Institute of Economic Studies, Faculty of Social Sciences
Charles University in Prague

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

Dominika Kolcunova
Tomas Havranek

IES Working Paper: 22/2018

Institute of Economic Studies,
Faculty of Social Sciences,
Charles University in Prague

[UK FSV – IES]

Opletalova 26
CZ-110 00, Prague
E-mail : ies@fsv.cuni.cz
http://ies.fsv.cuni.cz

Institut ekonomických studií
Fakulta sociálních věd
Univerzita Karlova v Praze

Opletalova 26
110 00 Praha 1

E-mail : ies@fsv.cuni.cz
http://ies.fsv.cuni.cz

Bibliographic information:
Kolcunova D. and Havranek T. (2018): "Estimating the Effective Lower Bound for the Czech National Bank’s Policy Rate" IES Working Papers 22/2018. IES FSV. Charles University.

This paper can be downloaded at: http://ies.fsv.cuni.cz

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

Dominika Kolcunova[a,b]
Tomas Havranek[a,b]

[a]Institute of Economic Studies, Faculty of Social Sciences, Charles University
Opletalova 21, 110 00, Prague, Czech Republic
[b]Czech National Bank, Na Prikope 28, 115 03 Prague 1, Czech Republic
Email (corresponding author): tomas.havranek@cnb.cz

September 2018

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 preferable to deposits with negative yields. This bound is approximated based on storage, insurance and transportation costs of cash and the loss of convenience associated with cashless payments and complemented with the estimate based on interest charges which present direct costs to the bank profitability. Overall we get a mean value slightly below –1%, approxi- mately in the interval (–2.0%, –0.4%). 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 similar in its effects to the impact of the Czech National Bank's exchange rate commitment during the years 2013–2017.

JEL: E52, E58, E43, E44
Keywords: effective lower bound, zero lower bound, negative interest rates, costs of cash, transmission of monetary policy

Acknowledgements: The authors note that the paper represents their own views and not necessarily those of the Czech National Bank. We would like to thank Branislav Saxa, Jonathan Witmer, Tomáš Holub and Michal Franta for useful comments. We would also like to thank Oldˇrich Deˇdek and Roman Horváth for useful comments concerning the previous version of the paper. All errors and omissions remain entirely the fault of the authors. We acknowledge support from Czech Science Foundation grant P402/12/G097.

IES Working Paper Series

2018

1. Karel Janda, Martin Strobl: *Smoking Czechs: Modeling Tobacco Consumption and Taxation*
2. Karel Janda, Michaela Koscova: *Photovoltaics and the Slovak Electricity Market*
3. Simona Malovana, Dominika Kolcunova, Vaclav Broz: *Does Monetary Policy Influence Banks' Perception of Risks?*
4. Karolina Vozkova: *Why Did EU Banks Change Their Business Models in Last Years and What Was the Impact of Net Fee and Commission Income on Their Performance?*
5. Jan Malek, Lukas Recka, Karel Janda: *Impact of German Energiewende on Transmission Lines in the Central European Region*
6. David Svacina: *Devaluation with Exchange rate Floor in a Small Open Economy*
7. Ladislav Kristoufek: *Are the Crude Oil Markets Really Becoming More Efficient over Time? Some New Evidence*
8. Karel Janda, Zuzana Lajksnerova, Jakub Mikolasek: *A General Equilibrium Model of Optimal Alcohol Taxation in the Czech Republic*
9. Nicholas Tyack, Milan Scasny: *Estimating the Value of Crop Diversity Conservation Services Provided by the Czech National Programme for Agrobiodiversity*
10. Laure de Batz: *Financial Impact of Regulatory Sanctions on French Listed Companies*
11. Matej Opatrny: *Extent of Irrationality of the Consumer: Combining the Critical Cost Eciency and Houtman Maks Indices*
12. Mojmir Hampl, Tomas Havranek: *Foreign Capital and Domestic Productivity in the Czech Republic*
13. Miroslav Palansky: *The Value of Political Connections in the Post-Transition Period: Evidence from the Czech Republic*
14. Karel Janda: *Earnings Stability and Peer Selection for Indirect Valuation*
15. Ondrej Tobek, Martin Hronec: *Does the Source of Fundamental Data Matter?*
16. Stefan Schmelzer, Michael Miess, Milan Scasny, Vedunka Kopecna: *Modelling Electric Vehicles as an Abatement Technology in a Hybrid CGE Model*
17. Barbora Malinska, Jozef Barunik: *Volatility Term Structure Modeling Using Nelson-Siegel Model*
18. Lubomir Cingl, Vaclav Korbel: *Underlying Motivations For Rule-Violation Among Juvenile Delinquents: A Lab-in-the-Field Experiment*
19. Petr Jansky, Marek Sedivy: *Estimating the Revenue Costs of Tax Treaties in Developing Countries*
20. Yao Wang, Zdenek Drabek, Zhengwei Wang: *The Predicting Power of Soft Information on Defaults in the Chinese P2P Lending Market*
21. Matej Kuc: *Cost Efficiency of European Cooperative Banks*

1. Introduction

In the years after the outbreak of the global financial crisis, central banks have cut their policy rates 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 the ELB 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.

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 duration, the more probable converting into cash could be. Nevertheless, the international experience has already proven that negative interest rates 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 current best estimate of the ELB is −1.2%. Given the uncertainty around the point estimate, we suggest the ELB lies in the interval (−2.0%, −0.4%). With a shorter duration and a 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 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 total assets in the banking system that would be subject to negative rates (given the present conditions) shifts the value of the estimate closer to zero. Our 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.

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 estimated in 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 literature has been 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%, more conservative estimates suggest −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 and 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 advantageous it would be to build storage capacities instead of earning negative yields and thus 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 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 and Kimball, 2015) or using sovereign digital currencies bearing an interest rate set by a central bank (Bordo and 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 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, 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 until now. 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 and 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 and 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 role as well. 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 five years of negative rates have not proven to alter expectations such that it would trigger incentives for a move to cash.

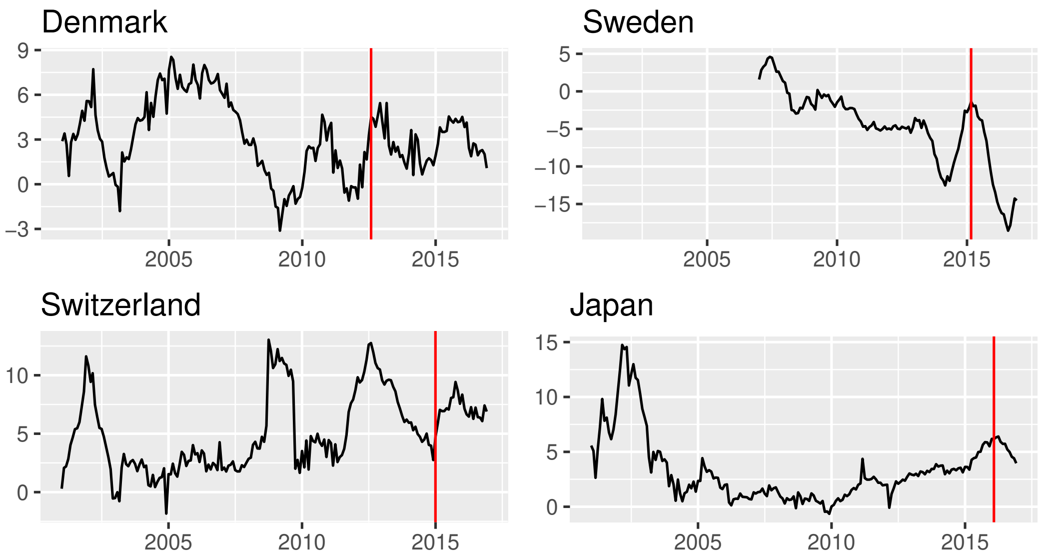
Money market rates are the second important indicator. It can be shown that money markets have continued to work smoothly, and there is no indication that the pass-through has been significantly weakened, as can be seen in Fig. 2 where three-month money market rates are almost perfectly correlated with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

Figure 1: Currency in circulation (year-over-year changes in %)



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

3. Negative rates in the Czech market

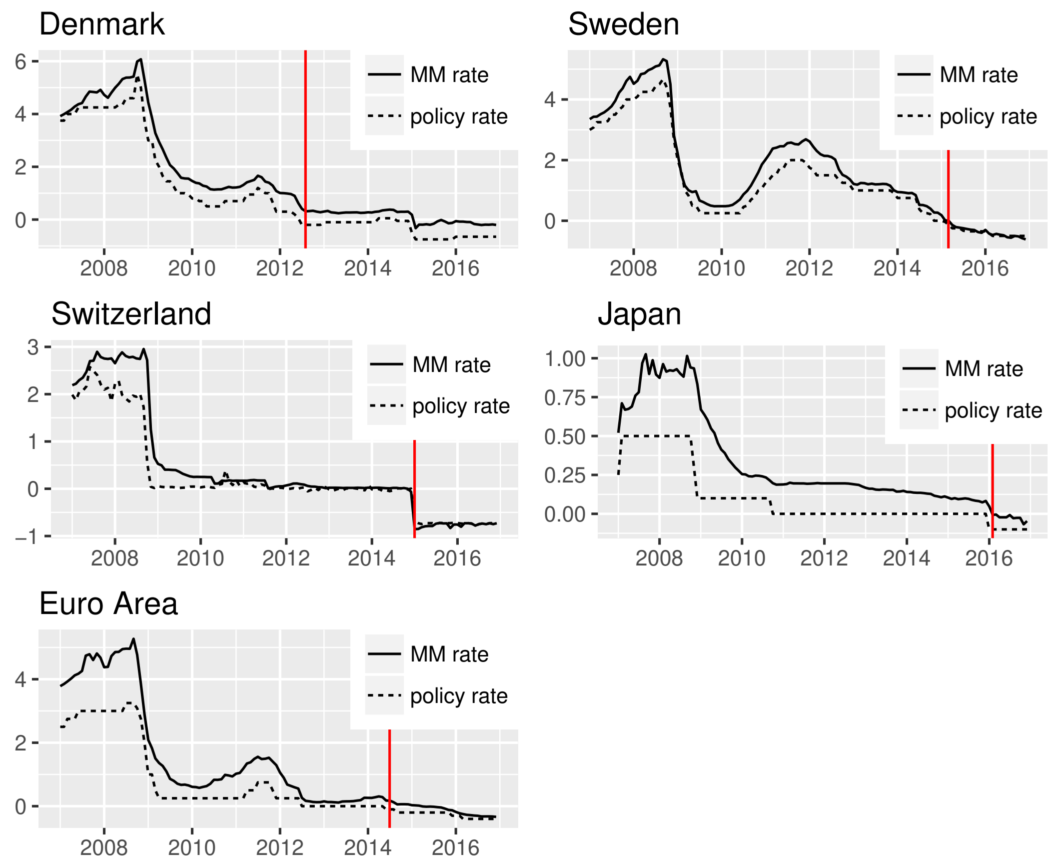
Even though the 2W repo rate as the CNB's main policy rate has been positive over the whole time period studied, negative rates already existed in different parts of the Czech financial market.[1]

Government bonds

At first, Czech government bonds, which financial institutions may store excessive money in, earned negative yields. That holds for all bonds with maturities ranging from one month to six years. Only the bonds with maturities over seven years yielded slightly positive returns during 2016. The yield on the basket of government bonds with an average residual maturity of two years was negative constantly since July 2015 to the end of our sample, similarly for the average five-year maturity basket (Fig. 3). The yield on government bonds was, 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.[2]

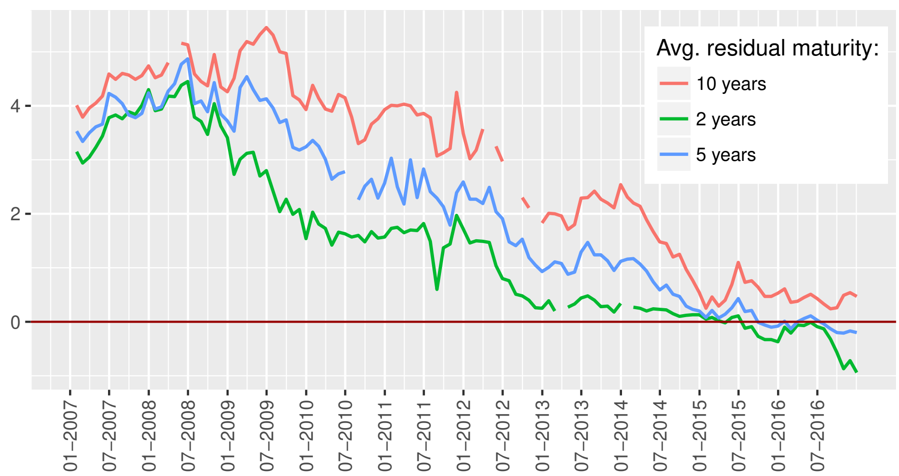
[1] All of the data used in the paper end in December 2016. With the exit from the exchange rate commitment in April 2017, the situation has been changing in many aspects, but monitoring this feature is not the aim of the paper.
[2] The next reason why negative rates were accepted might be a still positive interest rate differential for investors who funded their trades in currencies with negative interest rates.

Figure 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

Figure 3: Yields on the baskets of government bonds with different average residual maturities

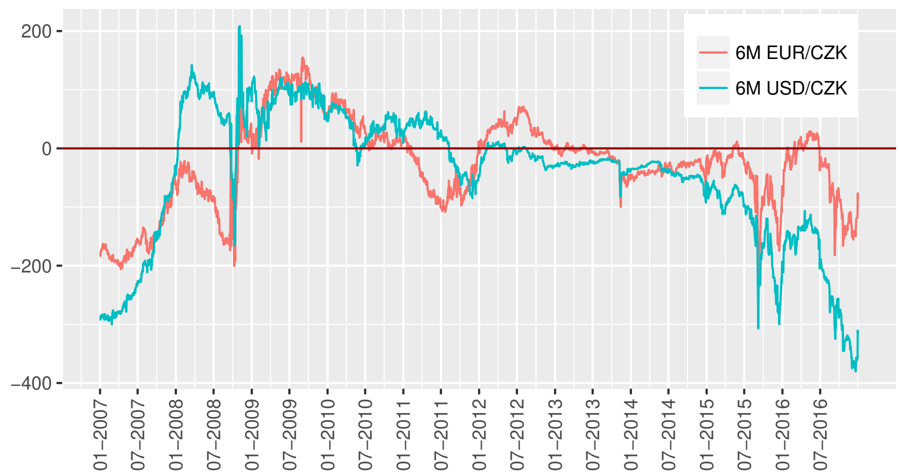


Source: Czech National Bank

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 were already negative for relatively long time. Since the beginning of the CNB's FX interventions, the forward points were 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 spot rate) is negative. At normal times, lower-interest rate currencies tend to trade at a forward foreign exchange rate premium (=positive forward 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 USD/CZK 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.

Figure 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 client 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 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. Mostly, negative interest rates have not been applied to private individuals, and even in cases they have, the threshold has been really high. However, 1% p.a. on over-the-limit deposits may insinuate at least something about the ELB. 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.[3]

[3] Negative rates were, for example, passed on to retail depositors on the balances over 100,000 EUR by several small banks in Germany.

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	0.15% of the differential balance
Ceska Sporitelna	Fee for additional deposits if the deposit balance exceeds CZK 100 million	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	0.15% of the differential balance
	Fee for client's over-the-limit deposits in CZK above CZK 100 million	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	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[2]	1% p.a.
	Fee for client's over-the-limit deposits in CZK above CZK 100 million[2]	0.5% p.a.
J&T Banka	x	x
Moneta Money Bank	Fee for additional deposits if the deposit balance exceeds CZK 100 million	0.15% of the differential balance
PPF banka	Fee for additional deposits if the deposit balance exceeds CZK 100 million	0.15% of the differential balance
Fio Banka	Fee for additional deposits if the deposit balance exceeds CZK 100 million[3]	0.15% of the differential balance
Air Bank	x	x
Sberbank	Fee for additional deposits if the deposit balance exceeds CZK 50 million	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	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] Applied only to financial customers. [3] Applied also to private individuals.

Note: The differential balance is the difference between the deposit balances as of 31 December of the respective year and (i) the amount of CZK 100 million, or (ii) the average balance of the total volume of deposits on the last day of each month in the period from January to November of the relevant year. I.e. the fees for additional deposits are paid yearly on differential balance. In comparison to that, over-the-limit deposits are paid monthly on all balances above the limit value.
The fees for additional deposits of 0.15% of the differential balance are the consequence of the obligatory contribution (based on the amount of deposits at the year-end) to the Single Resolution Fund, established by SRM Regulation (Regulation (EU) No 806/2014 to finance the restructuring of failing credit institutions.)
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. 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. We follow two approaches in the estimation of the ELB: the first one approximates the costs of holding cash (costs associated with storing, transporting and insuring cash) and costs of using cash (equivalent to the value of convenience of using non-cash payments). This approach (subsection 4.1 and 4.2) may be viewed as the 'bottom-up' approach, i.e. the one approximating the ELB from the point of view of households or firms. The second, direct approach, may be interpreted as holistic, or 'top-down', estimating the ELB from the point of view of financial institutions.

4.1 Storage, transportation and insurance costs

Storage, transportation/transactions and insurance costs represent significant impediments to provoking an abrupt move into cash at the zero level interest rates. For the smaller retail customers, Ján (2016) finds that the costs of storage constitutes 0.04-1% of the stored value ranging from 100,000 CZK to 2.7 mil. CZK in deposit boxes (i.e. security boxes in a banks, usually partly including insurance) and 0.13-3.5% for the same value in private safes, plus 0.6% of the value for the insurance costs, which are, however, difficult to determine, as there is almost no supply of this service in developed countries.[4]

Given the small capacities and non-developed market for storing cash overall, we continue with the possibility to approximate the costs of storage, transportation and insurance with the costs for other stores of value, especially precious metals like gold, silver or platinum or other minerals like crude oil, for which the market is larger and more developed. 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 and 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%.[5] This value is near the lower bound of the aforementioned intervals from Jackson (2015); Witmer and 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 are limited to satisfying low demand by retail

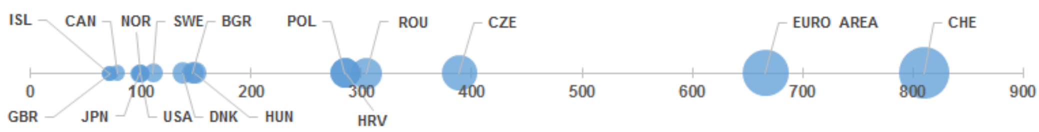
[4] To the best of our knowledge, it is also the case of the Czech Republic. No demand for this service is not surprising at all, given that bank deposits are insured with coverage 100% up to 100 000 EUR in the Deposit Insurance Fund. Ján (2016) uses the value of insurance costs for private safes from data for Myanmar, Kosovo, or Pakistan.

[5] 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.

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 those fees could be too low for determining the costs of storing cash on a larger scale. In summary, we 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 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). Out of countries in our sample, only Swiss franc and euro have larger denominations. The l argest 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 assume 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 and 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.

Figure 5: The largest denominations in real terms (PPP) in U.S. dollars



Note: As of December 2016. CHE = Switzerland, CZE = Czech Republic, ROU = Romania, HRV = Croatia, POL = Poland, HUN = Hungary, BGR = Bulgaria, DNK = Denmark, SWE = Sweden, NOR = Norway, JPN = Japan, CAN = Canada, GBR = United Kingdom, ISL = Iceland.
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 4.1 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 and 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

4.2.1 Interchange fees

The second component of the ELB is the loss of convenience of using electronic money instead of cash (i.e. the benefits of being able to make payments electronically, or the inconvenience of using cash), later on "convenience costs". One way sometimes mentioned in the literature uses the interchange fees as a proxy for these costs of the loss of convenience. Interchange fees are paid for the acceptance of card-based transactions between banks and are set by operators of payment cards schemes and incorporated in the final prices charged to consumers. As Witmer and Yang (2016) points out, however, these figures overestimate the convenience costs, as they are charged on transactions, not on the cash holdings. Moreover, we cannot really assume the figures equal to the customers' utility from using different kinds of electronic payments instead of cash payments, as consumers are not fully aware of the fees as the price is mostly the same for cash and electronic payments. Next to that, the current level of fees is not informative, since it is affected by the regulation on interchange fees for card-based payment transactions[6], 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. With respect to that, the interchange fees from the period before the regulation would be 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

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

value of a transaction. However, given the above-mentioned shortcomings of using the interchange fees we continue with the second possible approach.

4.2.2 Social costs of different payment instruments

An alternative to estimating the convenience costs by interchange fees is to use the concept proposed by Schmiedel et al. (2012), who estimated the social and private costs of retail payment instruments for 13 EU countries (the Czech Republic was not included). Social costs are defined as the sum of the pure costs of producing payment instruments incurred by the different stakeholders in the payments market, i.e. the costs to society of providing retail payment services reflecting the use of resources in the production of these services (Schmiedel et al., 2012). These costs are substantial, amounting up to 1% of GDP in the sample of countries. According to his conclusions, the social costs of cash payments constitute almost half of the total social costs of all payments.

With respect to our goal, we are interested in particular in the unit costs of payment instruments. 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 thus 0.6% higher than the social costs of card payments. Altogether, based on this approach, the convenience costs most probably lies in the interval of 0.4 - 2.1%, with the mean value of 1.4%, what is not far away from the interchange fees as well.

This is, however, the value related to the cash transactions, while the storage and insurance costs in the subsection 4.1 were expressed relative to cash holdings. We thus have to distinguish between transactional motive and the store of value motive of holding cash: if, for example, the 50% share of cash holdings is held for transactional purposes, the convenience costs should also enter the computation of ELB with this weight. In order to estimate the share held for transactional purposes vs. the the one held as a store of value, we examine the composition of the currency in circulation. We assume the banknote of the highest denomination, i.e. 5000 CZK, is held as a store of value only: it is not provided by almost no ATMs in the country.[7] The rest of the banknotes and coins in circulation are assumed to be held mainly for transactional purposes. In the last years, the share of value of the 5000 CZK banknotes has been 27% of total currency in circulation on average (ECB, 2017). Thus we assume that 73% of cash is held for transactional purposes mainly. This weight will be then used when summing up two components of the ELB.

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, 2017). On the other hand, the Czech Republic

[7] The second largest banknote in nominal value of 2000 CZK might be considered as both transactional and store of value, however, we incline to the former one, i.e. that the main motive of holding the 2000 CZK banknote is transactional, as it is commonly offered by ATMs and it is also the second most frequent banknote in circulation (ECB, 2017).

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 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 and 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 relatively high costs of using cash. It is also important to note that not only the electronic payments are convenient, the cash payments above 10 000 EUR equivalent are illegal, as set by Act No. 261/2014 Coll. Comparing with the subsection 4.1, the benefits of the possibility to make electronic payments are higher than the costs of storage or insurance of cash. Besides the households' preferences, the "bottom-up" approach of sections 4.1 and 4.2 covers also firms, for which convenience value could be really high, especially because of large and frequent transactions like payroll settlements etc. Thus we find the mean value of 1% (after adjusting for the share of cash held for transactional purposes) reasonable.

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.

Table 3: Direct costs of negative rates

	Total volume	Volume 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

This can be also interpreted as the *ceteris paribus* changes in return on assets (ROA) when interest expense changes. In other words, the ratio of interest expenses for banks stemming from negative interest rates to total assets equal to, e.g. 0.03%, means that by imposing negative rates (in comparison to zero interest rate), the ROA is decreased by 3bps.[8] Lacking better evidence, in accordance with Barr et al. (2016) we will take the Switzerland case, i.e. the change in ROA of 3bps not causing any disruptions or flight to cash, as the best possible value to calibrate the ELB. Using this value as a limit, we calculate the interest rate that would lead to the same change in ROA in the Czech Republic. However, we also provide sensitivity analysis and calculate respective interest rates that would lead to the change in ROA of 1, 5 and 10 bps (Table 5). We use monthly data on monetary statistics over the period 2013-2016, which are available from the CNB's ARAD database (Table 4).

Table 4: Monetary statistics, Czech Republic

	Total assets	ROA	O/N deposits at CNB	Reserves (required + excess)	Excess reserves	Repo operations
2013	4 764	1.47%	2 784.88	58.35	1.99	624.40
2014	5 207	1.27%	4 527.31	61.67	2.21	908.21
2015	5 491	1.31%	9 520.28	70.22	6.06	652.40
2016	5 900	1.21%	14 403.75	92.17	22.79	999.12

Note: Yearly averages of monthly values. In CZK billions (except for ROA).

The results are reported in Table 5. We calculate the interest rate that would correspond to the change of ROA of 1-10 bps. The columns in Table 5 differ in what items are subject to negative interest rate – whether it is only overnight deposit facility, or repo operations etc. First, if the negative rate was imposed only on deposits in the standing deposit facility (under the current non-tiered regime), the policy rate (discount rate in this case) could decrease to -0.64% (in case of 3 bps change in ROA; or from -0.21% to -2.1% in case of 1 or 10 bps change in ROA).

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, mainly, to the repo operations[9]. This latter option is of our main interest as repo operations are the main monetary policy instrument. In this case, the policy rate could go as low as -0.23%.

The fourth option introduces a tiered system under which only 25% of the previous stock is subject to the negative rate. It was suggested by Barr et al. (2016) based on the experience in foreign countries and it should ensure sufficient transmission of negative rates into the real economy. With this tiered system, the policy rate could go down as low as -0.93%. 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 -0.93% to be the most realistic estimate amongst other specified options.

[8] ROA = net income/total assets = (revenues - interest expense - other expenses)/total assets. Holding other things constant, with the change in interest expense, ROA changes by $-\Delta$(interest expense)/total assets.

[9] 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, i.e. when 2W repo rate was equal to 0.05%.

The fifth option shows a potential rate 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%, the same as in the forth option.

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

	Items subject to negative rate				
Change in ROA	O/N deposits	O/N deposits + reserves	O/N deposits + reserves + repos	25% of [O/N deposits + reserves + repos]	2% - 17% of GDP
1 bps	−0.21%	−0.17%	−0.08%	−0.31%	−0.60% - −0.07%
3 bps	−0.64%	−0.50%	−0.23%	−0.93%	−1.80% - −0.21%
5 bps	−1.07%	−0.83%	−0.41%	−1.55%	−3.00% - −0.35%
10 bps	−2.13%	−1.67%	−0.82%	−3.10%	−6.00% - −0.71%

Note: The table provides interest rates that would, on average, cause a given change in return of assets, changing the interest expense and other things being constant, using the data from 2013 to 2016. The preferred specification is 3 bps change in ROA. Including total amount of reserves (required and excess) vs. excess reserves only does not produce significantly different results, thus only the results with total reserves are included.

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., 2014a). 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 law forbidding the cash payments above 10 000 EUR equivalent has been already in place (Act No. 261/2014 Coll.). The international experience shows that technical problems of the negative interest rate policy 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 larger component of the ELB are the costs of the loss of convenience as proxied by social costs, and it is very probable that they attain values around 1% in the Czech Republic.[10] Summing up these two components, we can come up to the mean value 1.4% of annual costs, with intervals ranging from 0.6% to 2.1% (*positive* numbers of all different kinds of costs represent a *negative* ELB). Thus, based on the first approach, the ELB should lie in the interval (−0.6%, −2.1%).

[10] The value of convenience costs related to cash transactions were adjusted by the weight of 0.73, what is the average share of cash held for transactional purposes.

The mean value of the second approach of direct costs is near 1%, with intervals (0.2%, 1.8%), i.e. the ELB between −0.2% and −1.8%. The two approaches, each focused on different agents, do not yield significantly different results.[11] Averaging the two approaches leads to the mean value of approximately 1.2% Thus, in summary, we suggest the ELB for the CNB's policy rate to be slightly below −1%, with the most reasonable estimate suggesting −1.2%. Given the high uncertainty around a point estimate, we suggest that the ELB lies in the interval (−0.4%, −2.0%).

Table 6: Summary table - components of ELB

		Min	Mean	Max
Approach 1	Costs of storage and insurance	0.2	**0.4**	0.6
	Convenience costs	0.4	**1.0**	1.5
	Total	0.6	**1.4**	2.1
Approach 2	Direct costs to profitability	0.2	**1.0**	1.8
	Average	0.4	**1.2**	2.0

Note: *Positive* numbers of different kinds of costs represent a *negative* ELB. The results of Approach 1 and 2 are not fundamentally different. The result for convenience costs comes from the concept of social costs; using the interchange fees would not change the results significantly. The lower and upper intervals for single items corresponds to minimum/maximum values for a given item as found in the previous sections. The final estimate (bottom row) is calculated as a simple average of the two approaches. This also applies to final interval values: e.g., the lower interval of 0.4% is the average of lower intervals of two approaches 0.6% and 0.2%.

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., 2014b; 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 and Zha (1997); Zha (1999) or Jarociński (2010), who include foreign variables treated as exogenous variables in order to avoid mistaking monetary authorities' responses to ex-

[11] It is, however, important to note that while the second approach relates really to the ELB for the policy rates, the first approach relates to client rates. Nevertheless, the client's deposit rates follow the policy rate: the average spread between 2W repo rate and the clients' deposit rate on current accounts was only 0.1pp during the technical zero period.

ternal 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 and 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:

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

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 is:

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

Based on the information criteria, we use three lags.[12] 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 and Watson (1988).[13]

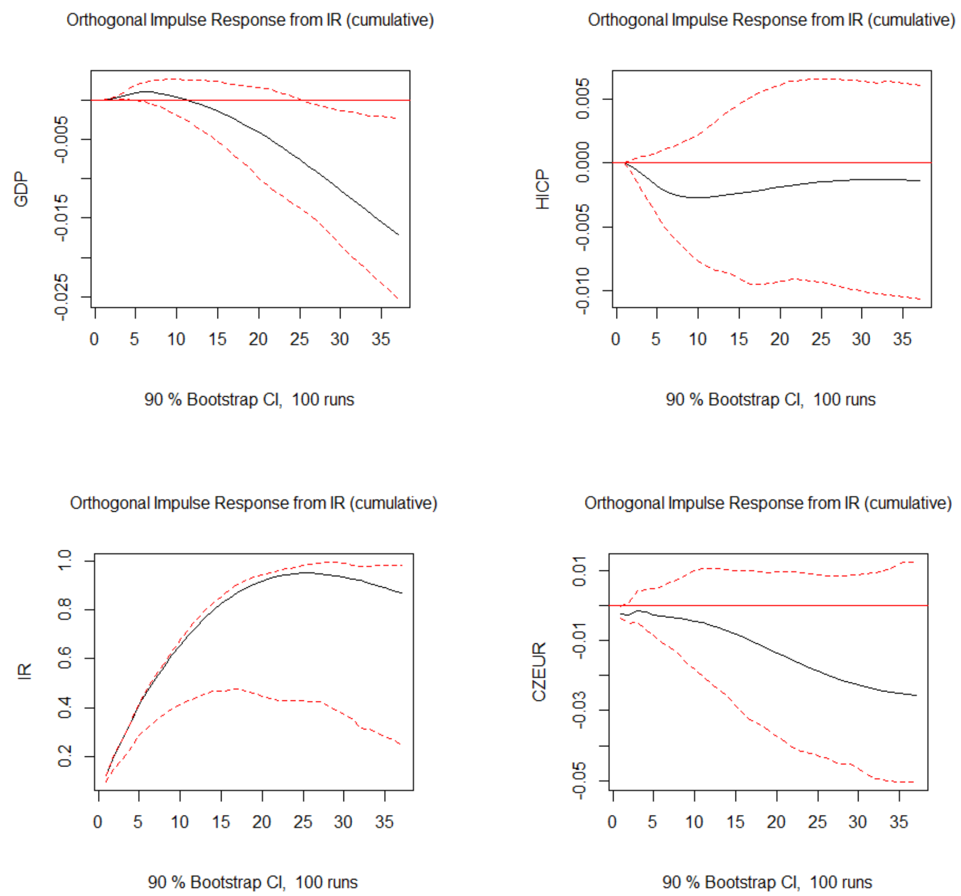
Since we are interested primarily in the interest rate transmission, only the impulse response with IR as a shocked variable are reported graphically. Fig. 6 shows the *cumulative* orthogonal impulse response functions for a three-year period ahead. After three years, expansionary (contractionary) monetary policy expressed by a one-unit (i.e. 1 pp) 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

[12] 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.

[13] 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.

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).

Figure 6: Cumulative impulse response functions - VARX model



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 (2017) 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 and 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.[14] 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

[14] It is important to note that we use cumulative responses of the one-period shock to interest rate, while the shocks used for estimation are usually smaller and hitting the economy for several periods. Assuming several smaller shocks to interest rate one-by-one would lead to slower convergence to the long-run cumulative response of GDP and thus to even smaller effect of interest rate on GDP at our compared time horizon.

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 and 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.[15] 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 and Kucharcukova-Babecka, 2013), Markov switching models (Fujiwara, 2006) and time-varying parameters models (Franta et al., 2014b). Most of the studies detect asymmetries in the effect of monetary policy over time.

This contributed 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) has been chosen as the most straightforward way. The details of TVAR estimation are provided in Appendix, section A2. 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 cannot confirm its significance in terms of credible intervals. Moreover, the consistency of a TVAR model may be threatened by non-stationary data. Therefore, to make conclusions about the interest rate channel, we stick to the more robust baseline model.

6. Conclusion

The paper provides the first 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, however, 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 $(-2.0\%, -0.4\%)$, with the mean value of -1.2%.

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 in the future research.

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

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.

References

AGARWAL, R. AND M. KIMBALL (2015): "Breaking Through the Zero Lower Bound." IMF Working Papers 15/224, International Monetary Fund.

ALSTERLIND, J., H. ARMELIUS, D. FORSMAN, B. JONSSON, AND A.-L. WRETMAN (2015): "How far can the repo rate be cut?." Economic Commentaries No. 11/2015, Sveriges Riksbank.

AMROMIN, G. AND S. CHAKRAVORTI (2009): "Whither Loose Change? The Diminishing Demand for Small-Denomination Currency." *Journal of Money, Credit and Banking,* 41(2-3): 315–335.

ARANGO, C. A., K. P. HUYNH, AND L. SABETTI (2011): "How do you pay? The role of incentives at the point-of-sale." Working Paper Series 1386, European Central Bank.

ARTETA, C., M. A. KOSE, M. STOCKER, AND T. TASKI (2016): "Negative Interest Rate Policies: Sources and Implications." Discussion Paper DP 11433, Centre for Economic Policy Research.

ATANASOVA, C. (2003): "Credit market imperfections and business cycle dynamics: A nonlinear approach." *Studies in Nonlinear Dynamics & Econometrics,* 7(4).

BALKE, N. S. (2000): "Credit and economic activity: credit regimes and nonlinear propagation of shocks." *The Review of Economics and Statistics,* 82(2):344–349.

BARR, M., B. KASMAN, AND D. MACKIE (2016): "Negative Policy Rates: The Bound is Lower than You Think." JPM Economic Research Series, February 9, 2016, J.P.Morgan.

BEAN, C. (2013): "Note on Negative Interest Rates for Treasury Committee." Bank of England, May 16, 2013

BORDO, M. AND A. LEVIN (2017): "Central Bank Digital Currency and the Future of Monetary Policy." Presented at Hoover Institution Policy Conference on The Structural Foundations of Monetary Policy, May 2017, Hoover Institution.

BORYS, M. M., R. HORVATH, AND M. FRANTA (2009): "The effects of monetary policy in the Czech Republic: an empirical study." *Empirica,* 36(4):419–443.

BRUHA, J. AND J. TONNER (2017): "An Exchange Rate Floor as an Instrument of Monetary Policy: An Ex-post Assessment of the Czech Experience." CNB Working Paper 4/2017, Czech National Bank.

BUITER, W. (2015): "It's Time to Remove the Lower Bound on Interest Rates and Here's the How-To." Conference on Removing the Zero Lower Bound on Interest Rates, London May 18, 2015.

CUSHMAN, D. O. AND T. ZHA (1997): "Identifying monetary policy in a small open economy under flexible exchange rates." *Journal of Monetary Economics,* 39(3):433–448.

ECB (2017): "Payment Statistics." ECB Statistical Data Warehouse. September 2017.

FRANTA, M., T. HOLUB, I. KUBICOVA, K. SMIDKOVA, AND B. VASICEK (2014): "The Exchange Rate as an Instrument at Zero Interest Rates: The Case of the Czech Republic." CNB Research and Policy Notes 3/2014, Czech National Bank.

FRANTA, M., R. HORVATH, AND M. RUSNAK (2014): "Evaluating changes in the monetary transmission mechanism in the Czech Republic." *Empirical Economics,* 46(3):827–842.

FUJIWARA, I. (2006): "Evaluating monetary policy when nominal interest rates are almost zero." *Journal of the Japanese and International Economies,* 20(3):434–453.

FUNG, B. S., K. P. HUYNH, AND L. SABETTI (2012): "The impact of retail payment innovations on cash usage." BoC Staff Working Paper 2012-14, Bank of Canada.

HANSEN, B. (1999): "Testing for linearity." *Journal of Economic Surveys,* 13(5):551–576.

HAVRANEK, T., R. HORVATH, AND J. MATEJU (2012): "Monetary transmission and the financial sector in the Czech Republic." *Economic Change and Restructuring,* 45(3):135–155.

HOLUB, T. (2008): "Causes of deviations from the CNB's inflation targets: an empirical analysis." *Czech Journal of Economics and Finance,* 58(09-10):425–433.

JACKSON, H. (2015): "The International Experience with Negative Policy Rates." BoC Staff Discussion Paper 2015-13, Bank of Canada.

JÁN, J. (2016): "Negative Interest Rates-How Far Can They Go?" Bachelor's Thesis, Charles University in Prague.

JAROCIŃSKI, M. (2010): "Responses to monetary policy shocks in the east and the west of Europe: a comparison." *Journal of Applied Econometrics,* 25(5):833–868.

JENSEN, C. M. AND M. SPANGE (2015): "Interest Rate Pass-Through and the Demand for Cash at Negative Interest Rates." Monetary Review, 2nd Quarter 2015, Danmarks Nationalbank.

JOBST, A. AND H. LIN (2016): "Negative Interest Rate Policy (NIRP): Implications for Monetary Transmission and Bank Profitability in the Euro Area." IMF Working Paper WP/16/172, International Monetary Fund.

KEOHANE, D. (2015): "Negative rates and Gesell taxes: how low are we talking here?." *FT Alphaville.* February 2, 2015.

KIMBALL (2015): "Negative Interest Rate Policy as Conventional Monetary Policy." *National Institute Economic Review,* 234(1):R5–R14.

KONECNY, T. AND O. KUCHARCUKOVA-BABECKA (2013): "Evaluating the Links Between the Financial and Real Sectors in a Small Open Economy: The Case of the Czech Republic." CNB Working Paper 10/2013, Czech National Bank.

LTP (2016): "How the Czech Republic and Poland Are Amongst the Leaders in Contactless Payments." Let's Talk Payments. July 5, 2016.

LUTKEPOHL, H. (2005): "New introduction to multiple time series analysis." *Econometric Theory,* 22(5):961–967.

MAĆKOWIAK, B. (2006): "How much of the macroeconomic variation in Eastern Europe is attributable to external shocks?." *Comparative Economic Studies,* 48(3):523–544.

MOOSLECHNER, P., H. STIX, AND K. WAGNER (2012): "The Use of Payment Instruments in Austria." Monetary Policy & the Economy Q4/12, Austrian Central Bank.

OPATRNY, M. (2017): "Quantifying the Effects of the CNB's Exchange Rate Commitment: A Synthetic Control Method Approach." *Finance a Uver: Czech Journal of Economics & Finance,* 67(6).

PESARAN, H. H. AND Y. SHIN (1998): "Generalized impulse response analysis in linear multivariate models." *Economics Letters,* 58(1):17–29.

ROGOFF, K. (2016): *The Curse of Cash.* Princeton University Press, 1 edition. ISBN 9780691172132.

SCHMIEDEL, H., G. KOSTOVA, AND W. RUTTENBERG (2012): "The social and private costs of retail payment instruments: a European perspective." Occasional Paper Series 137, European Central Bank

SMART PAYMENT ASSOCIATION (2016): "An Overview of Contactless Payment Benefits and Worldwide Deployments." Smart Payment Association, April 2016.

STOCK, J. H. AND M. W. WATSON (1988): "Variable trends in economic time series." *The Journal of Economic Perspectives,* 2(3):147–174.

SVACINA, D. (2015): "Impacts of the Euro Adoption in the Czech Republic." Master Thesis, Institute of Economic Studies, Charles University in Prague.

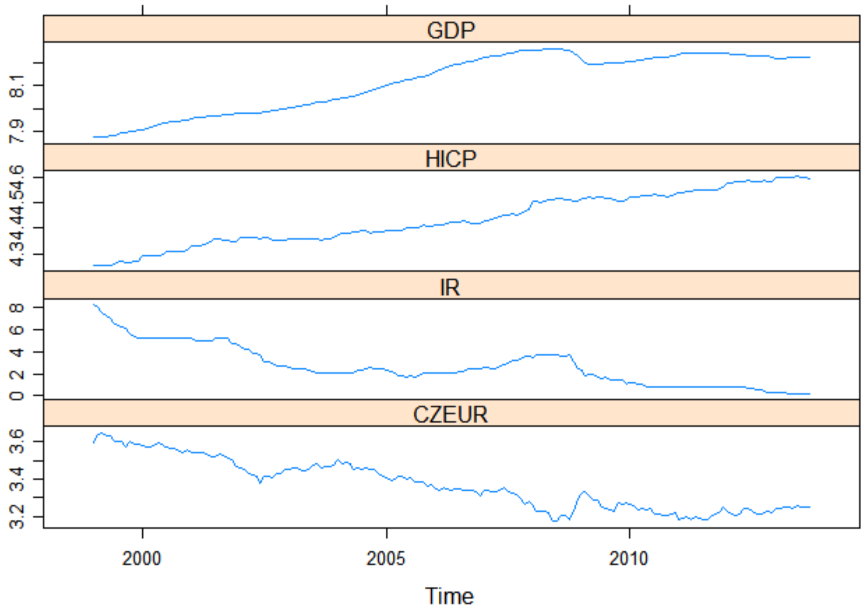
WITMER, J. AND J. YANG (2016): "Estimating Canada's Effective Lower Bound." Bank of Canada Review, Spring 2016.

ZHA, T. (1999): "Block recursion and structural vector autoregressions." *Journal of Econometrics,* 90(2):291–316.

Appendix

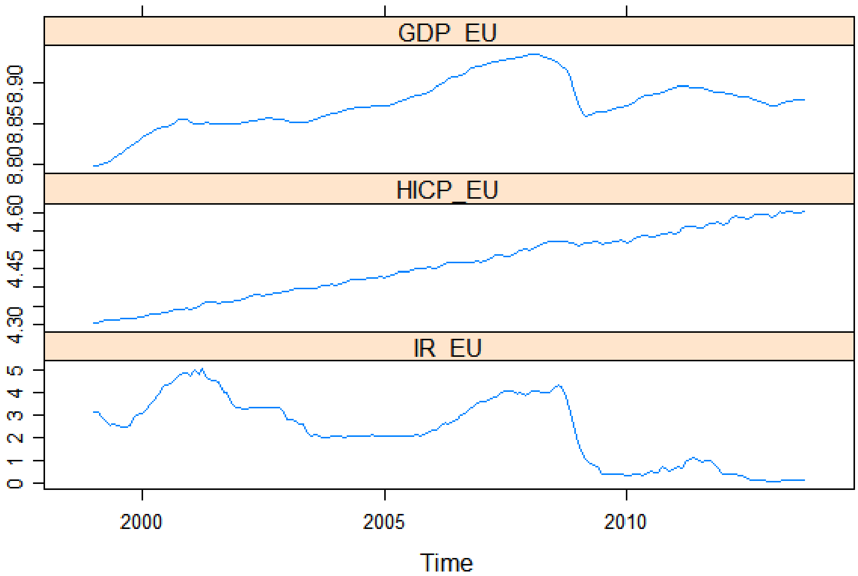
A1. VAR analysis

Figure 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

Figure 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

A2. TVAR analysis

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:

$$Y_t = A^1 Y_t + B^1(L)Y_{t-1} + (A^2 Y_t + B^2(L)Y_{t-1})I(c_{t-d} > \gamma) + U_t \tag{A1}$$

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.[16] A TVAR model is estimated on the same data and with the same lag structure as in the baseline model, except that the exogenous variables are not included. 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 6).

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).[17] 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 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 CZK/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.[18] We can still, however, make conclusions about symmetry or asymmetry in responses across two regimes.

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 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. (2014b), 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.

[16] In case of three regime TVAR model, two indicator functions enter equation A1.

[17] The middle regime covers only a short period (12%) of a hump in the interest rate between 06/2007 and 12/2008.

[18] GIRF, as defined by Pesaran and 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.

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.

Figure A3: Grid search and threshold value in the TVAR model

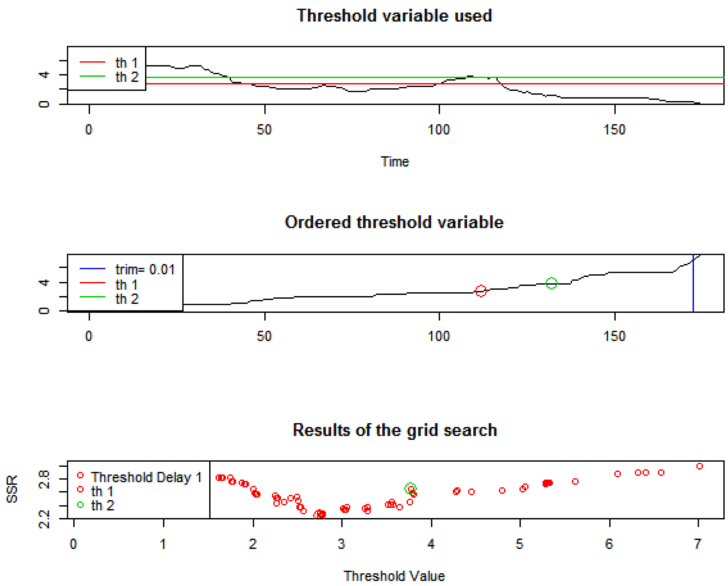
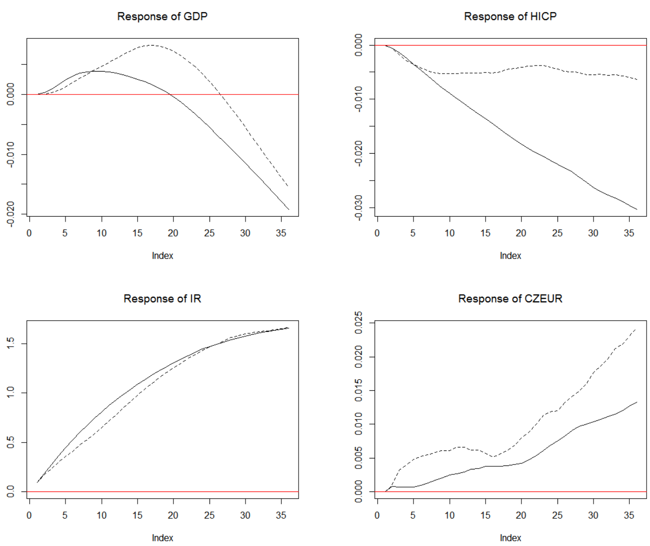


Figure A4: Cumulative GIRF of the TVAR model



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

22. Dominika Kolcunova, Tomas Havranek: *Estimating the Effective Lower Bound for the Czech National Bank's Policy Rate*

All papers can be downloaded at: http://ies.fsv.cuni.cz

Univerzita Karlova v Praze, Fakulta sociálních věd
Institut ekonomických studií [UK FSV – IES] Praha 1, Opletalova 26
E-mail : ies@fsv.cuni.cz http://ies.fsv.cuni.cz