Estimating the Effective Lower Bound for the Czech National Bank's Policy Rate

Kolcunova, Dominika and Havranek, Tomas

Czech National Bank, Charles University, Prague

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Dominika Kolcunova, Tomas Havranek*

Abstract

The paper focuses on the estimation of the effective lower bound for the Czech National Bank's policy rate. The effective lower bound is determined by the value below which holding and using cash would be more convenient than deposits with negative yields. This bound is approximated based on storage, the insurance and transportation costs of cash and the costs associated with the loss of the convenience of cashless payments and complemented with the estimate based on interest charges, which present direct costs to the profitability of the bank. Overall, the estimated value is below −1% and is approximately in the interval −1.6%, −1.1%. In addition, by means of a vector autoregression, we show that the potential of negative rates would not be sufficient to deliver monetary policy easing with effects similar to those of the exchange rate commitment.

JEL Classification: E52, E58, E43, E44

Keywords: effective lower bound, zero lower bound, negative interest rates, costs of holding cash, transmission of monetary policy

*Dominika Kolcunova (corresponding author), Charles University in Prague and Czech National Bank, dominika.kolcunova@cnb.cz

Tomas Havranek, Charles University in Prague and Czech National Bank, tomas.havranek@cnb.cz

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1 Introduction

In the years after the outbreak of the global financial crisis, central banks have cut their policy rates, which are now at their historical minimum, on average every three days. Since 2012, several central banks in Europe and the Bank of Japan have moved their key policy rates even further into the negative territory as one of the unconventional monetary policy measures aimed at providing further monetary policy easing. In addition to potential benefits, negative rates, however, also comprise several drawbacks, including reducing the profits of banks and consequent potential negative effects on their stability as well as the stability of insurance companies and pension funds. Irrespective of whether pros or cons prevail, by imposing negative policy rates, central banks have disproved the traditional view that nominal interest rates cannot fall below zero as implied by the concept of the zero lower bound (ZLB).

The ZLB resides in the assumption that investors can always switch from deposits to cash, which is often characterized as an asset with zero yield, instead of accepting negative interest rates. Thus, it may seem that the power of negative rates is inherently limited by the existence of cash. However, holding and using cash, especially in large amounts, is not costless, and therefore, the effective yield of cash *is negative*. Therefore, the notion of an effective lower bound (ELB) on interest rates is introduced. This lower bound is given by a threshold below which holding deposits with negative interest rates is more costly than holding cash and below which a flight to cash could be provoked, consequently causing the ineffectiveness of negative rates.

The main aim of the paper is to estimate the level of this lower bound for the policy rate in the Czech Republic. Specifically, we want to approximate the level of costs of holding and using cash that consist of storage, transportation and insurance costs and the costs of loss of convenience associated with electronic transactions. Within the second approach to the problem, we estimate the direct costs to banks' profitability induced by negative interest rates with respect to the specific characteristics of the Czech economy and financial market conditions. We are interested primarily in two hypotheses: first, whether the ELB is below −1%, and second, whether the more important sources of the ELB are the costs of storage and insurance or, alternatively, the convenience of cashless payments.

In addition to the costs of holding and using cash itself, the expected duration of negative rates is important in determining the ELB. The longer the duration of negative rates is, the more probable converting into cash should be. Nevertheless, the international experience with negative rates has already proven that they may last several years without any significant signs of a surge in the demand for cash, muted transmission to money market rates or disruptions in the functioning of the financial system. Overall, our results suggest the ELB is indeed below −1%, most likely in the interval −1.6%, −1.1%. With a shorter duration and a kind of tiered system, the estimate could be less conservative. On the other hand, with a longer duration and/or without a tiered system, the rate could be closer to −1% or even closer to zero. The estimate for the ELB is found to be pulled down by the high costs of loss of convenience, which are significantly higher than the costs of storage and insurance. In contrast, a high share of assets that would be subject to negative rates shifts the value of the estimate closer to zero.

The remainder of the paper is organized as follows. Section 2 briefly presents the related literature and the international experience with negative interest rates. Section 3 overviews negative rates in different parts of the Czech financial market, and Section 4 contains the estimation of the ELB. Sections 5 complements the paper with a monetary VAR model suggesting that the policy rate would have had to fall below its ELB from Section 4 in order to provide sufficient monetary policy stimulus if it had been the only unconventional instrument used. Section 6 provides concluding remarks.

2 Related literature and the international experience

The current literature is rich in research addressing the zero lower bound and mentioning low or negative interest rates as one of the unconventional monetary policy measures. While it could be beneficial to discuss both the merits and drawbacks of this instrument, such a discussion is well beyond the scope of the paper. Rather, we will focus purely on the estimate of the lower bound of negative rates itself. Regardless of whether economists agree with imposing the negative interest rate policy, there is a growing consensus that the ELB is negative rather than zero. Broad estimates suggest it may attain a level as low as -2.0%, and more conservative estimates -1.0% (Jackson, 2015). Nevertheless, the literature lacks the proper research that would explicitly determine the ELB.

Almost isolated country-specific research on this topic has been conducted by Witmer & Yang (2016), who estimated Canada's ELB. Based on evaluating the costs of transporting, storing and holding cash and inconvenience costs and using assessments of the market adaptation in other countries, their best estimate lies in the interval between -0.75% and -0.25%. Much less conservative is the recent report by Barr et al. (2016), who, based on calculating annual direct costs, suggest that rates could be cut to as low as -4.5% in the euro area, to -1.3% in U.S. and to -2.5% in the United Kingdom when using a tiered system without any critical risk of damage to banks' balance sheets and interest margins. The differences across countries stems from different ratios of reserves, to which negative rates are applied, to total assets. The calibration of tiers aims to be such that the stock of reserves subject to negative rates is as small as possible but still large enough to ensure transmission to money market rates.

The important parameter in determining the ELB is the length of the period of negative rates: the longer this period lasts, the more incentive there is to switch to cash. Bean (2013) argues that without some imposed restrictions on the convertibility of bank reserves into cash, rates much below -0.5% for more than a year or two could initiate a more or less rapid move into cash. Jackson (2015), however, suggests that as long as a positive spread between borrowing and lending rates exists, the absolute level of interest rates is of less importance for intermediaries.

An increasing strand of the literature covers suggestions on how to overcome the lower bound, i.e., restrictions that would prevent a flight to cash, including phasing out paper currency completely or at least phasing out high-denomination notes (Rogoff, 2016), taxing currency or a variable exchange rate between currency and deposits (Buiter, 2015). Instead of an intuitive fee for using cash or for excessive cash holding, Kimball (2015) proposes a premium for clients' withdrawals leading to decrease in the relative value of cash. Other approaches are switching to an electronic money standard and moving away from paper currency by imposing a fee on deposits at a central bank (Agarwal & Kimball, 2015) or using sovereign digital currencies bearing an interest rate set by a central bank (Bordo & Levin, 2017). We do not incorporate these measures into the ELB estimation as they could lead to further decreases in or even a complete removal of the ELB. The important message is that these measures affirm that it should be possible to overcome the binding lower bound in future.

In addition to the theoretical literature, it is important to explore the most crucial conclusions from the international experience with the negative interest rate policy. To date, nine central banks have imposed negative interest rates: the ECB and the central banks of Bosnia and Herzegovina, Bulgaria, Denmark, Hungary, Japan, Norway, Switzerland and Sweden. However, some of the countries are not true examples of the negative interest rate policy: in Bulgaria and Bosnia and Herzegovina, the negative rate was put into effect in order to transmit the ECB's monetary policy stance, not as a measure of active monetary policy, given their policy regime with the Euro as exchange rate anchor. Norway and Hungary are not characterized as countries with the true negative interest rate policy either; rather, their key policy rates remain positive. The rest of the countries (except of Sweden) use variously defined tiered systems: negative rates are applied only to a portion of reserves.

Examining the data from these countries, until now, there has not been any conspicuous evidence that the negative interest rates would cause a depositor flight to cash, significant volatility or impairments to the market functioning. Several authors claim that financial stability has not been compromised by using negative policy rates and that transmission was smooth and swift (Arteta et al., 2016; Alsterlind et al., 2015; Jackson, 2015; Jensen & Spange, 2015, inter alios).

Specifically, a substantial increase in the use of cash was not indicated in any of the countries, as can be seen in Fig. 1. Although the year-on-year percentage changes of the total amount of currency in circulation are positive in the cases of Denmark, Switzerland and Japan, this has been the case through the whole observed period with no exceptional increases after the implementation of the negative interest rate policy. Most of the increase in the currency in circulation can be explained by its normal relation to interest rate movements: the amount of currency in circulation increases when interest rates decline, regardless of whether these rates are positive or negative (Jobst & Lin, 2016). The exception to this assertion is Sweden, where the amount of notes and coins in circulation has been constantly falling since 2007.

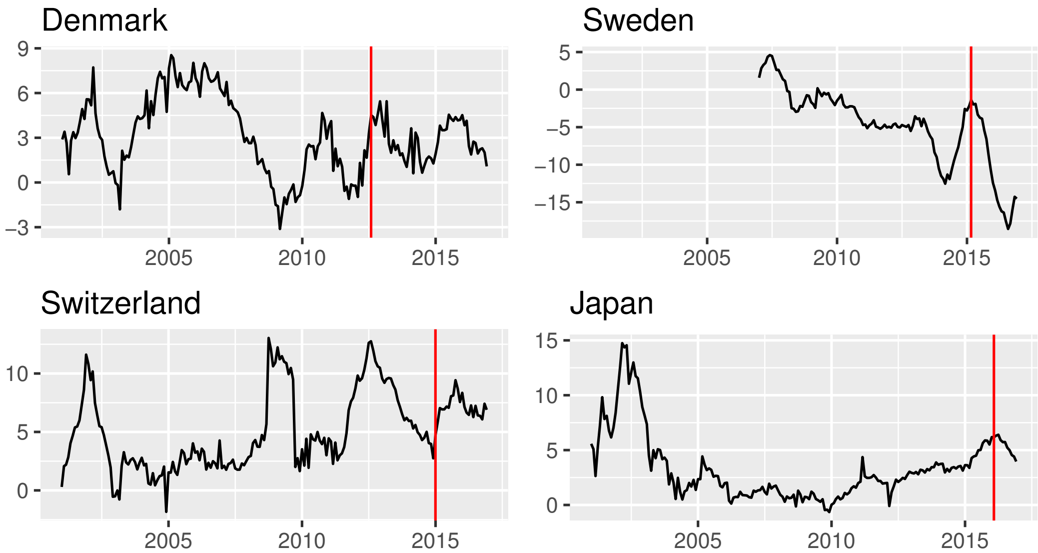
Apparently, the current interest rates did not surpass their lower bound. Nevertheless, as was mentioned before, duration expectations play a significant role in determining where is the threshold below which it would be more advantageous to build storage capacities instead of earning negative yields on excess reserves. Since Denmark implemented a negative interest rate policy already in 2012 (and the period of return to slightly positive rates in between was very short), at the time of this writing, it is possible to say that approximately four to five years of negative rates have not proven to alter expectations such that it would trigger incentives for a move to cash.

Money market rates are the second important indicator. It can be shown that money markets have continued to work smoothly, and there is no indication that the pass-through has been significantly weakened, as can be seen in Fig. 2 where three-month money market rates are almost perfectly correlated with the movement of monetary policy rates and followed policy rates into negative territory.

The last point of view considers commercial lending and deposit rates, which determine bank profitability. Jobst & Lin (2016) find that the lending rates for both the corporate and retail segments were lowered. Deposit rates decreased to some extent as well, allowing for preservation of the margins and increasing credit growth. Negative deposit rates are, however, usually charged only to large institutional depositors and are not passed through to smaller retail depositors, slackening the transmission of the negative interest rates. Similarly, Witmer & Yang (2016) assert that with respect to this reluctance to pass negative rates to retail depositors and decreasing bank profitability, the bank lending channel of transmission may prove to be less powerful. Given this restricted transmission, there are indications that the effect of a one-unit decrease in interest rates in negative territory is likely to have a smaller effect than the same one-unit decrease in rates in positive territory (e.g. Bean, 2013; Jackson, 2015).

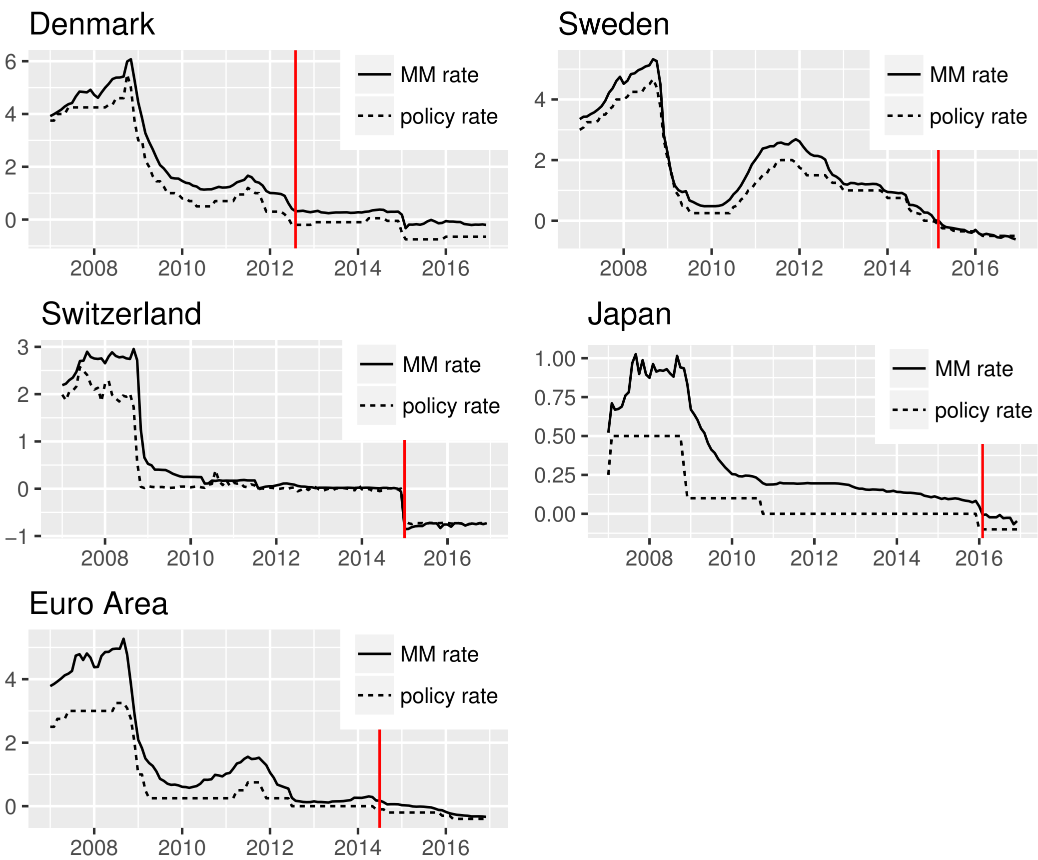
In spite of that, Jobst & Lin (2016) assert that the effect of the negative interest rate policy is so far positive and that its objectives are being fulfilled (lower funding costs, higher asset prices, enhanced signaling effect of monetary policy, enhanced portfolio rebalancing channels, modest credit expansion, and boosted aggregate demand), while concerns have not proven to materialize. The main concern related to banks' profitability has been mitigated until now. Jobst & Lin (2016) estimated that in the euro area, the effect was small, a decline of 50 basis points in interest rates caused a 7 basis-point reduction in net interest margins. Even in cases with sticky retail deposit rates, banks compensated the lower margins by the higher volume of lending and increases in fees and commissions and profited from lower funding costs. Nevertheless, this compensation of higher net interest margins is probably also limited, the impact on bank profitability is non-linear in further declines of policy rates and the returns of lower rates are diminishing.

Fig. 1. Currency in circulation (year-over-year changes in %)



Note: Red lines represent the introduction of the negative interest rates.
Source: National central banks

Fig. 2. Policy rates and money market rates (in %)



Note: Red lines represent the introduction of the negative interest rates. MM = money market.
Source: National central banks

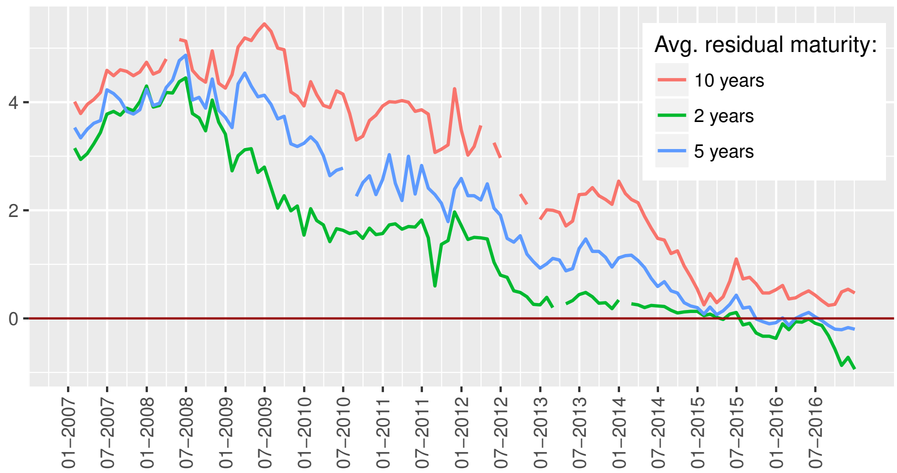
3 Negative rates in the Czech market

Even though the 2W repo rate as the CNB's main policy rate is positive, negative rates already have existed in different parts of the Czech financial market.[1]

Government bonds

At first, Czech government bonds, which financial institutions may store excessive money in, earn negative yields. That holds for all bonds with maturities ranging from one month to six years. Only the bonds with maturities over seven years yield slightly positive returns (as of December 2016). The yield on the basket of government bonds with an average residual maturity of two years has been negative constantly since July 2015, with an average five-year maturity since couple of months later, except for a short period of positive rates in 2016 (Fig. 3). The yield on government bonds has been, however, affected by the exchange rate commitment, and the negative yields may reflect a speculative motive of foreign investors who accepted negative yields in exchange for profits from expected currency appreciation after the exit from the exchange rate commitment.

Fig. 3. Yields on the baskets of government bonds with different average residual maturities



Source: Czech National Bank

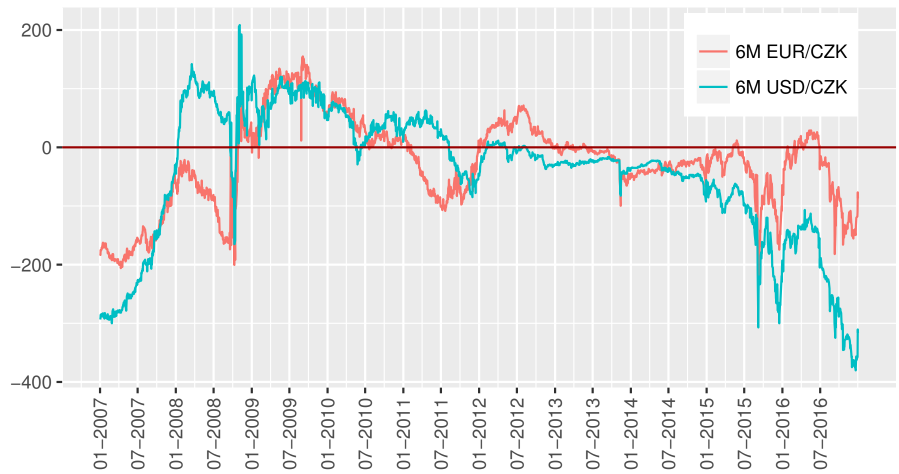
FX swap-implied interest rate

Fig. 4 shows that both the three- and six-month forward points for both currency pairs EUR/CZK and USD/CZK have been already negative for relatively long time. Since the beginning of the CNB's FX interventions, the forward points are almost constantly negative. The forward exchange rate can be calculated by dividing the forward points by 1000 and adding the result to the spot rate. Negative forward points thus imply that the forward exchange rate is below the spot rate, i.e., the implied swap rate (defined as the forward rate minus the forward rate) is negative. At normal times, lower-interest rate currencies tend to trade at a forward foreign exchange rate premium (=positive forward

[1] All of the data are up to date as of December 2016. With the exit from the exchange rate commitment in April 2017, the situation is changing, but monitoring this feature is not the aim of the paper.

points) in relation to another currency offering higher interest rates, according to the covered interest rate parity (CIP), so negative swap rates as such are not an example of the phenomenon of negative rates in an economy. CIP, however, appeared not to hold in every moment, especially not in crisis periods (e.g., negative forward points for CZK/USD and at the same time, the higher US interest rate). Still, a negative implied swap rate means that a nonresident who bought CZK (but did not want to invest in government bonds with negative yields) has to 'pay' for depositing CZK for a given period.

Fig. 4. Forward points EUR/CZK with three- and six-month maturities



Source: Czech National Bank

Selective fees of banks in the Czech market

Of perhaps the greatest interest, negative rates have been present for several months already also in the Czech banking sector. Several commercial banks have introduced selective fees on deposits above a certain limit, particularly on corporate and institutional depositors. This has been induced by two factors, first by negative rates imposed by central banks in Western Europe and banks' preparation for the quick accommodation to prospective negative rates in the domestic market and second by negative interest rates on government bonds, in which banks can store their excess funds. Instead of a negative rate itself, banks usually impose fees on deposits, what is effectively the same thing. A more detailed overview of fees on deposits can be found in Table 1.

Until now, negative interest rates have not been applied to the smaller deposits of retail clients. However, given the Western Europe experience from the recent months, this state does not seem truly unrealistic any more as two German banks introduced fees on over-limit deposits for private individuals. The longer there are conditions of low growth and negative policy rates, the more probable it will be to pass negative rates on smaller deposits or even on retail customers.

Table 1. Fees on deposits

Bank	**Deposits affected**[1]	**Fee**
Ceskoslovenska Obchodni Banka	Fee for additional deposits if the deposit balance exceeds CZK 100 million[2]	0.15% of the differential balance
Ceska Sporitelna	Fee for additional deposits if the deposit balance exceeds CZK 100 million[2]	0.15% of the differential balance
Komercni Banka	Fee for client's over-the-limit deposits in CHF above CHF 40 thousand	1% p.a.
	Fee for client's over-the-limit deposits in SEK above SEK 400 thousand	1% p.a.
	Fee for client's over-the-limit deposits in DKK above DKK 300 thousand	1% p.a.
	Fee for client's over-the-limit deposits in JPY above JPY 5 million	0.5% p.a.
	Fee for client's over-the-limit deposits in CZK above CZK 1 bilion	0.2% p.a.
	Fee for client's over-the-limit deposits in EUR above EUR 40 million	0.5% p.a.
Unicredit Bank	Fee for additional deposits if the deposit balance exceeds CZK 100 million[2]	0.15% of the differential balance
	Fee for client's over-the-limit deposits in CZK above CZK 100 million[2]	0.5% p.a.
	Fee for client's over-the-limit deposits in EUR above EUR 3 million	0.5% p.a.
	Fee for client's over-the-limit deposits in CHF above CHF 100 thousand	0.5% p.a.
Hypotecni banka	x	x
Raiffeisenbank	Fee for additional deposits if the deposit balance exceeds CZK 100 million[2]	0.15% of the differential balance
	Fee for client's over-the-limit deposits in CHF above CHF 1 million	1% p.a.
	Fee for client's over-the-limit deposits in JPY above JPY 100 million	1% p.a.
	Fee for client's over-the-limit deposits in DKK above DKK 3 million	1% p.a.
	Fee for client's over-the-limit deposits in SEK above SEK 3 million	1% p.a.
	Fee for client's over-the-limit deposits in EUR above EUR 1 million[3]	1% p.a.
	Fee for client's over-the-limit deposits in CZK above CZK 100 million[3]	0.5% p.a.
J&T Banka	x	x
Moneta Money Bank	Fee for additional deposits if the deposit balance exceeds CZK 100 million[2]	0.15% of the differential balance
PPF banka	Fee for additional deposits if the deposit balance exceeds CZK 100 million[2]	0.15% of the differential balance
Fio Banka	Fee for additional deposits if the deposit balance exceeds CZK 100 million[2,4]	0.15% of the differential balance
Air Bank	x	x
Sberbank	Fee for additional deposits if the deposit balance exceeds CZK 50 million[2]	0.18% of the differential balance
Equa Bank	x	x
Wuestenrot hypotecni banka	x	x
Expobank	Fee for additional deposits if the deposit balance exceeds CZK 30 million[2]	0.15% of the differential balance

[1] In most cases, fees are applied to the corporate sector, usually entrepreneurs, enterprises, public sector and other legal entities
[2] Fees are applied if the deposit balance exceeds a given amount as of 31 December and the deposit balance is higher than the average yearly deposit balance
[3] Applied only to financial customers [4] Applied also to private individuals
We include all big, medium-sized and small commercial banks except for two majority state-owned banks. Savings banks and branches of foreign banks are not included.

Source: Collected from the banks' price lists and websites

4 Effective lower bound estimate

Finally, the following section focuses on the estimation of the effective lower bound for the CNB's policy rate. The bound is given by the existence of cash that restricts interest rates to fall far below zero. At the same time, holding and using cash have some costs that induce the bound to be below zero. The costs of holding cash could be specified as costs associated with storing, transporting and insuring cash. The costs of using cash can be approximated by the costs of the loss of convenience of using non-cash payments. The following subsections focus more deeply on these particular sources of the ELB.

4.1 Storage, transportation and insurance costs

Storage, transportation and insurance costs represent significant impediments to provoking an abrupt move into cash near zero level. These costs can be approximated with the storage costs for other stores of value, for instance, precious metals like gold, silver or platinum or other minerals like crude oil.

Keohane (2015) asserts that the annual costs of carry for gold are approximately 0.2%. However, based on physical characteristics, he argues that crude oil may be the better approximation with respect to similar physical characteristics (space occupied, resistance, etc.). Depending on the type of storage, crude oil storage costs may attain values from 1 to even 10%. We will, however, consider the lower bound of this interval to be closer to the value for gold. Witmer & Yang (2016) suggest that storage costs, including insurance costs, are 0.2-0.35% for gold and 0.4-0.5% for silver (thus, the price is not linear in space, as with silver, the same value occupies much more than two times the space for gold). Jackson (2015) asserts that the costs of storage, including insurance costs, lie in the interval from 0.2-1.0%.

The costs associated with precious metals do not include only storage but also the costs of conversion between precious metals and cash, i.e., transaction costs. Transaction costs depend on the amount, and the time of storage can be found in the services of online bailment service providers, where large volumes incur storage costs of 0.12% and one-year total costs (including transaction costs) of 0.22%.[2] This value is near the lower bound of aforementioned intervals from Jackson (2015); Witmer & Yang (2016).

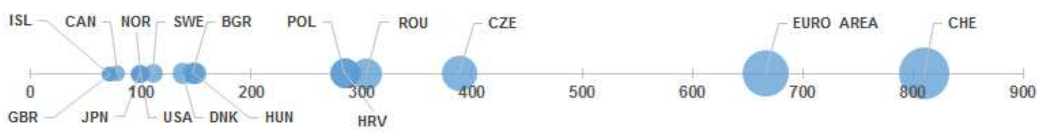
As far as the storage capacities of Czech Republic are concerned, they are provided only by the Czech Mint and several small vault providers and limited to satisfying the small demand of retail customers. The costs of storing precious metals in the Czech Mint are relatively low, ranging from 0.003% to 0.15% depending on the stored amount. However, the increased demand for cash storage after hypothetical cash hoarding would very likely lead to an escalation in storage and insurance costs as neither the amount of cash that can be stored nor the amount that can be insured is infinite. Therefore, we suspect that the current fees could be too low for determining the costs of storing cash on a larger scale. In summary, we will assume that the values of the costs of storing commodities do not differ a lot across countries, and therefore, we suggest the global (wholesale) estimates of the costs of storing and insuring precious metals from the literature are reasonable

[2] Source: https://www.bullionvault.com/cost-calculator.do. Online bailment service providers are an alternative to traditional full-service bailment companies and safe deposit boxes in vaults.

estimates for the Czech Republic as well.

What can, however, ensure a more accurate estimate of the level of currency storage and transportation costs in a given country is the real currency denomination. Currencies with larger denomination should incur smaller storage, transportation and insurance costs and vice versa (Jackson, 2015). The largest banknote in Switzerland is 1000 CHF (1027 USD), 500 EUR (560 USD) in the euro area, 1000 DKK (150 USD) in Denmark and 5000 CZK (214 USD) in the Czech Republic. In real terms (adjusted by purchasing power parities, PPP), the largest denomination of the Czech koruna is larger than the largest denominations in other countries outside the euro area (Fig. 5). However, the largest denomination of Swiss franc and euro is 2.1 times and 1.7 times larger than the largest denomination of Czech koruna. Based on that we could assume the storage costs should be higher for the Czech koruna than for the Swiss franc, however, we do not a linear dependence as there are some fixed costs associated with transportation and storage that do not depend on denomination. The real value of the largest denomination of the Czech koruna is just slightly below the middle point of the interval of the compared denominations of European currencies but well above the mean value and even more above the median. Accordingly, we estimate storage costs to attain the value in the lower half of the interval provided by Jackson (2015), i.e., 0.2-0.6%. In contrast to Jackson (2015), Witmer & Yang (2016) do not find this dependence important as they assert that insurance costs, which do not depend on denomination substantially, are the main component of costs of holding cash rather than the costs for the storage itself, and therefore, currency denomination does not play a crucial role.

Fig. 5. The largest denominations in real terms (PPP) in U.S. dollars (as of December 2016)



Source: OECD, author's calculations

The next way of approximating storage costs employs precious metal-backed ETFs (physically-backed ETFs), which are liquid financial instruments for investing in precious metals stored in vaults. Thus, Table 2 provides an overview of fees of physically backed ETFs traded on the European stock exchanges (London Stock Exchange, Deutsche Borse, Borsa Italiana) with vaults located in Europe (since ETFs can be traded globally and there are not any ETFs traded on Prague Stock Exchange with vaults located in the Czech Republic). Following Witmer & Yang (2016), we can assume that fund-management fees and expenses are a small portion of the total fees based on the fact that overall fees for many equity ETFs are low, between 5 and 10 basis points. Therefore, it appears that an excess fee for physically-backed commodity funds in comparison with non-physically-backed funds is a result of costs of storing and insuring bullions in vaults. This can be then regarded as an approximation of the costs of storing cash, and indeed, it is again similar to previous values of publicly available costs of storing precious metals: the average fee for ETFs is approximately 0.4%, and subtracting 0.05-0.1% of management fees yields 0.3-0.35% of storage and insurance costs.

Table 2. Precious metal-backed ETFs

ETF	Currency	Replication method	Vault location	MER (%)
ETFS Daily Hedged Physical Gold	EUR	bullion	London	0.39
ETFS Daily Hedged Physical Gold	GBP	bullion	London	0.39
ETFS Physical Gold	USD	bullion	London	0.39
ETFS Physical Gold	GBP	bullion	London	0.39
ETFS Physical Palladium	USD	bullion	Zurich, London	0.49
ETFS Physical Platinum	USD	bullion	Zurich, London	0.49
ETFS Physical PM Basket	USD	bullion	Zurich, London	0.44
ETFS Physical PM Basket	GBP	bullion	Zurich, London	0.44
ETFS Physical Silver	USD	bullion	London	0.49
ETFS Physical Silver	GBP	bullion	London	0.49
ETFS Physical Swiss Gold	USD	bullion	London	0.39
Gold Bullion Securities	USD	bullion	London	0.4
Gold Bullion Securities	GBP	bullion	London	0.4

Source: ETF Securities (2017). https://www.etfsecurities.com/retail/se/en-gb/products.aspx

4.2 Loss of convenience

Interchange fees

The second component of the ELB is the loss of convenience of using electronic money instead of cash (i.e., the inconvenience of using cash) and is often proxied by interchange fees set by operators of payment cards schemes and incorporated in the final prices charged to consumers. Assuming that consumers are aware of the fees, we may conclude that these fees are roughly equal to their utility from using different kinds of electronic payments instead of cash payments. Thus, the loss of this convenience must be included in the costs of using cash too.

The current state is, however, significantly affected by the regulation on interchange fees for card-based payment transactions[3], which lowers and unifies interchange fees across the EU to 0.2% of the value of transactions for consumer debit cards and to 0.3% for consumer credit cards. Nevertheless, given our objective, the interchange fees from the period before the regulation are of higher informative value, especially for the Czech Republic, since the country had one of the highest average levels of interchange fees in the EU: in 2014, the average fees charged by Visa were 1%, and those by MasterCard reached even 1.1%. The fees for commercial cards, which are not affected by the regulation, are even higher, with the average being approximately 1.5% of the value of a transaction.

The magnitude of the loss of convenience is the result of consumer preferences. On the one hand, the number of electronic transactions per household is much lower in the Czech Republic than in leading countries, the share of ATM cash withdrawals is higher than the European average, and the share of electronic POS transactions smaller (ECB, 2016). On the other hand, the Czech Republic is one of the top-performing countries in using contactless payments: there are 0.79 contactless cards per person, much above the European average, and 76% of the POS terminals are contactless, whereas the European average

[3] Regulation (EU) 2015/751 of the European Parliament and of the Council of 29 April 2015

is approximately 21% (LTP, 2016). Smart Payment Association (2016) points out that 77% of all in-store payments (processed by MasterCard) were contactless in 2015. This rate is higher than that in other Central European countries: 55% in Poland, 40% in Hungary and 38% in Slovakia.

While foreign studies show that cash is still dominant for low transaction amounts (e.g. Arango et al., 2011), others find that the share of cash payments is decreasing (e.g. Mooslechner et al., 2012; Amromin & Chakravorti, 2009). Moreover, an active user of contactless payments does not have any incentive to use cash even for small transaction amounts. According to Fung et al. (2012), the active usage of contactless payments leads to decrease in the ratio of cash purchases to total expenditures by 14% in volume and 13% in number of transactions.

In summary, the high preference for cashless and contactless payments in the Czech Republic and declining transactional demand for cash stemming from this preference justify high interchange fees. Given the consumer preferences, the value of the loss of convenience associated with electronic payments for retail users could be even higher than the 1-1.1% proposed by retail interchange fees and possibly up to 1.5% (given by fees for commercial transactions). This value is well above the costs of storage or insurance of cash.

Social and private costs of different payment instruments

An alternative to estimating the costs of the loss of convenience by interchange fees is to use the results from Schmiedel et al. (2012), who estimated the social and private costs of retail payment instruments for 13 EU countries (but not for the Czech Republic). According to his conclusions, the social costs of cash payments constitute almost half of the total social costs of all payments and on average have the lowest unit costs per transaction.

The average costs associated with cash payments per 1 euro of sale is 0.023 euro, i.e., 2.3%, ranging from 1.3 and 3.4%. Lacking a better estimate, we consider the mean value of 2.3% as the reasonable estimate of social costs of cash payments in the Czech Republic. Non-cash payment instruments incur costs as well, and therefore, the relative costs of cash can be determined as a difference between the costs of cash payments and costs of other types of payments. Credit transfers as the most important type with a share almost 70% on the total number of transactions carry average unit costs of 0.2%. Thus, the social costs of cash are approximately 2.1 percentage points higher than the social costs of credit transfers. The second most frequently used cashless payment instrument, a card payment, carries average unit costs of 0.017 per euro of sale (more precisely, a debit card payment, which is less costly). The social costs of cash are 0.6% higher than the social costs of card payments, and therefore, the negative rate of −0.6% should not surge any move to cash.

4.3 Direct costs of negative rates

A completely different approach to estimating the ELB resides in evaluating the direct costs of the negative interest rate policy imposed on the financial sector. We follow a procedure suggested by Barr et al. (2016), who calculates annualized interest rate charges on reserves subject to negative rates and compare them with the size of the aggregate balance sheet, i.e., he calculates the ratio of the amount subject to negative rates times the interest rate to total assets. We applied the same procedure and found that the highest costs inflicted on banking sector are in Switzerland, representing approximately 0.03% of total assets of the aggregated sector (Table 3). In other countries, the costs are considerably smaller. Lacking better evidence, we will assume that Switzerland is already at the lower bound, i.e., the maximal possible direct costs are 0.03% of total assets of the aggregated sector annually. Using this value as a limit, the interest rate that would lead to the same relative costs is calculated for the Czech Republic. We use monthly data on monetary statistics over the period 2013-2016, which are available from the CNB's ARAD database (Table 4).

Table 3. Direct costs of negative rates

	Total reserves	Reserves subject to negative rates	Total assets	**Ratio of annualized interest charges to total assets**
Switzerland	412.90	116.34	3 185.23	**0.027%**
Denmark	203.04	140.83	7 870.69	**0.012%**
Sweden	227.78	227.78	12 286.76	**0.009%**
Japan	297.35	23.80	990.54	**0.002%**

Note: In billions of local currency, except for Japan (trillions).
Averages over periods of the negative interest rate policy, for Denmark only since 2015/01

Source: National central banks, author's calculations

Table 4. Monetary statistics, Czech Republic

	Total assets	O/N deposits at CNB	Reserves (required+excess)	Excess reserves	Repo operations
2013	4 996.11	133.04	58.35	1.99	285.28
2014	5 345.38	216.59	61.67	2.21	420.63
2015	5 638.74	455.68	70.22	6.06	300.79
2016	6 019.38	683.74	92.17	22.79	453.93

Note: Yearly averages. In CZK billions.

Source: Czech National Bank

Several options are calculated as reported in Table 5. At first, we calculate the interest rate that would correspond to 0.03% annual costs if it was imposed only on deposits in the standing deposit facility (under the current non-tiered regime). This suggests the policy rate (discount rate in this case) could decrease to −0.46%.

The second and third options calculate the interest rate if a negative rate is applied in addition to (excess) reserves on the current account with the CNB and to the repo operations[4], which leads to results of −0.38% and −0.21%, respectively. This option is more

[4]Here, it is assumed that the discount rate attains the same value as the repo rate as it was during the periods of interest rate at technical zero.

important as repo operations are the main instrument of monetary policy.

The fourth option introduces a tiered system under which only 25% of the reserve stock is subject to the negative rate that was suggested by Barr et al. (2016) based on the experience in foreign countries and that should ensure sufficient transmission of negative rates into the real economy. With this tiered system, the policy rate could go down as low as −0.84% or −0.9% (depending on whether the required reserves are excluded from the stock subject to negative rates). Given the fact that a tiered system in certain forms is used in all countries with negative interest rates (except for Sweden), we assume this could be also a form used by the CNB in a hypothetical situation of negative rates; therefore, we find this number of approximately −0.9% to be the most realistic estimate amongst other specified options.

The fifth option shows a potential rate of when 2-17% of the national GDP is subject to negative rates. Seventeen percent of the GDP has been subject to negative rates in Switzerland on average; however, given the large size of the Swiss reserve stock, Barr et al. (2016) suggests a benchmark of 2% of GDP since this value was sufficient to keep money market rates close to the negative policy rate in the euro area. The mean value of the interval is slightly below −1%.

Table 5. How low can negative rates go - Czech Republic

Items subject to negative rates:				
O/N deposits	O/N deposits + reserves	O/N deposits + reserves + repos	25% of [O/N deposits + reserves + repos]	2% - 17% of GDP
−0.46%	−0.38% (−0.45%)	−0.21% (−0.23%)	−0.84% (−0.90%)	−1.97% – −0.23%

Note: rates calculated with amounts of excess reserves in brackets

4.4 Technical and legal problems with negative rates

It is important to note there can be also some technical and legal problems associated with the potential implementation of the negative rates in the Czech Republic (e.g. Franta et al., 2014). The costs of these problems could move the ELB back closer to zero. These constraints especially include by-laws where the penalty interest is defined as a multiple of the CNB's discount rate. Without a change in legislation, negative rates would imply that the penalty for debtors in arrears is in fact negative. Similarly, variable rate loans are priced at the PRIBOR rate plus a constant value (the bank's margin), which would decrease intended interest payments, or in extreme cases, creditors would have to start paying money to debtors. Nevertheless, we assume that this is not a sufficient argument for rejecting negative interest rates as by-laws or contracts can be adjusted or simply exempt from the effect of negative interest rates. The international experience shows that technical problems can be overcome.

4.5 Summary

Table 6 summarizes the main findings of the section. At first, the costs of storage and insurance lie in the interval (0.2%, 0.6%). The largest component of the ELB are the costs of the loss of convenience given by the interchange fees, and it is very probable that they attain values above 1% in the Czech Republic. Summing up these two components, we can come up to 1.5% of annual costs. Slightly higher values are attained when the concept of social costs is used.

The mean value of the second approach of direct costs is near 1%. Averaging the two approaches leads to the mean value of approximately 1.4% (*positive* numbers of all different kinds of costs represent a *negative* ELB). Thus, in summary, we suggest the ELB for the CNB's policy rate to be below −1%, and the most reasonable estimate suggests −1.35%. Given the high uncertainty around a point estimate, we suggest that the ELB lies in the interval (−1.6%, −1.1%).

Table 6. Summary table - components of ELB

			Min	Mean	Max
Approach 1	Costs of storage and insurance		0.2	**0.4**	0.6
	Loss of convenience	Interchange fees	1.0	**1.25**	1.5
		Social costs	0.6	**1.35**	2.1
	Total Approach 1			**1.7**	
Approach 2	Direct costs to profitability		0.2	**1.0**	1.9
	Average			**1.35**	

Note: *Positive* numbers of different kinds of costs represent a *negative* ELB.

5 Comparison of the potential of negative interest rates with the CNB's exchange rate commitment

The aim of the following section is to evaluate the strength of an interest rate channel of the monetary policy transmission in the Czech economy. While this has been already done several times (e.g. Havranek et al., 2012; Franta et al., 2014; Borys et al., 2009; Holub, 2008), our ultimate goal is novel: to estimate the effect of potential negative rates at the level of the ELB and to compare it with the effect of the exchange rate commitment, which was used as an unconventional measure from November 2013 to April 2017. In comparison with older studies, the data are updated for the new periods, and a threshold VAR is applied in order to detect potentially non-linear time-varying relations arising from attaining the ZLB. By means of cumulative impulse response functions, we calculate the approximate decrease in interest rate that would be required to equalize the effect of the exchange rate commitment.

Given that the Czech Republic is a small open economy strongly intertwined with the surrounding European economies, it seems important to control for the effect of euro area developments. Imposing block restrictions, under which a foreign block of variables has an impact on domestic variables but in which a shock on domestic variables is assumed to be too small to impact foreign variables, was suggested by many studies focused on small open economies, e.g., Maćkowiak (2006); Cushman & Zha (1997); Zha (1999) or Jarociński (2010), who include foreign variables treated as exogenous variables in order to avoid mistaking monetary authorities' responses to external developments for domestic monetary policy shocks. As far as the research on the Czech economy is concerned, block restrictions are included in e.g., Havranek et al. (2012) or Konecny & Kucharcukova-Babecka (2013).

At first, we start with a simple VAR model with a block of foreign exogenous variables (VARX) as a baseline model of the analysis motivated by the aforementioned Czech studies. The model in a reduced form is as follows:

$$Y_t = \alpha_0 + A_1 Y_{t-1} + \cdots + A_p Y_{t-p} + B_1 X_{t-1} + \cdots + B_q X_{t-q} + U_t \tag{1}$$

where $Y_t \in R^k$ represents endogenous variables, $X_t \in R^m$ is a vector of exogenous variables, α_0 is a vector of intercepts, the A_j and B_j are $k \times k$ and $m \times m$ coefficient matrices, and $U_t \in R^k$ is the vector of errors.

In order to identify structural shocks from the reduced form model, we employ the recursiveness assumption by a specific ordering of the variables. Five variables in the following ordering are used: GDP per capita, harmonized index of consumer prices, the one-month PRIBOR rate and the CZK/EUR exchange rate. The euro area foreign variables vector consists of euro area GDP per capita, harmonized index of consumer prices and the short-term money market rate. All of the data are available at a monthly frequency except for GDP, which is interpolated by the temporal disaggregation method. All of the variables are used in logarithms except for the interest rate, which is used in levels. Data are plotted in Fig. A1 and A2 in the Appendix. The model includes only data up to November 2013 in order to isolate the effect of exchange rate commitment, i.e., the data spans from January 1999 to October 2013. The notation of variables:

$$\begin{aligned} y'(t) &= (GDP_t^{CZ}, HICP_t^{CZ}, IR_t^{CZ}, CZEUR_t^{CZ}) \\ x'(t) &= (GDP_t^{EU}, HICP_t^{EU}, IR_t^{EU}) \end{aligned}$$

Based on the information criteria, we use three lags.[5] The system is stable as all eigenvalues of the companion matrix lie inside the unit circle. As Lutkepohl (2005) suggests, the stationarity of the series in a VAR model is not indeed necessary when the VAR satisfies the stability condition as a whole. Moreover, several studies advise using the additional information encompassed in levels over the differences, e.g., Stock & Watson (1988).[6]

[5]The Hannan-Quinn and Schwarz information criteria suggest lag order 3, and Akaike information criterion and Akaike's final prediction error suggest 6 lags. In order for the model to remain parsimonious, we continue with using 3 lags.

[6]The moduli of transformed eigenvalues of the coefficient matrix together with model diagnostics (the fit of the model, ACF/PACF function of residuals, OLS-CUSUM test for parameter stability) are available upon request.

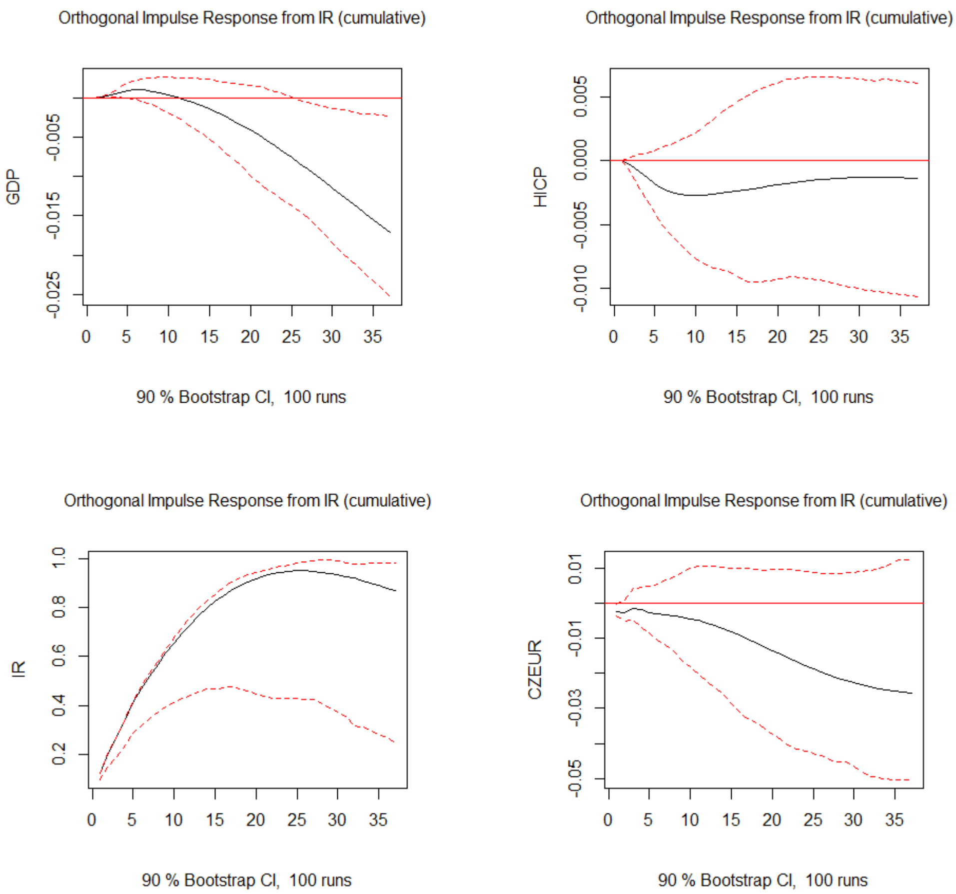
Since we are interested primarily in the interest rate transmission, only the impulse response with IR as a shocked variable are reported graphically. Fig. 6 shows the *cumulative* orthogonal impulse response functions for a three-year period ahead. After three years, expansionary (contractionary) monetary policy expressed by a one-unit negative (positive) shock to the short-term interest rate would lead to a 1.6% increase (decrease) in GDP. The response of GDP is, however, relatively persistent, and the non-cumulative IRF does not converge to zero after three years. After five years, the cumulative IRF is around two times as large. The cumulative effect on consumer prices is slightly negative (no price-puzzle) but is not significantly different from zero as the confidence interval is rather wide. The effect on CZK/EUR exchange rate is negative as expected - after three years, the cumulative response to a one-unit shock in IR causes a 1.3% decline in the exchange rate, even though the effect is less statistically significant. The own response of IR converges to one approximately after 20 months. Both in direction and magnitude, the results are very similar to those by e.g., Havranek et al. (2012).

In order to compare the potential effect of the decrease in interest rates with the observed effect of the exchange rate floor in years 2013-2017, we use results from several studies that are specifically aimed at evaluating the floor. At first, Opatrny (2016) estimates the exchange rate commitment to cause 2% growth in GDP over two years of the commitment and finds no economically or statistically significant effect on inflation. The newest estimates of the effect by Bruha & Tonner (2017) vary between 1.8-2.2% of additional GDP growth over a two-year period depending on the approach used, but they also find a significant effect on inflation. Rather similar results were obtained by Svacina (2015). In our VAR model, during a 24-month period, the effect of a shock to the interest rate accumulates to an approximately 0.7% change in GDP, i.e., the shock should be almost three times larger to equalize it. This would be, however, well below the estimated ELB from Section 4. Thus, given the average responses over the past 15 years, a decrease of the CNB's policy rates into negative territory would not provide enough stimulus, i.e., it would not be so effective in easing of monetary conditions as the exchange rate commitment. This is another argument supporting the views that the exchange rate floor was a correct policy action, as in, e.g., Bruha & Tonner (2017).

Next to the baseline model, different specifications were estimated as well in order to check for the robustness of the model, including a model in growths instead of logarithms and a model with the real effective exchange rate instead of the CZK/EUR rate. All of the results proved to be very similar.[7] Furthermore, in the long-lasting period of binding ZLB, several suggestions to model monetary policy transmission via non-linear VAR models have arisen in the literature in order to capture asymmetric responses to shocks in different periods as ZLB can be viewed as a structural break. VAR models with a non-linear nature can be estimated in various specifications, e.g., threshold models (Balke, 2000; Atanasova, 2003; Konecny & Kucharcukova-Babecka, 2013), Markov switching models (Fujiwara, 2006) and time-varying parameters models (Franta et al., 2014). Most of the studies detect asymmetries in the effect of monetary policy over time. This contributes to our need to examine the possible asymmetries between the period of positive and near-zero interest rates. With respect to this objective - to potentially differentiate between two regimes of behavior - a threshold VAR (TVAR) was chosen as the most straightforward way.

[7]Results are not reported but are available upon request.

Fig. 6. Cumulative impulse response functions - VARX model



The advantage of threshold models is that the threshold value is estimated endogenously, and endogenous switching between models is allowed. The threshold variable itself is chosen exogenously with respect to an intuition about a source of non-linearities, which in our case is the interest rate. A TVAR model can be specified as:

$$Y_t = A^1 Y_t + B^1(L)Y_{t-1} + (A^2 Y_t + B^2(L)Y_{t-1})I(c_{t-d} > \gamma) + U_t \tag{2}$$

where Y_t is a vector of variables, $B(L)$ are lag polynomial matrices and U_t are structural disturbances. c_{t-d} is the threshold variable determining a regime, and $I(c_{t-d} > \gamma)$ is an indicator function that equals one when the threshold variable c_{t-d} is above threshold value γ and is zero otherwise. A TVAR model is estimated on the same data and with the same lag structure as in the baseline model. We check for suspected non-linearity by the multivariate extension of the linearity test with a bootstrap distribution from Hansen (1999). The null hypothesis of a linear VAR is rejected (Table A1 in the Appendix).

Based on the linearity test, TVAR with 3 regimes, TVAR(3) seems more appropriate. We estimate two versions of the model, the first with the time period ending in 2013, when the exchange rate commitment started, in order to prohibit this period from affecting the estimates of the interest rate channel; and the second with a full sample up to the end of 2016 in order to account for a longer period of the ZLB and potentially a different threshold value. However, it is found that the threshold values are identical regardless of whether the last months are included or not. In TVAR(3) model, the thresholds are 3.79% and 2.75% (Fig. A3 in the Appendix).[8] Given the relatively high value of the threshold, we see that the model has not detected the technical zero period as a separate regime. This result can be caused by its short duration or by the fact that there could be indeed no significant asymmetry in ZLB periods (only in low-interest rate environments in general).

Fig. A4 in the Appendix shows the generalized impulse response functions (GIRF) of the TVAR(3) model in the high and low regime. Rather unexpectedly, in the low regime (solid lines), the cumulative response of both GDP and HICP to the shock in IR has a larger magnitude than that in the high regime (dashed lines). Nevertheless, as we showed in the baseline model, the response of HICP was not statistically significant, and for the GDP the difference, was almost negligible and very similar to the response in the baseline model. The response of CZ/EUR is rather puzzling and of opposite direction as in the baseline model. However, when comparing, it is important to have in mind that GIRFs are reported here rather than the orthogonalized IRFs in the baseline VAR.[9] We can still, however, make conclusions about symmetry or asymmetry in responses across two regimes.

In summary, this non-linear approach to VAR modeling showed that there could be potential dissimilarities in the responses to shocks in different regimes dependent on the level of interest-rate; however, the magnitude proved to be relatively small, and we

[8] The middle regime covers only a short period (12%) of a hump in the interest rate between 06/2007 and 12/2008. Detaching this period into another regime seems reasonable and in accord with the intuition and at the same time does not affect the other two regimes drastically.

[9] GIRF, as defined by Pesaran & Shin (1998) integrate variations in all variables after a shock to one variable caused by correlated residuals, while the orthogonalized IRFs control for the correlation among residuals. GIRF are invariant to the ordering of variables.

cannot confirm its significance in terms of credible intervals. The cumulative responses of GDP are similar across regimes and also similar to responses within the baseline model. This result is in line with Franta et al. (2014), who suggest that the monetary policy transmission has remained relatively stable. Therefore, to make conclusions about the interest rate channel, we stick to the more robust baseline model.

6 Conclusion

The paper provides the first publicly available estimate of the ELB for the CNB's policy rate. The ELB constitutes a limit on potential negative rates by setting a threshold below which a flight to cash could be provoked and the negative rate would become ineffective while causing disruptions to the financial system. The ELB is an important variable in monetary policy decision making. The results may be of considerable interest in the event of a future crisis and further need for monetary easing, when the question of negative rates will certainly re-emerge.

Our estimate considers several approximations in order to capture the value as precisely as possible. The ELB is given specifically by the costs of holding and using cash, which are approximated via the costs of storage and insurance of precious metals, costs of commodity-backed exchange traded funds and costs of loss of convenience of cashless payments. The second method tries to capture the direct costs to bank profitability caused by negative rates and set their acceptable level.

There is still relatively large uncertainty associated with the exact value of the ELB. Keeping this mind, the current best point estimate of the ELB lies in the interval $(-1.6\%, -1.1\%)$. This range is in line with our initial hypothesis that the ELB is below -1%. We also confirm that in Czech conditions, the largest proportion of the cost of holding and using cash are the costs of loss of convenience of electronic payments.

With respect to the uncertainty, it is recommended to further monitor the demand for cash, transmission of policy rates and functioning of the financial system in foreign countries with negative rates in order to detect information on whether negative rates are approaching their lower bound, and based on that, to update the estimate for the Czech Republic.

The second part of the paper provides a quantitative analysis of interest rate transmission in the form of a VAR model. Within that endeavor, we have not detected any significant asymmetries in the transmission between regimes of high and low interest rates. At the same time, we showed that given the average responses over the past 15 years, the policy rate would have to decrease below the level of its lower bound in order to provide sufficient monetary policy easing similar in its effects to the impact of the exchange rate commitment. Since quantitative easing is not suitable in the Czech context, CNB's intervention on the FX market was the only available tool that was sufficient to deliver substantial monetary policy easing in 2013.

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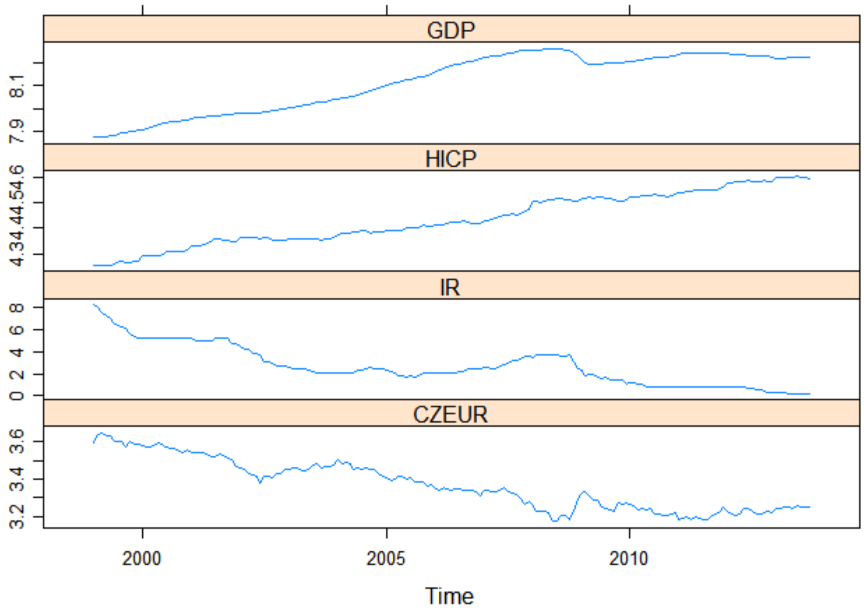
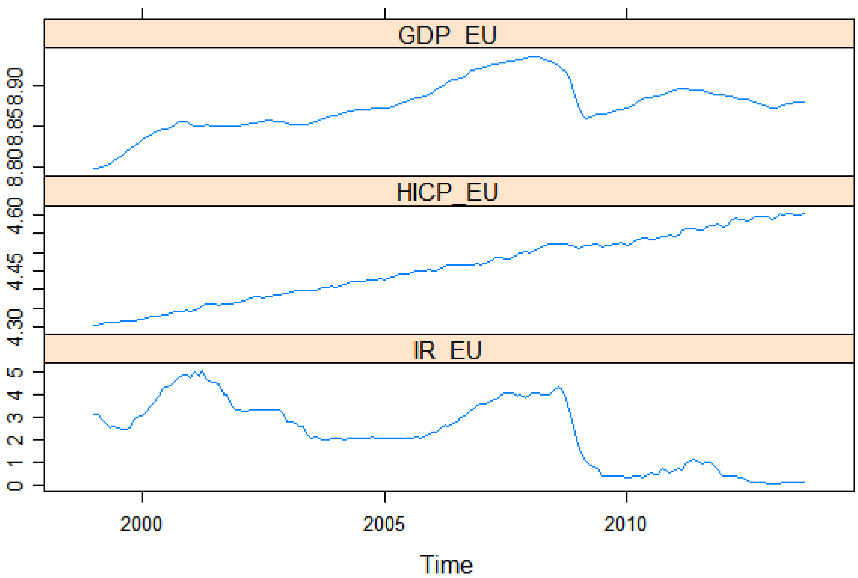
Appendix

Fig. A1. Plots of model variables - Czech variables



Note: GDP – GDP per capita, HICP – harmonized index of consumer prices, IR – one-month PRIBOR rate, CZEUR – CZK/EUR exchange rate. GDP, HICP, CZEUR in logarithms, IR in levels. Source: Czech National Bank, author's calculations

Fig. A2. Plots of model variables - Euro Area variables



Note: GDP_EU – euro area GDP per capita, HICP_EU – euro area harmonized index of consumer prices, IR_EU – euro area short-term money market rate. GDP_EU, HICP_EU in logarithms, IR_EU in levels. Source: Eurostat Database, author's calculations

Table A1. Likelihood ratio test of linear VAR against TVAR(2) and TVAR(3)

TVAR–log	1vs2	1vs3
Test	109.06	270.171
P-Value	0.10	0.00

Note: Bootstrap based p-values reported. TVAR – threshold vector autoregression.

Fig. A3. Grid search and threshold value in the TVAR model

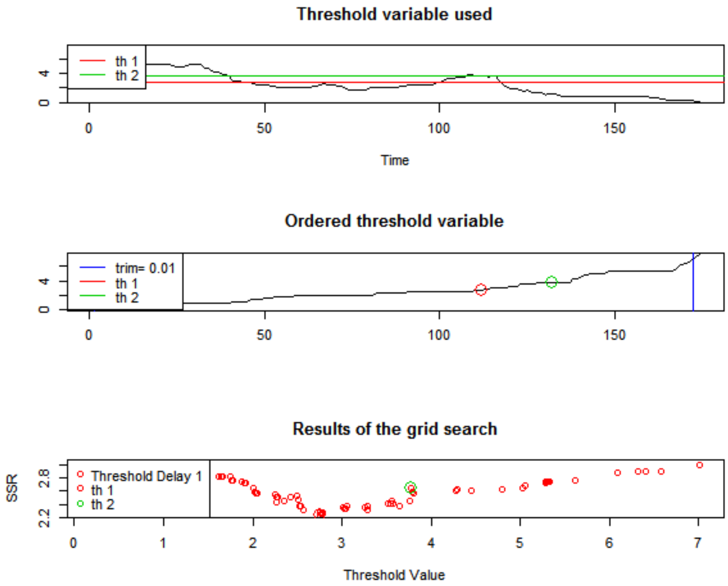
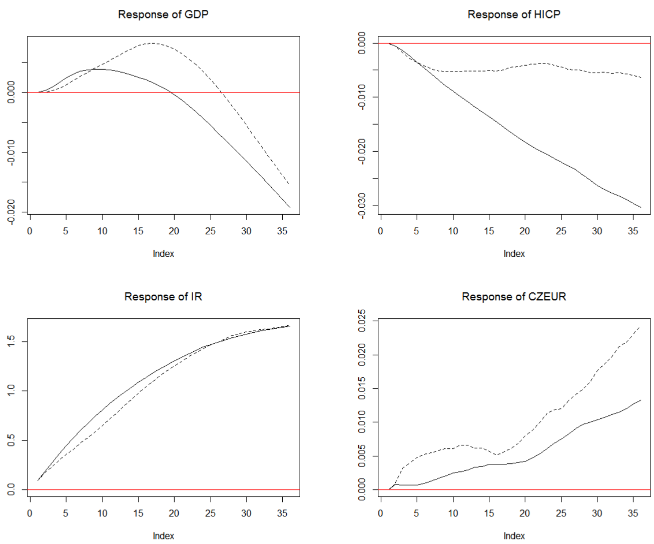


Fig. A4. Cumulative GIRF of the TVAR model



Note: Dashed line – high regime, solid line – low regime. GIRF – generalized impulse response function.