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# Estimating the Impact of Introducing the e-krona in the Swedish Economy

**Author**
Alejandro Moreno Puertas

**ABSTRACT**

This MSc Thesis analyzes the impact of introducing the e-krona in Sweden using a Dynamic Stochastic General Equilibrium (DSGE) model. The model includes the possibility for (i) patient households to convert their deposits into the e-krona and (ii) wholesale banks to borrow money through a market funding mechanism. The results indicate a higher pass-through rate, which enables Centrals Banks to have a more direct impact to the economy through monetary policy.

**Keywords**: *e-Krona*, *Central Bank Digital Currencies, DSGE, Financial Frictions*

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# 1. Introduction

In the past five decades, Central Banks have played an increasing role in innovating our financial markets and providing financial stability. They innovated payment systems, and influenced the economy through interest-rates and quantitative easing programs among other things (BIS 1996; Pereira Da Silva and Rungcharoenkitkul 2017). Nonetheless, those services were provided only to commercial financial institutions and not the final users, the consumers. Central Banks expected a pass-through mechanism that did not always materialize and resulted in a monopolistic competitive banking system (Gerali et al. 2009).

After the 2008 financial crisis, the level of trust between consumers and banks diminished and a new wave of criticism emerged disapproving the bank's privileged position (Edelman 2009). This backlash resulted in a series of proposed alternatives and the emergence of the first successful digital currency, Bitcoin (Nakamoto 2009). Bitcoin uses peer-to-peer (P2P) networks to transfer Satoshi's across the web and its money creation depends on the resources used to approve those transactions through a pre-defined protocol. Bitcoin is the first system that mimics the Central Bank reserves by allowing consumers to directly hold non-defaultable deposits and conduct transactions (Nakamoto 2008). Furthermore, its uniqueness relies on its resiliency. Bitcoin is the first digital currency that has not been shut down. This is due to its protocol, coined blockchain, that distributes the point of failure across different nodes making the cryptocurrency resistant to hackers and regulatory authorities. Bitcoin shows that a direct interaction between the monetary system and the consumer is possible through the open web in a secure environment.

Soon after the introduction of Bitcoin, a new wave of academic research stemming from Central Banks and universities started to investigate the possibility of introducing Central Bank Digital Currencies (CBDCs) that interact directly with the consumer bypassing banks' intermediation. In 2017, the Swedish Central Bank, the RiksBank, was one of the first Central Bank to seriously consider the introduction of a CBDC, the e-krona, in the market (Sveriges Riksbank 2017).

One of the main reasons behind their move is the decrease in the usage of cash among Swedes. The trend can potentially result in a complete monopoly of private agents in the transaction market and the inability of the Central Bank to directly interact with customer's through cash. For that reason, as an effort to maintain that direct relationship, the RiksBank started to investigate the potential impact of introducing the e-krona in Sweden. In their latest report, they concluded it would be beneficial to have an interest-bearing e-krona as a monetary policy mechanism (Sveriges Riksbank 2018).

This has profound implications in the financial market as it eliminates the monopolistic competition of commercial bank's deposits. Yet, the research conducted in this consequential matter is relatively scarce. For that reason, this MSc Thesis aims to further investigate the potential impact of introducing an interest-bearing e-market in the market using a Dynamic Stochastic General Equilibrium (DSGE) Model, which is a popular macroeconomic tool used by Central Banks to evaluate policy issues.

# 2. Motivation

In the early 1970s, after the Bretton Woods system collapsed, a large portion of the world switched from the gold standard to fiat money. Fiat money does not have any intrinsic value as it is not pegged to any physical asset and depends on the credibility of the Central Bank. Consequently, Central Banks gained a prominent role in safeguarding monetary and financial stability. Over the past five decades, they have dealt with a stream of challenges that determined their evolution and the current role that they play in our economies. Their evolution offers insights on its need to constantly develop in order to maintain the consumers' trust. The next paragraphs offer a brief background on the Central Banks' development in the age of fiat money. Then, I explain how the loss of trust caused by the 2008 Financial Crisis gave rise to the first resilient digital currency, Bitcoin. Bitcoins' emergence serves to understand the needed role of an innovative Central Bank that safeguards consumers trust in an increasingly digital world. This brings us to the last part of the motivation, which wraps everything described above into answering: "Why is it important to research the potential impact of Central Bank Digital Currencies?"

## 2.1 Central Banks' Evolution: from 1970 to 2008

In 1973, the world experienced the first oil shock and a subsequent period of stagflation. Most developed governments and Central Banks decided to combat it through an expansionary fiscal and monetary policy but failed to obtain results in terms of output and unemployment. Germany and Switzerland chose an alternative approach and maintained conservative monetary policies. Their approach was successful, obtaining both low unemployment and inflation. This gave rise to a new era of low inflation and a renewed focus on price stabilization that is still present today (BIS 1996).

In the 1980s, the financial industry experienced a tremendous transformation characterized by its internationalization, institutionalization of savings and an increase in the amounts of financial instruments, competition and volumes of transactions. However, this expansion also resulted in financial instability and fear of liquidity and credit risks. Consequently, Central Banks started to play an increasing role in safeguarding financial stability and generating common standards across countries from a micro and macro prudential level. Micro-prudential standards focused on regulation and supervision while macro-prudential ones help to increase the connection between different markets through payment and settlement systems. Examples of micro and macro-prudential standards are (i) the Basel Standards (such as the Capital Asset ratio), (ii) the development of the Real-Time Gross Settlement system(RTGs) and (iii) multilateral net systems (BIS 1996).

In the 1990s, Central Banks started to focus more on transparency and publicly announced their strategies, which made them accountable to the public and helped them obtain greater autonomy. This period is characterized by a series of laws guaranteeing Central Banks independence and an increasing interaction, in terms of publishing policy targets and forecast, between Central Banks and the public (BIS 1996).

In the early-to-mid 2000s, Central Banks enjoyed high credibility as their policies had given rise to the Great Moderation (1987-2007) in the industrial world, characterized by stable low inflation and high growth (BIS 2009). However, the 2008 Financial Crisis put their credibility into question (Edelman 2009).

## 2.2 The Loss of Trust – The 2008 Financial Crisis

In 2007, the first signs of a financial crisis started to emerge as subprime mortgages experienced high losses and banks charged high premiums in interbank lending markets, which indicated an increasing liquidity risk. In September 2008, Lehman Brothers, a large financial firm, filed for bankruptcy and exposed firms started to sell their assets in illiquid markets. This exacerbated the growing concerns about the stability of the banking systems and resulted in a large outflow of unsecured commercial paper and certificate of deposits, which further deprived banks from the needed liquidity, in the United States (BIS 2009).

The banking liquidity risks spread throughout the world putting the global financial system at risk. In Europe and United States, Central Banks started to jointly cut interest rates and governments began to recapitalize banks in need. Nonetheless, the confidence in the banking system was low and the losses spread throughout the economy. In the coming months, government bond yields, equity indexes, GDP, trade flows, and consumer spending deteriorated (BIS 2009).

This generated an overall distrust on financial services. According to Edelman trust barometer, in 2009, insurance was the least trusted industry sector followed by media companies and banks. Banks also had the highest trust percentage drop, going from 56% to 45% (Edelman 2009).

The increasing distrust towards financial services resulted in a series of proposals that challenged the current banking system. In 2008, a month after the Lehman Brothers collapse, Satoshi Nakamoto, an unknown entity, published "Bitcoin: a peer-to-peer electronic cash system", a digital substitute of the current fiat system (Nakamoto 2008).

## 2.3 The Emergence of the First Resilient Digital Currency

Bitcoin emerged as a protest against the banking system. In the release of its first version, Nakamoto stated that "The central bank must be trusted not to debase the currency, but the history of fiat currencies is full of breaches of that trust. Banks must be trusted to hold our money and transfer it electronically, but they lend it out in waves of credit bubbles with barely a fraction in reserve" and proposed Bitcoin as an alternative e-currency that bypassed the banking system (Nakamoto 2008).

Bitcoin offers its users non-defaultable reserves with transactions capabilities. Its money supply increases at a pre-defined rate and will peak at 21 BTC million in 2140. Furthermore, Bitcoin has never deviated from its original pre-defined rate. This has been achieved through the blockchain protocol (Bitcoin.org 2019; Moreno Puertas and Teigland 2018).

The protocol distributes the ledger, which contains the holdings of every user, across devices connected to the network called nodes. Users can request transactions to miners by proving ownership of their accounts through private keys. Miners collect transactions into a block, which initially amounted to 1MB, and engage in a competition to solve a mathematical puzzle that takes on average 10 minutes to complete. The winner obtains newly minted BTC in exchange. The puzzle's objective is to prevent fraudsters from conducting illegal transactions, as it is computationally expensive, and maintain a stable increase in the money supply. Furthermore, each block is chained to the previous one through a hash functions and has a timestamp. This ensures that nobody can change a past transaction as it would change the hash output of every subsequent block. Since the block-chain is stored across different nodes, it is practically impossible to change a past transaction without alerting the network (Moreno Puertas and Teigland 2018; Nakamoto 2008).

The resiliency of the blockchain protocol ensured that Bitcoin was not taken down by hackers or regulatory authorities and met its "policy" target every 10 minutes. This generated credibility and resulted in an increasing demand for BTCs. As a result, Bitcoin emerged as the first successful fiat digital currency that was not pegged by any asset and depended on the credibility and usability of its protocol.

The blockchain protocol was then modified and applied to many industries and resulted in the rise of cryptocurrencies, which are utility tokens that use similar cryptographic methods to be transacted. Most them are also not pegged to any asset and represent a digital form of fiat money.

Its success has resulted in a new wave of research discussing the possibility of having a Central Bank offering similar services to the consumer through the open web.

## 2.4 Why is it important to research the potential impact of CBDC?

Looking back to the developments of Central Banks in the past five decades, it is clear that they evolved to address a dynamic financial landscape. Their inability to prevent the 2008 Financial Crisis resulted in a loss of credibility and the rise of a substitute to their services (Edelman 2009; Moreno Puertas and Teigland 2018; Nakamoto 2008). As of 2018, Financial Services are still the third least trusted sector. The decreasing usage of cash means that individuals are becoming increasingly dependent on a distrusted sector, which could have several consequences in the financial and monetary stability of a country.

Furthermore, consumers have now access through the open web to non-defaultable reserves with transaction capabilities. In 2013, the Greek and Cyprus crisis showed how Bitcoin became an attractive alternative asset to Euro holders. The price rose from 13$ to 266$ and resulted in the introduction of Bitcoin to mainstream media. Although current cryptocurrencies have issues, such as high transaction cost and low scalability, they should not be ignored as a source of risk. Especially if consumers feel constrained to hold their reserves in banks.

For that reason, in light of the current changes in the financial landscape, I consider it important to contribute to the current research on Central Bank Digital Currencies as a way to bridge the relationship between the Central Bank and the consumer. In the context of this paper, the e-krona would offer consumers with non-defaultable and interest-bearing deposits. The objective of this MSc Thesis is thus to investigate the potential impact of introducing the e-krona in the Swedish economy using the DSGE modelling tool and introducing on it a set of assumptions made by Sverige Riksbank**.**

# 3. Literature Review

The literature on Central Bank Digital Currencies is on its nascent stage. Most of it has been conducted by Central Banks or international banking institutions, such as the Bank for International Settlements (BIS) or the International Monetary Fund (IMF), in the past two years. The published research focuses mostly on defining Central Bank Digital Currencies, its design principles, and estimating its macro-economic impact from a qualitative point of view (BIS 2018; Mancini et al. 2018). The following paragraphs will explain the main views on each topic and in each sub-section I will draw conclusions that will be used for my quantitative analysis.

## 3.1 Definition of a Central Bank Digital Currency

In general terms, a CBDC can be considered as a digital form of Central Bank money, which is "a central bank liability, denominated in an existing unit of account, which serves both as a medium of exchange and a store of value" (BIS 2018).

However, there is a disagreement among researchers about whether this general definition should also incorporate universality as a necessary condition. The logic behind this discussions is that, if it is not incorporated, reserves, which are bank's deposits hold by the Central Bank, are already CBDCs.

Meaning et al (2018), from the Bank of England, argues that the universality condition should not be included as CBDC can be designed for different sub-agents of the economy, such as retail and wholesale CBDCs. Yves Mersch (2017), an executive board member of the ECB, also supports the claim that CBDC does not need to be universally available. In his opinion, reserves are already a form of CBDC.

However, the Bank of International Settlements (2018) and Griffoli et al. (2018), from the IMF, claims the opposite. The BIS defines it as "a digital form of central bank money that is different from balances in traditional reserves and settlement accounts" and Griffoli et al. as "a new form of money, issued digitally by the central bank and intended to serve as a legal tender.. [that] would differ from… reserve balances…[as it] would be widely available." (Mancini et al 2018).

This debate cannot be settled as it is subjective. Nonetheless, the purpose of defining a new term is to provide an added functionality to the language. For that reason, I include the universally available condition to the Bank of International Settlements' definition of Central Bank money and define CBDC as:

> "A universally available digital form of Central Bank money, which is a central bank liability, denominated in an existing unit of account that serves both as a medium of exchange and a store of value".

Definition of CBDC

### 3.2 Characteristics of Central Banks Digital Currencies

Besides being a universally available digital form of Central Bank money, CBDCs can be implemented on a variety of ways. As of 2018, several Central Banks are investigating different approaches, which are described below (BIS 2018; Mancini et al. 2018).

Centralization vs Decentralization:

- **Decentralized systems** serve to ensure that a single entity, usually represented by a device connected to the network, cannot change the system without the approval of the rest of the network. This, nonetheless, requires cooperation among different nodes, which slows the system.
- **Centralized systems**, on the other hand, are the standard in current payment systems (e.g.: TIPs and RTGS). They require a high level of maintenance and depend on a single entity. They are highly scalable and able to process a large amounts of payments.

Token-based or Account-based

- In **account-based systems**, the account providers verifies the transaction by debiting and crediting accounts. (e.g.: Visa & Mastercard).
- In **token-systems**, the receiver verifies the token through a third-party system (e.g.: Bitcoin). Furthermore, only token-based systems can offer full anonymity.

Interest or non-interest bearing

- **Non-interest-bearing CBDC** simulates the function of cash as a mean of payments, but in the digital world.
- **Interest Bearing CBDC**, on the other hand, has many implications in the monetary policy and financial stability of a country.

Cap limited or non cap-Limited

- **Cap Limited** can be particularly useful to provide services to a large portion of the population while avoiding potential drawbacks, such as bank-runs.
- **Non-Cap Limited** requires more macro-prudential oversight as large fluctuations of money from deposits to CBDCs can occur.

For this MSc Thesis, I investigate the impact of an unlimited interest-bearing e-krona in Sweden as it allows me to investigate its macro-economic impact. This implies that citizens can convert their deposits into the e-krona, which provides them with an interest rate equal to the current policy rate. The rest of characteristics mentioned above are not considered as it is unclear how they may impact the economy.

## 3.3 The Macro-Economic Impact of an Unlimited Interest-Bearing CBDC

Central Banks influence the economy through interest-rates among others things. In most cases, interest rates are targeted through a corridor composed by a deposit and lending rate offered to banks. In our context, Central Bank Digital Currencies (CBDCs) would expand the same deposit rate to all consumers. This has several implications on the economy as CBDCs are a close substitute to commercial bank retail deposit rates (Juks 2018), which are used by commercial banks to fund long-term loans.

Keeping this in mind, this section discusses CBDCs impact on the interest-rate pass-through mechanism, financial intermediation and the commercial banks' balance sheet.

### 3.3.1 Interest Rate pass-through mechanism

The interest rate pass-through mechanism is divided into two sections, the deposit and lending rate.

**Deposit rate**

Historically, the Central Bank policy rate changes have not been fully transmitted to deposit rates. For instance, in Sweden, based on the past 25 years, a 1% increase in the policy rate resulted in a 0.6% increase in deposit rates (Armelius et al. 2018).

Under a CBDC regime, this pass-through rate of 0.6 is expected to increase as citizens have the commercially viable alternative of switching their deposits into interest-bearing CBDCs with a higher rate of return (Armelius et al. 2018; BIS 2018).

Armelius et al (2018) argue that the introduction of the e-krona, the Swedish CBDC, would increase the pass-through rate to 1. Equation 1 provides a framework of how the e-krona would impact nominal interest rates.

$$i^{ekr} - \varphi^{ekr} - \sigma^{ekr} \leq i^D - \varphi^D - \sigma^D$$

where:

$i$ is the risk-free rate;

$\varphi$ benefits of the asset at hand; and

$\sigma$ cost of holding the asset.

*Equation 1*

Armelius et al (2018) claim that the e-krona offers at least more benefits, such as broader means of payments and services, than the current deposit rate $(\varphi^{ekr} - \varphi^{D}) \geq 0$ and the same risks $(\sigma^{ekr} - \sigma^{D}) = 0$.

Nonetheless, their theory misses other potential benefits that can be obtained through deposits, such as overdrafts or better credit based on your behavior, and the price-sensitivity of consumers, which is not perfect (BIS 2018; Meaning et al. 2018). Furthermore, Central Banks are already innovating payment systems and offering real time settlements without a CBDC regime. For example, the ECB implemented in November of 2018 the Target Instant Payment Settlements, which offers real-time payments at a near zero cost (ECB 2018).

The equation thus serves to understand how to assess the potential impact of introducing a CBDC in the market but needs further research on valuing the advantages and disadvantages of an e-krona and include the price sensitivity of the consumer. Furthermore, although it is still unclear to what point would a CBDC increase the pass-through-rate to deposits, the current literature agrees on its positive impacts through increased competition (Armelius et al. 2018; BIS 2018; Meaning et al. 2018).

**Lending rate**

Central Bank Digital Currencies impact the lending rate indirectly through an increase in funding costs and competition (Meaning et al. 2018).

The increase in funding costs stems from CBDCs being an attractive alternative investment to commercial bank deposits, which are used to fund loans. The upper-bound of this increase is the lending rates offered by other financial institutions that do not use deposits to fund loans, such as corporate loan markets and retail investors (Juks 2018).

The increase in competition comes from a wider availability of settlement services to non-bank credit providers, which rely on commercial banks for those services (Meaning et al. 2018). This decrease on market power is expected to lower commercial banks' profit margins.

### 3.3.2 The Impact on Banks' Balance Sheet

With the introduction of a CBDC, we can expect an outflow of current retail deposits to CBDCs (BIS 2018; Juks 2018). This loss would depend on the consumers preference for CBDC.

The outflow would reduce the aggregate size of the Banks' balance sheet and require them to seek additional sources of funding to compensate for the loss of liquidity. This new type of funding could be either long-term senior unsecured bonds or another liquidity mechanism provided by the Central Bank. Furthermore, banks could also compete with CBDC by increasing the deposit rates above the CBDC levels or providing a wider range of services to customers. For instance, banks obtain advantages from seeing the user finances and can leverage it to provide better lending services.

Overall, CBDCs are expected to reduce margins and increase the pass-through rate to deposits. However, the literature does not yet on agree on its impact on the lending rate as there is a trade-off between more expensive funding sources and greater competition. For that reason, this MSc thesis includes the assumptions stated above into a set of equations in the baseline DSGE model to assess its impact.

# 4. DSGE

## 4.1 Brief History

This MSc Thesis uses the Dynamic Stochastic General Equilibrium (DSGE) model to estimate the impact of implementing an interest-bearing Central Bank Digital Currency. DSGE is a popular forecasting tool used by Central Banks for policy analysis that evolved from the Real Business Cycle (RBC) approach introduced by Kydland and Prescott (1982).

The RBC approach consists on a theoretical model of a perfect competitive economy, populated by rational utility-maximizing agents subject to budget constraints and profit-maximizing firms, that mimicks business cycles when it experiences stochastics(random) productivity shocks. The approach links microeconomic behavior to macroeconomic dynamics (Kremer et al. 2006).

However, the RBC model tended to exclude the role of monetary and fiscal policy as it only depended on households and firms. It was also not able to reproduce basic things, such as the co-movement of productivity and employment or wages and output, and fit empirical data. These problems lead to a new wave of research aiming to improve the RBC model (Kremer et al. 2006).

In the 1980s, a new school of thought was emerging, the New-Keynesian Macro-Economists (NKMs). The NKMs argued that market imperfections, such as price stickiness, were an important part of the economy as they generated short-term fluctuations (Kremer et al. 2006; Mankiw 2002). They incorporated those market imperfections in the microeconomic foundations of the RBC model. This disrupted the neutrality of money, which gave an important role to monetary policy (Kremer et al. 2006).

Over time, the new approach, coined the Dynamic Stochastic General Equilibrium(DSGE) model, became one of the dominant macroeconomic modelling strategies (Kremer et al. 2006) and it is widely used today by Central Banks.

## 4.2 Main Characteristics of a DSGE model

The DSGE model is a macroeconomic model derived from microeconomic foundations. The microeconomic foundations, which are expressed through a set of equations, describe the relationships between (i) firms, (ii) households and (iii) the country's monetary policy. The equations include market imperfections, such as price stickiness, and contain undefined parameters, which are either calibrated through observable behavior or estimated through, usually, a Bayesian approach.

The equations tend to have a non-linear dependency, which generally does not have a closed-form solution (Sims 2011). For that reason, they need to be log-linearized. The log-linearization process converts non-linear equations into linear ones that represent log deviations from the steady state. The most common method applied to approximate log deviations from the steady state is the Taylor Series Expansion, which I use in this MSc thesis. In the next section, I explain the baseline model and the procedure to calibrate and estimate parameters.

## 4.3 The Baseline Model: The Swedish Case

The DSGE baseline model follows the same set of micro-economic foundations as Gerali et al (2009) and has been obtained from the Macroeconomic Model Data Base (2018). The parameters are calibrated through observable behavior and estimated through a Bayesian approach.

### 4.3.1 Calibration

The calibrated parameters have been obtained from Chen & Columba (2016), which adapted the Swedish observable behavior collected from a series of papers, including Angelini et al (2014), Gerali et al (2009) and Iacoviello (2005), into the Gerali et al (2009) baseline model.

| Parameter | Description | Value |
|---|---|---|
| $\beta_P$ | Patient Households' discount factor | 0.9963 |
| $\beta_I$ | Impatient Households' discount factor | 0.975 |
| $\beta_E$ | Entrepreneur Households' discount factor | 0.975 |
| $\phi$ | Inverse of Frish elasticity | 2.98 |
| $\varepsilon^h$ | Weight of housing in household utility function | 0.2 |
| $\propto$ | Capital share in the production function | 0.25 |
| $\delta$ | Depreciation rate of physical capital | 0.025 |
| $\varepsilon_y$ | $\frac{\varepsilon_y}{\varepsilon_y - 1}$ is the markup in the goods market | 6 |
| $\varepsilon_l$ | $\frac{\varepsilon_l}{\varepsilon_l - 1}$ is the markup in the labour market | 5 |
| $\overline{m}^I$ | LTV households | 0.7 |
| $\overline{m}^E$ | LTV entrepreneurs | 0.35 |
| $v^b$ | Capital/loans ratio in steady state | 0.12 |
| $\bar{\varepsilon}^d$ | $\frac{\bar{\varepsilon}^d}{\bar{\varepsilon}^d{}_{-1}}$ markdown on deposit rate | -1.1 |
| $\bar{\varepsilon}^{bH}$ | $\frac{\bar{\varepsilon}^{bH}}{\bar{\varepsilon}^{bH}{}_{-1}}$ markup on rate on loans to HHs | 3.2 |
| $\bar{\varepsilon}^{bE}$ | $\frac{\bar{\varepsilon}^{bE}}{\bar{\varepsilon}^{bE}{}_{-1}}$ markup on rate on loans to firms | 2.4 |

*Table 1: Calibrated Parameters*

### 4.3.2 Estimation

The rest of the parameters are estimated through a Bayesian approach, which is done through the Metropolis-Hasting Algorithm. Similar to (Chen and Columba 2016), I use the following ten observable: (i) real GDP, (ii) real consumption, (iii) real investment, (iv) interest rate on mortgages, (v) interest rate on corporate loans, (vi) deposit rates, (v) the Riksbank's repo rate, (vi) real loans to households, (vii) real loans to firms, (viii) wage inflation, (ix) CPIF inflation, and (x) real house prices. The observables are based on Swedish quarterly data and range from 1996Q1 to 2018Q2. The data is linearized and then demeaned following Pfeifer's (2018) approach.

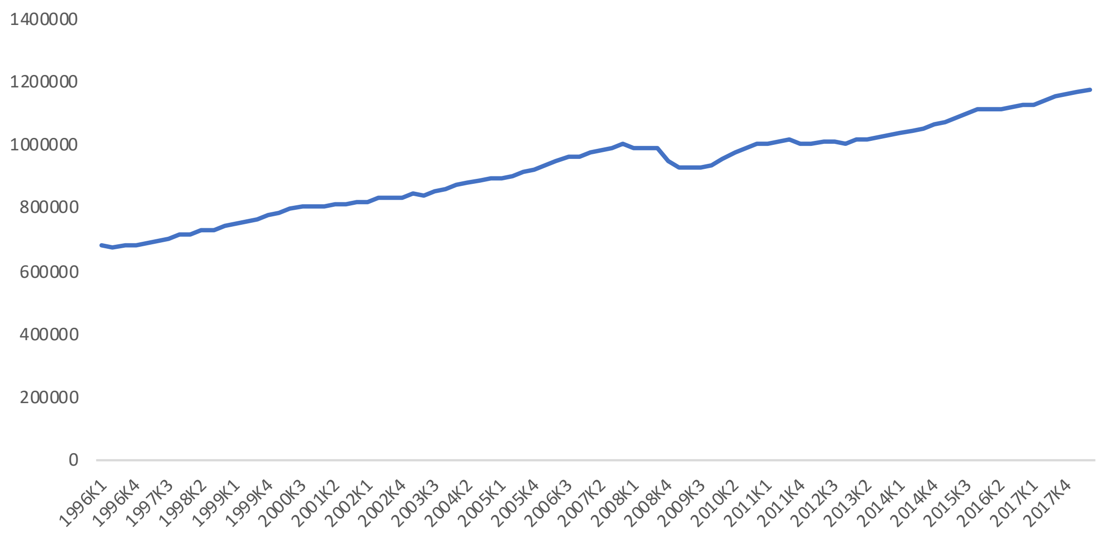


*Figure 1: Swedish GDP*

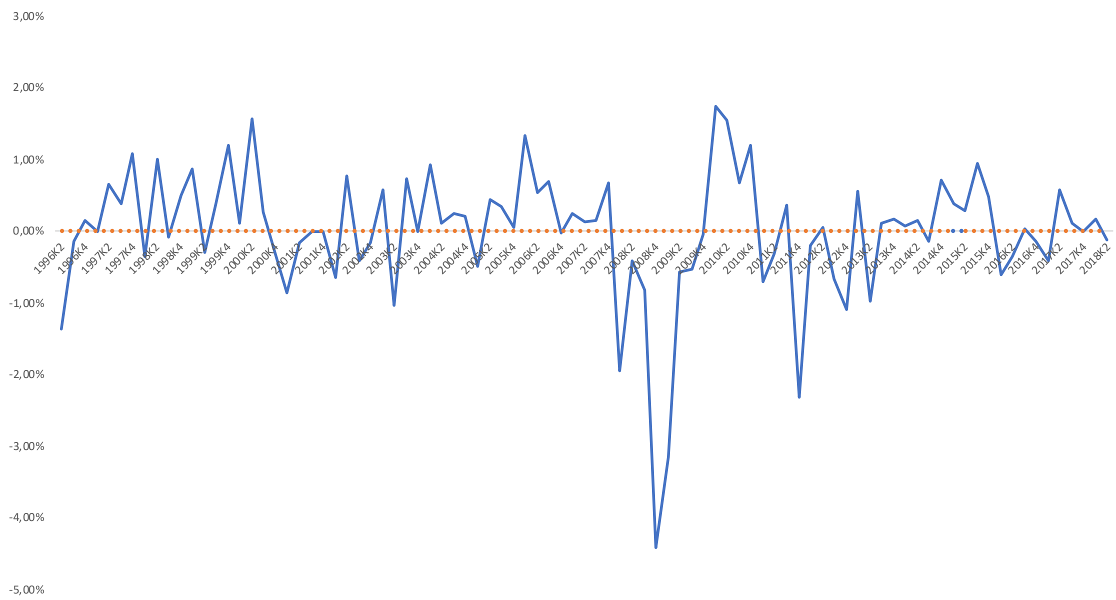


*Figure 2: Swedish GDP Demeaned and Detrended*

The same procedure is applied to the other nine observable variables. Once the variables have been demeaned and detrended, they are adapted to follow the same structure as the microeconomic foundations of the model. The last step to perform the Bayesian approach is to assume a series of prior distributions for the undefined variables. These prior distributions are obtained from Chen & Columba (2016), as they also estimated a similar model in Sweden.

Once I have the (i) calibrated parameters, (ii) observable data adapted to the model and (iii) a prio distribution, I can estimate the posterior distribution of the undefined variables through the Metropolis-Hasting algorithm. This approach uses observable data to obtain information about the real distribution of each of the undefined parameters. Table 2 & 3 shows the result of the estimation. Nonetheless, although we present the mean, we used the mode to calculate the impulse response functions. The reason is that the mean shows an unrealistic representation of irregular distributions while the mode does not. This rule of thumb approach was suggested by Pfeifer (2011).

| | Prior Distribution | | | Posterior Distribution | | |
|---|---|---|---|---|---|---|
| Variable | Distribution | Mean | St. Dev | Mean | 5 percent | 95 percent |
| $k_p$ | Gamma | 25 | 15 | 25.22 | 25.16 | 25.27 |
| $k_w$ | Gamma | 25 | 15 | 24.98 | 24.97 | 24.99 |
| $k_i$ | Gamma | 10 | 5 | 10.32 | 10.25 | 10.4 |
| $k_d$ | Gamma | 10 | 5 | 9.79 | 9.77 | 9.82 |
| $k_{bE}$ | Gamma | 10 | 5 | 10 | 9.98 | 10.02 |
| $k_{bH}$ | Gamma | 10 | 5 | 9.9 | 9.98 | 9.92 |
| $k_{Kb}$ | Gamma | 10 | 5 | 10.47 | 10.4 | 10.57 |
| $\phi_\pi$ | Normal | 1.7 | 0.1 | 1.87 | 1.84 | 1.9 |
| $\rho_{ib}$ | Beta | 0.82 | 0.05 | 0.89 | 0.88 | 0.91 |
| $\phi_y$ | Normal | 0.13 | 0.15 | -0.0086 | -0.06 | 0.02 |
| $\iota_p$ | Beta | 0.5 | 0.15 | 0.52 | 0.47 | 0.57 |
| $\iota_w$ | Beta | 0.5 | 0.15 | 0.09 | 0.06 | 0.12 |

Note: Results based in 2 chains, each with 5,000 draws of the Metropolis-Hasting algorithm

*Table 2:*

| | Prior Distribution | | | Posterior Distribution | | |
|---|---|---|---|---|---|---|
| Variable | Distribution | Mean | St. Dev | Mean | 5 percent | 95 percent |
| $\rho_a$ | Beta | 0.75 | 0.05 | 0.70 | 0.67 | 0.73 |
| $\rho_z$ | Beta | 0.75 | 0.05 | 0.80 | 0.77 | 0.84 |
| $\rho_j$ | Beta | 0.75 | 0.05 | 0.96 | 0.96 | 0.96 |
| $\rho_{mE}$ | Beta | 0.75 | 0.05 | 0.89 | 0.87 | 0.92 |
| $\rho_{mI}$ | Beta | 0.75 | 0.05 | 0.83 | 0.81 | 0.85 |
| $\rho_d$ | Beta | 0.75 | 0.05 | 0.45 | 0.42 | 0.5 |
| $\rho_{bE}$ | Beta | 0.75 | 0.05 | 0.63 | 0.60 | 0.65 |
| $\rho_{bH}$ | Beta | 0.75 | 0.05 | 0.74 | 0.73 | 0.76 |
| $\sigma_a$ | Inv. gamma | 0.01 | 0.05 | 0.04 | 0.04 | 0.05 |
| $\sigma_z$ | Inv. gamma | 0.01 | 0.05 | 0.082 | 0.07 | 0.09 |
| $\sigma_j$ | Inv. gamma | 0.01 | 0.05 | 1.03 | 0.97 | 1.08 |
| $\sigma_{mE}$ | Inv. gamma | 0.01 | 0.05 | 0.02 | 0.01 | 0.02 |
| $\sigma_{mI}$ | Inv. gamma | 0.01 | 0.05 | 0.06 | 0.06 | 0.07 |
| $\sigma_d$ | Inv. gamma | 0.01 | 0.05 | 1.82 | 1.76 | 1.88 |
| $\sigma_{bE}$ | Inv. gamma | 0.01 | 0.05 | 1.39 | 1.33 | 1.44 |
| $\sigma_{qk}$ | Inv. gamma | 0.01 | 0.05 | 0.05 | 0.04 | 0.06 |
| $\sigma_R$ | Inv. gamma | 0.01 | 0.05 | 0.003 | 0.003 | 0.00 |

Note: Results based in 2 chains, each with 5,000 draws of the Metropolis-Hasting algorithm

*Table 3*

## 4.4 The CBDC Model

In order to understand the impact of introducing a CBDC, I used Gerali et al. (2009) Credit and Banking DSGE model for the Euro area as a baseline. Their model focuses on the credit-supply factors, which makes it an adequate ground to test my theory, and is widely popular among Central Banks, Sverige Riksbank included.

In the model, patient households have the option to switch from retail deposits to CBDC, which pays an interest rate equal to the policy rate. Banks have the option to obtain funds at the market funding cost rate, which is 100 basis points above the official deposit rate (Juks 2018). Households substitution rate between CBDC and bank retail deposits depends on the markdown on the retail deposit rate. If the gap between the deposit rate and the policy rate is high, more people will switch to CBDCs and vice-versa.

The specified model helps to investigate the impact of CBDCs on lending rates and also understand how different shocks affect the CBDC economy. This is the first model that looks at the impact of introducing a CBDC in credit-supply factors of the economy through a DSGE modelling tool[1]

### 4.4.1 The Micro-Economic Foundations

All the equations for the micro-economic foundations are described in the Appendix A. In this section, I will offer a brief description of the theoretical economy and focus on the parts that are directly impacted by the introduction of a CBDC.

The economy is populated by households and entrepreneurs. Households maximize their utility by increasing their consumption over their habit level and housing services and reducing the amounts of hours worked. Households can be divided into patient and impatient households. Only patient households are directly affected by the introduction of CBDC.

In the pre-CBDC economy, patient households spend their income in consumption, housing services and deposits.

$$\underbrace{W_t^P l_t^P(i) + \frac{1 + r_{t-1}^d}{\pi_t} d_{t-1}^P(i) + T_t^P}_{Income} \geq \underbrace{c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t^P(i)}_{Expenses}$$

where:

$c^P$ is consumption

$q^h \Delta h_t^P(i)$ accumulation of housing services

$d^P$ is the total amount of deposits

$W^P$ is the wage

$l^P$ is the hours worked

[1] Barrdear and Kumhof (2016) also used DSGE to estimate the CBDC impact on the economy. However, they focused on its impact to the economy through fiscal policy and the liquidity generating function(LGF). They assumed a 30% reduction of GDP of debt through issuing new CBDC and lower transaction costs. I disagree with their stance as I do not expect governments to take such a bold approach. Furthermore, Central Banks are already offering cheap transactions networks, such as TIPs described before, that are expected to change the payment market. Hence, a CBDC would not provide greater liquidity functions compared to the newly implemented models.

$r^d$ is the deposit rate

$\pi_t$ is inflation

$T$ is a lump-sum transfer that includes (i) labour union fee, dividends from retail firms ($J^P$) and banking sector dividends $\frac{(1-w^b)J_{t-1}^b}{\pi_t}$.

*Equation 2*

In the post-CBDC economy, patient households can also spend their income in CBDC. CBDC also offer a return in the next period, which depends to the policy interest rate (as $r^{cbdc} = r^{policy\ rate}$).

$$\underbrace{W_t^P l_t^P(i) + \frac{1 + r_{t-1}^d}{\pi_t} d_{t-1}^P(i) + \frac{1 + r_{t-1}^{cbdc}}{\pi_t} CBDC_{t-1}^P(i) + T_t^P}_{Income}$$
$$\geq \underbrace{c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t^P(i) + CBDC^P}_{Expenses}$$

Where:

$r^{cbdc}$ is the interest rate paid on CBDC; and

CBDC depends on the rate of substitution between retail deposits and CBDC.

*Equation 3*

Equation 3 shows how the introduction of the CBDC increases the income of patient households through a higher rate of return $(r_{t-1}^{cbdc} > r_{t-1}^d)$ on the amount deposited.

The banking sector is composed of a wholesale, retail deposit and retail lending branch. They maximize profits by increasing their lending margins over the funding costs. They are subject to a penalty if they deviate from the optimal capital asset ratio. Only the wholesale branch, which lends money to the retail ones, is directly impacted by the introduction of CBDC.

In the pre-CBDC economy, the wholesale branch revenues come from debt repayments and its expenses stem from the rate paid to depositors and the cost of deviating from the optimal capital asset ratio.

$$\text{Max}\, E_0 \sum_{t=0}^{\infty} \lambda_{0,t}^{p} \left[ \underbrace{(1+R_t^b)B_t(j)}_{Debt\ repayment} - \underbrace{(1+R_t^D)D_t(j)}_{Depositors'payments} \underbrace{- K_t^b(j) - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t(j)} - v^b\right)^2 K_t^b(j)}_{\substack{Costs\ of\ deviating \\ from\ the\ optimal\ ratio\ (v)}} \right]$$

subject to the following constraint:

$$B_t(j) = D_t(j) + K_t^b(j)$$

where:

$\lambda_{0,t}^{p} = \lambda_t^P$ is the discount factor of the banks.

$R_t^b$ is the lending rate paid by wholesalers.

$B_{t(j)}$ are the total amount of loans given to wholesalers.

$R_t^D$ is the deposit rate paid to wholesalers.

$D_t(j)$ is the total amount of deposits.

$K_t^b(j)$ is the bank equity.

$\kappa_{Kb}$ is the cost of capital ratio divergences.

$v^b$ is the optimal capital/asset ratio.

*Equation 4*

In the post-CBDC economy, the wholesale branch deposits are reduced and compensated through market funding.

$$\text{Max}\, E_0 \sum_{t=0}^{\infty} \lambda_{0,t}^{p} \left[ \underbrace{(1+R_t^b)B_t(j)}_{Debt\ repayment} - \underbrace{(1+R_t^D)D_t(j)}_{Depositors'payments} - \underbrace{(1+R_t^F)F_t}_{\substack{Market\ funding\ costs \\ debt\ repayments}} \right.$$

$$\left. \underbrace{- K_t^b(j) - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t(j)} - v^b\right)^2 K_t^b(j)}_{\substack{Costs\ of\ deviating \\ from\ the\ optimal\ ratio\ (v)}} \right]$$

Subject to:

$$R_t^F = R_t^D + Premium$$

*Equation 5*

In this model, based on Juks (2018) assumption, the premium is 1%. As we can see, the banking sector experience a hike in their funding costs through an increase in the wholesale branch lending rate $R_t^b$.

The proposed model thus offers an increasing return on deposits to patient households at the expense of higher funding costs. The higher funding costs are spread through the economy impacting both entrepreneurs and impatient households. The final result is ambiguous as the economy is interlinked.

# 5. Results

## 5.1 Steady State Comparison

Having adjusted the data to the Swedish economy, we first compare the steady states before the introduction of the e-krona and after:

| Variable | Interpretation | Pre_e-krona | Post_e-krona | % Difference |
|---|---|---|---|---|
| C/Y | Ratio of Consumption to GDP | 0.868 | 0.865 | -0.28% |
| I/Y | Ratio of Investment to GDP | 0.115 | 0.109 | -5.04% |
| K/Y | Ratio of Capital Stock to GDP | 4.610 | 4.37% | -5.04% |
| B/Y | Loans to GDP | 2.684 | 2.566 | -4.39% |
| BH/B | % loans to households | 0.419 | 0.424 | 1.03% |
| BE/B | % loans to entrepreneurs | 0.580 | 0.576 | -0.74% |
| KB/B | % profits over loans | 0.1 | 0.096 | -4.12% |
| KB/Y | % profits in the economy | 0.268 | 0.246 | -8.33% |
| %CBDC | % CBDC over deposits and CBDC | | 37% | |
| Mkt_f/B | % Market funding over total loans | | 24.1% | |
| 4*rd | Annualized deposit rate | 1.48% | 1.48% | |
| 4*r | Annualized Policy rate | 2.5% | 2.5% | |
| 4*rbh | Annualized bank rate on loans to households. | 3.8% | 4.06% | +6.82% |
| 4*rbe | Annualized bank rate on loans to firms | 3.8% | 4.06% | +6.82% |

*Table 4*

After the introduction of the e-krona in Sweden, we can see that the composition of the economy changes. Investments, capital stock, profits and loans decreased substantially their share over GDP. This is due to the increase in funding costs, as the rate on loans to both households and firms increase by 6.82%. Nonetheless, interestingly, households received a relatively larger amount of loans once the e-krona has been introduced. The main conclusion that we can derive from Table 4 is that the increased costs on market funding are spread throughout the economy.

## 5.2 Impulse Response function

The impulse response function serves to understand how an unanticipated shock to an exogenous variable impacts the economy. The shock to an exogenous variable serves to generate fluctuations in the economy, which was in an steady state as explained in the DSGE model. The fluctuations throughout the economy occurs as the endogenous variables are interlinked and dependent on each other.

For that reason, Central Banks use DSGE models to understand how unanticipated changes in the interest rate impact the economy. In this MSc Thesis, I am interested in how the Sverige Riksbank can influence the economy. The impulse response function allows me to investigate the impact of an increase in the interest rate under this theoretical scenario and compare it to the current one. The interest rate shock amounts to 50 basis points and the figures below show its impact throughout 40 quarters.

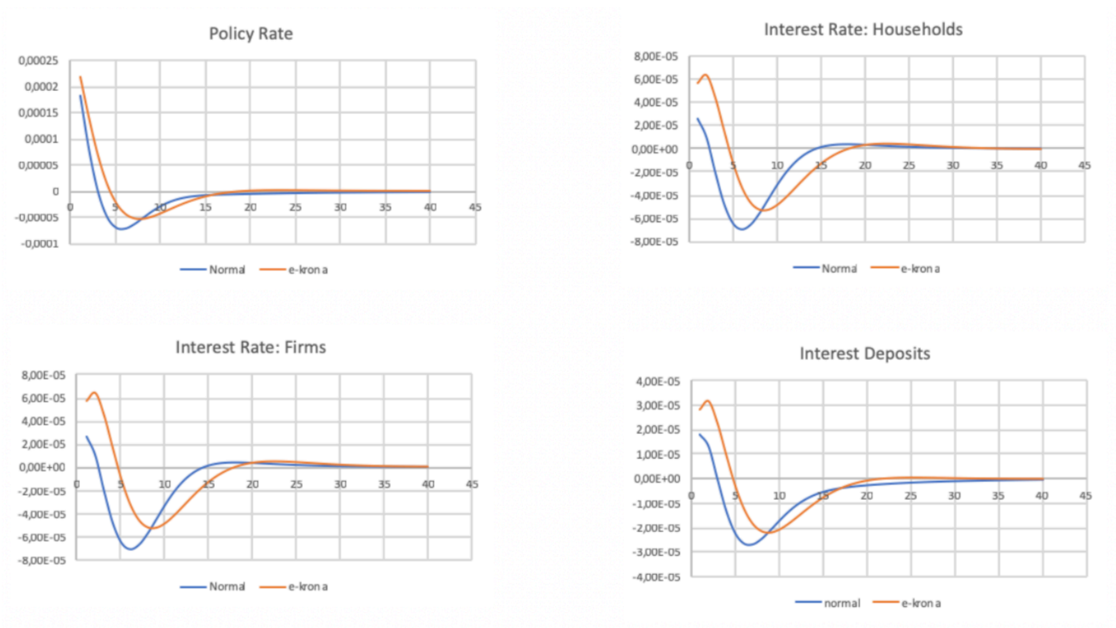


*Figure 3: Monetary Policy Shock to Interest Variables*

Figure 3 shows how an unanticipated increase in the policy rate impacts interest rates. As expected, both lending and deposit rates increase compared to the benchmark scenario. This indicates a better pass-through mechanism, as the Sverige Riksbank would be able to obtain the same results as in the benchmark model with a smaller shock.

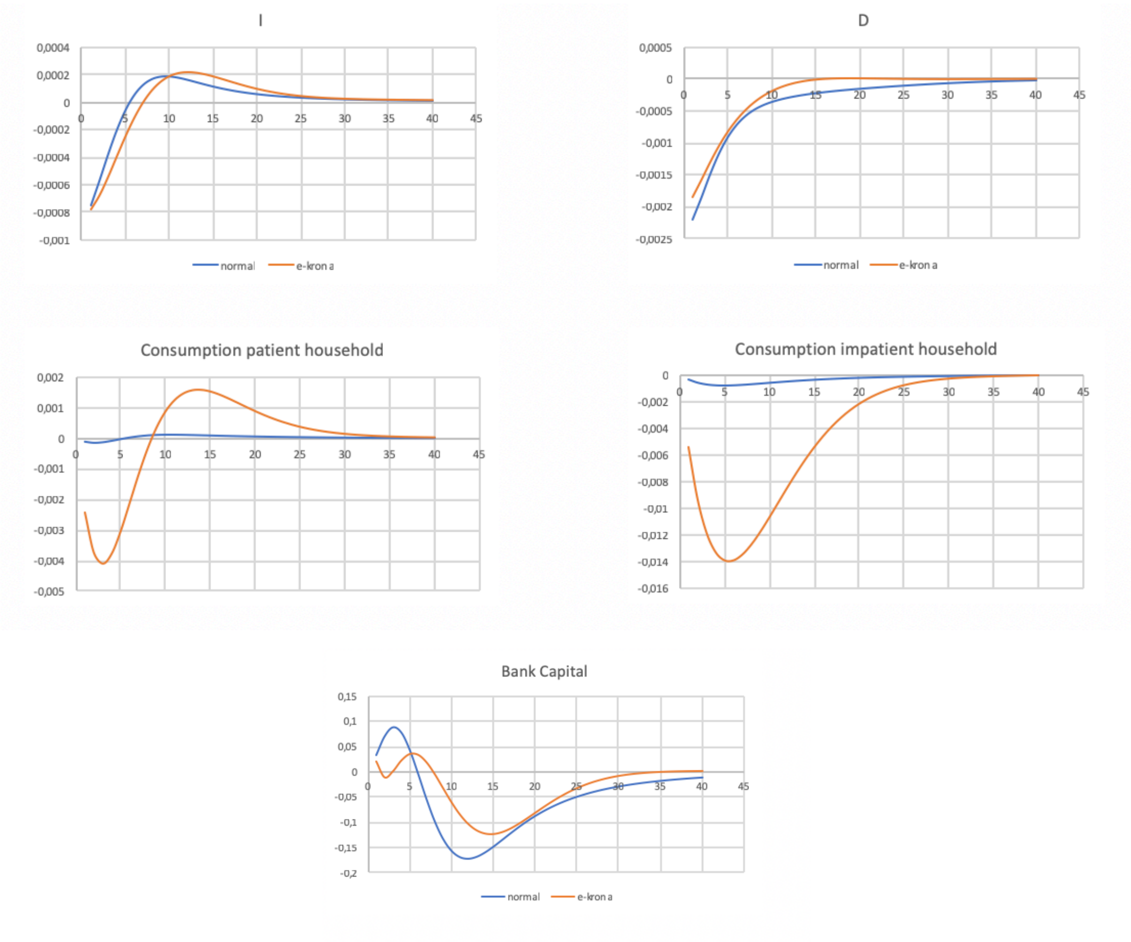


*Figure 4: Monetary Policy Shock to Macroeconomic Variables*

In the benchmark model, in response to the unanticipated increase in the policy rate, the economy contracts and standard macro-economic parameters, such as output, consumption, investment and deposits fall.

In the e-krona hypothetical model, we observe a larger contraction in the economy. Output, consumption and investments also take longer to recuperate from the interest rate shocks. Bank capital obtains a short-term gain in profits followed by a loss as financial activity diminishes (Gerali et al. 2009). Consumption depends largely on whether the household is patient or impatient. Patient households receive an initial short-term decline followed by a steep increase as the interest rate accumulated from the e-krona materializes.

The results of the impulse response function confirm the initial theory that introducing the e-krona in Sweden would reduce financial frictions and enable Central Banks to have a more direct interaction with the real economy. In our particular example, the interest rate increase, which aims to slow the economy, has a faster and larger impact on the economy. This is observed through the interest rates, main macro-variables and household consumption.

# 6. Further Research

This MSc Thesis focuses primarily on investigating how would the e-krona impact the pass-through rate mechanism. The objective is to start building a framework upon a set of assumptions that enables the reader to understand the potential implications of CBDC. For that reason, I encourage economists to introduce new assumptions in the proposed model. From my perspective, there are three topics that should be further expanded:

- *Central Banks Balance Sheet:* The conversion of deposits to the e-krona implies that the Central Bank balance sheet would increase substantially. Further research on its implications is desired.
- *The demand for the e-krona:* In the proposed model, I assume that the demand for the e-krona depends on the elasticity of substitution of deposits. This enables a dynamic model in which the larger the spread between policy rate and the deposit rate, the higher the demand for the e-krona. Nonetheless, the elasticity should instead be calculated through observable behavior.
- *Long-term market funding rates*: In the proposed model, I assume that are able to borrow money at the market funding cost rate, which is estimated to be 100 basis points above the policy rate. However, another possibility could be that the Central bank offers to use to lend money to financial institutions to cover the lost deposits. This assumption implies that the Central Bank would have a larger role in the economy as they would own a large portion of the banks' debt.

# 7. Conclusion

This MSc Thesis is the first paper to quantitatively assess the impact of the e-Krona in Sweden and has presented an innovative framework to assess the introduction of a CBDC in an economy. In the model, we enable households to convert their deposits into the e-krona and banks to obtain funds directly from the Central Bank. The introduced changes are expected to increase the pass-through mechanism as monetary policy has a more direct transmission channel towards both households and wholesale banks. The proposed model uses as a benchmark Gerali et al (2009) DSGE model, which is known from introducing financial frictions in the economy. The result is a reduction of those financial frictions and an increase in the pass-through mechanism. Through impulse response functions we can observe how an unexpected increase in the interest rate is transmitted faster through the economy, resulting in a faster (i) contraction of macro-economic variables, such as output, consumption and investments, and (ii) increase in the deposit and loan rates.

## References


Angelini, Paolo, Stefano Neri, and Fabio Panetta. 2014. "The Interaction between Capital Requirements and Monetary Policy." *Journal of Money, Credit and Banking* 46(6): 1073–1112. http://doi.wiley.com/10.1111/jmcb.12134 (May 7, 2019).

Armelius, Hanna et al. 2018. "The E-Krona and the Macroeconomy." : 23.

Barrdear, John, and Michael Kumhof. 2016. *Staff Working Paper No. 605 The Macroeconomics of Central Bank Issued Digital Currencies*. www.bankofengland.co.uk/research/Pages/workingpapers/default.aspx (December 9, 2018).

BIS. 1996. "Bank for International Settlements 67th Annual Report." https://www.bis.org/publ/ar67f02.pdf (November 28, 2018).

———. 2009. "BIS 79th Annual Report - June 2009." : 250. https://www.bis.org/publ/arpdf/ar2009e.pdf (December 6, 2018).

———. 2018. *Central Bank Digital Currencies*. www.bis.org (November 30, 2018).

Bitcoin.org. 2019. "FAQ - Bitcoin." https://bitcoin.org/en/faq#isnt-speculation-and-volatility-a-problem-for-bitcoin (June 3, 2019).

Chen, Jiaqian, and Francesco Columba. 2016. *Macroprudential and Monetary Policy Interactions in a DSGE Model for Sweden IMF Working Paper European Department Macroprudential and Monetary Policy Interactions in a DSGE Model for Sweden*. https://www.imf.org/external/pubs/ft/wp/2016/wp1674.pdf (May 7, 2019).

ECB. 2018. "What Is TARGET Instant Payment Settlement (TIPS)?" https://www.ecb.europa.eu/paym/target/tips/html/index.en.html (December 9, 2018).

Edelman. 2009. *2009 Edelman Trust Barometer*. https://www.edelman.com/sites/g/files/aatuss191/files/2018-10/2009-Trust-Barometer-Global-Deck.pdf (December 6, 2018).

Gerali, Andrea et al. 2009. *Credit and Banking in a DSGE Model of the Euro Area*. https://www.federalreserve.gov/events/conferences/fmmp2009/papers/Gerali-Neri-Sessa-Signoretti.pdf (December 9, 2018).

Griffoli, Mancini; et al. 2018. *Casting Light on Central Bank Digital Currencies*. https://www.imf.org/en/Publications/Staff-Discussion-Notes/Issues/2018/11/13/Casting-Light-on-Central-Bank-Digital-Currencies-46233 (June 3, 2019).

Iacoviello, Matteo. 2005. "House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle." https://www2.bc.edu/matteo-iacoviello/research_files/AER_2005.pdf (May 7, 2019).

Institute for Monetary and Financial Stability. 2018. "Macroeconomic Model Data Base." https://www.macromodelbase.com/ (May 7, 2019).

Juks, Reimo. 2018. "When a Central Bank Digital Currency Meets Private Money: Effects of an e-Krona on Banks." : 21. https://www.riksbank.se/globalassets/media/rapporter/pov/artiklar/svenska/2018/181105/20183-when-a-central-bank-digital-currency-meets-private-money---effects-of-an-e-krona-on-banks.pdf.

Kremer, J., G. Lombardo, L. von Thadden, and T. Werner. 2006. "Dynamic Stochastic General Equilibrium Models as a Tool for Policy Analysis." *CESifo Economic Studies* 52(4): 640–65. https://academic.oup.com/cesifo/article-lookup/doi/10.1093/cesifo/ifl014 (November 21, 2018).

Kydland, Finn E, and Edward C Prescott. 1982. 50 *Time to Build and Aggregate Fluctuations*. https://www.fep.up.pt/docentes/pcosme/S-E-1/kP-Econ.pdf (November 21, 2018).

Mancini, Tommaso et al. 2018. "Casting Light on Central Bank Digital Currencies." https://www.imf.org/en/Publications/Staff-Discussion-Notes/Issues/2018/11/13/Casting-Light-on-Central-Bank-Digital-Currencies-46233 (November 30, 2018).

Mankiw, Gregory. 2002. "New Keynesian Economics - Econlib." https://www.econlib.org/library/Enc/NewKeynesianEconomics.html (December 7, 2018).

Meaning, Jack, Ben Dyson, James Barker, and Emily Clayton. 2018. *Staff Working Paper No. 724 Broadening Narrow Money: Monetary Policy with a Central Bank Digital Currency*. www.bankofengland.co.uk/working-paper/Working-papers (November 29, 2018).

Moreno Puertas, Alejandro, and Robin Teigland. 2018. "Blockchain Technology: The Internet of Value." In *The Rise and Development of Fintech: Accounts of Disruption from Sweden and Beyond*, eds. Robin Teigland et al. London, UK: Routledge, 276–308.

Nakamoto, Satoshi. 2008. "Bitcoin: A Peer-to-Peer Electronic Cash System." https://bitcoin.org/bitcoin.pdf (February 17, 2019).

———. 2009. "Bitcoin Open Source Implementation of P2P Currency | Satoshi Nakamoto Institute." https://satoshi.nakamotoinstitute.org/posts/p2pfoundation/1/ (December 9, 2018).

Pereira Da Silva, Luiz Awazu, and Phurichai Rungcharoenkitkul. 2017. *QE Experiences and*

*Some Lessons for Monetary Policy: Defending the Important Role Central Banks Have Played.* https://www.bis.org/speeches/sp170407.pdf (November 28, 2018).

Pfeifer. 2011. “Should We Use Posterior Mean or Posterior Mode.” https://forum.dynare.org/t/should-we-use-posterior-mean-or-posterior-mode/2138 (June 3, 2019).

Pfeifer, Johannes. 2018. *A Guide to Specifying Observation Equations for the Estimation of DSGE Models.*

Sims, Eric. 2011. *Graduate Macro Theory II: Notes on Log-Linearization.* https://www3.nd.edu/~esims1/log_linearization_sp12.pdf (May 12, 2019).

Sveriges Riksbank. 2017. *The Riksbank’s e-Krona Project (1).* Stockholm, Sweden.

———. 2018. *The RiskBank’s e-Krona Project (2).*

Yves Mersch. 2017. “Digital Base Money: An Assessment from the ECB’s Perspective.” https://www.ecb.europa.eu/press/key/date/2017/html/sp170116.en.html (November 30, 2018).

# Appendix A – Baseline DSGE Model

As explained throughout this MSc Thesis, the baseline model described below has been obtained from Gerali et al (2009).

**Households**
Households are divided into two groups; (i) patient and impatient households and (ii) entrepreneurs.

**Patient households**
Patient households do not borrow and only deposit money in their banks. Their utility depends on (i) the amount of consumption relative to the previous period, (ii) the housing services received and (iii) the hours worked.

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \varepsilon_t^z \left[ \log(c_t^P(i) - a^P c_{t-1}^P) + \varepsilon_t^h log h_t^P(i) - \frac{l_t^P(i)^{1+\phi}}{1+\phi} \right]$$

where:

$\beta_P$ is the discount rate for patient households

$\varepsilon^z$ is the intertemporal shock to preferences

$c^P$is consumption of households

$a^P$ is the degree of habit formation in consumption

$\varepsilon^h$ is exogenous shock to the demand of housing

$h^P$ are housing services

$l^P$ is the hours worked

$\phi$ is a symbol that defines the hours worked impact on the household utility.

Their income is obtained through (i) labour, (ii) past deposits and (iii) a lump-sum transfer, which includes a labor fee and dividends from the retail and banking sector. Their expenses include (iv) its current level of consumption, (v) the accumulation of housing services and (vi) the money deposited at the bank.

$$\underbrace{W_t^P l_t^P(i) + \frac{1 + r_{t-1}^d}{\pi_t} d_{t-1}^P(i) + T_t^P}_{Income} \geq \underbrace{c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t^P(i)}_{Expenses}$$

where:

$q^h \Delta h_t^P(i)$ accumulation of housing services

$d^P$ are deposits made in this period.

$W^P$ is the wage

$\pi_t$ is inflation

$T$ is a lump-sum transfer that includes (i) labour union fee, dividends from retail firms ($J^P$) and banking sector dividends $\frac{(1-w^b)J_{t-1}^b}{\pi_t}$.

**Impatient household**

Impatient households only borrow from their banks and do not deposit money on them. Their utility follows a similar path to the patient ones.

$$E_0 \sum_{t=0}^{\infty} \beta_I^t \varepsilon_t^z \left[ \log(c_t^I(i) - a^I c_{t-1}^I) + \varepsilon_t^h log h_t^I(i) - \frac{l_t^I(i)^{1+\phi}}{1+\phi} \right]$$

where:

$c^I, h^I, a^I, l^I, \beta_I$ are the impatient parameters.

However, their income can be increased through new loans and their expenses also take into account the debt repayments.

$$W_t^I l_t^I(i) + b_t^I(i) + T_t^I \geq \ c_t^I(i) + q_t^h \Delta h_t^I(i) + \frac{1 + r_{t-1}^{bH}}{\pi_t} b_{t-1}^I$$

where:

$r^{bH}$ is the interest rate paid on loans

$b^I$ is the total amount of loans

$T^I$ net fees paid to labour unions.

Furthermore, the loans that will be repaid on the next period must be lower than the expected housing stock in the next period multiply by the loan-to-value ratio.

$$\left(1+r_t^{bH}\right)b_t^I(i) \leq m_t^I E_t[q_{t+1}^h h_t^I(i)\pi_{t+1}]$$

where:

$m^I$ is the (stochastic) loan-to-value ratio (LTV) for mortgages and $(1-m^I)$ is the proportional cost of collateral repossession for banks given default.

**Entrepreneurs**

Entrepreneurs utility only depend on its current consumption relative to its previous one.

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \log\left(c_t^E(i) - a^E c_{t-1}^E\right)$$

Nonetheless, their income and expenses varies a lot compared to both patient and impatient households. Entrepreneurs income depends on the sale of the produced good, which is sold to wholesalers at a fraction of the final price, loans and old physical stock that has been depreciated. Their expenses depend on the current consumption, paid wages, debt repayments, physical stock obtained and the cost of setting an utilization rate.

$$\frac{y_t^E(i)}{x_t} + b_t^E(i) + q_t^k(1-\delta)k_{t-1}^E(i)$$
$$\geq c_t^E(i) + W_t l_t^E(i) + \frac{\left(1+r_{t-1}^{bE}\right)b_{t-1}^E(i)}{\pi_t} + q_t^k k_t^E(i) + \psi\left(u_t(i)\right)k_{t-1}^E(i)$$

where:

$y^E$ is the output produced by the entrepreneur

$x$ is the ratio between the final price and the wholesale price ($\frac{P}{P^W}$)

$W_t$ is the aggregate wage index;

$q^k$ is the price of one unit of physical capital in terms of consumption;

$k^E$ is the stock of physical capital

$\psi\left(u(i)\right)k^E(i)$ is the cost of setting a level $u_t(i)$ of utilization rate;

The produced good ($y^E$) depends on the productivity level, the utilization rate of the previous physical capital stock and labour employed.

$$y_t^E(i) = a_t^E[k_{t-1}^E(i)u_t(i)]^\alpha l_t^E(i)^{1-\alpha}$$

where:

$a^E$ is an exogenous process for total factor productivity (TFP)

Furthermore, the loans that will be repaid in the next period depend on the entrepreneurs loan-to-value ratio with respect to the expected depreciated capital stock of the current period.

$$(1 + r_t^{bE})b_t^E \leq m_t^E E_t\left(q_{t+1}^k \pi_{t+1}(1-\delta)k_t^E(i)\right)$$

where:

$m^E$ is the loan-to-value ratio of the entrepreneur

**Loan and Deposit Demand**

<u>Impatient Household Loan</u>

The demand for a loan at bank j depends on the (i) borrowing rate they offer compared to the average borrowing rate, (ii) the household elasticity of substitution and (iii) the aggregate demand for household loans. The elasticity of substitution indicates the household response to an increase in the interest rate.

$$b_t^H(j) = \left(\frac{r_t^{bH}(j)}{r_t^{bH}}\right)^{-\varepsilon_t^{bH}} b_t^I$$

$$r_t^{bH} = \left[\int_0^1 r_t^{bH}(j)^{1-\varepsilon_t^{bH}} dj\right]^{\frac{1}{1-\varepsilon_t^{bH}}}$$

Where

$b_t^I \equiv \gamma^I b_t^I(i)$ is the aggregate demand for household loans in real terms; and

$r_t^{bH}$ is the average interest rate on loans to households

$\varepsilon_t^{bH}$ elasticity of substitution between loan and policy rate

<u>Entrepreneur Loan</u>

The entrepreneur loan demand follows the same structure as the impatient household loans but with different parameters ($r_t^{bE}, b^E, etc \ldots$).

Deposits

The demand for deposits also follows a similar structure to the loan demand.

$$d_j^P(j) = \left(\frac{r_t^d(j)}{r_t^d}\right)^{\varepsilon_t^d} d_t$$

$$r_t^d = \left[\int_0^1 r_t^d(j)^{1-\varepsilon_t^d} dj\right]^{\frac{1}{1-\varepsilon_t^d}}$$

Where:

$d_t^d(j) \equiv \gamma^P d_t^P(i)$ is the aggregate demand for deposits; and

$r_t^d$ is the aggregate deposit rate.

## The Banking Sector

The Banking sector is composed of (i) wholesale branches, (ii) retail deposit branches and (iii) retail lending branches. Wholesale branches face a perfectly competitive market while retail branches face a monopolistic competitive one.

Wholesale Branches

Wholesale branches revenues come from debt repayments and their expenses stem from the rate paid to depositors and the cost of deviating from the optimal capital asset ratio.

Whole Branches profits:

$$\max E_0 \sum_{t=0}^{\infty} \lambda_{0,t}^p \left[\underbrace{(1+R_t^b)B_t(j)}_{Debt\ repayment} - \underbrace{(1+R_t^D)D_t(j)}_{Depositors'payments} \underbrace{- K_t^b(j) - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t(j)} - v^b\right)^2 K_t^b(j)}_{\substack{Costs\ of\ deviating \\ from\ the\ optimal\ ratio\ (v)}}\right]$$

subject to the following constraint:

$$B_t(j) = D_t(j) + K_t^b(j)$$

where:

$\lambda_{0,t}^p = \lambda_t^P$ is the discount factor of the banks.

$R_t^b$ is the lending rate paid by wholesalers.

$B_{t(j)}$ are the total amount of loans given to wholesalers.

$R_t^D$ is the deposit rate paid to wholesalers.

$D_t(j)$ is the total amount of deposits.

$K_t^b(j)$ is the bank equity.

$\kappa_{Kb}$ is the cost of capital ratio divergences.

$v^b$ is the optimal capital/asset ratio.

Loan Retail Branches

Loan retail branches revenues come from the interest rates paid by households and entrepreneurs while its expenses stem from the cost of obtaining wholesale loans and the adjustment cost from changing those rates.

The loan retail branches aim to maximize profits given the following equation:

$$\max_{\{r_t^{bH}(j), r_t^{bE}(j)\}} E_0 \sum_{t=0}^{\infty} \lambda_{0,t}^P \left[ r_t^{bH}(j) b_t^H(j) + r_t^{bE}(j) b_t^E(j) - R_t^b B_t(j) - \frac{\kappa_{bH}}{2} \left( \frac{r_t^{bH}(j)}{r_{t-1}^{bH}(j)} - 1 \right)^2 r_t^{bH} b_t^I - \frac{\kappa_{bE}}{2} \left( \frac{r_t^{bE}(j)}{r_{t-1}^{bE}(j)} - 1 \right)^2 r_t^{bE} b_t^E \right]$$

subject to:

$$B_t(j) = b_t(j) = b_t^I(j) + b_t^E(j)$$

where:

$\lambda_{0,t}^P = \beta^P$ is the discount factor for the banks;

$r_t^{bH}$ is the lending rate given to households

$b_t^H$ is the total amount of loans given to households

$r_t^{bE}$ is the lending rate given to entrepreneurs

$b_t^E$ is the total amount of loans given to entrepreneurs

$R_t^b$ is the wholesale rate paid on loans

$\kappa_{bH}$ is the adjustment costs from changing the interest rate to households

$\kappa_{bE}$ is the adjustment cost from changing the interest rate to entrepreneurs

Deposit Retail Branches

Deposit retail branches revenues come from the risk free rate obtained from deposits while its expenses stem from the rate paid to depositors and the adjustment costs from changing that rate.

The deposit retail branches maximize profits given the following equation:

$$\max_{\{r_t^d(j)\}} E_0 \sum_{t=0}^{\infty} \lambda_{0,t}^P \left[ r_t D_t(j) - r_t^d(j) d_t(j) - \frac{\kappa_d}{2} \left( \frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right)^2 r_t^d D_t \right]$$

subject to deposit demands

$$d_t(j) = \left( \frac{r_t^d(j)}{r_t^d} \right)^{\varepsilon_t^d} D_t$$

Capital Good Producers

Capital Good Producers (CGP) are necessary to obtain a market price for capital. This is essential to establish the entrepreneur's collateral, which is used against bank loans. The following equation shows the composition of new capital stock:

$$k_t(j) = (1-\delta) k_{t-1}(j) + \left[ 1 - \frac{\kappa_i}{2} \left( \frac{\varepsilon_t^{qk} i_t(j)}{i_{t-1}(j)} - 1 \right)^2 \right] i_t(j)$$

Where:

$1 - (\delta)$ is the depreciation rate

$\kappa_i$ is the parameter measuring the cost for adjusting investment

$\varepsilon_t^{qk}$ is a shock to the productivity of the investment good.

$i(j)$ is the final good from the retailer

This new capital stock is then sold, to the entrepreneur, at $P_t^k$.

**Monetary Policy**

Assumption: Zero width policy-rate corridor. Profits are evenly rebated in a lump-sum fashion to households and entrepreneurs. Monetary authority follows a Taylor-rule of the type:

$$(1 + r_t) = (1 + r_t)^{1-\phi_R}(1 + r_{t-1})^{\phi_R}\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\phi_R)}\left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_y(1-\phi_R)}\varepsilon_t^R$$

Where:

$\phi_\pi$ is the weight assign to inflation stabilization

$\phi_y$ is the weight assign to output stabilization

$r$ is the steady state nominal interest rate

$\varepsilon_t^R$ is an exogenous shock to monetary policy.

Aggregation and Market Clearing

Equilibrium is reached through the following equation

$$Y_t = C_t + q_t^k[C_t - (1-\delta)K_{t-1}] + K_t\psi(\mathrm{u_t}) + Adj_t$$

Where:

$C_t = c_t^P + c_t^I + c_t^E$ is aggregate consumption;

$Y = \gamma^E y^E(i)$ is the aggregate output;

$K = \gamma^E k^E(i)$ is the aggregate stock of physical capital; and

$Adj$ is the real adjustment cost for prices, wages, and interest rate.

Finally, equilibrium in the housing market is reached through:

$$\bar{h} = \gamma^P h^P(i) + \gamma^I h^I(i)$$

Where $\bar{h}$ is the exogenous fixed housing supply stock.

# Appendix B – Data Sources description

| | |
|---|---|
| GDP | Working day and seasonally adjusted, constant prices ref. year 2017, SEK million. GDP at market prices. Statistics Sweden |
| Consumption | Household consumption expenditure (ESA2010), seasonally adjusted current prices, SEK million by purpose and quarter, total consumption. Statistics Sweden. |
| Investment | Fixed capital formation (ESA2010) seasonally adjusted constant prices reference year 2017, SEK million by industrial classification NACE Rev. 2 and quarter. Statistics Sweden. |
| CPIF | CPIF index by month. Statistics Sweden. |
| Real Wage | Labour cost index for wage-earners in private sector, preliminary index figures by industrial classification NACE Rev. 1.1 and month |
| Real Loans to firms | Loans to non-financial corporations. Statistics Sweden |
| Real loans to households | Loans to households. Statistics Sweden |
| Real house prices | Assessed value for one- and two-dwelling buildings for permanent living, average in 1 000 SEK by region and quarter. Statistics Sweden |
| Firm lending rate | Lending rates to non-financial corporations, percent by reference sector, counterparty sector, agreement, original rate fixation and month. Statistics Sweden. |
| Household Lending rate | Lending rates to households percent by reference sector, counterparty sector, agreement, original rate fixation and month. Statistics Sweden |
| Deposit Rate | Deposit Rate – average. The Sverige Riksbank |
| Repo Rate | Repo Rate – average. The Sverige Riksbank. |