible (without restrictions) and supplied according to demand. The properties may also be necessary conditions for parity between an e-krona and other forms of the Swedish krona. Furthermore, and importantly, they also imply that an e-krona would constitute a safe and liquid asset with essentially zero transaction costs that could be held by all (including professional investors) and in unlimited quantities. This is, as we shall see in later sections, important since some of our key conclusions apply only to such an e-krona. If, instead, an e-krona were not universally accessible or provided only in limited quantities its effects would be much smaller.

In our analysis, we distinguish between two cases, which in turn have very different consequences for the conduct of monetary policy:

a) *The e-krona does not carry interest.* In this case the policy rate continues to be the monetary policy instrument and the implementation of monetary policy can be conducted largely as it is today (see Nessén et al. 2018). However, negative policy rates will, as we explain below, most likely not be implementable.
b) *The e-krona carries interest.* In this case, the interest rate on an e-krona – positive or negative – could become a monetary policy tool, and it would have to be set in line with the overall stance of monetary policy.

2 Impact on the lower bound of the policy rate

We begin by examining the consequences of an e-krona – with the characteristics outlined above – on key instruments of monetary policy. Normally, we think of monetary policy as aiming to affect inflation and the real economy by influencing market interest rates, the exchange rate and expectations about future policy and the economy. Traditionally, the principal tool for influencing short-term market rates is the policy rate at which monetary policy counterparties (typically banks) can borrow or deposit their reserves at the central bank.[3]

Since the onset of the global financial crisis ten years ago, central banks in several advanced economies, including Sweden, have also used other policies to spur economic activity. One example is quantitative easing (QE) which consists of purchasing large quantities of long-term securities with the objective of reducing long-term interest rates.

2 An e-krona that fulfils 1–3 and is interest bearing will be quite reminiscent of what is sometimes called 'reserves for all' (see Niepelt 2018). A possible difference could be that we allow for a spread between the policy rate and the e-krona rate.

3 In a corridor system, other interest rates than the policy rate may matter too. For example, in Sweden banks currently deposit reserves at the Riksbank partly at the policy rate, partly at the repo rate minus a fixed spread, see Nessén et al. (2018) for details.

In this section, we analyse the implications of an e-krona for the lower bound of the policy rate and other interest rates in the economy. Specifically, we demonstrate why a universally accessible zero-interest e-krona that is supplied according to demand most likely will raise the lower bound not only for the policy rate but also for market interest rates. This, in turn, may also have implications for the efficacy of QE.

2.1 The current lower bound to interest rates comes from cash

The policy rate of the central bank was traditionally thought to be subject to a zero lower bound (ZLB), meaning that any cuts in the policy rate below zero would have no effect. The reasoning was that with the option to hold cash, yielding a zero rate of interest, banks would exchange their reserves for cash if the policy rate was set below zero. Likewise, firms and households, it was thought, would quickly substitute into cash if interest rates became negative. However, holding and handling cash is risky and costly for firms and households and for banks (see e.g. Alsterlind et al. 2015). It is costly to acquire safe and secure transportation, storage and insurance, for instance. For banks, it is certainly less expensive to keep reserves at the central bank than to hold large amounts of cash. As a consequence, the Riksbank and some other central banks have in recent years been able to successfully implement negative policy rates. However, there is still a limit to how low the policy rate can go and still have an effect on market rates. This limit is determined by the risks and associated costs of holding cash. This point is somewhere below zero, may vary over time and is often called 'the effective lower bound' (ELB) for the policy rate (see Nessén 2016).

While negative nominal policy rates are a relatively new phenomenon, the lower bound constraint and its implications have long been analysed. The concept was first introduced by Keynes (1936) who discussed it in terms of a 'liquidity trap'. In modern macroeconomics, a liquidity trap has come to identify situations in which the lower bound for the policy rate is strictly binding, in that it prevents the central bank from setting the real interest rate at its desired level. Therefore, the problem with a liquidity trap is that even though the policy rate is zero (or somewhere slightly below), the real (short-term) interest rate is too high and economic activity and/or inflation is too low. The central bank would therefore prefer a more expansionary monetary policy in the form of a lower real interest rate, if that were at all possible.

It has been suggested by a number of researchers (see for example Bordo and Levin 2017 and Goodfriend 2016) that an interest-rate bearing CBDC could relax current lower bound constraints on nominal interest rates. In their view, the ability of paying interest on CBDCs would constitute a clear advantage compared to physical cash. However, as noted by Camera (2017), the current cash-related lower bound will not disappear as long as cash is a viable mean of payment.[4]

2.2 A non-interest-bearing e-krona raises the lower bound

We turn now to the effects of a non-interest-bearing e-krona on the lower bound for the interest rates in the economy. The effects of such an e-krona will depend on how attractive an asset it is relative to other ones. In order to analyse this, we set up a simple relationship that builds on the basic principle that an asset will be preferred if it provides net benefits that are at least as high as those that can be obtained from an alternative one.

We can start by noting that the yield of an asset *A* may be divided into two components: the average of expected short (risk free) rates (i) over the maturity of the asset (n) and a premium ($P_t^{A,n}$),

4 If the introduction of an e-krona were to be accompanied by the phasing out of cash, this way of escaping negative rates would disappear. This, however, has been neither a goal of the Riksbank, nor a part of the e-krona project. It is also worth noting that in a country like Sweden, where the use of cash is declining rapidly, cash may cease as a medium of payments anyway. For example, Bigoni et al. (2018) show that if money is accepted infrequently, its value decreases, which in turn has a feedback effect on its use. Simply put, the value of cash declines if it is accepted less frequently.

(1) $i_t^{A,n} = \frac{1}{n}\Sigma_1^n E[i_{t+i}] + P_t^{A,n}$.

The premium represents the net of compensation for illiquidity, risk etc. and 'discounts' for services that the asset may provide (for instance if it can be used as collateral, for payments, etc.).

Inspired by (1) we define a similar expression where the premium represents the difference between the interest on an e-krona and the alternative asset. Let i^{ekr} and i^A be the nominal interest rate on an e-krona and an alternative asset *A* respectively, over an arbitrary time horizon. An agent *j* will be indifferent between holding an e-krona and an alternative asset if

$$i^A = i^{ekr} + P_j$$

where P_j is a premium over the same arbitrary time horizon.[5]

Let φ_j^{ekr} and φ_j^A represent the benefits that an e-krona and an alternative asset *A* provide respectively for agent *j*.[6] Moreover, let σ_j^{ekr} and σ_j^A represent the cost of holding an e-krona and an asset *A,* respectively, including the cost of the perceived risk for agent *j*. We can then define the premium as

$$P_j = (\varphi_j^{ekr} - \varphi_j^A) + (\sigma_j^A - \sigma_j^{ekr}).$$

By combining the expression for i^A and the one for P_j, we derive the following relationship, where we abstract from the agent subscript *j* since the argument is the same for all agents:

(2) $i^{ekr} + \varphi^{ekr} - \sigma^{ekr} = i^A + \varphi^A - \sigma^A$.

Relationship (2) describes a condition that has to hold in order for an agent to be indifferent between holding an e-krona and an alternative asset. If $i^{ekr} + \varphi^{ekr} - \sigma^{ekr} > i^A + \varphi^A - \sigma^A$, then the agent will prefer to hold an e-krona, and vice versa if $i^{ekr} + \varphi^{ekr} - \sigma^{ekr} < i^A + \varphi^A - \sigma^A$.

In the remainder of this section, we will use variations of equation (2) to analyse the effect of a non-interest-bearing e-krona on the lower bound of returns of different types of assets.[7]

Central bank reserves

To study how an e-krona will affect the effective lower bound for the policy rate we can think of the alternative asset in equation (2) as central bank reserves. Then, i^A denotes the policy rate, which is the interest rate on bank reserves.

Given our assumptions, an e-krona and bank reserves can be seen as investments with very short maturities and very close substitutes. In fact, they are both claims on the central bank and the risk should be the same for both. Thus, $(\sigma^{ekr} - \sigma^{reserves}) = 0$. A difference between the two is that an e-krona could be used as a broader means of payment and thus might provide some more services and is more liquid than reserves. We therefore have that $(\varphi^{ekr} - \varphi^{reserves}) \geq 0$. Using this together with equation (2) we get

$$i^{ekr} + (\varphi^{ekr} - \varphi^{reserves}) = i^{reserves},$$

5 In general equilibrium, the (endogenous) market rate i^A may change with the introduction of an e-krona. However, for the argument in this section we can take the market rate i^A as given. Meaning et al. (2018) provide a framework for analysing how the endogenous (market) premiums will depend on the introduction of a CBDC.

6 The value of the service φ^{ekr} is likely to depend on how much e-krona the individual has. However, even if the marginal utility of holding an e-krona is decreasing it does not affect our results.

7 A similar asset-by-asset comparison is found in Meaning et al. (2018) although there the focus is not on the lower bound.

that is, the interest rate on reserves cannot be lower than the one on an e-krona. Thus, if an e-krona is universally accessible without limitations, does not carry interest and is supplied according to demand, then the rate on reserves cannot fall below zero. Compared to the situation today, this means that the effective lower bound for the policy rate would rise to zero, or even slightly above it if $(\varphi^{ekr} - \varphi^{reserves}) > 0$ with a non-interest bearing e-krona.

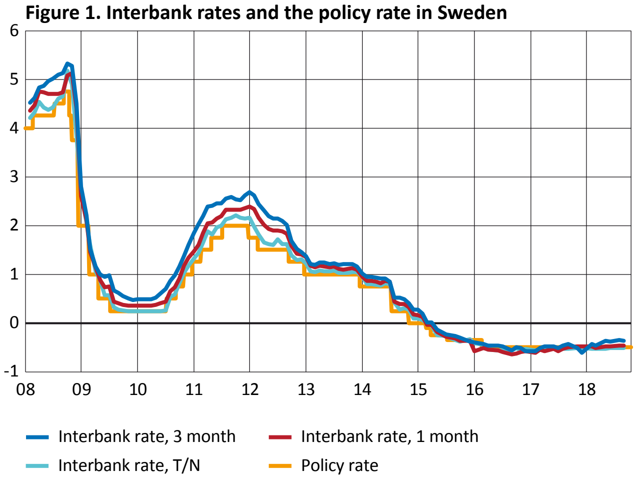
Interbank rates

Let now the alternative asset be interbank debt, which provides fewer services compared to an e-krona. For instance, it cannot be used as a broad means of payment. Thus $(\varphi^{ekr} - \varphi^{interbank}) > 0$. Furthermore, lending to a private bank is typically more risky than to the central bank, so that $(\sigma^{interbank} - \sigma^{ekr}) \geq 0$. Thus, in the presence of a non-interest-bearing e-krona available without limitations, we get

$$i^{ekr} + (\varphi^{ekr} - \varphi^{interbank}) + (\sigma^{interbank} - \sigma^{ekr}) = i^{interbank},$$

that is, interbank rates are unlikely to fall below zero (the two terms in parentheses are (weakly) non-negative). Looking at Figure 1, which shows the policy rate and interbank market rates of different maturities from 2008 until 2018, we can see that this would constitute a change from the current situation in Sweden, where interbank interest rates have been negative for the past three years.

Figure 1. Interbank rates and the policy rate in Sweden



Sources: Macrobond and the Riksbank

Commercial bank deposit rates

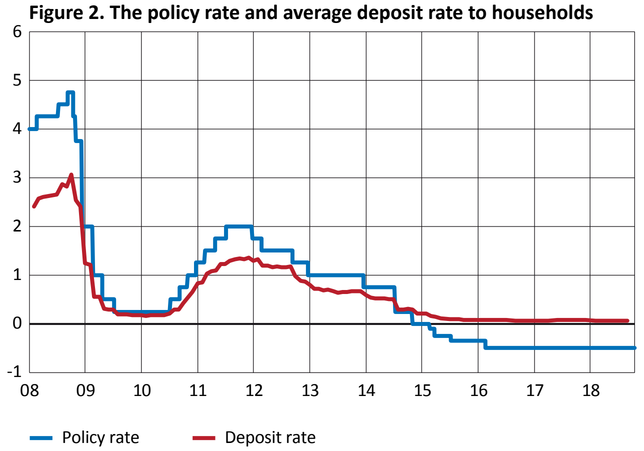
In comparing commercial bank deposit rates with an e-krona, we can first notice that deposits covered by deposit insurance can be viewed as being as risk free as an e-krona. Deposits that are not covered by deposit insurance are more risky. Thus, $(\sigma^{bankdep} - \sigma^{ekr}) \geq 0$. At the same time, bank-deposit accounts are often bundled together with other services, e.g credit lines, so that we may have $(\varphi^{bankdep} - \varphi^{ekr}) > 0$. In that case, bank deposit rates may be below the return on an e-krona:

$$i^{ekr} - (\varphi^{bankdep} - \varphi^{ekr}) + (\sigma^{bankdep} - \sigma^{ekr}) = i^{bankdep}.$$

Thus, if $\varphi^{bankdep}$ is sufficiently high, then the interest rate payed on deposits could possibly be lower than the one on an e-krona, that is, it could be negative in case of a non-interest bearing e-krona, at least for some customers.

It should be noted here that there may be other factors influencing how commercial banks set deposit rates, in effect preventing them from dropping below zero. This has been the case in the recent period with a negative policy rate in Sweden, where banks have not passed this on to household's deposit accounts. Indeed, as seen in Figure 2, such rates have remained at zero during the last three years.[8]

Figure 2. The policy rate and average deposit rate to households



Note. MFIs' (monetary and financial institutes) average deposit rate is a weighted average of all interest rates on deposits with different maturities.
Sources: Statistics Sweden and the Riksbank

Government bonds

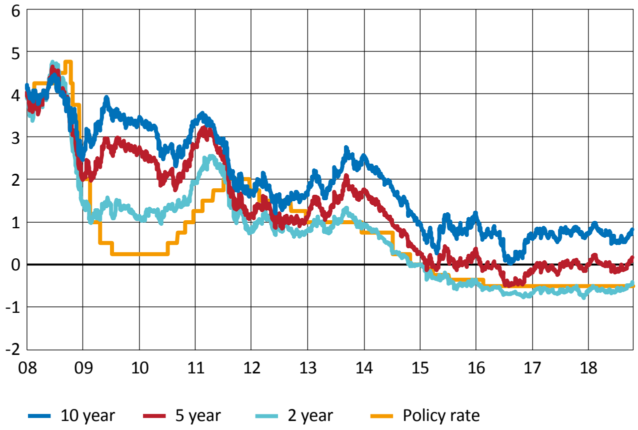
Next, comparing government bonds with an e-krona we use (2) and let government debt be the alternative asset. We then get

$$i^{ekr} + (\varphi^{ekr} - \varphi^{gov}) + (\sigma^{gov} - \sigma^{ekr}) = i^{gov}.$$

We see that government bond yields can be below the interest rate on an e-krona if government bonds provide more services ($(\varphi^{ekr} - \varphi^{gov}) < 0$) and/or are associated with less risk ($(\sigma^{gov} - \sigma^{ekr}) < 0$). However, an e-krona is just another form of government debt and its credit risk should therefore not be higher than for government bonds. Furthermore, an e-krona is more liquid than a government bond. Thus, $(\varphi^{ekr} - \varphi^{gov}) \geq 0$ and $(\sigma^{gov} - \sigma^{ekr}) \geq 0$. Consequently, government bond yields would not fall below the interest rate on an e-krona. Looking at Figure 3, which shows the policy rate and government bond rates of different maturities, we can see that this would constitute a change from the situation in Sweden, where medium term government bond rates have been negative for the past three years or parts of these three years. However, and importantly, if various forms of regulation were to favour government bonds over an e-krona, it is possible that $(\varphi^{ekr} - \varphi^{gov}) < 0$ and government bond rates could go below zero even in the case of a zero-yielding e-krona. We return briefly to this important issue in Section 2.3.

8 Customer relations and competition between banks have been mentioned as possible causes. See Alsterlind et al. (2015).

Figure 3. The policy rate and 2, 5 and 10-year government bond yields in Sweden



Note. Implied zero-coupon yields from government bonds.
Source: The Riksbank

Risky assets

To conclude our comparison across various types of assets, we now turn to more risky assets. These are assets with more credit risk than government bonds such as e.g. corporate bonds, so that $(\sigma^{risky} - \sigma^{ekr}) > 0$. Furthermore, risky assets provide fewer services compared to an e-krona, so that $(\varphi^{ekr} - \varphi^{risky}) \geq 0$. Thus, it follows from (2)

$$i^{ekr} + (\varphi^{ekr} - \varphi^{risky}) + (\sigma^{risky} - \sigma^{ekr}) = i^{risky},$$

that is, the rate of return on risky assets will be higher than the one on an e-krona, and as such higher than zero.

To summarize, an e-krona that is universally accessible without limitations, does not carry interest and is supplied according to demand is likely to impose a zero lower bound constraint on all market rates. However, and importantly, if various forms of regulation favour government bonds, returns on other assets could still be below the return on an e-krona. If there is a zero lower bound on government bond yields, this may in turn also reduce the effectiveness of QE. In the next section we explain why.

2.3 Quantitative easing with a non-interest bearing e-krona

As mentioned above, QE has been used as an expansionary monetary policy tool whereby the central bank buys assets, typically government bonds, in the secondary markets. One of the aims of QE is to lower longer-term market rates.[9]

9 Indeed, there is substantial *empirical* evidence showing that quantitative easing can alter long-term interest rates, as shown for example by Krishnamurthy and Vissing-Jorgensen (2011), Hamilton and Wu (2012), Gagnon et al. (2010) and Williams (2014) among others. This is why QE is considered as having had beneficial effects on the economy, in particular at the ELB. *Theoretically*, Woodford (2012) and Bhattarai et al. (2013) have argued that QE may have real effects by reinforcing forward guidance. By increasing the size of the central bank balance sheet and exposing it to capital losses if interest rates rise, the central bank commits to keeping interest rates lower than is optimal. Auerbach and Obstfeld (2005), instead, show that open market operations at the ZLB can be welfare-improving provided that long-term interest rates are positive and short-term interest rates are expected to be positive at some point in the future. Williamson (2016) is a model where QE is beneficial because purchases of long-maturity government debt by the central bank will always increase the value of the stock of collateralizable wealth. However, Wallace (1981) showed that Modigliani-Miller applies to a central bank's balance sheet, and thus QE-type policies should be ineffective. Eggertsson and Woodford (2003) and Cúrdia and Woodford (2011) show a similar result in a New-Keynesian model once the ZLB is reached. There remains a tension in the theoretical literature about whether QE is beneficial or not.

From (1) we have that government bond yields (i^{gov}) may be divided into two components, the average of expected short (risk free) rates (i) over the maturity of the bond (n) and a so-called term premium (TP)

(3) $$i_t^{gov,n} = \frac{1}{n}\Sigma_1^n E[i_{t+i}] + TP_t^n.$$

There are different accounts of how QE affects government bonds yields. Some emphasize the effect on expected short rates, while others focus on the effects that QE may have on term premiums. A pragmatic interpretation of the empirical literature would suggest that the QE programs put in place by several central banks in recent years have affected both components.

From equation (3) we see that there are two channels through which the introduction of an e-krona could dampen the efficacy of QE. First, a floor for the policy rate affects expected future short rates as they can no longer be negative. Since the longer-term market rate is the average of expected future short rates, higher (expected) short-term rates make the longer-term rates higher. Another way of stating this is that the lower bound truncates the yield curve so that yields of longer maturities are also affected (see for instance Swanson and Williams 2014 and De Rezende 2017).

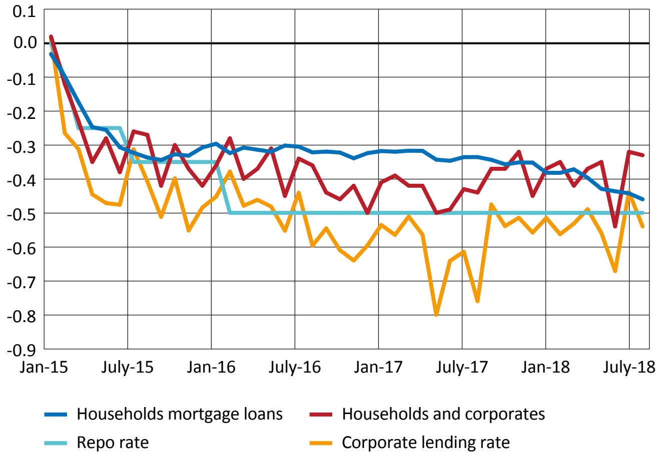
Second, QE is thought to work by lowering the term premium (TP_t^n). As mentioned in the previous section, government bonds provide certain 'services' that make them attractive. For example, there are leverage constraints, needs for collateral, and other features and frictions in financial markets that make some investors willing to pay more for government-emitted debt instruments than other types of assets. As long as an e-krona is not considered a perfect substitute in this regard, QE could still work by lowering term premiums. However, if an e-krona came to be perceived as providing the same services as government bonds and there were no regulations that made investors prefer government bonds over an e-krona, the efficacy of QE could be diminished.

2.4 Implications for the conduct of monetary policy

In the decade since the onset of the Great Financial Crisis, several advanced-economy central banks have engaged in various forms of unconventional monetary policy. Specifically, some central banks have conducted large scale asset purchases (or QE), others have lowered policy rates below zero, and some others have employed forward guidance. A few central banks have implemented all of the above.

Beginning in 2015 the Riksbank lowered the policy rate in steps into negative territory. At the same time the Riksbank began purchasing government bonds, and current holdings amount to about 40 per cent of the outstanding stock of government debt. As briefly mentioned above (and shown in Figure 3), through these various measures the Riksbank has been able to lower government bond rates down below zero, at times even been below the policy rate. Even though deposit rates and many other rates have stayed above zero, changes in the policy rate into negative territory have led to reductions in other (positive) rates. For instance, and as can be seen in Figure 4, lending rates to households have decreased after negative policy rates were implemented, although by less than the decrease in the policy rate. It is also worth noting that corporate lending rates have decreased by at least as much as the policy rate. These figures and more formal analyses by e.g. De Rezende and Ristiniemi (2018) and Laséen and De Rezende (2018) indicate that the unconventional policies pursued by the Riksbank in recent years have indeed led to more expansionary financial conditions.

Figure 4. Change of repo rate and lending rates to households and companies since 2015
Percentage points



Note. The cumulative changes in each rate since the start of January 2015. Outcomes are monthly data and lending rates are value-weighted averages of the actual lending rates reported by the banks.
Sources: Statistics Sweden and the Riksbank

The discussion in sections 2.3 and 2.4 however suggests that the impact of these types of unconventional policies on financial conditions would be smaller if a non-interest bearing e-krona were to be introduced.

A relevant question then is whether it is likely that such unconventional policies will be needed in the future. The root cause of the low levels of nominal interest rates and the fact that the lower bound has become a constraint on traditional interest rate policy is the secular decline in global interest rates in the past decades. Indeed, there are many studies documenting how global real rates have fallen in the past decades, and also indicating that real rates will remain low in the future (see e.g. Armelius et al. 2014, and Holston et al. 2016). This development, together with low inflation rates, means that nominal interest rates will most likely remain low in the foreseeable future, thus implying that central banks could in the future again hit the zero lower bound. This implies that with an e-krona that is universally accessible without limitations, does not carry interest and is supplied in unlimited quantities, the room for manoeuvre for monetary policy by means of the key policy rate and QE could be curtailed in the future.

Other options

QE and negative interest rates are not the only tools available to a central bank if there is a need for more monetary stimulus. There are further measures that work through other channels, such as for instance procedures that improve the transmission mechanism or that work through the exchange rate channel. These measures will generally not be affected by an e-krona. It is also worth mentioning that lower-bound constraints for the policy rate can be alleviated if the inflation target is raised. That is because if inflation is higher on average, the nominal interest rate will also be higher on average, thus reducing the risk of the policy rate becoming too low and hitting the lower bound. See Apel et al. (2017) for a discussion.

Furthermore, some argue that a CBDC opens up the possibility of a new form of unconventional monetary policy, as money transfers to households would be easier to implement, much like a digital helicopter drop. The idea behind such measures is not new and dates back to Friedman (1969). It involves the central bank supplying large amounts of money to the public, as if the money was being distributed or scattered from a helicopter. Colourful images aside, helicopter money is meant to be made directly available to consumers to increase spending in times of weak demand. Former Federal Reserve Chairman Ben Bernanke popularized this idea in 2002 as a money-financed (as opposed to debt-financed) tax cut policy that theoretically generates demand and should therefore ideally be used in a low-interest-rate environment when an economy's growth remains weak.[10] However, in Sweden it is not obvious that helicopter drops would be easier to implement with an e-krona since almost all adult Swedes already have accounts at commercial banks (see Sveriges Riksbank 2017).

In sum, we can conclude that raising the effective lower bound for the policy rate means that there is a risk that the primary tool for monetary policy cannot be used optimally. In the absence of other policies, this could impact negatively on economic activity. We discuss long run effects of an e-krona in Section 4.

3 Effects on the monetary transmission mechanism

We have shown that a non-interest bearing e-krona could reduce the effectiveness of monetary policy if it raises the effective lower bound. BIS (2018) and Meaning et al. (2018) amongst others have suggested that an interest-bearing CBDC may make monetary policy more effective through improved pass-through of policy rate changes. In this section we analyse if this is the case for an e-krona.

The monetary policy transmission mechanism normally describes the process by which changes in the policy rate influence the real economy and inflation. The mechanism can be divided into two parts. The first describes how changes in the policy rate pass through to changes in deposit rates, lending rates and other market interest rates that matter for economic decisions. The second part describes how changes in these interest rates influence the real economy and inflation. As explained above, the pass-through may be hampered when the effective lower bound is increased to zero. In our analysis below we focus on scenarios with an interest-bearing e-krona and thus no binding effective lower bound induced by it.

3.1 Transmission from the policy-rate to market rates

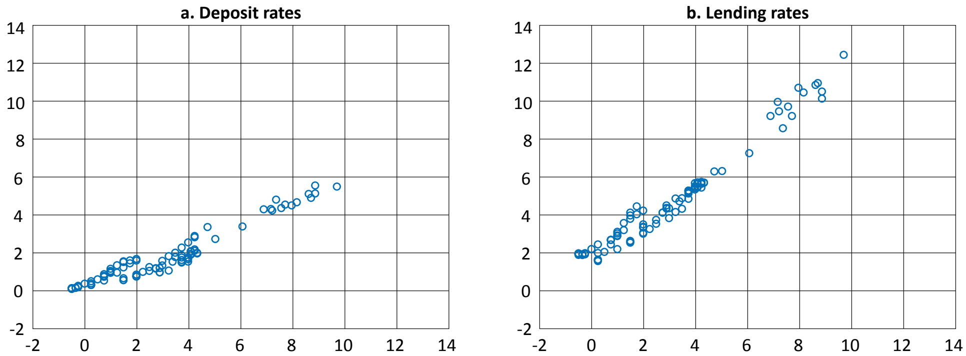
In order to keep the analysis in this subsection tractable, we add a few assumptions. First, we focus solely on the pass-through to banks' deposit and lending rates, which are considered key in the transmission mechanism. Second, we only consider an attractive e-krona, i.e. an e-krona that pays a high enough interest rate to create competition with bank deposits, since an unattractive one would not influence the banks' behaviour. Third, we assume a fixed spread (which could be zero) between an e-krona and the policy rate. If the spread could vary it would not make sense to talk about the pass-through from the policy rate to market rates. Furthermore, if the spread were allowed to vary, the spread itself would be a separate policy instrument.

The left-hand panel of Figure 5 contains a scatter plot of average bank deposit rates and the policy rate in Sweden over the past 25 years. It illustrates that the pass-through from the policy rate to deposit rates has been less than one to one in this period. Specifically, a regression based on the data in the figure suggests that an increase in the policy rate by one percentage point leads to an increase in deposit rates by on average 0.6 percentage points during the same quarter.[11] Thus, historically when the policy rate has increased in Sweden, deposit rates have also increased but by a smaller amount.

10 See Bernanke (2002). Helicopter money is enjoying a new revival as a last-resource option with influential advocates including Caballero (2010) and Galí (2014) among others. Such an unconventional idea has its critics too. For example, since central banks pay interest on reserves, Kocherlakota (2016) observes that new money created would eventually have the same cost as if the fiscal authority borrowed it. Along those same lines, Borio et al. (2016) find that helicopter money becomes more expansionary than a debt-financed programme only if the central banks credibly commits to setting policy at zero once and for all, thus implying giving up monetary policy for ever.

11 An OLS estimation of the following equation $\Delta i_t^D = \beta \Delta i_t^R + \epsilon$, where i_t^D and i_t^R denote the deposit and the policy rate respectively, gives (p-values in brackets) $\beta = 0.64$ (0.00), $R^{2adj} = 0.86$. We exclude the most recent years when the policy rate has been negative.

Figure 5. Pass-through from the policy-rate to banks deposit rates and lending rates for households



Note. Quarterly data for the period 1993:Q1 to 2018:Q2. Deposit rates for new agreements. Lending rates for floating rate contracts.
Sources: The Riksbank and Statistics Sweden

We assess that with an e-krona **the pass-through to banks' deposit rates** is likely to increase and become close to one to one. To see why, consider as an example a representative bank. If such a bank wants to retain deposits, it has to make them at least as attractive as an e-krona. In formal terms, this implies:

$$(4) \qquad i^{ekr} + \varphi^{ekr} - \sigma^{ekr} \leq i^{D} + \varphi^{D} - \sigma^{D},$$

where '*D*' refers to 'bank deposits'. It follows directly that for any given φ^{ekr}, σ^{ekr}, φ^{D} and σ^{D}, an increase in the e-krona rate (i^{ekr}) will have to be followed by a similar increase in the interest rate on deposit accounts (i^{D}). Similarly, the bank can follow a reduction in the e-krona rate with a corresponding reduction in the interest rate on deposit accounts without fear of losing deposits. Thus, unless the bank compensates e-krona rate changes by altering φ^{D} and σ^{D}, the pass-through from the policy rate changes to the bank's deposit rates will become one to one with an e-krona under the assumptions made at the beginning of the current section.[12]

The bank, however, might not find it profitable to compete with an e-krona. In that case, that bank's deposits will flow into deposit accounts at other banks that compete with an e-krona instead and where the pass-through is again close to one to one. Alternatively, deposits might flow into e-krona accounts. We can therefore conjecture that with an attractive e-krona, pass-through to deposit rates will be close to one to one. Indeed, in Appendix A we prove that this conjecture holds in a formal banking model.

One might also argue that an e-krona will speed up the pass-through as it will be a very explicit competitive alternative to bank deposits. Meaning et al. (2018), however, suggest that a potential offsetting effect could be for banks to respond to the increased competition from a CBDC by making it more costly to move funds out of the bank. Such effects may also slow down the pass-through and we cannot exclude a priori that this would happen in Sweden.

In sum, our analysis suggests that an interest bearing e-krona with a fixed spread vis-à-vis the policy rate may improve pass-through from the policy rate to deposit rates in Sweden.[13]

Results for **the pass-through to banks' lending rates** are less clear cut. There are two reasons for why this is the case.

12 An important caveat is that these mechanisms may not come into play when the interest rate on the e-krona is close to zero, see Appendix A.

13 However, if – differently from the assumptions of this subsection – the spread between the policy rate and an e-krona were allowed to vary this conclusion would not necessarily hold. For example, if the e-krona rate were kept constant while the policy rate increased, the mechanisms described above would not come into play.

First, the pass-through to banks' lending rates is already high, close to one to one, without an e-krona. This can be seen in Figure 5, Panel b., which contains a scatterplot of the average of Swedish banks' lending rates and the policy rate. As can be seen in the figure, the dots lie on a 45 degree-line. Furthermore, a regression based on the data in Figure 5 suggests that an increase in the policy rate by one percentage point leads to an increase in the lending rate of one percentage point.[14]

Second, theoretically it is not obvious that an e-krona would influence the pass-through from the policy rate to lending rates. Think for example of banks as pursuing business in two separate markets: a deposit market and a lending market (see Appendix A for a formal model).[15] Under this scenario, banks in the deposit market borrow from depositors and invest in the money market. The profit from this activity arises from the *deposit intermediation margin*, i.e. the spread between the money market rate and the deposit rate. In the lending market, banks borrow in the money market to invest in loans. The profit from this activity arises from the *lending intermediation margin*, i.e. the difference between the lending rate and the money market rate.[16] An e-krona would have no direct effect on the lending market in this environment. If it had any, such effects would have to come from changes in the way the policy rate affects money market rates, changes in loan demand relations, altered competition in the lending market, or changes in banks' costs for providing loans. It is not obvious that any of these would be affected by an e-krona. A formal and more thorough discussion of these theoretical arguments can be found in Appendix A. Notice that such a conclusion might differ depending on the interconnectedness of the deposit and lending markets. However, the assumption of separate deposit and lending markets makes sense in Sweden where the banks rely heavily on market funding.

In sum, our analysis suggests that the pass-through from the policy rate to bank interest rates is already high in Sweden and any marginal improvement would most likely occur on the deposit side. Two things are important to notice in connection with this. First, the improved pass-through might not be of much help as the improvement in the pass-through might only take place for high levels of the policy rate (see Appendix A). However, it is primarily when the policy rate is low and close to the lower bound that a stronger pass-through is useful. At higher levels, weak pass-through can be fully compensated for by larger changes in the policy rate. Second, an improved pass-through to deposit rates coupled with an unchanged pass-through to lending rates might be problematic, since the aggregate demand effects of a change in the deposit rate are ambiguous.[17]

3.2 Transmission from market rates to the real economy and inflation

We now turn to how an e-krona may impact the second part of the transmission mechanism. That is, we analyse whether an e-krona would change the transmission from deposit-, lending- and other market rates to the wider economy. We find it useful to formulate the discussion along the following channels of the transmission mechanism: the interest rate channel, the exchange rate channel, the credit channel and the risk-taking channel.

The **interest rate channel** refers to the effect of interest rate changes on households' savings and consumption, as well as firms' investment. If prices and inflation expectations are sticky, a reduction in nominal market rates will also reduce the real interest rate in the

14 OLS estimation of $\Delta i_t^L = \beta \Delta i_t^R + \epsilon$ gives (p-values in brackets) $\beta = 1.00(0.00)$, $R^{2adj} = 0.795$. We shorten the sample to exclude the recent years with a policy rate below zero.

15 Result 1 in Appendix A shows that this separation derives from disjoint variable costs of managing loans and deposits.

16 This (theoretical) separation does not mean that all bank deposits are literary invested in the money market and all lending is literary funded by the money market. The banks use deposits to finance lending. Only the gap between deposits and lending is actually financed or invested in the money market.

17 The income effect of a lower deposit rate reduces the 'income' from deposits and leads to a reduction in demand. The price effect (substitution effect) of a lower deposit rate reduces the price of consumption today relative to tomorrow and leads to an increase in demand today.

economy. Lower real interest rates make it more beneficial for households to consume and borrow and less beneficial to save. Similarly, firms will prefer to borrow and invest. The increased demand in the economy gradually results in prices and wages starting to increase more quickly. The effects will be the same but of opposite sign when the interest rate increases.

We, as other authors, assess that an e-krona is unlikely to affect how changes in real market rates affect agents' consumption, savings and investments decisions. These relations are determined by underlying preferences which are not expected to be influenced by the introduction of an e-krona.

The **exchange rate channel** refers to the mechanism through which monetary policy influences inflation and the real economy by affecting the exchange rate. A reduction in the policy rate normally leads to an exchange rate depreciation. If prices are sticky, the exchange rate also weakens in real terms, which in turn makes domestically-produced goods cheaper compared to foreign ones. This leads to an increase in the demand for exports and for products that compete with imported goods, which gradually result in inflation rising as well. The exchange rate channel also has a more direct effect on inflation. That is because the domestic price of imported goods, which are included in the consumer price index, rises when the exchange rate weakens.

The parity conditions determining the exchange rate are unchanged by the introduction of an e-krona. However, a universally available e-krona would constitute a new, liquid and safe deposit where to hold money balances in Swedish Krona. To the extent that this leads to more active currency management by different actors, an e-krona might induce the exchange rate to become more sensitive to changes in market rates. This, in turn, would imply stronger and/or faster exchange rate movements for a given change in the market rates in Sweden and abroad.[18] However, we are not aware of any formal theory of this effect.

The **credit channel** refers to the mechanism through which interest rate changes affect the credit market and thereby the macroeconomy. A lower interest rate generally leads to an increase in the price of various kinds of assets. For example, it leads to an increase in the net present value of the future cash flows that a financial asset can be expected to generate. This means that the price of the financial asset increases. When the interest rate is low, the demand for and prices of real assets such as houses also increase. As these assets are used as collateral for loans and the collateral increases in value, banks become more willing to lend money. In addition, future wages of households and future profits of companies tend to rise when demand increases as a result of the lower interest rate levels. On the whole, the credit channel is a mechanism by which the effect of changes to the policy rate is enhanced through lending from the banks.

The main reason for why the introduction of an e-krona would matter for the credit channel is the reduced supply of credit if banks were to cut down on their lending due to lower revenues on the deposit side. In this case, the credit channel could become weaker. Theoretically, whether this will occur depends –among other things – on the interconnectedness of the lending and deposit markets. If the two are independent of each other, then it may be less likely that banks will decrease lending as a response to lower profits from the deposit market (see Appendix A). It is also worth pointing out that a CBDC may enable greater competition in the provision of credit for instance through improved possibilities for peer-to-peer lending (Meaning et al. 2018).[19]

Another, and much discussed, channel in the transmission mechanism is the so-called **risk-taking channel.** It suggests that low policy rates lead banks and other financial

18 This change is different from the one described in Meaning et al. (2018). They suggest that the exchange-rate channel might become stronger because market rates become more sensitive to changes in the policy rates.

19 'For instance, peer-to-peer lenders would no longer have to clear settlements through their competitors in the banking sector, as is currently necessary in the existing system of tiered access to central bank money. This process incurs a cost which CBDC could potentially eliminate, putting non-bank credit providers on a more equal footing with their banking sector counterparts and would limit the extent to which banks could vary margins in light of changes in funding costs.' Meaning et al. (2018), p. 21.

institutions to take greater risks. This is not a specific, well-defined monetary policy channel, but a collective term used to denote different kinds of mechanisms, whereby monetary policy can affect the risk-taking of banks, financial institutions and the economy as a whole. One mechanism is due to low interest rates resulting in a so called search for yield, whereby banks start to search for riskier investments with a higher expected return (Rajan, 2005). One reason for doing this could be that banks have a specific nominal rate of return that they have to achieve. Another mechanism might be due to the economy experiencing low risk and low interest rates over a long period of time, thus leading economic actors to become too complacent and placing a disproportionally low weight on risk factors.[20] Again, we consider it to be unlikely that the relationship between market interest rates and risk-taking in the economy would change with the introduction of an e-krona.

In sum, we assess that the exchange-rate channel and possibly also the credit channel are the only channels that may be altered in a significant way by the introduction of an e-krona.

4 Other effects on the economy

4.1 Small open economy aspects of an e-krona

As discussed in the introduction, the e-krona we study is universally available and supplied according to demand. This opens up new questions, since investment in an e-krona by international investors could give rise to large capital flows, thus amplifying the potential volatility of the balance sheet of the central bank and possibly creating greater exchange rate volatility.[21]

But it is very hard to anticipate more precisely what effects an e-krona might have on the exchange rate. As long as an e-krona is primarily used for domestic payments it will most likely not influence the exchange rate at all. However, there is an important difference between an e-krona and cash, and that is that an e-krona can be a good substitute to other forms of saving vehicles such as government bonds or savings accounts. There is also the added factor that an e-krona can be purchased and sold much faster than cash, thus increasing the risk of volatility. If an e-krona became an attractive asset among foreign institutional investors then it could influence the exchange rate, both its level and its volatility.

Here we can return to the simple framework introduced in Section 2, expressing it in terms of foreign currency:

$$(5) \qquad i^{ekr*} + \varphi^{ekr*} - \sigma^{ekr*} = i^{A} + \varphi^{A} - \sigma^{A},$$

where all terms now are denominated in foreign currency, e.g. i^{ekr*} is the return on an e-krona in foreign currency. The term σ^{ekr*} includes exchange rate risk from the point of view of the international investor. The interpretation of equation (5) is that there will be inflows to the domestic economy if the left-hand side exceeds the right-hand side, e.g. if the interest rate on an e-krona is high, if it provides useful services, etc. It is possible that financial stress abroad (here represented by an increase in σ^{A}) could trigger large inflows to an e-krona, for instance. Conversely, there could be large flows out of e-krona holdings if financial conditions change.

In sum, for a small open economy, a CBDC that is universally accessible without restrictions and limitations could facilitate large capital flows that might in turn lead to volatility in the exchange rate and in the size of the central bank's balance sheet.[22]

20 See Apel and Claussen (2012) for a detailed discussion of the risk-taking channel.
21 See also Nessén et al. (2018), Danmarks Nationalbank (2017) and BIS (2018).
22 See the appendix of Nessén et al. (2018) for a very simple illustration using highly simplified balance sheets.

4.2 Financial stability

Juks (2018) analyzes the effects an e-krona might have on Swedish banks. In what follows, instead, we summarize the current literature on the consequences CBDCs might have on financial stability. Engert and Fung (2017), for example, suggest that if a CBDC is non-interest bearing, then it is unlikely that it would lead to a significant shift away from traditional instruments such as deposit accounts. That is because financial institutions can effectively compete with CBDC as a store of value since they can offer enhanced financial services such as wealth management or engage in cost-cutting measures. Nonetheless, in times of economic stress, there may be an increase in demand for CBDC, which would be viewed as risk free. The shift away from traditional deposits would be likely to disrupt the financial system and increase volatility, as discussed by Camera (2017).

In this regard, the analysis in Kumhof and Noone (2018) distinguishes between runs on individual banks and systemic runs. In the first case, they claim that the presence of CBDCs could potentially make it easier and faster to resolve an individual troubled institution, by giving the authorities the option of repaying its depositors in safe CBDC at an early stage and thus reducing the potential for contagion. Since bank depositors would know this ex-ante, this may in fact reduce the probability of a bank run compared to a world without CBDCs. They do find that systemic bank runs would be more difficult to solve instead, even in a world with CBDCs. Indeed, in such a case the run to CBDCs could potentially be so large at the current CBDC interest rate, that CDBC holders would not be willing to sell sufficient quantities of CBDC to satisfy the demand for it. The high demand could be addressed by the central bank with a decrease in the interest rate on CBDC, if any were paid. However, there would be potential limits to such a policy if it required a highly negative interest rate, which could become politically untenable.

4.3 Economic activity

In the standard models used in policy analysis, monetary policy effects on the real economy are usually due to nominal frictions that limit the speed of the adjustment of the general level of prices. Such frictions are short-term phenomena and their empirical significance is a matter of ongoing research. There is a general consensus among economists that long-term economic growth, instead, is driven by factors such as technological change, population growth, and human capital accumulation, thus implying monetary policy's effects on real economic activity are small in the long term. We should thus expect an e-krona to have no significant effect on long-term growth via monetary policy.

However, an e-krona could potentially lead to significant level effects on economic activity because of its interaction with the payment system and the banking sector. Indeed, it has been shown that a well-functioning payment infrastructure enhances the efficiency of financial markets and the financial system as a whole, boosts consumer confidence and facilitates economic interaction and trade both in goods and services (see ECB 2010). At the same time, unsafe and inefficient payment systems may hamper the efficient transfer of funds among individuals and economic actors (Humphrey et al. 2006). Hasan et al. (2013) even confirm that more efficient electronic retail payments stimulate the overall economy, consumption and trade. Indeed, they find that developments in the use of electronic payment systems are related to notable improvements in banking performance, due to both a decrease in costs and an increase in revenues. Moreover, as shown by Berger (2003), switching to electronic payment instruments has significant effects in terms of banks' gains in productivity and economies of scale. So, to the extent that an e-krona would enhance the resilience and the efficiency of the Swedish payment system, we could expect it to have meaningful positive effects on the real economy (see Sveriges Riksbank 2017 and 2018).

Moreover, an e-krona may raise the seigniorage revenue of central banks (see e.g. BIS, 2018). If such increases were large and transferred to the government, they would allow for less distortionary taxation and might therefore even have GDP effects. Barrdear and Kumhof (2016) argue that there could be such positive consequences for the level of GDP.

However, as we already discussed, an e-krona could also have negative implications for financial stability. This could in turn have detrimental effects on economic activity even in the long run. For example, Ennis and Keister (2003) use an endogenous growth model to show that bank runs can have permanent effects on the levels of the capital stock and of output. That is because as the probability of a run increases, it becomes more likely that a bank will have to liquidate investments early. Since the liquidation value of illiquid investments is relatively low, the bank prefers to hold more liquid assets to deal with a run if it occurs, thus leading to substantially less investment in new capital. Moreover, if banks' funding costs were to increase in a meaningful way and if such costs were passed onto consumers, we would expect the real economy to be negatively affected.

5 Concluding remarks

We have analysed possible implications of introducing an e-krona for monetary policy and overall macroeconomic activity. Since an e-krona that is universally accessible and supplied according to demand would be a perfect substitute for bank reserves, a non-interest bearing e-krona would introduce a zero interest rate floor for the policy rate and plausibly all other interest rates in the economy. This result arises as an e-krona is less risky and offers a level of other benefits or payment services that are of equal magnitude (or higher) than other assets. The inability to implement negative interest rates in economic downturns could possibly be compensated for by the use of other monetary policy tools. However, the zero interest rate floor would also most likely apply to government bonds, which would reduce the effectiveness of QE during times of a binding lower bound constraint. We also argue that the effects on the transmission mechanism are likely to be small in normal times.

It is possible that an e-krona could have consequences for both the level and the volatility of the exchange rate of the Swedish krona and the balance sheet of the Riksbank if it were to become attractive for foreign investors. It is also plausible that an e-krona could affect the financial system and increase its volatility in times of economic stress. Moreover, while an e-krona could be helpful in dealing with runs on individual institutions, systemic runs would be more difficult to solve as that might require highly negative interest rates.

Finally, we argued that an e-krona could potentially have long-run level effects on economic activity because of its interaction with the payment system and the banking sector. On the one hand, it could improve the efficiency and resilience of the payment system thus stimulating economic activity. On the other hand, we would expect detrimental long-run effects if an e-krona impinges on financial stability.

In sum, there seems to be an 'impossible quaternity' or 'quadrilemma' for the type of CBDC envisioned in the Riksbank's first e-krona report.[23] If an e-krona is designed with similar characteristics to cash – i. e. *non-interest bearing,* in *perfectly elastic supply* and *attractive* to use – then it will most likely not be compatible with *unchanged macroeconomic risks*. Consequently, a CBDC cannot have these four features at the same time.

It is worth noting that the negative effects we have identified could be mitigated by giving up one or more of the four features in the quaternity which would give the Riksbank a mechanism to influence the demand for an e-krona. One obvious example is to let the e-krona be interest bearing, but there are other alternatives such as fees or other frictions that would limit the attractiveness of an e-krona in relation to other assets. However, adding limits to the amount of e-krona that can be held risks breaking the parity against other forms

23 Bjerg (2017) discusses a CBDC 'trilemma'. He argues that in the presence of a CBDC a central bank that tries to uphold free convertibility between private money and CBDC, and parity between all forms of money, would have to give up monetary sovereignty.

of krona, such as money held in private bank accounts or bank reserves at the Riksbank. Other types of frictions, such as fees on withdrawals might therefore be preferable, but would have to be carefully calibrated so that an e-krona would still function as a viable payment instrument.

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Appendix A. The effects of an e-krona on pass-through: A banking model

In this appendix, we use an industrial organization model of banking to analyse the effects of an e-krona on the pass-through from policy rate changes to banks' deposit and lending rates.[24] The model helps structure the analysis and provides some key insights. In particular, it demonstrates that the conclusions conjectured in Section 3 hold in a standard banking model.

A representative bank

To keep the analysis as simple as possible, we consider a monopolistic bank and our discussion follows what is known as the Monti-Klein model from Monti (1972) and Klein (1971). Qualitatively, the results will be analogous with an oligopolistic banking sector.[25]

Consider a representative bank accepting deposits D and giving out loans L.[26] Let $i^L = i^L(L)$ denote the (inverse) loan demand where i^L is the lending rate, and assume $\frac{di^L(L)}{dL} < 0$. Similarly, let $i^D = i^D(D)$ denote the (inverse) deposit supply where i^D is the deposit rate, and assume $\frac{di^D(D)}{dD} > 0$.

The bank has also access to a money market, from which it can borrow and lend in unlimited quantities at the policy rate i^R. Note that this assumption is reasonable in Sweden where monetary policy is implemented in a corridor system, and where the (short-term) money-market rate is typically close to the policy rate.

Finally, the bank is subject to managing costs $C(D, L)$ satisfying $C_L(D, L) > 0$, $C_D(D, L) > 0$, $C_{LL}(D, L) \geq 0$ and $C_{DD}(D, L) \geq 0$. Note that the sign of the mixed partial derivative $C_{DL}(D, L)$ is related to the notion of economies of scope. If $C_{DL}(D, L) < 0$, a universal bank jointly offering loans and deposits is more efficient than two separate entities specializing in loans and deposits. If $C_{DL}(D, L) > 0$, there are diseconomies of scope. If $C_{DL}(D, L) = 0$ there are neither.

As a monopolist, the bank takes into account that lending demand and deposit supply depend on the respective interest rates, which are under the control of the monopolist. The bank's profit therefore is: $\pi = L[\, i^L(L) - i^R\,] + D[\, i^R - i^D(D)] - C(L, D)$.

Thus, the bank's profit is the sum of the intermediation margins on loans and deposits, net of managing costs. The first order conditions for profit maximization then are:

$$(6) \qquad \frac{\delta\pi}{\delta L} = 0 \rightarrow \left(\frac{di^L}{dL}L + i^L\right) = i^R + C_L(L, D)$$

$$(7) \qquad \frac{\delta\pi}{\delta D} = 0 \rightarrow i^R = \left(\frac{di^D}{dD}D + i^D\right) + C_D(L, D)$$

Note that marginal revenues and marginal costs are on the left- and right-hand-side of the equations, respectively. This implies the monopolistic bank sets the lending and the deposit rates so that marginal revenues in the two markets equal marginal costs.

24 See, for example, Freixas and Rochet (2008) and Matthews and Thompson (2014) for a textbook presentation of the model.
25 See Freixas and Rochet (2008), pp. 79–80 for details.
26 This simplifies the analysis, but qualitatively the results are the same in more elaborate versions of the model featuring several identical banks.

The following observation is a key result in the model, and we refer to it extensively in Section 3:

Result 1: *If there are no joint variable costs in the managing of loans and deposits, then the bank sets deposit and loan volumes separately.*

Proof: Set $C_{LD}(L, D) = C_{DL}(L, D) = 0$. Then, Result 1 follows from (6) and (7). ■

Case 1: Pass-through without an e-krona

The following result holds in this case.

Result 2: *The pass-through from the repo rate to deposit and lending rates can be different from one to one.*[27]

Proof: If the pass-through is one to one, then the deposit intermediation margin $i^R - i^D$ must be constant. From (7) it follows that this can only be the case if

$$(8) \qquad \frac{di^D(D)}{dD} D + C_D(L, D) = k$$

where k is a constant. Thus, equation (8) will only hold under some very specific assumptions regarding the deposit supply and the managerial cost relations.[28] The proof for the pass-through to lending rates is similar. ■

Result 2 implies that we can expect the pass-through to be typically different from one to one without an e-krona.

Case 2: Pass-through with an e-krona

We hereby examine the effects of the introduction of an e-krona on the pass-through from the policy rate to lending and deposit rates in the case of a monopolistic bank. Let i^D_{MON} be the deposit rate that such a bank would set if there were no e-krona. If $i^{Ekr} < i^D_{MON}$, an e-krona would be unattractive and therefore not used in equilibrium.[29] In that case, the introduction of an e-krona would not impact the pass-through.

Before looking at the pass-through with an attractive e-krona, it is useful to notice that if the e-krona margin $i^R - i^{Ekr}$ is fixed, the attractiveness of an e-krona and therefore also the pass-through may depend on the level of the policy rate. To see why that is the case, notice that it follows from (7) that the optimal deposit intermediation margin $i^R - i^D$ can be increasing in D. That is true, for instance, if the marginal managerial cost is constant or increasing in D and the deposit supply function is linear in D. Thus, if the e-krona margin $i^R - i^{Ekr}$ is sufficiently large, the optimal intermediation margin $i^R - i^D$ can be smaller than the margin $i^R - i^{Ekr}$ for D smaller than a threshold value $\underline{D}$. Thus, if $D < \underline{D}$, the profit-maximizing monopolist may anyhow set a deposit rate that is higher than the e-krona rate thus rendering an e-krona unattractive. If instead $D > \underline{D}$, this will no longer be the case and an e-krona will be attractive.

The following result holds for the case when an e-krona is attractive.

Result 3: *If the e-krona margin $i^R - i^{Ekr}$ is constant and an e-krona is attractive, then the pass-through from policy-rate changes to deposit rates will be one to one.*

27 Pass-through will be one to one under perfect competition if C_{DD} is constant as in that case the term $\frac{di^D}{dD} D$ disappears from expression (8). Similarly, the pass-through to lending rates will be one to one under perfect competition and constant marginal managerial costs.

28 For example, this will be true if $i^D(D) = ln(D)$ and $C(D,L) = \Upsilon^D D + \Upsilon^L L$

29 Note that here we disregard the gains from additional services and from differences in risk and set $\varphi_t^{ekr} - \sigma_t^{ekr} = \varphi_t^D - \sigma_t^D$ (see equation (4) in Section 2.2).

Proof: If $i^{Ekr} \leq i^{D}_{MON}$, we need to identify two separate cases:

(i) If $i^{Ekr} > i^{D}_{BRE}$, where i^{D}_{BRE} is the bank's break-even deposit interest rate (i.e. $i^{D}_{BRE} D - C(D, L) = 0$), the bank will cease its deposit-taking activities as they are loss-making. Then, all deposits will be e-krona. Moreover, the pass-through will be one to one as long as the margin between the policy-rate and the e-krona rate is constant.

(ii) If instead $i^{Ekr} \leq i^{D}_{BRE}$ the monopolist bank will set $i^{D} = i^{Ekr}$, and the pass-through to deposit rates becomes one to one as long as the margin between the policy rate and the e-krona rate is constant. ■

The following result also holds.

Result 4: *If there are no joint variable costs in the managing of loans and deposits, the pass-through from policy-rate changes to lending rates will not be affected by the introduction of an e-krona.*

Proof: This follows directly from Result 1. ■