Charles University in Prague

Faculty of Social Sciences

Institute of Economic Studies

DISSERTATION THESIS

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Interbank markets, monetary transmission and bank efficiency

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Declaration

Hereby I declare that I compiled this thesis using only the listed literature and resources.

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Jitka Lešanovská

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The views expressed do not necessarily represent those of the Czech National Bank or Charles University.

References

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Abstract

The dissertation thesis comprises three essays which interlink monetary policy transmission and bank characteristics, particularly bank cost efficiency, in the light of recent financial crisis. The first essay focuses on the development of the interbank market risk premium in the Czech Republic during the global financial crisis. We explain the significant departure of interbank interest rates from the key monetary policy rate by a combination of different factors, including liquidity risk, counterparty risk, foreign influence, interbank relations, and strategic behavior. The results suggest a relevant role of market factors, and some importance of counterparty risk.

The second essay examines the pass-through from financial market interest rates, directly influenced or targeted by central banks, to the rates that banks charge firms and households. It examines the pass-through mechanism using a unique data set of Czech loan and deposit products and focus on bank-level determinants of pricing policies, especially cost efficiency, which we estimate employing both stochastic frontier and data envelopment analysis. The main results are threefold: First, the long-term pass-through was close to complete for most products before the financial crisis, but has weakened considerably afterward. Second, banks that provide high rates for deposits usually charge high loan markups. Third, cost-efficient banks tend to smooth loan rates for their clients.

The last essay analyzes the relation between capital and bank efficiency by considering both directions of the Granger causality for the Czech banking industry. The essay is based on an exhaustive dataset of Czech banks from 2002 to 2013 and measures the cost efficiency of banks using stochastic frontier analysis. We find no relation between capital and efficiency, as neither the effect of capital on efficiency, nor the effect of efficiency on capital is significant. The financial crisis does not influence the relation between capital and efficiency. Our findings suggest that tighter capital requirements like those under Basel III do not affect financial stability through the efficiency channel. Policies favoring capital levels and efficiency of the banking industry can therefore be designed separately.

Keywords: interbank market, risk premium, cost efficiency, interest rate pass-through, stochastic frontier analysis, bank capital, bank efficiency

JEL Codes: G19, G21, G28, E43, E58

Abstrakt (in Czech)

Disertační práce se skládá ze tří článků, které propojují vztah transmise měnové politiky s charakteristikami bank, zejména jejich nákladovou efektivitou. První článek vysvětluje vývoj rizikové prémie na mezibankovním trhu v České republice během globální finanční krize. Významné odchýlení mezibankovních úrokových sazeb od měnověpolitické sazby je vysvětlováno kombinací různorodých faktorů včetně likviditního rizika, rizika protistrany, zahraničními vlivy, mezibankovními vztahy a strategickým chováním bank. Výsledky naznačují relevantní roli tržních faktorů a určitý význam rizika protistrany.

Druhý článek zkoumá průsak změn sazeb finančního trhu ovlivňovaných centrálními bankami do sazeb, které banky stanovují pro firmy a domácnosti. Článek analyzuje mechanismus průsaku na unikátním souboru dat, který pokrývá české depozitní a úvěrové produkty, a zaměřuje se na roli determinant cenové politiky jednotlivých bank, a to zejména na roli nákladové efektivity bank, kterou odhadujeme pomocí stochastické hraniční analýzy a analýzy obalu dat. Naše hlavní výsledky jsou následující: Zaprvé, dlouhodobý průsak úrokových sazeb byl před krizí u většiny produktů téměř kompletní, ale poté výrazně zeslábl. Zadruhé, banky, které poskytují vysoké úrokové sazby na depozita, také často vyžadují vyšší rizikové prémie na úvěry. Zatřetí, nákladově efektivní banky často oddalují reakce svých sazeb na změny mezibankovních sazeb, čímž vyhlazují úrokové míry pro své klienty.

Poslední článek analyzuje vztah mezi kapitálem a efektivitou bank. Zkoumáme obousměrnou Grangerovu kauzalitu mezi těmito proměnnými pro český bankovní sektor na kompletním souboru dat od roku 2002 do roku 2013. Nákladovou efektivitu bank měříme pomocí stochastické hraniční analýzy. Vztah mezi kapitálem a efektivitou nebyl identifikován, neboť ani vliv kapitálu na efektivitu, ani vliv efektivity na kapitál není významný. Finanční krize vztah mezi kapitálem a efektivitou nezměnila. Naše zjištění tak naznačují, že přísnější kapitálové požadavky, jako jsou ty v rámci regulace Basel III, neovlivní finanční stabilitu přes kanál efektivity. Opatření ovlivňující úrovně kapitálu nebo míry efektivity bankovního sektoru tak lze tvořit samostatně.

Klíčová slova: mezibankovní trh, riziková prémie, nákladová efektivita, průsak úrokových sazeb, stochastická hraniční analýza, bankovní kapitál, bankovní efektivita

JEL kód: G19, G21, G28, E43, E58

Contents

List of Figures

List of Tables

List of abbreviations

BCBS	Basel Committee on Banking Supervision
BMA	Bayesian Model Averaging
CAR	Capital Adequacy Ratio
CDS	Credit Default Swap
CEE	Central and Eastern Europe
CET	Central European Time
CNB	Czech National Bank
CRD/CRR	Capital Requirements Directive/Regulation
CZEONIA	Czech Overnight Index Average
DEA	Data Envelopment Analysis
DSGE	Dynamic Stochastic General Equilibrium
ECB	European Central Bank
EONIA	Euro Overnight Index Average
EU	European Union
EURIBOR	Euro Interbank Offered Rate
FRA	Forward Rate Agreement
GMM	General Method of Moments
IMF	International Monetary Fund
IRS	Interest Rate Swap
LIBOR	London Interbank Offered Rate
NPL	Non-Performing Loans
OIS	Overnight Indexed Swap
PIP	Posterior Inclusion Probability
PM	Posterior Mean
PMP	Posterior Model Probability
PRIBID	Prague Interbank Bid Rate
PRIBOR	Prague Interbank Offered Rate
PT	Pass-Through
PVAR	Panel Vector Autoregression
ROA	Return on Assets
SFA	Stochastic Frontier Analysis
SPM	Standardized Posterior Mean
YTM	Yield To Maturity

Introduction

The dissertation thesis comprises three essays which interlink monetary policy transmission and bank characteristics, particularly bank cost efficiency, in the light of the recent financial crisis following the failure of the US Lehman Brothers bank in September 2008. We provide evidence on the decrease in the effectiveness of the interest rate channel of the monetary policy transmission in the Czech Republic during the financial crisis. We also analyse the role of bank efficiency for monetary transmission, particularly by trying to analyse whether more efficient banks fully and quickly reflect the changes in the monetary policy interest rates in their client interest rates charged on various bank products. We also understand that monetary transmission can be effective only in a stable banking sector. Thus, we also focus on bank efficiency in the context of financial stability and the expected consequences of the Basel III regulation in the Czech Republic. We analyse the relation between bank cost efficiency and bank capital, to estimate the impact of the increased Basel III capital requirements on financial stability through bank efficiency in the Czech Republic.

The first essay on *Explaining the Czech Interbank Market Risk Premium* analyses the interbank market in the Czech Republic. The interbank market serves as a first stage of monetary transmission mechanism as the change in the monetary policy rate is first transmitted to the interbank market rates which further influence the pricing of individual bank loan products. If the functioning of the interbank market is disrupted by an increase in the risk premium charged by banks for interbank lending, the changes in the monetary policy rate might not be fully transmitted to the rates on individual bank loan products, hence the impact of the monetary policy might significantly decrease.

During the global financial crisis, which started in the US sub-prime mortgage segment in 2007, interbank markets worldwide experienced an increase in volatility and a decrease in liquidity. While interbank market rates usually closely mirror the monetary policy rate in normal times, a quite strong departure of interbank rates from the key central bank rate has been observed since the onset of the global financial crisis. Having this evidence in mind, our paper analyses the development of the interbank market risk premium in the Czech Republic during the global financial crisis. This risk-premium increased in the Czech Republic at the beginning of the global crisis, firstly only slightly but then rather abruptly after September 2008. Such an increase in the risk premium negatively influences the transmission of monetary policy to the real economy.

The Czech case is specific in certain aspects. Firstly, Czech banks were not directly hit by losses from subprime-related structured products and the Czech banking sector proved to also be stable during the crisis. Indeed, there were no bank failures or bank runs due to the global financial crisis. Secondly, the overall activity on the Czech interbank market is rather low, both in the crisis and also pre-crisis period, and is concentrated at the shorter end of the maturity curve. This is a consequence of structural excess of liquidity in the Czech banking sector. These specific characteristics of the Czech banking sector open a question whether the interbank risk premium in the Czech Republic observed since the global financial crisis was influenced solely by an increase in counterparty risk and/or liquidity risk (in line with the evidence from other interbank markets), or there are other more important sources of interbank risk premium in the Czech Republic.

The contribution of the paper is twofold. Firstly, we discuss the construction of the Czech interbank rate PRIBOR. We find that the definition of PRIBOR differs from the definition of Euro interbank rate (EURIBOR) and London interbank rate (LIBOR). As a result, these might not be fully comparable and might be associated with different difficulties. PRIBOR suffers particularly from the low number of reference banks which provide their quotes for PRIBOR calculation and from the fact that the resulting PRIBOR rates are not binding, i.e., banks only indicate what the approximate price of lending to other reference banks would be. The real price might differ from the quoted price in PRIBOR, however.

Secondly, we explain the significant departure of interbank interest rates from the key monetary policy rate by a combination of different factors. We consider counterparty risk and liquidity risk as potentially significant determinants of the interbank risk premium in the Czech Republic. However, we also examine other factors that might significantly influence interbank lending conditions in the Czech Republic, such as market conditions in relevant domestic as well as international markets, the interbank lending relations of banks, and possible strategic behavior.

The results using daily data show significant persistence of the risk premium and a relevant role of market variables such as bond market liquidity and the euro area interbank risk premium. We find some role of the counterparty risk, as measured by the average ratio of non-performing loans to total client loans of potential interbank counterparties and the dispersion of the credit default swap spreads of parent companies of potential interbank counterparties. The latter variable indicates possible cross-border contagion effects via foreign ownership on the Czech interbank market risk premium. We do not find robust evidence for strategic behavior of banks when quoting PRIBOR rates.

This paper has been written in cooperation with Adam Gersl (Joint Vienna Institute & Charles University) and was published in 2014 in *Economic Systems*. I assess my contribution to the first paper to be 80%.

In the second essay on *Bank Efficiency and Interest Rate Pass-Through: Evidence from Czech Loan Products*, we continue with the analysis of monetary policy transmission mechanism. Specifically, we investigate whether the effectiveness of the monetary policy transmission differs for different banking products. We estimate the interest rate pass-through from financial market interest rates to interest rates of each bank product both before and after the crisis. Each product category is paired with a corresponding financial market interest rate according to the term structure. PRIBOR is used as the corresponding rate for loans with floating or short fixed rates, for longer fixations the most promising cost of funds is captured by the yield on the 10-year government bond. We then analyse the long-term relationship between the market rate and the bank rate (we assume that the bank sets its rate according to its cost of funds, determined by the corresponding market rate, and adds a markup), the immediate (short term) reaction of bank rates to changes in the market rate and the adjustment process between the short and long run.

We find strong and almost complete long-term pass-through from financial market rates to the rates that banks charge their clients before the crisis, but document a substantial deterioration of pass-through after the crisis (with the exception of mortgage rates).

Next, we explore the heterogeneity in the price-setting behaviour of individual banks by linking the pass-through coefficients estimated at the bank and product level to the characteristics of the banks. Among others, we analyse the effect of bank cost efficiency on the price-setting behaviour of banks. Our results show no relation between cost efficiency and long-term pass-through. We also fail to confirm the intuition that more efficient banks tend to charge lower markups. However, we find that cost-efficient banks tend to respond to changes in market rates with longer lags, thus smoothing loan rates for their clients.

This paper has been written in cooperation with Tomas Havranek (Czech National bank & Charles University) and Zuzana Havrankova, born Irsova (Charles University) and was published in 2016 in *Economic Modelling*. I assess my contribution to the second paper to be 30%.

In the third essay titled *Does Greater Capital Hamper the Cost Efficiency of Banks? A Bi-Causal Analysis*, we analyse the effect of bank cost efficiency on the capital of banks in the Czech Republic. We also assume the opposite direction of the causality that bank capital might affect the cost efficiency of banks. The hypotheses on the impact of capital on cost efficiency come from the agency costs literature, which demonstrates the existence of conflicts of interest between firm stakeholders, as mentioned by Jensen and Meckling (1976).

The new capital rules commonly known as the Basel III reforms have led to a wide debate. These reforms include tighter capital requirements aimed at improving the resilience of the banking industry. However, they may also contribute to reducing bank lending and might therefore hamper growth. A couple of studies have thus analyzed how bank lending and then output will be affected by the Basel III reforms. However, the investigation of the effects of tighter capital requirements on bank performance and through this channel on financial stability remains limited. This lack of interest is surprising, as there are theoretical arguments for the existence of a relation between capital and performance and as there is empirical evidence that the efficiency of banks influences financial stability.

Thus, if capital exerts an impact on financial stability through bank efficiency, it is of utmost interest to consider the influence of capital on bank efficiency to have a broad view of the consequences of capital requirements for financial stability. If capital reduces (increases) cost efficiency, capital requirements can potentially have negative (positive) consequences for financial stability through the cost efficiency channel. The findings of this paper are therefore of major interest for regulators.

Our investigation to identify a link between capital and efficiency showed no significant relation. Neither the effect of capital on efficiency, nor the effect of efficiency on capital is significant. In addition, the financial crisis does not influence the relation between capital and efficiency. From a normative perspective, our findings suggest that tighter capital requirements do not affect financial stability through the efficiency channel. The implementation of Basel III should not affect the efficiency of Czech banks. Our results also support the view that changes in efficiency do not influence capital. In other words, policies favoring capital levels and efficiency of the banking industry can be designed separately.

This paper has been written in cooperation with Laurent Weill (University of Strasbourg) and was published in 2016 in *Comparative Economic Studies*. I assess my contribution to the third paper to be 60%.

1. Explaining the Czech Interbank Market Risk Premium

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Explaining the Czech Interbank Market Risk Premium

Abstract

This paper focuses on the development of the interbank market risk premium in the Czech Republic during the global financial crisis. We explain the significant departure of interbank interest rates from the key monetary policy rate by a combination of different factors, including liquidity risk, counterparty risk, foreign influence, interbank relations, and strategic behavior. The results suggest a relevant role of market factors, and some importance of counterparty risk.

Keywords: counterparty risk, interbank market, liquidity risk, risk premium

JEL Codes: G19, G21

1.1. Introduction

The interbank markets play an important role in many aspects in almost all economies. They serve as a source of funding and a venue for liquidity management of banks. Moreover, interbank markets play a key role in the monetary policy transmission mechanism and represent one of the main channels through which the official interest rates set by central banks are transmitted further to commercial bank rates and to the real economy. Finally, interbank market rates reflect the actual situation of the demand for and supply of liquid funds in the market and play an important role as reference rates for a number of financial products – be they selected derivatives, bank loans or deposits.

During the global financial crisis which started in the US sub-prime mortgage segment in 2007, interbank markets worldwide experienced an increase in volatility and decrease in liquidity. While interbank market rates usually closely mirror the monetary policy rate in normal times, a quite strong departure of interbank rates from the key central bank rate has been observed since the onset of the global financial crisis. This increase in risk premium and a parallel significant decrease in interbank market liquidity also happened in the Czech interbank market despite the fact that Czech banks were not directly hit by losses from subprime-related structured products.

The objective of this paper is to identify individual components of the interbank risk premium in the Czech interbank market during the global financial crisis period. We consider credit and liquidity risk as potentially significant determinants of the interbank risk premium in the Czech Republic. However, we also examine other factors that might significantly influence interbank lending conditions in the Czech Republic. Specifically, we examine the role of other bank-specific characteristics (e.g., market share, interbank lending relations, portfolio composition of the bank) and the situation in the relevant domestic as well as international markets.

The paper is structured as follows. The following section 2 is devoted to a review of relevant literature, while section 3 describes the Czech interbank market. Section 4 introduces the hypotheses that are tested. Section 5 describes the data used for the analysis and explains the methodology. Section 6 discusses the results and section 7 concludes.

1.2. Literature Review

A number of theoretical and empirical papers examine interbank markets and try to explain the interbank market freeze during the global financial crisis. Heider et al. (2009) show that the unsecured interbank market freeze stems mainly from counterparty risk and the asymmetric information problem, where an interbank market breakdown occurs when average counterparty risk and the dispersion of counterparty riskiness are high. Similarly, Freixas and Jorge (2008) find that asymmetric information might lead to credit rationing in the interbank market.[1]

[1] Credit rationing is the situation where demand for credit exceeds supply and borrowers do not receive the full amount of credit they require or some of the borrowers are completely turned down (Afonso and Aubyn, 1998).

According to Gai et al. (2011) an interbank market freeze can occur not only due to the counterparty credit risk, but also due to liquidity hoarding, possibly with the precautionary motive.[1] The precautionary motive becomes more important as the funding risk of the "creditor" bank increases. In their model, hoarding behavior by one bank leads to liquidity hoarding by other banks, where the probability and scope of such a domino effect is dependent on the interbank market structure. Although precautionary hoarding can introduce reputational costs for the hoarding bank, the authors assume such costs to be lower than the costs resulting from fire sales of banking assets.

Caballero and Simsek (2009) emphasize the role of the complexity of the interbank market structure and the cost of information gathering in a potential interbank market freeze. In normal times, it might be sufficient for a bank to assess the riskiness of its direct counterparties only. However, when financial distress occurs, the bank should become better informed not only about its direct trading partners, but also about the trading partners of its trading partners, and so on. Information gathering becomes impossible during the crisis due to the complex interbank structure, so the bank decides to withdraw its loan commitments from its counterparties and starts hoarding liquidity. This can lead to a credit crunch.

Moreover, Acharya et al. (2010a) show that if market power is concentrated in highly liquid banks, borrowing becomes too costly for banks that need liquidity even when there is no shortage of liquidity on the aggregate level. Weaker banks are then left with the option of either using expensive interbank borrowing or selling their assets. Banks with a liquidity surplus will then be able to purchase those assets at a price well below their fundamental value (predatory behavior). Acharya et al. (2010a) provide a rationale for the role of a central bank as a lender of last resort, enabling small banks to borrow from the central bank and to avoid being under pressure from banks with predatory intentions.

Similarly to the theoretical literature, empirical papers on the interbank market assume credit and liquidity risk factors to be the main drivers of the interbank risk premium during the global financial crisis. The pioneering testing of this hypothesis was undertaken by Taylor and Williams (2008) and Michaud and Upper (2008). Both studies use the London Interbank Offer Rate (LIBOR) over the overnight indexed swap[2] (OIS) spread.[3] However, the results of these

[1] Since the functioning of the interbank market might be disrupted in the crisis, banks might be uncertain about whether they will be able to obtain sufficient liquidity in the market in future if they are hit by a liquidity shock (i.e., significant withdrawals by depositors). Hence, banks might become reluctant to lend to other banks and instead keep sufficient liquidity in their balance sheets. Moreover, such behavior might be more apparent among banks with weaker balance sheets, since these banks might be facing even higher funding risk. Acharya and Merrouche (2010) found that banks with higher losses were more prone to liquidity hoarding during the crisis.

[2] An overnight indexed swap is an interest rate swap where the floating leg of the contract is linked to a particular index of overnight interest rates (for example EONIA in the euro area or CZEONIA in the Czech Republic). Given its construction – the counterparties exchange only the difference between the fixed and floating rate times the nominal value of the contract – it should be (almost) free of counterparty credit risk and liquidity risk premium and capture expectations of future short-term interest rates well.

[3] The spread between LIBOR and OIS should capture only the risk premium in the interbank market, as both the LIBOR rate and the OIS rate incorporate expectations of future short-term interest rates, which are mainly

studies differ. Michaud and Upper (2008) suggest that the increase in the interbank premium was driven mainly by liquidity factors, specifically by concerns about the banks' own funding liquidity position, and that the credit risk measured by credit default swap (CDS) spreads[1] is transmitted to LIBOR rates over a longer period of time. Taylor and Williams (2008), on the other hand, focus solely on the US interbank market and find a strongly significant effect of counterparty credit risk on the interbank premium, but a low impact of liquidity risk. Liquidity risk seemed to be of minor importance, since the impact of the Term Auction Facility of the Federal Reserve System on the interbank premium turned out to be insignificant.

Nobili (2009) and Kamps (2009) examine the risk premium in the European interbank market (EURIBOR-OIS spreads) during the global financial crisis. They find that both credit risk and liquidity risk were sources of the excessive EURIBOR-OIS spreads, and Nobili (2009) shows that their relative importance varied over time. Liquidity risk was more apparent at the beginning of the crisis and its weight significantly weakened in the last quarter of 2008. This decrease in liquidity risk is attributed to the effectiveness of the ECB's unconventional monetary policy.

Angelini et al. (2009) focus on interbank market rates of longer maturities (beyond one week) before and during the global crisis. Unlike the previous studies, which looked at aggregate reference rates, their analysis is conducted using micro data on real euro-denominated transactions executed by Italian and other European banks further merged with bank-specific characteristics. Their results show that in the pre-crisis period, borrowers' capital and liquidity position played no significant role, while lenders' capital and liquidity position mattered, i.e., more liquid and less risky lenders provided their funds at lower rates. Lenders' behavior has changed since the onset of the crisis, with highly liquid banks charging higher interest rates. They conclude that this might be in line with the predatory behavior suggested by Acharya et al. (2010a) or it may reflect idiosyncratic risk aversion of liquidity-rich banks. Moreover, the effect of borrower capitalization became significant during the crisis.

Acharya and Merrouche (2010), analyzing the sterling secured and unsecured interbank markets, find precautionary hoarding due to increased funding liquidity risk to be the main factor contributing to the elevated interbank market spreads in the UK, in line with the theoretical explanation by Gai et al. (2011). However, their analysis only includes the crisis period between the start of the crisis in August 2007 and June 2008, whereas the role of counterparty credit risk might have become more crucial in the post-Lehman period. Moreover, the stress on the secured market might also have been influenced by a decrease in the debt capacity of assets[2] used in repo transactions. Acharya et al. (2010b) show that the debt capacity of an asset can decrease quickly when the rollover frequency of debt is sufficiently high, even though the quality of the asset is respectable.

determined by central bank monetary policy. Monetary policy expectations are therefore cancelled out by deducting the OIS rate from the LIBOR rate.

[1] A credit default swap (CDS) is a financial derivative that allows the security holder to insure against debtor default. The CDS price paid by the buyer of the insurance, called the CDS spread, should therefore be a good indicator of counterparty credit risk.

[2] The debt capacity of an asset represents the size of borrowing that can be obtained using the asset as collateral.

1.3. The Czech Interbank Market and the Role of PRIBOR

- **Characteristics of the Czech Interbank Market**

The interbank market is used by commercial banks to exchange short-term liquid funds among themselves at a pre-specified price. In a wider sense, the interbank market also includes the transactions of commercial banks with the central bank. The interbank market is of key relevance for the monetary transmission mechanism, since monetary policy rates are expected to be transmitted to interbank market rates and on to the real economy (the interest rate channel), possibly also influencing the amount of credit to the private sector due to balance-sheet effects (the credit channel). Moreover, interbank rates – especially "reference" rates such as LIBOR, EURIBOR, and (in the Czech Republic) PRIBOR – often serve as base rates for pricing different financial products, both retail (client loans and deposits) and wholesale (derivatives such as interest rate swaps). While the interbank market serves as an important source of funding for banks in a number of countries (e.g., the UK, Italy, and Sweden) banks in the Czech Republic use interbank lending rather to balance their short-term liquidity needs.

The size of the Czech banking sector has risen significantly over the last decade. The total assets of Czech banks have doubled since 2000 and currently amount to roughly 120% of GDP, while the number of banks has increased only marginally (from 40 in 2000 to 44 in 2012). The Czech banking sector consisted of 18 banks, 21 foreign bank branches and 5 special-purpose building societies in 2012. The development of the Czech banking sector has been influenced by large-scale privatizations of large, previously state-owned banks in the early 2000s as well as by subsequent mergers and acquisitions.[1] A distinct feature of the Czech banking sector is that the majority of banks are foreign owned.[2]

The Czech banking system exhibits favorable values of key indicators such as profitability and solvency (capital adequacy exceeding 15%), a relatively low level of non-performing loans, and, unlike Hungary or Poland, no household FX loans. Moreover, there is an overhang of deposits over loans, leading to a structural excess of liquidity in the sector. This contributes to a favorable liquidity position of most banks and no dependence on foreign funding (CNB, 2012). This holds not only for the pre-crisis period, which was marked by respectable credit growth, but also for the peak of the 2008–2009 crisis. Due to the strong position of the banking sector there have been no bank failures or bank runs since the global financial crisis started and thus there has been no need for public intervention (Frait et al., 2011).

The structural excess of liquidity in the domestic banking sector is regularly absorbed by the CNB via its repo operations, unlike in the euro area, where the ECB injects liquidity into

[1] The development of the Czech banking sector is discussed, for example, in Bárta and Singer (2006).
[2] Almost 97% of the banking sector's balance-sheet assets are controlled (directly or indirectly) by foreign owners (CNB, 2012).

the banking sector.[1] In October 2008, following a liquidity crisis in the Czech government bond market, the CNB launched a temporary liquidity-providing facility with 2W and 3M maturities, in which Czech government bonds can be used as collateral.[2] This facility proved to be of great importance, since around 15% of banking assets consist of government bonds (CNB, 2012). It helped to calm the government bond market (as holders were reassured that they could always exchange it for liquidity using the CNB facility). Given the continuing stress in the international financial markets in the period 2008–2012, it is still in place for prudential reasons, although only for 2W maturity. Nevertheless, there is very often no interest in the auctions; the facility is used rather sporadically.

An important feature of the Czech interbank market is its relatively low market liquidity not only in the crisis period, but also in the pre-crisis period. Average trading volumes of unsecured Czech koruna deposits amount to around CZK 60 billion (more than half of which conducted with non-resident banks) and are heavily concentrated at the shorter end of the maturity curve (O/N trading usually represents around 80% of daily trading volumes).[3,4] Interbank trading on a secured basis has increased since the onset of the global financial crisis, but there is still much less activity in comparison to unsecured lending. Finally, Czech banks are quite active in trading interest rate derivatives linked to interbank market rates, especially forward rate agreements (FRA) and interest rate swaps (IRS).

- **Specifics of PRIBOR**

Unlike in the case of EURIBOR and LIBOR, reference interbank market rates are quoted for both the bid (PRIBID, Prague Interbank Bid Rate) [5] and offer (PRIBOR, Prague Interbank Offered Rate) sides of the contract in the Czech Republic. The benchmark PRIBOR and PRIBID are calculated from individual quotes submitted by so-called reference banks. Reference banks are supposed to be significant participants in the interbank market for deposits and products derived from interest rates, even under rapidly changing market conditions (CNB, 2006).

The official definition of PRIBOR differs from the definition of EURIBOR and LIBOR. PRIBOR is defined as the reference interest rate on the interbank deposit market calculated (fixed) by the calculation agent for the Czech Forex Club from the quotations of reference banks for the sale of deposits (CNB, 2006).[6] The "quotation" is the price at which a reference

[1] In total, roughly 10% of aggregated banking sector assets are deposited with the CNB as a result of these repo operations.

[2] See Geršl and Komárková (2009).

[3] See the results of the regular money market turnover survey on the CNB website: http://www.cnb.cz/en/financial_markets/money_market/mm_turnover/.

[4] In addition, there are long-term lending links between domestic banks that are also connected via ownership (like building societies/mortgage bank and their domestic parent banks), but those links that are of longer maturities or in the form of holdings of covered bonds are thus not being captured by interbank market activity figures mention in this paper.

[5] PRIBID stopped being quoted since 7/2015.

[6] The reference bank submits data for the calculation of the PRIBID and PRIBOR reference rates every business day between 10.30 a.m. and 10.45 a.m. local time. The calculation of PRIBID and PRIBOR takes place at 11.00 a.m. local time and the PRIBOR and PRIBID rates are published immediately after the calculation is completed.

bank is willing to sell an interbank deposit to another reference bank (CNB, 2006). EURIBOR is the rate at which euro interbank term deposits are offered by one prime bank to another prime bank within the EMU zone, and is published at 11.00 a.m. (CET) for spot value (T+2) (European Banking Federation). In contrast, LIBOR is the rate at which an individual contributor panel bank could borrow funds, were it to do so by asking for and then accepting interbank offers in reasonable market size, just prior to 11.00 a.m. London time (British Bankers' Association).

Since the definitions of LIBOR, EURIBOR, and PRIBOR differ, they might not be fully comparable and might be associated with different difficulties. Quotes for the benchmark LIBOR might be biased downwards, since LIBOR banks should indicate via their quotes how costly it would be to secure funding for themselves. By providing lower quotes, LIBOR banks might prevent negative signaling about their possibly tight funding risk position (Kamps, 2009). The EURIBOR rate might be influenced by the unclear definition of the term "prime bank," as the notion of prime bank might differ across the banks providing quotes for EURIBOR and also across time (Taboga, 2013). In the case of PRIBOR, both the lender and the borrower (counterparty bank) are exactly defined, as both of them are reference banks. However, the Czech banking sector is rather small by international comparison and the dozen or so reference banks providing quotes for PRIBOR differ significantly from each other in various respects, such as the size of the bank, its legal form (subsidiaries versus branches of foreign banks), and riskiness. Hence, it might be challenging for a representative of a reference bank to provide an appropriate quote for such a heterogeneous group of potential counterparties.[1]

PRIBOR and PRIBID reference rates are calculated as the mathematical arithmetic mean rounded to two decimal places for overnight (O/N) maturity and for maturities of 1 and 2 weeks and 1, 2, 3, 6, 9, and 12 months. Since there are 11 reference banks in the PRIBOR and PRIBID panel as of June 2012, the two highest and two lowest quotes are removed from the calculations in order to prevent deliberate manipulation of the PRIBOR index.[2] The resulting PRIBOR and PRIBID rates are not binding, i.e., banks only indicate what would be the approximate price for lending to or depositing the money of other reference banks. The real price might differ from the quoted price in PRIBOR and PRIBID.[3]

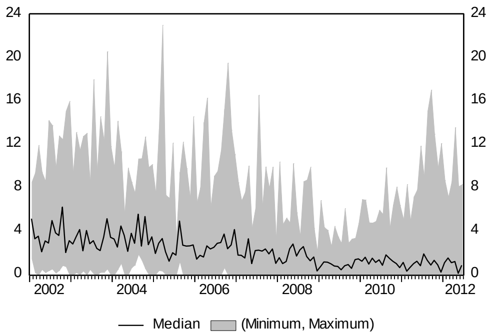
[1] There are other additional differences between LIBOR, EURIBOR, and PRIBOR fixing, e.g. differences in the number of panel banks or the number of quotes that are excluded from the calculation of the benchmark rates.

[2] When 11 or more banks provide quotes, the two highest and two lowest quotes are removed from the calculations. When the number of quotes is between 6 and 10, the highest quote and the lowest quote are excluded. When the number of quotes is 4 or 5, all the quotes are included in the calculation sample. When the number of quotes is less than 4, the interest rate for the relevant maturity is not fixed.

[3] Unfortunately, data on whether the interest rate on real transactions is close to the quoted PRIBOR rates are not available.

Figure 1

Share of Interbank Exposures in Balance Sheet of Reference Banks (%)

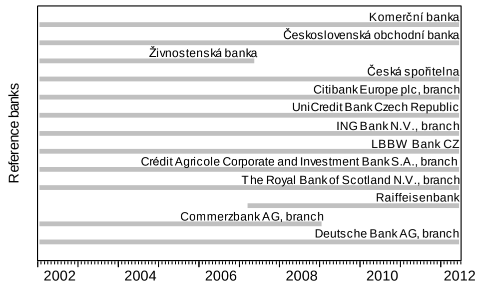


Note: *Exposures to resident banks in CZK*

Source: CNB

Figure 2

Number of Reference Banks Over Time



Note: The bank names are as of June 2012. Živnostenská banka stopped being a reference bank due to M&A (see footnote).
Source: CNB, Thomson Reuters

The 11 reference banks account for 69% of the total assets of the Czech banking sector and for 51% of total domestic interbank lending in CZK as of June 2012. On average, however, the interbank exposures of the reference banks as a proportion of their assets are rather small (Figure 1). The panel of reference banks comprises all four large banks, five branches of foreign banks, and two small and medium-sized banks. All reference banks are under foreign control.

However, the number of reference banks has varied between 11 and 13 over the last decade (Figure 2). Moreover, there have been some mergers and acquisitions (M&As) during the period, influencing not only the size and market shares of the banks concerned, but also their ownership structure and related corporate governance structure (domestically owned bank vs. subsidiary of foreign bank vs. branch of foreign bank).[1]

Out of the nine maturity buckets for both PRIBOR and PRIBID (O/N, 1W, 2W, 1M, 2M, 3M, 6M, 9M, and 12M), the 1M, 3M, and 6M PRIBORs are the most followed reference interbank rates, since they represent the base rate for pricing financial products such as interest rate derivatives and certain deposits and loans, mainly to non-financial corporations. In

[1] First, BAWAG Bank CZ merged with BAWAG International Bank CZ (previously Dresdner Bank) on March 31, 2005. BAWAG Bank CZ became a reference bank instead of BAWAG International Bank CZ. Moreover, the change of ownership of BAWAG Bank CZ on September 1, 2008 was also connected with the rebranding of the bank to LBBW Bank CZ. LBBW Bank CZ continued to serve as a reference bank. Second, the merger of HVB Bank Czech Republic and Živnostenská banka reduced the number of reference banks from 13 to 12, since both of them had been providing quotes in PRIBOR/PRIBID fixing until then. The result of the merger on November 5, 2007 was UniCredit Bank Czech Republic, the fourth biggest bank in the Czech banking sector, which continued to be a reference bank in PRIBOR/PRIBID fixing. Third, Raiffeisenbank started providing quotes for PRIBOR/PRIBID fixing at the beginning of March 2007. This temporarily increased the number of reference banks to 13. On July 7, 2008, Raiffeisenbank and eBanka completed their merger and Raiffeisenbank continued providing quotes in PRIBOR/PRIBID fixing. Fourth, Crédit Agricole (in that time CALYON BANK, previously Crédit Lyonnais) and Citibank Europe changed their governance structures from a subsidiary to a branch of a foreign bank at the end of 2005 and 2007/2008, respectively. Both remained reference banks. Fifthly, ABN AMRO Bank N.V. changed its name to The Royal Bank of Scotland N.V. in 2010.

comparative analyses and models, the 3M PRIBOR plays an important benchmark role. Also, the official forecasting model of the CNB (the DSGE-type "g3" model) includes the 3M PRIBOR as a market proxy for the monetary policy. In this paper, we focus mainly on the 3M PRIBOR, acknowledging the fact that the other PRIBORs are correlated with the 3M rate to a large extent.

- **Development of the Risk Premium in the Czech Interbank Market**

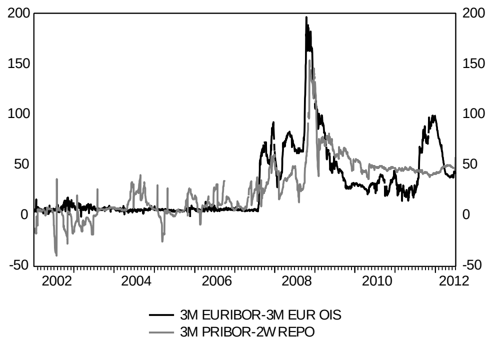
Prior to the global crisis, the situation in the domestic interbank market was stable and the 3M PRIBOR closely mirrored the key monetary policy rate (the CNB's 2-week repo rate), resulting in a very tight spread between these two rates, with its occasional variation mainly reflecting short-term (3-month) expectations of changes in the monetary policy rate (Figure 3). However, the 3M PRIBOR–2W repo spread increased at the beginning of the global crisis, first only a little and then rather abruptly after September 2008. Given the foreign ownership of Czech banks and the resulting close links with European banks that were hit by the sub-prime crisis, the uncertainty observed in the international financial markets and the unexpected difficulties of large banks abroad could also have been transmitted to their Czech subsidiaries' and branches' behavior.

The risk premium between 2009 and 2011 was even higher in the Czech interbank market in comparison with the Euro interbank market (Figure 3). The significant decrease in the Euro interbank risk premium was likely due to decrease in liquidity risk as a result of the introduction of ECB's unconventional monetary policy as suggested by Nobili (2009). The fact that it was even lower than in the Czech Republic might have been due to several factors, including structurally different interbank markets (the particularly good liquidity position of Czech banks), more aggressive actions taken by the European Central Bank to calm the interbank market relative to measures taken by the Czech National Bank or potentially by the higher risk aversion of domestic banks relative to European banks after the peak of global crisis. We have observed a similar situation, e.g. in Poland (Appendix E).

Figure 3

Risk Premium in Czech and Euro Interbank Markets

(bp)

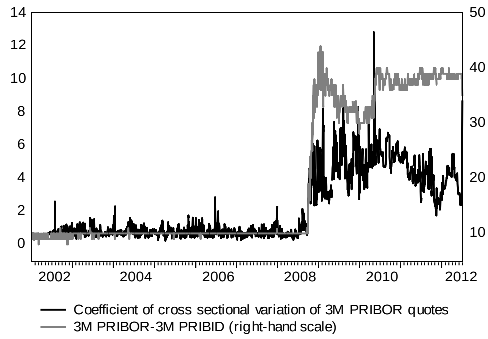


Source: CNB, Thomson Reuters Datastream

Figure 4

Coefficient of Cross-sectional Variation of 3M PRIBOR Quotes and Bid-ask Spread

(%, bp)



Source: CNB, Thomson Reuters, authors' calc.

In parallel to the increase in the 3M PRIBOR−2W repo spread there was a significant rise in the bid-ask spread in the interbank market, connected with higher cross-sectional variation of the individual quotes from the end of September 2008 onwards as measured by the standard deviation of the individual quotes divided by the mean (Figure 4). Until then, the market practice had been to keep the spread between the quotes submitted for PRIBOR and PRIBID at 10 bp, limiting arbitrage opportunities in the interbank market. This practice, however, stopped in September 2008, as some reference banks – reflecting the conditions then prevailing in international financial markets – increased the quoted PRIBOR independently of their quoted PRIBID. As a result, the PRIBOR-PRIBID spread increased to around 40 bp, which also contributed to higher dispersion of PRIBOR and PRIBID quotes.

In order to gain more information on the market practice as regards PRIBOR quoting, we conducted several interviews with reference bank representatives. The main messages can be summarized as follows. First, there was a clear structural change in PRIBOR quoting in September/October 2008, when banks stopped quoting a PRIBOR-PRIBID spread of 10 bp and started to take more account of various risks related to interbank market lending (counterparty, liquidity, etc.) as well the general uncertainty in markets and the economy. The preceding period (say 2002–early 2007) had been rather exceptional from today's perspective, as there had been a high persistence in quoting, the main driver had been monetary policy expectations, and the role of counterparty and other risks had been limited. Second, the liquidity in the Czech money market has always been and remains rather low (with the exception of the O/N segment), so the quotes should be understood only as reference or benchmark rates. Actual interest rates in trading with other banks could differ from the reference rate. Third, charging different rates for different counterparties – although also used to some degree – was not the main strategy. Rather, banks increased or reduced their credit lines/limits for particular counterparties and/or the maturity of interbank loans to reflect counterparty risk. In addition, the risk management strategy was often influenced or even set by the parent bank. Moreover, when assessing counterparty risk, banks looked at the situation of parent banks of possible domestic counterparties, including their CDS spreads. Finally, when providing quotes to PRIBOR, banks took significant account of market developments such as euro area spreads and other market variables.

Going beyond the time span of this paper, the Czech National Bank has continued with the easing of monetary conditions. After the central bank rates hit the zero-lower-bound in 2012 in the Czech Republic, the CNB started actively managing the exchange rate as an additional instrument for easing the monetary conditions in the Czech Republic. It kept the artificially weak Czech crown against EUR meaning that the EUR/CZK exchange rate could not drop below the 27 level from November 2013 to April 2017. The use of the exchange rate commitment influenced the domestic banks and domestic interbank market in several ways.

Firstly, the use of the exchange rate commitment has led to a further increase in the liquidity surplus of the Czech banking sector as the CNB issued a new amount of CZK to defend the exchange rate commitment. Secondly, on the one hand, transaction activity among domestic banks almost disappeared in the interbank market. On the other hand, there was a significant increase in the activity between domestic banks and non-residents (again highly concentrated at the O/N maturity). This happened due to the fact that the counterparty for the newly issued CZK, by the Czech National Bank, were often non-residents who subsequently deposited their CZK liquidity into the Czech banks. Thirdly, all these developments described above contributed to a further decrease in the interbank risk premium to around 15 bp in 3/2018. As there were no significant changes in the Czech interbank risk premium after 6/2012 and it continued in a decreasing trend (Appendix E), our paper covers the most interesting period regarding the development of Czech risk premium.

1.4. Hypotheses

The literature overview provides a number of potential hypotheses that could be tested in the Czech context. Generally, the increase in the interbank risk premium is seen as a consequence of liquidity hoarding by banks reluctant to lend in the interbank market during the global crisis. However, there are various possible sources of such hoarding behavior. Heider et al. (2009), Freixas and Jorge (2008), and Taylor and Williams (2008) suggest that the source of liquidity hoarding is counterparty credit risk, while Gai et al. (2011), Acharya and Merrouche (2010), and Michaud and Upper (2008) explain liquidity hoarding behavior by concerns about the banks' own liquidity position.

Precautionary hoarding due to liquidity effects is influenced not only by the current liquidity position of a bank, but also by expectations about the future development of the market situation and banks' solvency position. For example, expectations of increasing credit risk losses on the loan portfolio might reduce liquidity inflows (interest income) and increase liquidity risk in terms of a possible bank run should the bank come closer to insolvency.

Further, the complex and highly interconnected structure of the interbank market might influence banks' behavior in the interbank market. The complexity of interbank relationships might increase the interbank risk premium in crisis times (Caballero and Simsek, 2009). However, the market complexity hypothesis is difficult to test, since banks' representatives quoting PRIBOR do not directly observe the complexity of the market over time. On the other hand, long-term lending relationships between banks (relationship lending) and high connectivity of the reference banks with other reference banks (reference banks are very well known counterparties) might decrease the interbank risk premium.

Besides the above-mentioned factors discussed in the theoretical and empirical literature, specific features of the Czech banking sector are also taken into account. First, conditions abroad might be relevant for PRIBOR quoting by domestic reference banks due to their foreign ownership and specific corporate governance structure. A worsening of the liquidity and solvency position of a parent bank could be transmitted to increased PRIBOR quotes provided by its Czech subsidiary, since the parent bank usually needs to satisfy some liquidity and solvency standards on the consolidated banking group level, so the parent bank might aim to influence the behavior of its subsidiary on the Czech interbank market.[1] Moreover, the counterparty risk of domestic banks might not be viewed by the quoting reference bank as completely separated from the riskiness of the counterparty's parent bank. Second, given the high exposure of domestic banks to Czech government bonds, which account for an important part of their liquid assets, market conditions in this particular asset market are covered by our data, as they directly influence banks' balance-sheet positions. Finally, we also reflect individual banks' business models in the data construction.

More recently, the LIBOR manipulation scandal revealed that the quoting behavior of individual reference banks might be driven by strategic considerations and attempts to manipulate the final benchmark rate.[2] The manipulation of LIBOR and EURIBOR submissions was motivated by making profit (or limiting the loss) on derivatives trades. The derivative traders requested the LIBOR/EURIBOR submitters to make particular submissions which were favorable to their derivatives position. In the crisis period, the submission of lower LIBOR quotes compared to the real price of funding was done in order to avoid negative media perception about the banks' funding position.[3] Having these strategic manipulations in mind, we also test for strategic behavior potentially relevant for the Czech case.

The manipulation of the reference/index rates has led to the creation of new European regulation regarding benchmarks („BMR") – in application as of 1 January 2018 – which should reduce the risk of the manipulation of benchmarks and ensure the integrity and reliability of the

[1] Eventually, the risk of subsidiaries could also be transmitted to parent banks, influencing the riskiness of the whole banking group. However, the Czech subsidiaries of Western European banks did not increase the risk of the group compared to the losses of the parent bank or other subsidiaries. On the contrary, even in the crisis period the highly profitable Czech banks helped stabilize the overall banking group position.

[2] See UK Treasury Wheatley Review of LIBOR: Initial Discussion Paper, available at http://www.hm-treasury.gov.uk/d/condoc_wheatley_review.pdf.

[3] http://www.fsa.gov.uk/static/pubs/final/barclays-jun12.pdf

benchmarks/input data to benchmarks. In the Czech Republic, there is a new benchmark administrator Czech Financial Benchmark Facility (instead of previous Czech Forex Club) starting 24 July 2017, which should be authorized by the Czech National Bank.

In the Czech context, such strategic behavior could emerge if there were benefits in doing so in terms of profitability considerations. Banks in the Czech interbank market could have had an incentive to report higher rates in order to increase profits on financial products held in their balance sheets and linked to PRIBOR, such as PRIBOR-linked loans to non-financial corporations or interest rate derivatives such as FRA and IRS.[1] However, while the potential incentive to manipulate PRIBOR upwards to generate income on PRIBOR-linked loans exists across all banks, the direction of potential manipulation of PRIBOR to influence the value of derivatives held and linked to PRIBOR can differ across banks, as net exposures and their sensitivity to changes in PRIBOR also differ. Moreover, predatory behavior could also have played a role given the good liquidity position of some reference banks and the strong concentration of the Czech banking sector, in which the four biggest banks have dominant positions.

In the empirical investigation, we test the following hypotheses:

H1: Higher funding liquidity risk of the reference banks, as measured by liquidity and – due to their impact on possible funding liquidity risk – solvency risk indicators, including indicators of the foreign parent bank, increases the risk premium in the domestic interbank market.

H2: Counterparty risk, as measured by indicators of potential counterparties and – allowing for contagious effects – of their foreign parent banks, increases the risk premium in the domestic interbank market.

H3: Market variables, especially higher uncertainty, lower liquidity, and higher volatility in other domestic and foreign markets, contribute to the risk premium in the domestic interbank market.

H4: Higher connectivity of reference banks among themselves, together with long-term interbank lending relationships (relationship lending), increases the knowledge of reference banks about each other, leading to a decrease in the interbank risk premium.

H5: Some strategic behavior by domestic reference banks emerged during the crisis period.

1.5. Empirical Approach

- **Data**

Data for the empirical analysis were taken from various sources. Firstly, a full dataset comprising PRIBOR and PRIBID quotes by individual reference banks was obtained from Thomson Reuters. Secondly, reference banks' bank-level data were extracted from CNB supervisory reporting and the CNB's credit register. Thirdly, market data were obtained from Bloomberg and Thomson Reuters Datastream. The bond market liquidity index is internally calculated by the CNB using the methodology described in Geršl and Komárková (2009).

[1] Mortgages and consumer loans are traditionally provided with longer interest rate fixations (3–5 years being the most common period over which the interest rate is fixed in the case of mortgages).

All variables used in the empirical analysis are summarized in Appendix A in the structure defined by the hypotheses. We construct a number of ratios and indicators following the related literature as well as our judgment as to what could best capture the determinants of the quoting behavior of reference banks. The reference-bank-specific data, originally at monthly and quarterly frequency, were linearly interpolated in order to obtain a daily data set, in contrast to the counterparty banks' characteristics, where constant observation was applied, reflecting the information available to the representatives of the reference banks at the time of PRIBOR quoting. Alternatively, to obtain the monthly dataset used for the robustness check of the results based on daily frequency, monthly averages of the daily variables were created.

The interbank risk premium in the Czech interbank market is represented by the 3M PRIBOR less the 2W repo. We use this spread to capture the domestic interbank risk premium – despite the fact that it includes a term premium and expectations about the monetary policy rate over the next 3 months – for three main reasons. Firstly, the alternatives (such as the PRIBOR–OIS spread[1]) are not reliable due to the low liquidity of the CZK OIS market. Secondly, the 3M PRIBOR–2W repo spread is often publicly discussed, since monetary policy analysts compare the repo rate and the benchmark 3M PRIBOR rate. Thirdly, the official CNB "g3" forecasting model includes this premium, so the results of this analysis can help complement the forecasts based on the g3 model. Moreover, we control for expected monetary policy changes using the 1x4 FRA rate, which captures expectations about future monetary policy in the immediate future. We also include dummies for individual banks to capture bank-specific effects.

The first group of explanatory variables comprises funding liquidity and solvency indicators which indirectly influence *funding liquidity risk*, such as bank run risk if a bank's solvency position deteriorates, to test the H1. Liquidity indicators are represented by traditionally used indicators such as the ratio of liquid assets[2] to total assets and the loan-to-deposit ratio. We cannot use the traditional solvency indicators, such as the regulatory capital adequacy ratio or the capital to assets ratio, as a number of reference banks are foreign bank branches without regulatory capital. Thus, we use variables that are related to or influence solvency, i.e., credit risk indicators of banks' portfolios (the ratio of non-performing loans, the loan loss provisions ratio, and the 3M default rate on corporate loans) and one profitability indicator (return on assets, ROA). Finally, this group includes the CDS spreads of the parent banks of reference banks quoting PRIBOR as a variable capturing group-wide pressure related to the group-wide liquidity or solvency position, to reflect possible contagion effects from the parent bank to the domestic reference bank.

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[1] The difference between the interbank market rate (e.g., EURIBOR) and the OIS of the corresponding maturity and currency is commonly used in the literature as an approximation of the interbank risk premium. This expression of the interbank risk premium has the advantage that expectations about monetary policy are effectively removed from the spread. However, the OIS in CZK is illiquid and thus cannot be used as a good proxy for expectations of future policy rates anyway.

[2] Liquid assets are defined by the CNB and comprise cash, claims on the CNB, government bonds, and short-term interbank claims.

The second group of variables serves to test H2 on *counterparty risk*. While it is easy for a bank to judge its own liquidity and solvency position, given that all the necessary data are available internally in the bank, it is much more difficult to get information about potential counterparties for interbank transactions. As a proxy for counterparty solvency, the CDS spreads of the counterparty bank are usually used in the literature. However, the CDS of Czech banks are not traded. Instead, the average counterparty's ratio of non-performing loans (NPL) and the average counterparty's return on assets (ROA) are used, since we believe there is close link between a potential counterparty's level of bad loans and profitability on the one hand and its solvency on the other hand. The NPL ratio is published monthly by the CNB as an aggregate for the banking sector, so each reference bank can roughly estimate the average for the rest of the banking sector using its knowledge of its own NPL ratio and the aggregate NPL ratio. Moreover, NPL data for banking groups (such as large, medium-sized, and small banks and foreign bank branches) are available on a quarterly basis. ROA is publicly available on the CNB website at quarterly frequency for the aggregated banking sector and for some large banks also on an individual basis and is usually closely monitored by banking sector analysts. Ideally, one would also like to include some measure of the dispersion of these variables among potential counterparties, but individual data for all reference banks are not publicly available, hence banks would not be able to calculate it.[1]

This group of variables also includes indicators related to the parent banks of potential counterparties. We construct average CDS spreads across all parent banks of potential counterparties as well as the dispersion of CDS spreads, since individual data are publicly available for this variable to capture the source of potential counterparty risk premium that is due to the contagion effect of parent (foreign) banks.[2] By using these CDS spreads, we also indirectly test for spillovers from other countries' risk. While it would have been interesting to test whether the risks related particularly to the parent banks' countries of domicile play a more prominent role than risks stemming from other countries' markets, we don't think that there are any strong channels through which such other countries would have had an effect on the Czech interbank market risk premium. Czech banks are neither significantly exposed on their assets side nor on their liabilities side to other countries than countries of their parent banks.

The third group includes variables to test H3 on the effect of domestic and foreign *financial markets*. For domestic markets, we use indicators of bond market liquidity constructed by the CNB, long-term (5Y) government bond spreads vis-à-vis 5Y IRS, and exchange rate volatility. For foreign markets, we use the risk premium in the euro interbank market, constructed as the difference between the 3M EURIBOR and the 3M EUR OIS. The inclusion of the euro interbank risk premium also captures the potential contagion from the euro area interbank market to the Czech interbank market.

[1] The problem is particularly with the branches of foreign banks which do not usually publish their results on a monthly or quarterly basis on their webpage.

[2] Interviews with reference bank representatives confirmed that when judging counterparty risk, a bank takes into account the CDS of parent banks.

The fourth group of variables captures *interbank market activity* to test H4 and includes the ratio of net interbank market exposure to total assets, the connectivity of the reference bank with other reference banks, and the durability of interbank exposures.

The final group of variables allows for testing various aspects of possible *strategic behavior* (H5). Firstly, we include the share of corporate loans linked to PRIBOR in total assets to see whether banks with a higher share of these loans strategically push PRIBOR up. Secondly, to test whether banks take into account the sensitivity of their derivatives exposures to changes in PRIBOR when submitting quotes (i.e., if a bank would earn when PRIBOR goes up, it could strategically push PRIBOR upwards), a good variable to capture this sensitivity is needed. Unfortunately, the CNB reports on interest rate derivatives only at monthly frequency and only includes their real and nominal values and not such a sensitivity parameter. Thus, we constructed an indicator of sensitivity ourselves in a simplified manner – we divided the monthly changes in the real value of the interest rate derivatives by the monthly changes in the 3M PRIBOR. Positive figures of this measure would indicate that the derivatives portfolio increases with the 3M PRIBOR. A significant and positive coefficient of this measure would be indicative of possible strategic behavior to push up PRIBOR in order to earn. If banks were passive holders of such derivatives, this would capture the sensitivity relatively well. Clearly, however, banks use these derivatives in an active manner and thus the indicator of sensitivity (which is, moreover, only at monthly frequency) is probably a very weak proxy, so the results must be interpreted with caution.

- **Methodology**

With respect to the time and cross-sectional dimension of the data set, our preferred approach to exploring the relevant determinants of the interbank market spread is the panel estimation method. We opt for the fixed-effects model, allowing for unobserved effects specific to the individual reference banks. The reduced-form equation in matrix notation can be expressed as:

$$spread = c_\gamma + X_\gamma \beta_\gamma + \varepsilon \qquad \varepsilon \sim (0, \sigma^2 I),$$

where $spread$ is the vector of the dependent variable, the 3M PRIBOR–2W repo spread, X represents the matrix of explanatory variables (see Appendix A), β_γ is the vector of the coefficient to be estimated, and ε denotes the vector of disturbances. Lower-index γ represents a particular model which includes a particular subset of potentially relevant explanatory variables.

The common approach to removing fixed effects from the data is to use a within transformation. Alternatively, one may include dummy variables for individual reference banks in order to capture bank-specific effects. Since we have up to 13 cross sections (banks) and the number of time periods is high in our sample, we are able to use the dummy variable approach without losing a significant number of degrees of freedom. The estimated equation can be rewritten into:

$$spread = c_\gamma + X_\gamma \beta_\gamma + D_\gamma \eta_\gamma + \varepsilon,$$

where matrix D represents dummies for individual cross sections (banks). Although the fixed-effect technique seems to be appropriate for addressing our task, we still face high uncertainty about the "true" model which reflects the decision-making process of reference banks when quoting PRIBOR and hence influencing the interbank market spread. We identify 23 potentially relevant explanatory variables (excluding dummies). To examine all the potential models, we would have to run 2^{23} regressions, which would be computationally demanding.

Therefore, we take advantage of the Bayesian Model Averaging (BMA) method in combination with the Markov Chain Monte Carlo Model Composition (MC3) algorithm, which can effectively tackle the issue of a large number of potential explanatory variables.[1] This method is becoming popular also in the finance literature for dealing with the problem of model uncertainty (Sousa and Sousa, 2011; Crespo-Cuaresma et al., 2010). The crucial outputs of BMA are the posterior model probability (PMP), the posterior inclusion probability (PIP) of each variable, and the posterior mean (PM) of the coefficients. Posterior model probabilities denote the probability that a particular model is the "true" model. Given the prior model probability $p(M_\gamma)$, the PMP can be calculated using Bayes' Rule:

$$p(M_\gamma \mid y, X) = \frac{p(y \mid M_\gamma, X)\, p(M_\gamma)}{\sum_{s=1}^{2^K} p(y \mid M_s, X)\, p(M_s)},$$

where $p(y \mid M_\gamma, X)$ is the marginal likelihood of the model and $p(M_\gamma)$ is the prior model probability reflecting our prior beliefs about the model space. We use the binomial-beta model prior as suggested by Ley and Steel (2009). The denominator (integrated likelihood), given by the sum of the marginal likelihoods of all individual models weighted by the prior model probability, is constant over all models. The marginal likelihood can in theory be calculated in the following way:

$$p(y \mid M_\gamma, X) = \int p(y \mid \theta^\gamma, M_\gamma)\, p(\theta^\gamma \mid M_\gamma)\, d\theta^\gamma,$$

where $p(y \mid \theta^\gamma, M_\gamma)$ is the likelihood and $p(\theta^\gamma \mid M_\gamma)$ represents the prior density of the parameter vector θ^γ under model M_γ. Setting prior densities is of crucial importance. To reflect the lack of knowledge, we set a non-informative prior on the intercept and error variance, thus $p(c_\gamma) \propto 1$ and $p(\sigma) \propto \sigma^{-1}$. Further, we employ Zellner's g-prior (Zellner, 1986) for parameters β_γ with a benchmark hyper-prior on g according to Fernández et al. (2001) in the form of $g = \max(N, K^2)$, where N is the number of observations and K is the total number of covariates.

[1] For more details on MC^3 see Madigan and York (1995). The computations of BMA in combination with MC^3 were done using the BMS package by Feldkircher and Zeugner (2009).

PIP determines the robustness of a variable with respect to the dependent variable and is calculated as the sum of the PMPs of models where the variable was included, formally:

$$PIP = p(\beta_\gamma \neq 0 \mid y, X) = \sum_{\beta_\gamma \neq 0} p(M_\gamma \mid y, X)$$

The PM of a coefficient β is calculated as the weighted average, with the weights being the PMPs, formally:

$$PM = E(\beta \mid y, X) = \sum_{\gamma=1}^{2^K} E(\beta_\gamma \mid y, X, M_\gamma)\, p(M_\gamma \mid y, X)$$

Additionally, we report the standardized version of the posterior mean (SPM) of the coefficients, which might provide more helpful information on the importance of the explanatory variable with respect to the dependent variable.[1] Finally, we also report the posterior standard deviation of the coefficients and their conditional posterior sign.

A special approach is applied to address the uncertainty about the appropriate number of lags of market-based variables included in the BMA estimation.[2] In principle, it would be possible to include, say, up to five lags of all market-based variables. However, this would substantially increase the number of models and possibly introduce multicollinearity into the models, to which BMA is not robust. Hence, we employ the panel VAR (PVAR[3]) approach, similarly to Babecký et al. (2011), which allows for heterogeneity among individual cross sections. The PVAR approach should suggest how fast a change on a given market is reflected in the domestic interbank risk premium. The estimated bivariate PVAR with 5 lags is of the form:

$$spread\_d_{it} = c_1 + \alpha_{1,1} spread\_d_{it-1} + ... + \alpha_{1,5} spread\_d_{it-5} + \beta_{1,1} market\_d_{it-1} + ... + \beta_{1,5} market\_d_{it-5} + \varepsilon_{1,it}$$
$$market\_d_{it} = c_2 + \alpha_{2,1} spread\_d_{it-1} + ... + \alpha_{2,5} spread\_d_{it-5} + \beta_{2,1} market\_d_{it-1} + ... + \beta_{2,5} market\_d_{it-5} + \varepsilon_{2,it}$$

where $spread\_d_{it}$ stands for the change in the risk premium for bank i at time t and $market\_d_{it}$ is the change in the respective market variable. The optimal lag of the market-based variables is set based on the response of the dependent variable in terms of magnitude and the sign to the shock to the respective market variable. The results of the PVAR analysis are provided in Appendix A (column "Lag(method)") and Appendix B (impulse-response functions).

1.6. Results

We run the BMA on the period 2007–2012 using daily data, given that the quoting behavior is a process that happens daily, with banks judging daily market developments as well as less frequent balance-sheet information. Each model includes dummy variables representing

[1] Standardized coefficients arise if both the dependent variable and the explanatory variables are normalized (zero mean and variance of one), hence effectively bringing the data down to the same order of magnitude.
[2] For other variables, expert-based judgment is used to determine the optimal number of lags.
[3] The program for PVAR was written and first used by Love and Zicchino (2006).

reference-bank-specific effects which were not subjected to the BMA selection procedure.[1] The results indicate strong persistence of the risk premium, as evidenced by the large standardized posterior mean (SPM) of the lagged risk premium. The control variable for expectations of future monetary policy has large posterior inclusion probability (PIP) and the expected sign.

As to the individual hypotheses, the results can be summarized as follows (see Figure 5; a table with detailed underlying BMA results, including PIP, PM, and SPM, can be found in Appendix C): First, we do not find strong support for the funding liquidity risk hypothesis H1. The only variable from this group of explanatory variables that has large PIP is the provisions ratio (*provisionsratio*), with the correct sign. This variable represents the materialization of credit risk in the bank's loan portfolio, which influences bank profitability and furthermore also bank solvency. It might be problematic for riskier banks to receive funding when needed. Hence this variable indicates some role of indirect funding liquidity risk through decreased solvency.

Second, two variables on counterparty risk, namely, the average NPL ratio of potential counterparties (*nplratioavg_l*) and the dispersion of the CDS spreads of foreign parent banks of potential counterparties (*cdsstd_l*), have high PIP and the correct signs. This can be considered supportive of H2 on the role of counterparty risk. The former variable shows that an increase in riskiness of an average counterparty is reflected by reference banks when indicating the price for lending (when quoting PRIBOR), hence pushing the risk premium upwards. The latter variable is also indicative of possible cross-border contagion effects via foreign ownership links, causing the Czech interbank market risk premium to increase if the dispersion of the CDS spreads of foreign parent banks increases. This means that higher uncertainty about the potential counterparty riskiness is also reflected in the interbank risk premium. This is in line with Heider et al. (2009), who suggest that the dispersion of riskiness among potential counterparties is crucial during turbulent times. The average of the CDS spreads of foreign parent banks of potential counterparties (*cdsavg_l*) has large PIP, too, but the incorrect sign. Michaud and Upper (2008) suggest that it takes longer for the information in CDS spreads to feed into the interbank risk premium. Moreover, our results indicate that the dispersion of counterparty riskiness might be more relevant for the interbank risk premium than the average counterparty riskiness within a short period of time, as supported by the higher PIP of *cdsstd_l* compared to *cdsavg_l*. This result is rather intuitive, since in the Czech case the counterparty bank might be any of the reference banks, which are quite heterogeneous in their characteristics (see section 3.2).

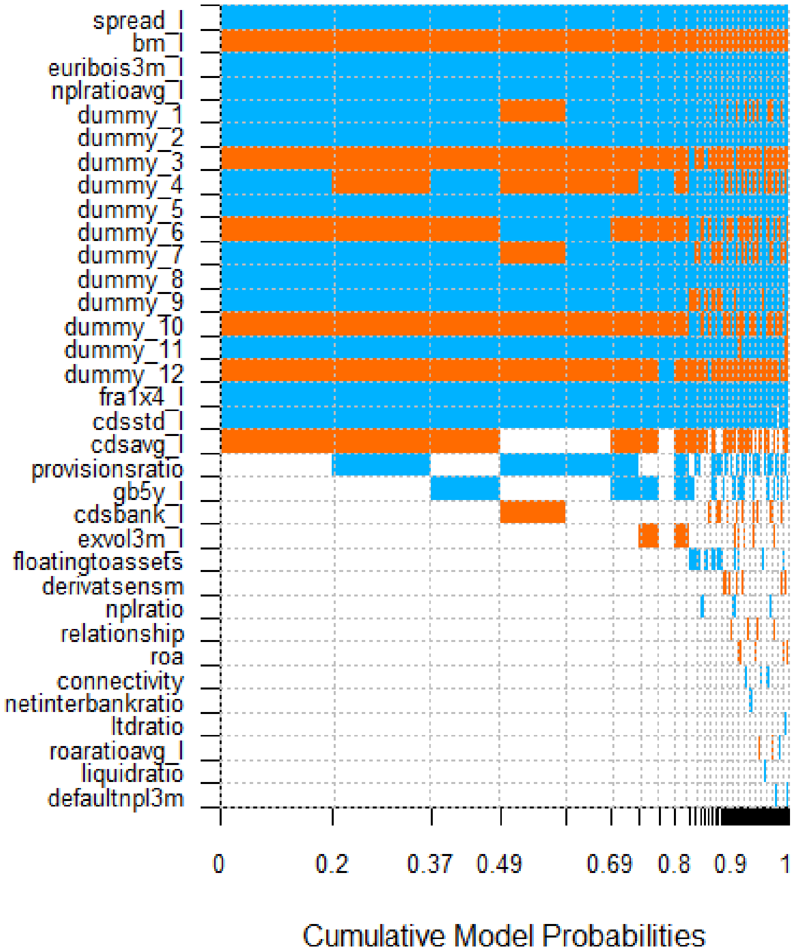
Third, market variables – in particular domestic bond market liquidity (*bm_l*) and the euro area money market risk premium (*euribois3m_l*) – are relevant for the determination of the domestic interbank risk premium (hypothesis H3). When banks are not able to easily sell their assets in the market (due to the low liquidity of that market) banks are less willing to lend in the interbank market, or at least are willing to lend for higher prices, which increases the interbank

[1] The number of dummy variables representing reference-bank-specific effects corresponds to the number of reference banks operating within a given period minus one in order to avoid perfect multicollinearity, since each model also includes an intercept. In this case, the intercept represents a benchmark bank to which other reference-bank-specific effects are compared.

market risk premium. Further, as there is a close interconnection between the Czech Republic and the Eurozone, the stress in the Eurozone interbank market is also transmitted to the Czech interbank market (i.e. contagion effect from abroad). Fourth, the connectivity indicators (*connectivity* and *relationship*) have low PIP, thus not supporting H4. Finally, we do not find any strong evidence of strategic behavior in the BMA analysis (hypothesis H5).

Figure 5

Results of BMA Based on Daily Data (1/1/2007−6/30/2012)

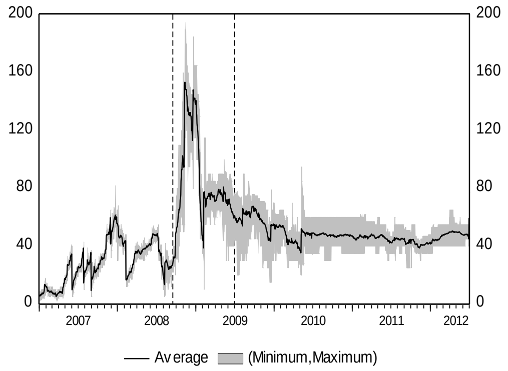


Note: This figure shows the 1000 best models indicated by the BMA procedure resulting from 2 million iterations after 1 million burn-ins. The order of the variables is set according to their PIP. The colors in the figure represent the sign of the coefficient, i.e., blue (+), red (-). The dummy variables representing reference-bank-specific effects are included in each model by default, i.e., they are not subjected to the selection procedure.
Source: authors' calculations

We look additionally at two sub-periods of our sample. Since the pre-crisis period 2007–September 2008 is characterized by low cross-sectional volatility of individual PRIBOR quotes supported by the convention of a 10 bp bid-ask spread, we run the BMA only for the sub-periods after September 2008, namely, September 15, 2008–June 2009 (the crisis period) and July 2009–June 2012 (the recession period) – see Figure 6 and Table 1. The crisis period is the turbulent period following the collapse of Lehman Brothers, characterized by significant uncertainty. The recession period mainly covers the low interest rate environment and economic recession in the Czech Republic and abroad, but with a high level of uncertainty about future economic developments. The results for the two sub-samples can be found in Appendix D.

Figure 6

Individual Quotes of Reference Banks for 3M PRIBOR Less 2W Repo (bp)



Source: CNB, Thomson Reuters Datastream

Table 1

Estimation Details

Dependent variable (pp)	3M PRIBOR quote - 2W repo
Period	1/1/2007–6/30/2012
Number of cross sections (reference banks)	13
Number of time periods (daily/monthly)	1435/66
Number of explanatory variables	22*
Crisis subperiod	9/15/2008–6/30/2009
Recession subperiod	7/1/2009–6/30/2012

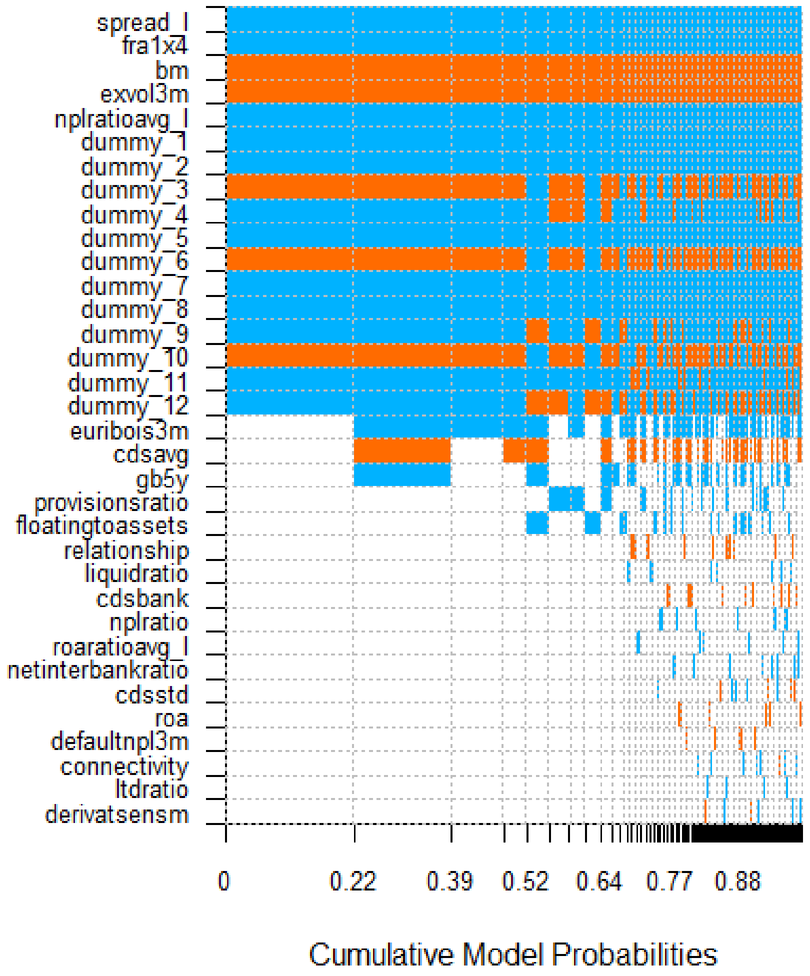
Note: **Due to its relatively low variation and hence relatively high correlation with reference banks' dummy variables, market share has been excluded from the initial set of variables examined by BMA*

In the *crisis period*, the most important explanatory variable (next to the lagged risk premium and FRA to control for expectations about monetary policy) is bond market liquidity, confirming the impact of the bond market crisis in October 2008 on banks' behavior. In the *recession period*, the counterparty credit risk variables – mainly the dispersion of the CDS spreads of parent banks of potential counterparties and the average ROA of potential counterparties – take over. This is in line with the characteristics of this sub-period. The euro area interbank market risk premium has large PIP, too, but the incorrect sign. The main reason could be that the stress in the euro area banking system reflecting the government debt crisis in 2010–2011 did not affect the Czech banking sector which experienced even slight decrease in the interbank risk premium in that time (see Figure 3).

As a robustness check, we performed the BMA analysis for the whole period on monthly data (see Figure 7; a table with detailed underlying BMA results, including PIP, PM, and SPM, can be found in Appendix C). The main reason for running monthly estimations is to exclude the possibility that the various balance-sheet indicators which are originally at monthly frequency have lower variability vis-à-vis daily market variables and thus could end up as unimportant in the daily estimations. The monthly results broadly confirm the main results of the analysis performed on daily data, especially for H2 on counterparty risk and H3 on market variables. The negative sign for the coefficient for exchange rate volatility, which was also observed in the daily estimations but with much lower PIP, might reflect a preference for domestic interbank lending relative to interbank lending abroad in an environment of increased exchange rate uncertainty.

Figure 7

Results of BMA Based on Monthly Data (January 2007−June 2012)



Note: This figure shows the 1000 best models indicated by the BMA procedure resulting from 2 million iterations after 1 million burn-ins. The order of the variables is set according to their PIP. The colors in the figure represent the sign of the coefficient, i.e., blue (+), red (-). The dummy variables representing reference-bank-specific effects are included in each model by default, i.e., they are not subjected to the selection procedure.

Source: authors' calculations

To assess the relative importance of each explanatory variable we report the standardized posterior mean (SPM) which shows how many standard deviations the dependent variable (in our case risk premium) changes per one standard deviation change in a given explanatory variable. In the regression using daily data, we see that the most relevant determinant is the lagged risk premium demonstrating a high persistence of the risk premium over time. When using monthly data, we observe that the highly relevant variables are again the lagged risk premium

(SPM 0.6232) and bond market liquidity index (SPM -0.5945), thus, a decline in bond market liquidity, such as the one that happened in October 2018, has a strong effect on interbank market risk premium, the reason being that banks are involved in both markets and thus shocks from a bond market can easily spill over to the money market. The SPM of FRA 1x4 (0.3581) shows that it is important to control for the expectations of future monetary policy in our regressions. The average NPL ratio of potential counterparties (SMP 0.3522) – a proxy for counterparty credit risk – and the exchange rate volatility (SPM -0.2962) – a variable capturing possible spillovers from FX markets – are also important determinants of the risk premium, while the impact of the euro money market risk premium is of some, but lower importance (SPM 0.0688).

To fully exclude the possibility of strategic behavior we also examine the cross-sectional variability rather than the within-variation, because part of the cross-sectional variability causing strategic behavior might be hidden in the fixed effects. Therefore, we employ analysis based on the estimated fixed effects (dummies for individual reference banks, *dummy_1–dummy_12*). We divide reference banks into two groups depending on whether their bank-specific intercept (i.e., the sum of the common intercept and the bank-specific dummy) is above or below the average of the bank-specific intercepts.[1] For these two groups, we report separately the average ratio of liquid assets to total assets and the average market share to test for possible predatory behavior, and the average ratio of PRIBOR-linked corporate loans to total assets to test for strategic behavior aiming at increasing revenues from PRIBOR-linked loans.[2] Table 2 shows that banks with above-average bank-specific intercepts have on average better liquidity ratios and large market shares, suggesting the possibility of predatory behavior (larger and more liquid banks quoting higher PRIBOR and earning more on lending interbank funds). The average results also indicate that there might have been some strategic behavior in terms of quoting higher PRIBOR rates to increase interest income from PRIBOR-linked loans in loan portfolios.

Table 2

Analysis Based on the Estimated Fixed Effects

	Averages over 1/1/2007–6/30/2012		
	Predatory behavior		Intentions to increase profits
	Ratio of liquid assets to total assets (%)	Market share (%)	Ratio of PRIBOR-linked corporate loans to total assets (%)
Banks with above-average intercept	24.2	7.7	21.3
Banks with below-average intercept	21.4	4.1	17.4

Source: authors' calculations

Nevertheless, the results of the analysis based on the bank-specific intercepts must be interpreted with caution. First, the differences among bank-specific intercepts are very low, so

[1] The former group of banks includes banks with an above-average intercept identified in both the daily and monthly estimations.

[2] The averages are constructed first as averages across time and then as averages across banks with 1) an above-average intercept and 2) a below-average intercept.

that the economic significance of the potential strategic behavior is also very low. Second, a detailed look at the bank-specific intercepts suggests that there is quite some heterogeneity in banks' characteristics within the two groups. Thus, while on average the banks with above-average intercepts have higher liquidity, there are also banks in this group with relatively low liquidity, and the other way round. This also holds for market share and PRIBOR-linked loans, so that these factors are not necessarily the only ones to contribute to above-average intercepts.

There might also be other factors playing a role in the cross-sectional variability, often working against strategic behavior, for example possible higher risk aversion of larger and more liquid banks. Thus, our findings provide relatively weak support for strategic behavior. Finally, if only a small number of banks give above-average quotes, the effect on the final PRIBOR would be reduced by dropping the two highest quotes (CNB, 2006), effectively preventing the manipulation of PRIBOR.

This paper identifies determinants of the interbank risk premium for the Czech case. One might wonder whether the findings can be generalized for other emerging European economies. We believe that our findings might be relevant particularly to those CEE countries that experience permanent liquidity surplus and whose banking sectors are majority owned by European (western) banks. In a more recent study, Hryckiewicz (2017)[1] finds that due to liquidity surplus in number of CEE countries, the introduction of liquidity measures by central banks does not help to decrease the interbank spreads, moreover, she shows that the interbank spread even increases after such a policy announcement. She also finds that central bank actions have spillover effects across countries in Central and Eastern Europe as banking sectors in CEE countries have been dominated by the same foreign capital.

1.7. Conclusion

The global financial crisis has featured an increase in risk premium in interbank markets worldwide. This paper focuses on explaining the risk premium – defined as the departure of the reference 3M PRIBOR from the monetary policy 2W repo rate – in the Czech interbank market. Given the structural features of the Czech banking sector (a comfortable solvency and liquidity situation of banks and foreign ownership as a potential channel for contagion), we tested a number of specific hypotheses on banks' behavior in terms of their quoting contributing rates for PRIBOR, using bank-level, sector-level, and market data. Our results, based on the Bayesian Model Averaging method, can be summarized as follows:

First, funding liquidity risk measured by various liquidity and solvency indicators based on balance-sheet ratios is not found to influence the interbank risk premium significantly. Although some liquidity tensions might have been felt by the banks, the results could reflect the fact that domestic banks have long had comfortable liquidity positions and thus liquidity risk did

[1] Hryckiewicz (2017) analyses the interbank markets in six CEE countries, namely in Poland, Hungary, the Czech Republic, Lithuania, Latvia and Estonia, and evaluates the impact of policy instruments on the interbank spreads in these countries on over the period 2007-2011.

not increase sufficiently in the crisis and recession period to be fully reflected in the interbank market risk premium.

Second, the explanatory variables used to capture counterparty risk proved to be important, especially in the period after 2009. Some of these variables are based on the characteristics of foreign parent banks of Czech banks, indicating possible cross-border contagion effects influencing the Czech interbank market premium. Third, market variables reflecting risks abroad and risks in the domestic bond market played an important role in the quoting behavior of reference banks. Fourth, the results do not suggest any high relevance of reference banks' interbank lending relations. Finally, we do not find robust evidence for strategic behavior of banks when quoting PRIBOR rates.

There are several policy implications of this paper. Firstly, heterogeneity of the panel of reference banks might be problematic along with the current definition of the counterparty for interbank lending – "another reference bank". More concrete definition of the counterparty might be more appropriate (e.g. like a prime bank as a counterparty in the euro area) or the panel might be created from more homogenous reference banks. Secondly, as the counterparty risk was one of the sources of the risk premium in the crisis, countercyclical regulation and effective supervision ensuring the stability of banks (and also of the parent banks) can help to limit the interbank risk premium in a future crisis. Thirdly, as the important share of liquid assets of Czech banks is created by domestic government bonds, the existence of the liquidity-providing facility in which Czech government bonds can be used as collateral (the CNB introduced this facility in October 2008), helps to decrease the risk premium on the interbank market.

The results of this analysis might also be relevant for other emerging European countries facing a liquidity surplus in the system and having significant foreign ownership of the majority of banks. However, further research on the sources of the interbank risk premium in other countries in Europe with similar characteristics might be desirable.

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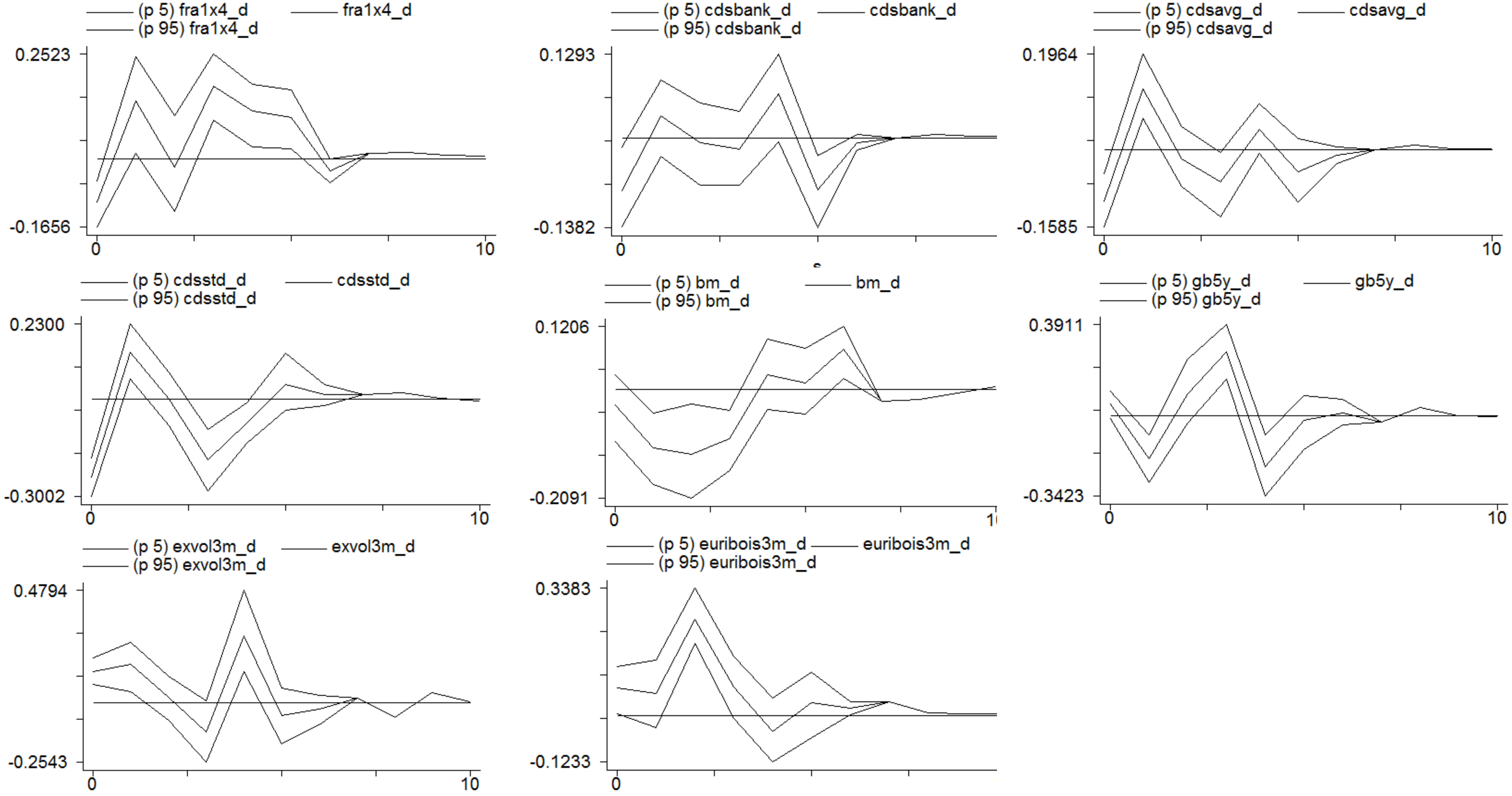
Appendix A: List of Explanatory Variables

Category	Shortcut	Variable	Description	Expected Sign	Lag (method)	Linearly interpolated	Original frequency
Dependent	spread	3M PRIBOR quote less 2W REPO (bp)					daily
Lag of dependent variable and control of monetary policy expectations	spread_l	One-day lag of 3M PRIBOR quote less 2W REPO (bp)					daily
	fra1v4	Forward rate agreement (FRA 1x4, %)			3 days (VAR)		daily
(1) Funding liquidity risk	liquidratio	Ratio of liquid assets to total assets (%)	Liquidity risk of a reference bank	-		LI	monthly
	ltdratio	Loan-to-deposit ratio (%)		+		LI	monthly
	roa	Return on assets (%)	Credit risk of a reference bank	-		LI	monthly
	npl	Ratio of NPLs to total client loans (%)		+		LI	monthly
	provisionsratio	Ratio of loan loss provisions to total client loans (%)		+		LI	monthly
	defaultnpl3m	3M default rate of corporate loans (%)		+		LI	monthly
	cdsbank_l	5Y CDS of parent bank (bp)		+	4 days (VAR)		daily
(2) Counterparty risk	roaratioavg_l	Average return on assets across counterparty reference banks (%)	Credit risk of "average" counterparty reference bank	-	1 month (expert-based)		quarterly
	nplratioavg_l	Average ratio of NPLs to total client loans across counterparty reference banks (%)		+	1 month (expert-based)		monthly
	cdsavg_l	Average 5Y CDS spreads across parent banks of counterparty reference banks (bp)		+	1 day (VAR)		daily
	cdsstd_l	Standard deviation of 5Y CDS spreads across parent banks of counterparty reference banks divided by mean (%)		+	1 day (VAR)		daily
(3) Financial markets	bm_l	Bond market liquidity index	Domestic markets	-	2 days (VAR)		daily
	gb5y_l	Risk premium on 5Y bonds (5Ygovernment bond yield less 5Y IRS, bp)		+	3 days (VAR)		daily
	exvol3m_l	3M implied exchange rate volatility CZK/EUR (%)		+	4 days (VAR)		daily
	euribois3m_l	Risk premium on euro interbank market (3M EURIBOR less 3M EUR OIS, bp)	Foreign market	+	2 days (VAR)		daily
(4) Interbank market activity	netinterbankratio	Net interbank exposure to total assets (%)		-		LI	monthly
	connectivity*	Connectivity of a reference bank with other reference banks (%)		-		LI	quarterly
	relationship+	One-year persistence of lending relationship of a reference bank with other reference banks (%)		-		LI	quarterly
(5) Strategic behavior	floatingtoassets	Ratio of PRIBOR-linked corporate loans to total assets (%)		+		LI	monthly
	derivatsensm	Sensitivity of derivatives to change in PRIBOR index (thousands of CZK)		+		LI	monthly
	marketshare	Market share of a bank according to assets (%)		+		LI	monthly
Bank dummies	dummy_x	Dummies for individual reference banks	Bank-specific effects				daily

Note: This table is related to the analysis based on daily data. For the analysis based on monthly data, monthly averages of daily variables were calculated without assuming any lag of these variables except for a one-month lag of the dependent variable.

- The bond market liquidity index is normalized (i.e., expressed in standard deviations from the historical mean) and moves roughly between 2.5 and -2.5 with zero mean and a standard deviation of one.
- The variables expressed in percent are to be understood in units of percent (for example, a value of 26.2 for 26.2%).
- Connectivity is calculated as the ratio of the number of lending relations with other reference banks to the maximum number of relations which can potentially be created with other reference banks. +Relationship lending is defined as the ratio of lending relations with other reference banks lasting for one year to total lending relations with other reference banks existing in a given period.

Appendix B: Results of PVAR Used for the Determination of the Optimal Lag



Note: Each figure represents the impulse response functions of the dependent variable (spread_d) resulting from the PVAR with five lags to a shock to a particular market variable (the market variables are mentioned at the top of each figure). The impulse response functions of the market variables to spread_d are not reported in order to limit the number of output figures.

Appendix C: Underlying Results of BMA

Results of BMA based on daily data (1/1/2007−6/30/2012)

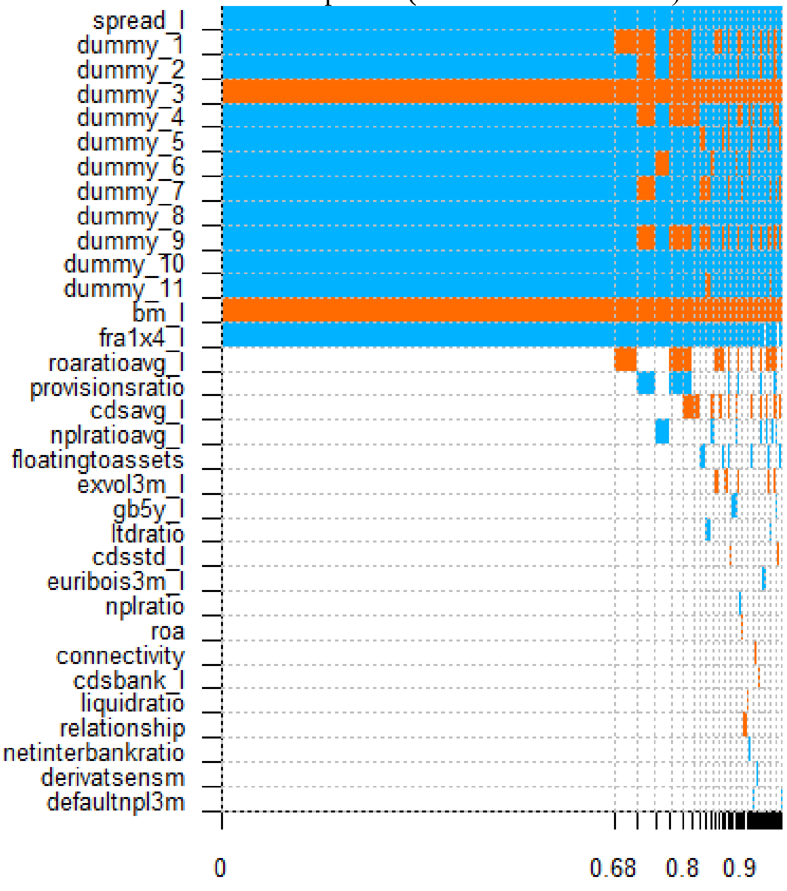
	PIP	Posterior mean	Posterior standard deviation	Posterior mean (standardized)	Conditional posterior sign
spread_l	1.00	0.9360	0.0026	0.9369	1.00
bm_l	1.00	-1.0804	0.1095	-0.0281	0.00
euribois3m_l	1.00	0.0171	0.0028	0.0248	1.00
nplratioavg_l	1.00	0.7565	0.0796	0.0438	1.00
dummy_1	1.00	0.1173	0.2116	0.0013	0.86
dummy_2	1.00	0.2850	0.2281	0.0033	1.00
dummy_3	1.00	-0.1692	0.1966	-0.0019	0.02
dummy_4	1.00	0.0391	0.2159	0.0004	0.50
dummy_5	1.00	0.3411	0.1787	0.0039	1.00
dummy_6	1.00	-0.0935	0.2486	-0.0011	0.27
dummy_7	1.00	0.1533	0.2574	0.0018	0.82
dummy_8	1.00	0.3428	0.1875	0.0039	1.00
dummy_9	1.00	0.1678	0.2126	0.0019	0.95
dummy_10	1.00	-0.0037	0.2244	0.0000	0.07
dummy_11	1.00	0.1028	0.2450	0.0007	0.99
dummy_12	1.00	-0.0768	0.4821	-0.0002	0.04
fra1x4_l	1.00	0.7165	0.1525	0.0328	1.00
cdsstd_l	1.00	0.0210	0.0044	0.0109	1.00
cdsavg_l	0.73	-0.0027	0.0019	-0.0092	0.00
provisionsratio	0.53	0.0773	0.0792	0.0053	1.00
gb5y_l	0.30	0.0023	0.0038	0.0032	1.00
cdsbank_l	0.16	-0.0003	0.0007	-0.0012	0.00
exvol3m_l	0.08	-0.0059	0.0212	-0.0008	0.00
floatingtoassets	0.05	0.0016	0.0074	0.0006	1.00
derivatsensm	0.02	0.0000	0.0000	-0.0001	0.00
nplratio	0.02	0.0007	0.0054	0.0001	1.00
relationship	0.01	0.0000	0.0004	0.0000	0.00
roa	0.01	-0.0010	0.0129	0.0000	0.00
connectivity	0.01	0.0000	0.0003	0.0000	0.92
netinterbankratio	0.01	0.0001	0.0013	0.0000	1.00
ltdratio	0.01	0.0000	0.0002	0.0000	0.98
roaratioavg_l	0.01	-0.0006	0.0429	0.0000	0.40
liquidratio	0.01	0.0000	0.0004	0.0000	0.77
defaultnpl3m	0.00	0.0000	0.0026	0.0000	0.85
intercept	1.00	-3.2084		-0.1305	

Results of BMA based on monthly data (January 2007−June 2012)

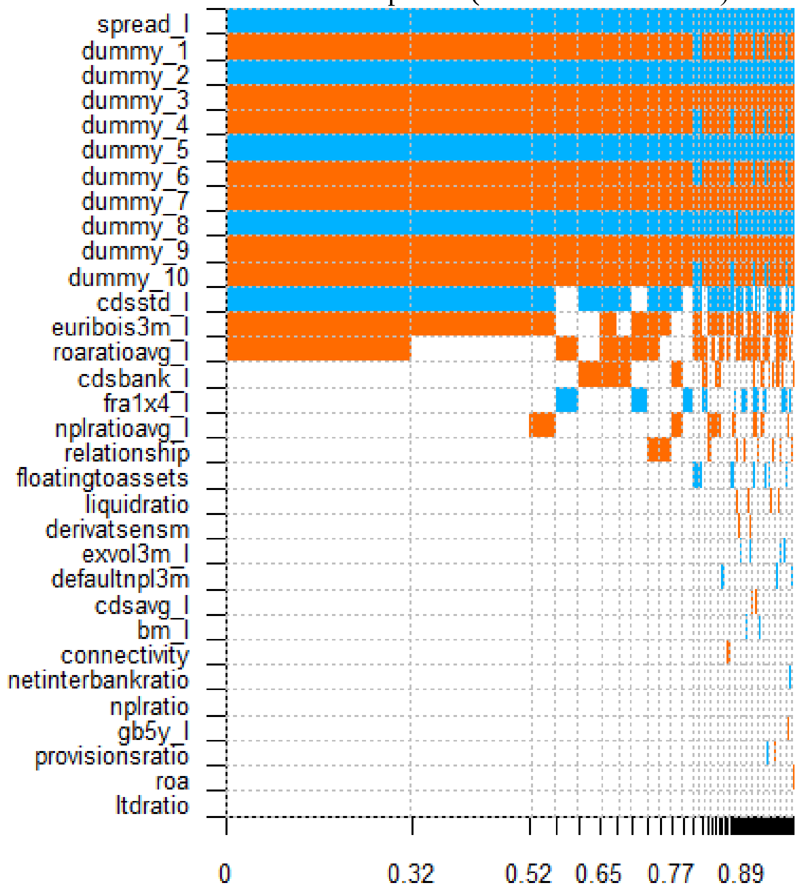
	PIP	Posterior mean	Posterior standard deviation	Posterior mean (standardized)	Conditional posterior sign
spread_l	1.00	0.6093	0.0192	0.6232	1.00
fra1x4	1.00	7.4256	1.7795	0.3581	1.00
bm	1.00	-23.6528	1.8384	-0.5945	0.00
exvol3m	1.00	-2.1421	0.2800	-0.2962	0.00
nplratioavg_l	1.00	5.7582	0.7261	0.3522	1.00
dummy_1	1.00	1.6234	1.5283	0.0197	1.00
dummy_2	1.00	2.9081	1.8160	0.0353	1.00
dummy_3	1.00	-0.1462	1.5255	-0.0018	0.20
dummy_4	1.00	0.9235	1.5874	0.0112	0.87
dummy_5	1.00	2.1935	1.4417	0.0267	1.00
dummy_6	1.00	-1.2200	2.0670	-0.0148	0.14
dummy_7	1.00	2.3072	1.6445	0.0280	1.00
dummy_8	1.00	2.0711	1.6116	0.0252	1.00
dummy_9	1.00	1.4049	1.7973	0.0167	0.86
dummy_10	1.00	0.4339	2.2181	0.0053	0.22
dummy_11	1.00	0.3243	1.9655	0.0025	0.94
dummy_12	1.00	0.3007	3.8516	0.0010	0.76
euribois3m	0.61	0.0456	0.0429	0.0688	1.00
cdsavg	0.42	-0.0137	0.0176	-0.0485	0.00
gb5y	0.38	0.0305	0.0429	0.0432	1.00
provisionsratio	0.16	0.1200	0.3047	0.0088	1.00
floatingtoassets	0.14	0.0333	0.0905	0.0125	1.00
relationship	0.05	-0.0011	0.0061	-0.0012	0.00
liquidratio	0.04	0.0021	0.0133	0.0010	1.00
cdsbank	0.03	-0.0002	0.0016	-0.0009	0.01
nplratio	0.03	0.0044	0.0355	0.0006	0.96
roaratioavg_l	0.03	0.1082	1.0128	0.0005	0.90
netinterbankratio	0.02	0.0019	0.0177	0.0004	1.00
cdsstd	0.02	0.0008	0.0085	0.0004	0.83
roa	0.02	-0.0076	0.1001	-0.0002	0.01
defaultnpl3m	0.02	-0.0030	0.0439	-0.0002	0.00
connectivity	0.02	0.0002	0.0032	0.0002	0.89
ltdratio	0.02	0.0000	0.0022	0.0000	0.74
derivatsensm	0.02	0.0000	0.0000	0.0000	0.54
intercept	1.00	-11.7948		-0.5064	

Appendix D: Results of BMA for the Crisis and Recession Periods (Daily Data)

Results of BMA for the crisis period (9/15/2008−6/30/2009)



Results of BMA for the recession period (7/1/2009−6/30/2012)



Cumulative Model Probabilities **Cumulative Model Probabilities**

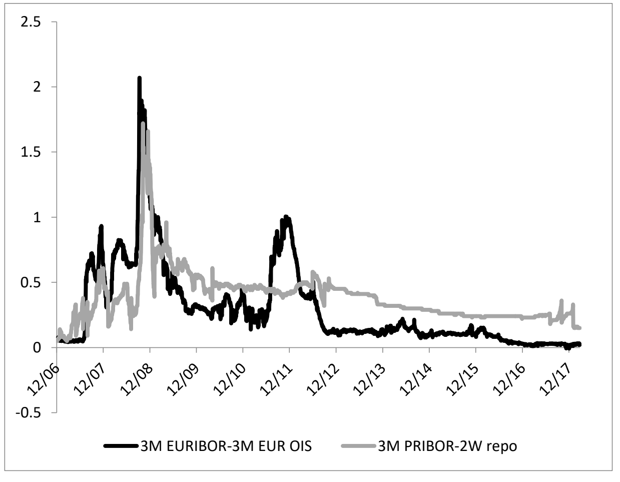
Note: This figure shows the 1000 best models indicated by the BMA procedure resulting from 2 million iterations after 1 million burn-ins. The order of the variables is set according to their PIP. The colors in the figure represent the sign of the coefficient, i.e., blue (+), red (-). The dummy variables representing reference-bank-specific effects are included in each model by default, i.e., they are not subjected to the selection procedure.

Source: Authors' calculation

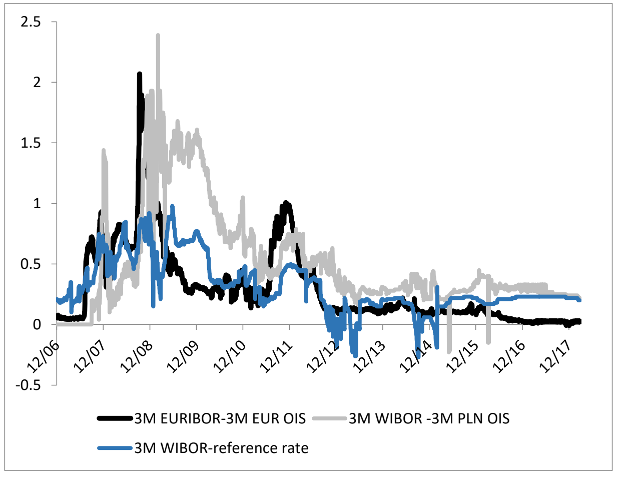
Appendix E: Risk premium in the Czech, Polish, and Euro Interbank Markets

(including development after 6/2012)

Czech interbank risk premium



Polish interbank risk premium



Note: Poland: reference rate = rate on 7-day open market operations.

Source: Bloomberg

2. Bank Efficiency and Interest Rate Pass-Through: Evidence from Czech Loan Products

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Bank Efficiency and Interest Rate Pass-Through: Evidence from Czech Loan Products

Abstract

An important component of monetary policy transmission is the pass-through from financial market interest rates, directly influenced or targeted by central banks, to the rates that banks charge firms and households. Yet the available evidence on the strength and speed of the pass-through is mixed. We examine the pass-through mechanism using a unique data set of Czech loan and deposit products and focus on bank-level determinants of pricing policies, especially cost efficiency, which we estimate employing both stochastic frontier and data envelopment analysis. Our main results are threefold: First, the long-term pass-through was close to complete for most products before the financial crisis, but has weakened considerably afterward. Second, banks that provide high rates for deposits usually charge high loan markups. Third, cost-efficient banks tend to smooth loan rates for their clients.

Keywords: monetary transmission, cost efficiency, bank pricing policies, stochastic frontier analysis, data envelopment analysis

JEL Codes: E43, E58, G21

2.1. Introduction

To understand the process of monetary policy transmission in their country well, central bankers need to know how financial market interest rates pass through to client rates corresponding to various loan and deposit products offered by commercial banks. With more widespread availability of bank- and product-level data in recent years, researchers have begun to explore the determinants of the pass-through mechanism at the level of individual banks (for example, de Graeve *et al.*, 2007; Gambacorta, 2008), which yields more granulated information for policy makers. Nevertheless, the empirical examinations of interest rate pass-through often produce different results depending on the country or time period under investigation, and hence recommendations cannot be easily carried from one examined country to another. The role of the late 2000s financial crisis on the pass-through mechanism is especially unclear, with some studies suggesting little change in transmission (Illes & Lombardi, 2013), some significant distortion in passthrough (Hristov *et al.*, 2014), and some changes in transmission only for certain products (Hansen & Welz, 2011).

Using a unique data set for the Czech Republic, we provide a comprehensive study of the interest rate pass-through before and after the fall of Lehman Brothers and explore the relationships between the pricing policies of individual banks and bank characteristics. The case of the Czech Republic is interesting because, among other things, its banking sector remained stable during the crisis and did not suffer the tremors that affected many other European countries. Any change in pass-through, therefore, can be interpreted as a change in pricing policies, not a change induced by banks' liquidity problems. To be specific, we focus on the role of banks' cost efficiency, which has been shown for some other developed countries to be associated with the pass-through mechanism (Schlüter *et al.*, 2012). Our analysis consists of three main steps. First, we estimate the interest rate pass-through for each product both before and after the crisis. Each product category is paired with a corresponding financial market interest rate according to the term structure. For the estimation we use the mean group estimator (Pesaran & Smith, 1995) and pooled mean group estimator (Pesaran *et al.*, 1999), which take into account bank-level heterogeneity in pricing policies.

Second, we estimate cost efficiency scores for each bank both before and after the crisis. To our knowledge, we provide the first examination of changes in the cost efficiency of Czech banks after the crisis and employ both stochastic frontier analysis and data envelopment analysis. Third, we extract pass-through coefficients for individual banks, focusing on the strength of the long-term pass-through (the equilibrium response of bank rates to changes in the corresponding market rate), the mean adjustment lag between the short and the long term, and the spread (markup) between the bank and market rates. We then relate these coefficients to the characteristics of each bank. In contrast to previous studies that examine heterogeneity in pricing policies, we use weighted least squares estimation where more precise estimates of the pass-through coefficients for individual banks get more weight.

Our results suggest that the financial crisis changed the pass-through mechanism dramatically. Before the crisis the long-term pass-through was close to complete for most products, but after 2008 it weakened for all product categories except mortgages. Moreover, average spreads between bank and market rates increased a lot and banks started to change their rates more frequently. Both before and after the crisis we find evidence of significant heterogeneity in bank pricing policies in the short run, but less so in the long run, which is consistent with the results of Gambacorta (2008) and Horvath & Podpiera (2012). Concerning the determinants of pricing policies, we find that the pass-through mechanism for deposit products influences the given bank's pass-through for loan products. To be specific, large markups in loan rates over the corresponding market rates are associated with large spreads between deposit rates and market rates. In other words, banks that offer attractive deposit rates usually charge high loan markups, which reflects more risk taking. Finally, we find that cost-efficient banks tend to respond to changes in market rates with longer lags, thus smoothing loan rates, which is in line with Schlüter *et al.* (2012). We fail to find any strong relationship between banks' cost efficiency and loan markups.

The remainder of the paper is structured as follows: Section 2 discusses some of the related literature on the topic. Section 3 briefly describes the main features of the data set used for the estimation. Section 4 presents the analysis of the pass-through mechanism before and after the crisis. Section 5 describes the stochastic frontier and data envelopment analysis approaches. Section 6 explores the determinants of bank level pass-through coefficients. Section 7 concludes the paper. Appendix A presents several robustness checks of our main results, while Appendix B shows supplementary information related to the estimation of cost efficiency.

2.2. Related Literature

The authoritative literature survey by de Bondt (2005) concludes that most empirical studies on the topic report that the pass-through of market interest rates to bank lending rates is incomplete in the short run and that the speed of adjustment between the rates varies across countries. On the other hand, in the long run the interest rate pass-through is typically found to be close to complete. The existing studies take into account various bank products, separating corporate loans from household loans (Hansen & Welz, 2011) and differentiating between the loan amount of corporate loans and between mortgages and consumer loans (Hristov *et al.*, 2014). For example, studies like Rocha (2012), Belke *et al.* (2013), and Aristei & Gallo (2014) find more complete long-run pass-through for corporate loans than for household loans.

Holton & Rodriguez d'Acri (2015) report the extent of pass-through to be weaker for smaller corporate loans than for larger corporate loans in the euro area during the late 2000s crisis. Another study of pass-through during the crisis period, Hansen & Welz (2011), finds impaired long-term pass-through in Sweden specifically for loans with a long interest rate fixation. In contrast, Illes *et al.* (2015) use the weighted average cost of funds as a proxy for European market rates and find that the pass-through mechanism remained stable throughout the crisis. Moreover, Rocha (2012) analyzes the interest pass-through for deposit rates in Portugal and reports that the long-term pass-through is incomplete and the adjustment of deposit rates is faster for rate decreases than for rate increases. A similar result is obtained by Belke *et al.* (2013) for euro area lending rates.

While the previously discussed stream of literature focuses on the general question of whether the interest rate pass-through mechanism works and what the speed of adjustment is, several recent studies have tried to explain what bank characteristics (or banking sector characteristics) explain the heterogeneity in interest rate pass-through across banks (or countries): see, for example, Sander & Kleimeier (2006), de Graeve *et al.* (2007), Gambacorta (2008), or more recent studies by Stanisl awska (2014) and Holton & Rodriguez d'Acri (2015). A wide range of bank-level factors, including liquidity, capital adequacy, and relationship banking, have been explored as potential determinants of the interest rate pass-through mechanism. Gambacorta (2008) and de Graeve *et al.* (2007) conclude that well-capitalized and liquid banks are less sensitive to market interest rate changes. Nevertheless, these findings apparently do not hold for Polish banks (Stanisl awska, 2014), which highlights the heterogeneity of results found in the literature and the need for more empirical research on the pass-through mechanism in post-transition countries. In a detailed study of the determinants of interest rate spreads in the Czech Republic, Hainz *et al.* (2014) find that bank characteristics are important for the setting of spreads for mortgages and small corporate loans, but matter little for consumer loans and large corporate loans.

One of the frequently investigated bank-level characteristics is cost efficiency. The usual proxies for cost efficiency involve simple accounting-based ratios, such as the total-costs-to-total-assets ratio, total-costs-to-total-revenues ratio, and cost-income ratio (Koetter *et al.*, 2006; de Graeve *et al.*, 2007). Bauer *et al.* (1998), however, argue that these financial ratios do not sufficiently capture banks' efficiency as they are driven by price differences and other exogenous factors. Schlüter *et al.* (2012) employ stochastic frontier analysis for cost efficiency estimation in their examination of interest rate passthrough in the German banking sector. Their findings suggest that more cost efficient banks can be expected to offer more competitive lending rates in comparison to less efficient banks. Although there are studies estimating the cost efficiency of Czech banks using stochastic frontiers (Podpiera & Podpiera, 2005; Podpiera *et al.*, 2007; Irsova & Havranek, 2011) or deterministic frontiers (Havranek & Irsova, 2013), these scores have not been used as a determinant of bank-specific interest rate pass-through for the Czech Republic. Moreover, we are not aware of any other study focusing on an emerging or post-transition economy that relates interest rate pass-through to properly computed measures of efficiency.

Several studies have estimated the interest rate pass-through mechanism in the Czech banking sector. Egert *et al.* (2007) investigate pass-through in several countries of Central and Eastern Europe during the period 1994–2005. They find insignificant passthrough for household loans but nearly full pass-through for long-term non-financial companies' loans. In contrast, Tieman (2004), examining the 1995–2004 period, suggests that the long-run pass-through in the Czech Republic is incomplete. Horvath & Podpiera (2012) examine the link between the money market rate and bank interest rate during the period 2004–2008 and find well-functioning, although not full, pass-through for both mortgages and corporate rates in the long run. They also investigate interest rate pass-through heterogeneity on the bank level, finding evidence that banks with a stable pool of deposits smooth interest rates and require a higher spread as compensation. Nevertheless, the above-mentioned studies do not use frontier approaches to capture and control for cost efficiency and do not examine the potential changes in pass-through related to the financial crisis.

2.3. Data

The computations in this paper are based on bank-level data and data on money market rates covering the period between January 2004 and December 2013, where the starting date is given by the availability of most bank-specific data that we need for the analysis. The main data set covers 52 banks[1] and is obtained from the Czech National Bank's internal databases. For the analysis of interest rate pass-through we use monetary statistics data regarding the interest rates charged on new loans and paid on deposits; for the analysis of cost efficiency and determinants of banks' pricing policies we use a regulatory data set which consists of data from bank balance sheets, income statements, and capital adequacy information. The money market data include Czech interbank interest rates, interest rate swaps, and Czech government bond rates obtained from Bloomberg.

The bank-level data on new loans display a monthly frequency, and loans in foreign currencies are excluded from the computations.[2] We follow Horvath & Podpiera (2012) in the differentiation of several loan product categories and summarize them in Table 1. With respect to the product type of a loan, we assume four basic categories: small corporate loans up to CZK 30 million and large corporate loans above CZK 30 million provided to firms, and mortgages[3] and consumer loans provided to households.[4]. We keep a limited number of bank products to ensure a certain simplicity of the analysis. Nevertheless, further research could focus on more granular fixations of individual bank loan categories like in Bruha (2011), to capture the possibility that the transmission mechanism could be affected by changes on the yield curve slope, or the changes in the share of the different fixation categories for the different loan categories.

[1] Most of these are small banks that do not provide all the financial products we investigate in this paper. Most specifications in the empirical part therefore involve about 25 banks.

[2] Loans denominated in foreign currency are negligible for the housing sector in the Czech Republic, where they have an almost zero share (0.1%). For non-financial companies, the share of such loans is around 20%, but these are mainly export-oriented companies with natural hedging.

[3] A detailed exposition of the Czech mortgage sector can be found in Bruha *et al.* (2013) and Hlavacek & Komarek (2011).

[4] The distribution of loans provided to non-financial companies and households is relatively even, as non-financial companies represent 38% and households 48% of total loans provided by banks (financial institutions, governments, and residents of other countries account for the rest). Mortgages form 80% of all loans provided to households.

Table 1
Categories of bank products

Firm rates	
Small loans, floating	Commercial loans up to CZK 30M, interest rate floating or fixed up to 1 year
Small loans, fixed	Commercial loans up to CZK 30M, interest rate fixed more than 1 year
Large loans, floating	Commercial loans larger than CZK 30M, interest rate floating or fixed up to 1 yea
Large loans, fixed	Commercial loans larger than CZK 30M, interest rate fixed more than 1 year
Household rates	
Mortgages	Loans for house or apartment purchase
Consumer loans	Loans for household spending on (mostly) durable goods
Deposit rates	
Overnight deposits	Deposits from clients with a withdrawal term up to 1 day
Term deposits	Deposits from clients with a withdrawal term more than 1 day

Corporate loans are further divided with respect to interest rate fixation into the following categories: “floating interest rate loans” represented by loans with truly floating rates and those with rates fixed for up to 1 year; and “fixed interest rate loans” with rates fixed for more than 1 year. To analyze the interest rate pass-through mechanism from market rates to bank deposit rates, we additionally collect information on bank deposits and distinguish overnight deposits from term deposits.

The bank-level information used for the computation of efficiency scores results in a highly unbalanced data set. Table B1 in Appendix B shows the summary statistics of the variables that we use to estimate the stochastic frontier. The definition of output and input prices employed in the cost function follows the intermediation approach explained by (Berger & Humphrey, 1997). We assume three distinct types of outputs: commercial loans, inter-bank loans, and securities; three inputs: fixed assets, borrowed funds, and labor; and one netput: equity capital. Total costs are defined as the sum of interest and non-interest expenses. The cost function further includes a time trend and inefficiency covariates, some of which also serve as potential determinants of interest rate pass-through (see Table 2 for more details).

The inefficiency covariates cover individual bank-specific characteristics. Among these characteristics we include profitability ratios such as return on assets and return on equity, the liquidity ratio measuring the share of liquid assets in banks’ balance sheets (quick assets to total assets), leverage of banks (equity over assets), and three ratios computed from regulatory data describing the resilience of banks by the share of regulatory capital in risk-weighted assets (capital adequacy ratio), credit risk in banks balance sheets by the share of non-performing loans in the bank balance sheet (credit risk to total assets), and the share of risky assets in the bank balance sheet (risk-weighted to total assets).

Table B3 in Appendix B shows the summary statistics of the variables used to estimate the deterministic frontier scores of different banks. Since the computation of the deterministic frontier requires the panel data to be fully balanced, deterministic estimation only employs a subsample of the entire data set used for stochastic estimation and thus serves as a mere robustness check in our analysis. To conduct both frontier analyses we are able to exploit data on 35 Czech banks in total, but this number gets smaller for the individual frontier analyses of the pre- and post-crisis periods

Table 2

Determinants of pricing policies

Variable	Definition
Bank size	Assets of *i*-th bank/median bank assets
Capital adequacy	Regulatory capital/risk-weighted assets
Cost efficiency	Frontier estimates from Section 5
Credit risk	Non-performing loans/total assets
Deposits	Deposits/liabilities
Liquidity	Quick assets/total assets

The money market data that we use in the paper consist of the yields on instruments that are relevant to banks' decision making concerning the setting of interest rates on their products (see Table 3 in the following section). The short-term market interest rates are represented by the CZEONIA reference interest rate and by Czech money market benchmark rates (PRIBORs) with maturities of up to one year. While CZEONIA is the average interest rate on unsecured overnight deposits placed by banks on the market on a given date, PRIBOR is the average quotation of reference banks for the sale of deposits. CZEONIA would be the preferred rate for our analysis, but it is only available for overnight deposits and not for longer maturities. Long-term market interest rates are represented by Czech interest rate swaps and yields on Czech government bonds with maturities of up to 10 years.

2.4. Pass-Through Estimation

We employ the error-correction model framework to examine how financial market interest rates are passed through to the rates that banks charge borrowers and the rates that banks pay to depositors. The framework assumes a long-term equilibrium relationship between the market rate and the bank rate: the bank sets its rate according to its cost of funds, determined by the corresponding market rate, and adds a markup. The long-term relationship is important and determines the ultimate strength of the pass-through mechanism. Nevertheless, it is also important to look at the immediate (short-term) reaction of bank rates to changes in the market rate and the adjustment process between the short and long run. The error-correction model allows us to make inference regarding all these aspects of interest rate pass-through.

Because we work with product- and bank-level data, we estimate the model using dynamic heterogeneous panel techniques; our most flexible estimator is the mean group estimator (Pesaran & Smith, 1995), which allows each regression coefficient to vary across banks. Pesaran & Smith (1995) show that the traditional panel estimators, such as fixed effects, which restrict all coefficients except intercepts to be equal across panels, may easily yield inconsistent results. The mean group estimator can be described in the following way:

$$\Delta bank\ rate^k_{i,t} = \alpha_i^k \Delta market\ rate^k_t + \beta_i^k \Delta bank\ rate^k_{i,t-1} + \gamma_i^k (bank\ rate^k_{i,t-1} - \delta_i^k market\ rate^k_{t-1} - \mu^k_i), + \epsilon^k_{i,t} \quad (1)$$

where $\Delta bank\ rate^k_{i,t} = bank\ rate^k_{i,t} - bank\ rate^k_{i,t-1}$ stands for the change in bank i's rate on product k between months $t-1$ and t,[1] $\Delta market\ rate^k_t$ is the change in the corresponding financial market interest rate in period t for product k, α^k measures the short-term pass-through of the market rate to bank i's rate for product k, $\Delta bank\ rate^k_{i,t-1}$ is the change in the bank rate in the previous month, β_i^k captures persistence in bank rate changes, δ_i^k denotes the long-term equilibrium pass-through coefficient, μ^k_i is the mean markup (spread) over the market rate, γ_i^k denotes the speed of adjustment, and $\epsilon^k_{i,t}$ is a disturbance term. The mean adjustment lag at which the market rates are fully passed through to the bank rates can be computed as $(\delta - \alpha)/\gamma$ (Hendry, 1995).

The mean group estimator is very flexible, but Pesaran *et al.* (1999) show that a compromise between traditional estimators[2] and the mean group estimator can be the preferred choice under certain conditions. They introduce the so-called pooled mean group estimator, which allows the short-run coefficients to vary across panels, but restricts the long-term equilibrium relationship to be the same for all banks. The pooled mean group estimator is often more efficient than the mean group estimator, and the advantage gets significant when the number of panels in the data set is relatively small, which is the case with Czech data. We specify the pooled mean group estimator as follows:

$$\Delta bank\ rate^k_{i,t} = \alpha_i^k \Delta market\ rate^k_t + \beta_i^k \Delta bank\ rate^k_{i,t-1} + \gamma_i^k (bank\ rate^k_{i,t-1} - \delta^k market\ rate^k_{t-1} - \mu^k), + \epsilon^k_{i,t} \quad (2)$$

A qualification of this methodology is in order: the method assumes spreads that are constant across the time period under examination. If, however, spreads increase gradually, the estimated long-run pass-through might be biased. Consider, for example, the case of the Czech economy during the financial crisis, when risk aversion (and thus spreads) was rising, while market rates were decreasing. A failure of client rates to react to a decrease in market rates might thus be associated with rising spreads, not with a lack of pass-through. Nevertheless, the spreads rose quite steeply after the fall of Lehman Brothers and did not continue to increase during the rest of the period, so we expect the potential bias to be modest.

[1] Due to data limitations we use a maximum of one lag in all estimations of the pass-through mechanism.
[2] The traditional estimators restrict all slope coefficients to be equal

An important step in the estimation of the pass-through mechanism is the selection of the financial market interest rate corresponding to each product rate. The market rates serve as the cost of funds for banks, and it is intuitive to assume that term structure will play a crucial role in determining the association between different market and product rates. For example, for loans with floating rates we expect market rates with short maturities to serve as the corresponding cost of funds. In contrast, mortgage rates should be associated with the rates of return of instruments with several-year maturities, such as ten-year government bonds. Following previous literature on the interest rate pass-through (for example, Schlüter *et al.*, 2012), we evaluate the correlations between market and product rates and choose the market rate with the highest correlation for each product rate. It is worth noting that our main results presented later in this paper hold irrespective of the financial market rate used as a reference for each product category (the market rates are highly correlated with each other).

The correlations, computed as mean values across individual banks' correlation coefficients, are shown in Table 3. Regarding small loans (under CZK 30 million) provided to non-financial companies with either flexible rates or fixed rates for up to one year, we find that the most promising cost of funds is the 6-month PRIBOR (the correlation coefficient is 0.544). In contrast, for small loans with rates fixed for a longer period than one year the market rate with the highest correlation is the rate on the 10-year Czech government bond (but the correlation is lower than in the previous case: only 0.273). The results are very similar when we consider large loans (above CZK 30 million) instead of small loans. The 6-month PRIBOR is the corresponding rate for loans with floating or short fixed rates, and the correlation is 0.716. For longer fixations the most promising cost of funds is captured by the yield on the 10-year government bond (correlation 0.276).

Concerning household products, we find that mortgage rates are associated the most with yields on the 10-year government bond, which is again intuitive; the correlation is 0.379. In contrast, we fail to find any financial market rate that shows a statistically significant correlation with the rate on consumer loans. The largest correlation is again with the rate on the 10-year government bond, but the correlation coefficient of 0.01 is negligible. It follows that using Czech data we cannot pursue a reasonable analysis of the pass-through of market rates to consumer loans; consumer loan rates seem to be driven by factors other than market interest rates. Next, we turn to deposit rates. Rates on overnight deposits are correlated the most with the 1-month PRIBOR (correlation 0.202), while the mean rate on term deposits is driven by the 6-month PRIBOR (correlation 0.524). These results are consistent with a similar correlation analysis for Czech data presented in Kucharcukova et al. (2013).

Table 3

Correlations between product rates and financial market rates

	CZEONIA	1M PRIBOR	3M PRIBOR	6M PRIBOR	1Y PRIBOR
Firm rates					
Small loans, floating	0.517	0.537	0.541	**0.544**	0.542
Small loans, fixed	0.079	0.116	0.142	0.173	0.190
Large loans, floating	0.660	0.698	0.709	**0.716**	0.715
Large loans, fixed	0.199	0.208	0.216	0.223	0.227
Household rates					
Mortgages	0.280	0.295	0.300	0.305	0.309
Consumer loans	-0.018	-0.012	-0.010	-0.009	-0.010
Deposit rates					
Overnight deposits	0.202	**0.202**	0.201	0.199	0.196
Term deposits	0.491	0.514	0.524	**0.524**	0.520

	IRS1	IRS2	IRS3	IRS5	IRS10	YTM2	YTM5	YTM10
Firm rates								
Small loans, floating	0.529	0.518	0.509	0.493	0.479	0.527	0.517	0.472
Small loans, fixed	0.131	0.151	0.154	0.145	0.135	0.146	0.221	**0.273**
Large loans, floating	0.689	0.664	0.644	0.610	0.577	0.673	0.639	0.572
Large loans, fixed	0.208	0.218	0.226	0.230	0.235	0.218	0.257	**0.276**
Household rates								
Mortgages	0.297	0.310	0.323	0.332	0.341	0.316	0.367	**0.379**
Consumer loans	-0.022	-0.023	-0.021	-0.017	-0.010	-0.018	-0.003	**0.010**
Deposit rates								
Overnight deposits	0.197	0.187	0.179	0.170	0.163	0.192	0.169	0.140
Term deposits	0.497	0.468	0.449	0.420	0.393	0.477	0.444	0.392

Notes: Averaged over the banks in the sample; the largest correlations for each product category are shown in bold. CZEONIA = Czech Overnight Index Average; the weighted average of the interest rates of unsecured overnight deposits placed by banks on the interbank market. PRIBOR = Prague Interbank Offer Rate; the average rate at which banks are willing to lend to each other. IRS = interest rate swaps. YTM = yield on Czech government bonds

Because our intention is to use the error-correction model framework, we need to make sure that our time series are indeed non-stationary and that the product rates are cointegrated with the corresponding market rates. To test for non-stationarity we employ Fisher's unit root test (Maddala & Wu, 1999), which allows for the examination of unbalanced panel data; the results suggest that for each of the product rates in our sample and the corresponding market rates with the largest correlation coefficients we cannot reject the null hypothesis of non-stationarity. Next, to test for cointegration we resort to the Pedroni (1999) residual test, which can also handle unbalanced panel data (the results are not reported in full, but are available on request). We reject the null hypothesis of no cointegration for each pair of product and market interest rates with the exception of consumer loans—but we have already noted that the correlation between the rate on consumer loans and any of the financial market rates is negligible; therefore, we will not evaluate the pass-through mechanism for consumer loan rates.[1]

To choose between the mean group estimator and the pooled mean group estimator we employ the Hausman test and evaluate whether the assumption of homogeneity of the long-term coefficients holds across banks. The hypothesis cannot be rejected at the 5% level, and we thus opt for the pooled mean group estimator, which is more efficient, and report the corresponding results in the main body of the manuscript. In Appendix A we present the results of the mean group estimator (Table A1 and Table A2), from which we would draw similar conclusions. While we prefer the pooled mean group estimator for the evaluation of the pass-through mechanism, the mean group estimator is necessary for the next step of our analysis (determinants of pricing policies), because for that we need to extract bank-level coefficients for each aspect of interest rate pass-through, including the long-term equilibrium relationship, which is restricted to be the same across banks by the pooled mean group estimator.

Table 4 shows the results of the pooled mean group estimator for interest rate passthrough in the Czech banking system for the period 2004:01–2008:08; that is, from the start of our data sample to the onset of the financial crisis (the sub-prime mortgage crisis had not affected the Czech economy much before Lehman Brothers fell, but our main results hold even if we define the beginning of the crisis as summer 2007 or, alternatively, the start of 2009). The table shows almost complete long-term pass-through for most products—the long-term coefficients tend to be close to one, indicating that financial market rates are fully transmitted to the rates that banks charge their clients. The only exceptions in this respect are mortgages and overnight deposits, where the pass-through is far from complete (45% for mortgages and 28% for overnight deposits). These findings point to a well-functioning transmission mechanism before the financial crisis.

The estimated error-correction parameters are in all cases negative and statistically significant, which suggests that the error correction model is specified well: if the bank rate exceeds the rate that would correspond to the long-term equilibrium with respect to the corresponding financial market rate, the bank rate decreases in the next period, and vice versa. The parameter can also be thought of as the speed of adjustment between the short-term reaction and the long-

[1] Rates on consumer loans therefore seem to be unrelated to money market interest rates. One reason may be that in a low-inflation environment, such as the one that prevailed during most of the period we examine, the movements in risk premia related to fluctuations in non-performing loans dwarf the movements in market rates. See also Hainz *et al.* (2014) for a related discussion. Similarly, Brož and Hlaváček (2018) find no pass-through in case of consumer loans for the period 2007–2011, but they show that limited size of pass-through existed over the period 2012–2017 if an alternative measure of client rate (modus instead of mean client rate) is considered. Using modus instead of the mean client rate they address the fact that consumer loans consist of quite heterogeneous types of loan categories (ranging from "Xmas gifts" loans to car loans, or to housing-related loans), hence the distribution of the loans here matters.

term equilibrium. The speed of adjustment is relatively homogeneous across bank products, with slightly smaller values for household-related products compared with firm-related products. The short-run reaction of bank rates to changes in the market rate varies a lot across products and signals incomplete short-term pass-through for all products except large loans with a floating rate.

Table 4

Interest rate pass-through before the crisis

	Firm rates				Households	Deposit rates	
	Small loans, floating	Small loans, fixed	Large loans, floating	Large loans, fixed	Mortgages	Overnight deposits	Term deposits
Long-term PT	0.970***	1.343***	1.133***	0.896*	0.453***	0.282***	0.905***
	(0.0279)	(0.152)	(0.0359)	(0.543)	(0.0423)	(0.0207)	(0.0123)
Error corr.	-0.653***	-0.451***	-0.546***	-0.889**	-0.378***	-0.317***	-0.307***
	(0.0931)	(0.109)	(0.0745)	(0.38)	(0.0831)	(0.0727)	(0.049)
Short-term PT	0.381**	0.822	0.943**	-3.716**	0.0448	0.168**	0.282***
	(0.194)	(0.585)	(0.412)	(1.827)	(0.0494)	(0.0652)	(0.0474)
Persistence	-0.116**	-0.193***	-0.140***	-0.0926	0.0723	-0.121***	-0.0742*
	(0.0474)	(0.0669)	(0.045)	(0.296)	(0.0666)	(0.0415)	(0.0395)
Spread	1.319***	1.284***	0.573***	1.599***	1.161***	0.0957	-0.105***
	(0.193)	(0.416)	(0.156)	(0.221)	(0.281)	(0.0817)	(0.032)
Adjustment lag	0.9	1.2	0.3	5.2	1.1	0.4	2
Observations	849	427	693	48	888	1623	1551

Notes: Estimated for the period 2004:01-2008:08 by the pooled mean group estimator (Pesaran et al., 1999); standard errors are shown in parentheses. The mean adjustment lag is computed as (short-term PT minus long-term PT)=(error correction) and is denominated in months. PT stands for pass-through. *denotes statistical significance at the 10% level,** at the 5% level, and *** at the 1% level.

Table 5

Interest rate pass-through after the crisis

	Firm rates				Households	Deposit rates	
	Small loans, floating	Small loans, fixed	Large loans, floating	Large loans, fixed	Mortgages	Overnight deposits	Term deposits
Long-term PT	0.842***	0.792***	0.870***	0.696***	0.842***	0.0515***	0.279***
	(0.0371)	(0.17)	(0.0342)	(0.259)	(0.06)	(0.0073)	(0.0295)
Error corr.	-0.541***	-0.607***	-0.860***	-1.379***	-0.098***	-0.178***	-0.089***
	(0.0927)	(0.14)	(0.305)	(0.196)	(0.0374)	(0.0337)	(0.0125)
Short-term PT	0.216	0.32	-1.737	0.542	0.0334	0.0589	0.277***
	(0.352)	(0.499)	(2.762)	(1.132)	(0.0299)	(0.0447)	(0.048)
Persistence	-0.227***	-0.0407	-0.085	-0.125	-0.00745	-0.170***	-0.0328
	(0.0544)	(0.053)	(0.0733)	(0.217)	(0.0613)	(0.0351)	(0.0661)
Spread	1.463***	3.324***	2.294***	5.515***	0.105***	0.0891***	0.0693***
	(0.238)	(1.123)	(0.854)	(0.223)	(0.0402)	(0.0213)	(0.0155)
Adjustment lag	1.2	0.8	3	0.1	8.3	0	0
Observations	930	354	742	44	1081	1966	1869

Notes: Estimated for the period 2008:08-2013:12 by the pooled mean group estimator (Pesaran et al., 1999); standard errors are shown in parentheses. The mean adjustment lag is computed as (short-term PT minus long-term PT)=(error correction) and is denominated in months. PT stands for pass-through. *denotes statistical significance at the 10% level,** at the 5% level, and *** at the 1% level.

Our results also suggest that the spread (markup) between the market rate and the bank rate differs a lot across products. The spread is statistically insignificant or negative for deposits, which is intuitive as banks tend to set deposit rates that are lower than their alternative costs of funding.[1] For loan products, the spread tends to be the smallest for loans with collateral (mortgages) and large loans with floating rates. Small loans display larger spreads, as do large loans with a fixed rate, but for the latter product we only have a few observations in the data, since few banks regularly provide loans above CZK 30 million with a fixed rate. Finally, we compute the mean adjustment lag as (*short-term PT* minus *long-term PT*)/(*error correction*). With the exception of large loans with a fixed rate, our results point to relatively fast adjustment from the short-run reaction to the long-term equilibrium: between 1 and 2 months. We conclude that before the financial crisis market interest rates were fully passed through to the rates that bank charge firms within 2 months following a change in the market rate.

The conclusions change dramatically when we consider interest rate pass-through in the post-crisis period (2008:09–2013:12), as shown in Table 5. We observe a decrease in the long-term pass-through coefficients for all bank products with the exception of mortgages.[2] For mortgages, in contrast, the pass-through coefficient almost doubles. Moreover, the short-term reaction of bank rates to changes in the market rate now becomes insignificant for all products except term deposits, which also suggests weaker transmission. The error correction coefficients are still negative and statistically significant in all cases, but we observe faster adjustment for deposit rates and slower adjustment for mortgages. Spreads (markups) increase dramatically from the situation before the crisis, again with the exception of mortgages. Concerning adjustment lags, we do not observe any systematic changes with respect to the previous estimation; the most important difference is the long adjustment lag of more than 8 months for mortgages, which indicates that while the relationship between mortgage rates and their reference market rates strengthened, it now takes much longer for mortgage rates to fully react to changes in the market rate.

The results for mortgages, which are quite different in comparison to other bank loan products, correspond to the specific situation on the mortgage market during the post-crisis period in the Czech Republic. After a certain slow down in new mortgage production in the beginning of the post-crisis period, there was a significant increase in the number of new mortgage loans since 2011. A significant part of this increase was also due to the refixation of interest rates (the start of a new period during which the interest rate for a given client will be kept the same) with the client's original bank or due to refinancing of the mortgage by another bank. The small and medium-sized banks were quite successful in gaining clients from large banks and refinancing loans provided by large banks with their banks (CNB, 2014). This strengthened the competition in the Czech mortgage market which helped to improve the interest rate pass-through in this segment in the post-crisis period. A significant growth in volume of mortgage loans continued well beyond 2013. Similarly Hristov et al. (2014) show that the functioning of interest rate pass-

[1] In recent years there have been exceptions in the Czech bank sector in this respect, and we will comment on this issue when discussing the results computed for the post-crisis period.

[2] [9]In Section 2.6 we will evaluate the statistical significance of this decrease.

through is among others related to the degree of competition in the way that weaker competition decreases the interest rate pass-through.

In general, our results are consistent with the notion that banks tightened their lending standards considerably after the financial crisis.[1] The increased aversion to risk is reflected by higher markups on loans, and banks tend to react less to changes in financial market rates, both in the short and the long run. The increased spreads for deposit products may be associated with the entry of new smaller banks into the Czech market in the years following the financial crisis; their aggressive approach often includes offering rates far above the corresponding financial market benchmarks in order to lure clients away from large established banks. The pass-through to mortgage rates improved significantly, which might also reflect increased competition in the Czech market. The tightening of credit standards for loans without collateral could have driven banks to try to increase their market share in the mortgage market, which has been characterized by low delinquency rates (CNB, 2014).

Our findings therefore suggest that supervisors should promote high-quality lending practices in the boom periods for all loan segments, which would ensure reasonable delinquency rates on all banks' products over the business cycle, limiting the risk of deviation of banks from certain loan products/segments towards other significantly less risky products like mortgages. This would ensure more balanced interest rate pass-through across individual bank loan products in the periods of economic slow downs.

2.5. Cost Efficiency

Operational efficiency can theoretically be one of the most important determinants of a bank's pricing policy. Multiple studies on interest rate pass-through take this bank characteristic into account but only consider the traditional accounting ratios as proxies for efficiency (see, for example, Maudos & Fernandez de Guevara, 2004; de Graeve *et al.*, 2007; Gambacorta, 2008). Following Schlüter *et al.* (2012), we employ frontier analysis tools to estimate cost efficiency and use it to examine heterogeneity in interest rate passthrough. Frontier efficiency is a relative measure telling us how close a specific bank's cost is to what the best-practice bank's cost would be if both were producing the same output under the same conditions. Because the frontier efficiency scores are deprived of market price effects and other exogenous factors that may influence the observed performance of banks, we consider frontier efficiency to be more suitable for the ranking of institutions than the traditional accounting ratios. The simple ratios relate only one input to one output and ignore relative prices between inputs; the benefits of the frontier approach are described in detail, for example, by Hanousek *et al.* (2015); Podpiera *et al.* (2007).

The most common frontier tools used to estimate banking efficiency are the statistical stochastic frontier approach (SFA) and deterministic data envelopment analysis (DEA). Some of the advantages of SFA over DEA are that SFA accounts for statistical noise and can be used to

[1] The tightening of banks' lending standards after the financial crisis was a common feature in the post-crisis period both in the euro area countries (ECB, 2013) and emerging countries (IIF, 2013).

conduct the conventional tests of hypotheses, while DEA lacks parameters suitable for economic interpretation. DEA can also be influenced by outliers to a larger extent than SFA. On the other hand, in SFA one needs to specify the assumed distribution of the inefficiency term and the functional form for the production function. To capture cost efficiency more comprehensively and check the robustness of our results, we evaluate the efficiency scores of the Czech banking sector using both the SFA and DEA approaches.

The stochastic frontier approach was developed independently by Aigner *et al.* (1977) and Meeusen & van den Broeck (1977). The general idea of the method is that banks behave according to a given production function that captures how they maximize their output generated by inputs, accounting for the presence of inefficiencies and random shocks. We follow Kumbhakar & Lozano-Vivas (2000), who rewrite the production function to its cost analogy. The cost function captures a cost-minimizing bank controlling for the amount of every input used to produce a given output.[1] Therefore, our preferred cost minimization model is defined following a transcendental logarithmic functional form as:

$$\ln\frac{C}{w_1} = \beta_0 + \sum_{j=1}^{3}\beta_j^y \ln y_j + \sum_{k=2}^{3}\beta_k^w \ln\frac{w_k}{w_1} + \frac{1}{2}\sum_{j=1}^{3}\sum_{n=1}^{3}\beta_{jn}^y \ln y_j \ln y_n + \\ + \frac{1}{2}\sum_{k=2}^{3}\sum_{m=2}^{3}\beta_{km}^w \ln\frac{w_k}{w_1}\ln\frac{w_m}{w_1} + \sum_{j=1}^{3}\sum_{k=2}^{3}\beta_{jk}^{yw}\ln y_j \ln\frac{w_k}{w_1} + \\ + \sum_g \beta_g^{cov} covariates_g + v + u, \tag{3}$$

where, in line with Table B1 in Appendix B, *C* are the operating costs, w_k is the price of the *k*-th input, and y_j stands for the *j*-th output (for simplicity, bank and time subscripts are omitted from the equation). To account for correct functional properties, we normalize costs and prices by w_1. Because we want to estimate bank-specific inefficiencies, we need to separate inefficiency *u* and random shocks *v*. Thus, we impose additional assumptions into the computation: for the *i*-th bank at time *t*, $u_i \sim^{iid} N^+(\mu, \sigma_u^2)$ truncated at 0 and $v_{it} \sim^{iid} N(\mu, \sigma_v^2)$ are independent of each other as well as of other regressors. Specification (3) is thus estimated by the maximum likelihood method. Since we also assume the shape of the frontier to be the same for all banks, we include bank-specific variables *covariates* (see Section 3) and equity capital as regressors in the frontier.

The detailed results of the models we estimate can be found in Table B2 in Appendix B. Our preferred econometric model is panel estimation of the time-varying decay model using the translog functional form. As a robustness check we also provide estimation results for cross-sectional models with Cobb-Douglas and translog functional forms including the mean-conditional model with bank-specific variables *covariates* explaining the mean inefficiency term μ. A

[1] This implies that the functional form needs to fulfill the properties of linear homogeneity and concavity in input prices, and monotonicity in input prices and output.

complementary robustness check to our preferred stochastic model is the deterministic DEA model.

The concept of data envelopment analysis was formally developed by Charnes *et al.* (1978). This approach calculates efficiency scores from the cost minimization problem, where banks minimize costs with respect to a piecewise linear convex frontier that envelopes input and output data. We follow the specification introduced by Cooper *et al.* (2006):

$$\begin{aligned} &\min \ \theta_I \\ &s.t. \quad \sum_{i=1}^{n} \lambda_i x_{ki} - \theta_I x_{kI} \leq 0 \quad \forall k, \quad \sum_{i=1}^{n} \lambda_i y_{ji} - y_{jI} \geq 0 \quad \forall j, \quad \lambda_i \geq 0 \quad \forall i, \end{aligned} \tag{4}$$

where θ is the technical efficiency score, λ_i are dual variables, y_{ji} stands for the j-th output of the i-th bank, and x_{ki} is the k-th input of the i-th bank. We use the original model of Charnes-Cooper, which assumes constant returns to scale (all the banks in the sample are subject to the same regulatory background). The input-oriented DEA model roughly corresponds to cost minimization: improvement in efficiency happens through proportional expansion of output quantities without quantitatively changing the inputs used. The solution to the optimization problem would be defined as the solution to the optimization problem of $min \sum_{k=1}^{m} w_{kI} x_{kI}^{*}$ for a technical efficiency program defined in (4), and economic efficiency would be defined as $\sum_{k=1}^{m} (w_{ki} x_{ki}^{*}) / (w_{ki} x_{ki})$

DEA applied to panel data must be estimated using a balanced panel. Since we have to adjust our data set for DEA estimation (the original data set is heavily unbalanced), the DEA efficiency scores only serve as a robustness check of the baseline SFA estimates (the summary statistics in Table B3 for the annual data used for DEA and the summary statistics in Table B1 for the annualized data used for SFA are fairly similar). Figure B1 also shows that the values of the two efficiency scores exhibit a similar trend throughout the time period we examine, although SFA suggests more improvement in cost efficiency after the financial crisis.

The probability distributions of the efficiency scores estimated by both preferred frontier models, DEA and SFA, in Figure B2 provide a further insight into the estimated values; nevertheless, we are more interested in the relative ranking of banks. As indicated by Table B4, the correlation between frontier measures is strong but the correlation between accounting proxies for efficiency and their frontier alternatives is relatively weak. We conclude that simple accounting ratios constitute poor proxies for bank cost efficiency and we therefore employ efficiency scores in the analysis of bank-level determinants of pricing policies.

2.6. Determinants of Pricing Policies

In this section we explore the heterogeneity in the price-setting behavior of individual banks by linking the pass-through coefficients estimated at the bank and product level to the characteristics of the banks. The first step of the analysis involves the collection of coefficients from Section 4, because we need bank-level coefficients for both the short and long-run relationships, we use the results of the mean group estimator, which allows all the coefficients to vary across individual banks. We focus on three coefficients: the strength of the long-term pass-through, the mean adjustment lag after which the response of bank rates to changes in the market rate reaches its long-term equilibrium, and the spread (markup) between the bank and market rate. We do not investigate short-term pass-through coefficients because these are statistically insignificant in many cases.

An important aspect of methodology not addressed by previous studies on the determinants of interest rate pass-through is that we take into account the precision of the pass-through coefficients estimated for individual banks. The estimates for some banks, especially those with shorter time series, are relatively imprecise, and we need to give such observations less weight in our regressions to reflect the uncertainty surrounding these estimates.[1] The mean adjustment lag is not directly estimated by the mean group estimator; instead, it is a nonlinear combination of three coefficient estimates. To compute the approximate standard error for the adjustment lag we therefore employ the delta method, also frequently used in meta-analysis. Results of simple OLS estimation, not reported in the paper, are available on request.

To investigate the bank-level differences in the strength of the long-term pass-through we estimate the following regression:

$$\begin{aligned} \textit{long-term } PT_{ijk}/SE_{ijk} = \alpha_0 &+ \alpha_1 \textit{efficiency}_{ij}/SE_{ijk} + \alpha_2 \textit{liquidity}_{ij}/SE_{ijk} \\ &+ \alpha_3 \textit{capital adequacy}_{ij}/SE_{ijk} + \alpha_4 \textit{credit risk}_{ij}/SE_{ijk} \\ &+ \alpha_5 \textit{bank size}_{ij}/SE_{ijk} + \alpha_6 \textit{deposits}_{ij}/SE_{ijk} \\ &+ \alpha_7 \textit{post-crisis}_j/SE_{ijk} + \alpha_8 \textit{deposits LTPT}_{ij}/SE_{ijk} \\ &+ \sum_{k=1}^{4} \alpha_9^k \textit{product}_k + \epsilon_{ijk}, \end{aligned} \tag{5}$$

where SE_{ijk} denotes the standard error of the estimate of the long-term pass-through for bank *i*, period *j*, and product *k*.[2] The efficiency variable is estimated according to the approach described in Section 5; in our baseline estimation we use efficiency scores obtained by employing stochastic frontier analysis, but use scores from data envelopment analysis as a robustness check.

To increase the number of degrees of freedom in our regressions, we include estimates of the pass-through coefficients both before and after the financial crisis.[3] The corresponding dummy variable (*post-crisis*) controls for changes in the strength of the long-term pass-through

[1] A similar approach is frequently used, for example, in meta-analyses, where the dependent variable captures estimates of the effect in question taken from various studies; see, for instance, Havranek (2015); Havranek & Irsova (2011).

[2] The definitions of bank-level characteristics *liquidity*, *capital adequacy*, *credit risk*, *bank size*, and *deposits* are available in Section 3: these are standard control variables used for the explanation of heterogeneity in bank pricing policies in several studies (see, for example, de Graeve *et al.*, 2007; Horvath & Podpiera, 2012).

[3] The occurrence of crisis is denoted by period *j*, which equals 0 for pre-crisis periods and 1 for post-crisis periods.

since the crisis.[1] We also include among the explanatory variables the long-term pass-through coefficients for overnight deposits estimated for each bank: because deposits serve as a source of financing for loans, the way market rates are passed through to deposit rates for each bank may influence the pass-through mechanisms for loan products as well.[2] Finally, in Section 4 we estimate the pass-through coefficients separately for various loan products, so in (5) we add a set of dummy variables corresponding to each loan category. Standard errors in all regressions in this section are clustered at the bank level to reflect the fact that most of our explanatory variables are defined at the bank level—if we omitted clustering we would exaggerate the precision of our estimates.

We specify a similar weighted-least-squares regression for the mean adjustment lag:

$$\begin{aligned} adjustment\ lag_{ijk}/SE_{ijk} = \alpha_0 &+ \alpha_1 efficiency_{ij}/SE_{ijk} + \alpha_2 liquidity_{ij}/SE_{ijk} \\ &+ \alpha_3 capital\ adequacy_{ij}/SE_{ijk} + \alpha_4 credit\ risk_{ij}/SE_{ijk} \\ &+ \alpha_5 bank\ size_{ij}/SE_{ijk} + \alpha_6 deposits_{ij}/SE_{ijk} \\ &+ \alpha_7 post\text{-}crisis_j/SE_{ijk} + \alpha_8 deposits\ adj.\ lag_{ij}/SE_{ijk} \\ &+ \sum_{k=1}^{4} \alpha_9^k product_k + \epsilon_{ijk}, \end{aligned} \tag{6}$$

where SE_{ijk} denotes the standard error of the estimate of the adjustment lag for bank *i*, period *j*, and product *k* (the standard error is approximate and estimated using the delta method). Similarly to the previous case we include the corresponding pass-through coefficient for deposits.

Finally, we estimate an analogous regression for the spread:

$$\begin{aligned} spread\ (markup)_{ijk}/SE_{ijk} = \alpha_0 &+ \alpha_1 efficiency_{ij}/SE_{ijk} + \alpha_2 liquidity_{ij}/SE_{ijk} \\ &+ \alpha_3 cap.\ adequacy_{ij}/SE_{ijk} + \alpha_4 credit\ risk_{ij}/SE_{ijk} \\ &+ \alpha_5 bank\ size_{ij}/SE_{ijk} + \alpha_6 deposits_{ij}/SE_{ijk} \\ &+ \alpha_7 post\text{-}crisis_j/SE_{ijk} + \alpha_8 deposits\ spread_{ij}/SE_{ijk} \\ &+ \sum_{k=1}^{4} \alpha_9^k product_k + \epsilon_{ijk}, \end{aligned} \tag{7}$$

where SE_{ijk} denotes the standard error of the estimate of the spread for bank *i*, period *j*, and product *k*. The variable *deposits spread* denotes the mean spread between the deposit rate and the corresponding market rate for each bank. Our hypothesis is that banks that offer larger spreads on deposits (more attractive rates for depositors) tend to engage in riskier behavior and provide loan products with a higher markup.

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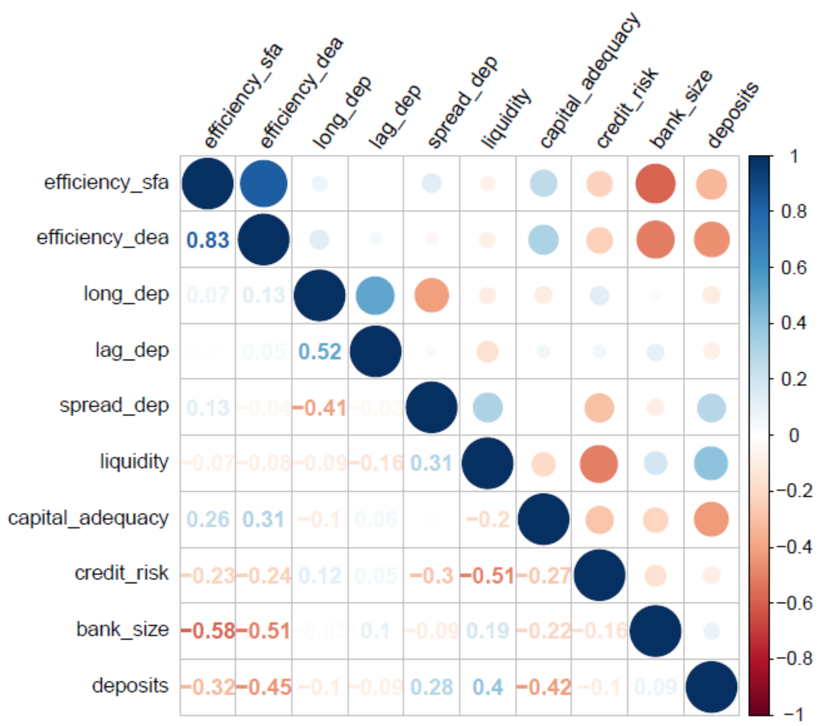
[1] Due to the limited number of banks in our data set, we cannot estimate the determinants of passthrough separately before and after the crisis. Therefore, we impose the condition that the crisis did not change the slope coefficients in the regression.

[2] Another reason to control for the pass-through to deposit rates is the recent entry of many small banks into the Czech market. These banks were often deliberately in losses for several years trying to attract new customers (especially depositors), and this could influence the estimated cost efficiency.

Figure 1 shows the correlation coefficients between the individual explanatory variables. We observe the largest correlations between the two alternative efficiency measures, 0.83 (but note that the two measures are never included in the same regression). The high correlation suggests that stochastic frontier analysis and data envelopment analysis yield similar rankings of banks according to cost efficiency. Next, the efficiency measures are negatively correlated with bank size (the coefficients range from −0.5 to −0.6), which suggests less cost efficiency for large banks, consistent with our results from Section 5. Also less efficient are banks that show a higher share of deposits in total liabilities. Credit risk is negatively correlated with liquidity: more liquid banks display lower credit risk scores. Moreover, banks with a higher share of deposits tend to score worse in terms of capital adequacy, which is also intuitive. In addition, Figure 1 suggests that strong long-term pass-through for deposits is often associated with long mean adjustment lags and low spreads

Figure 1

Correlations between bank-level characteristics



Notes: Efficiency sfa stands for banks' efficiency scores estimated using the Stochastic Frontier Analysis method; *efficiency dea* stands for scores obtained using Data Envelopment Analysis. *Long dep*, *lag dep*, and *spread* _*dep* denote for each bank the mean strength of the long-term pass-through to deposit rates, the adjustment lag for deposit rates, and the spread for deposit rates, respectively.

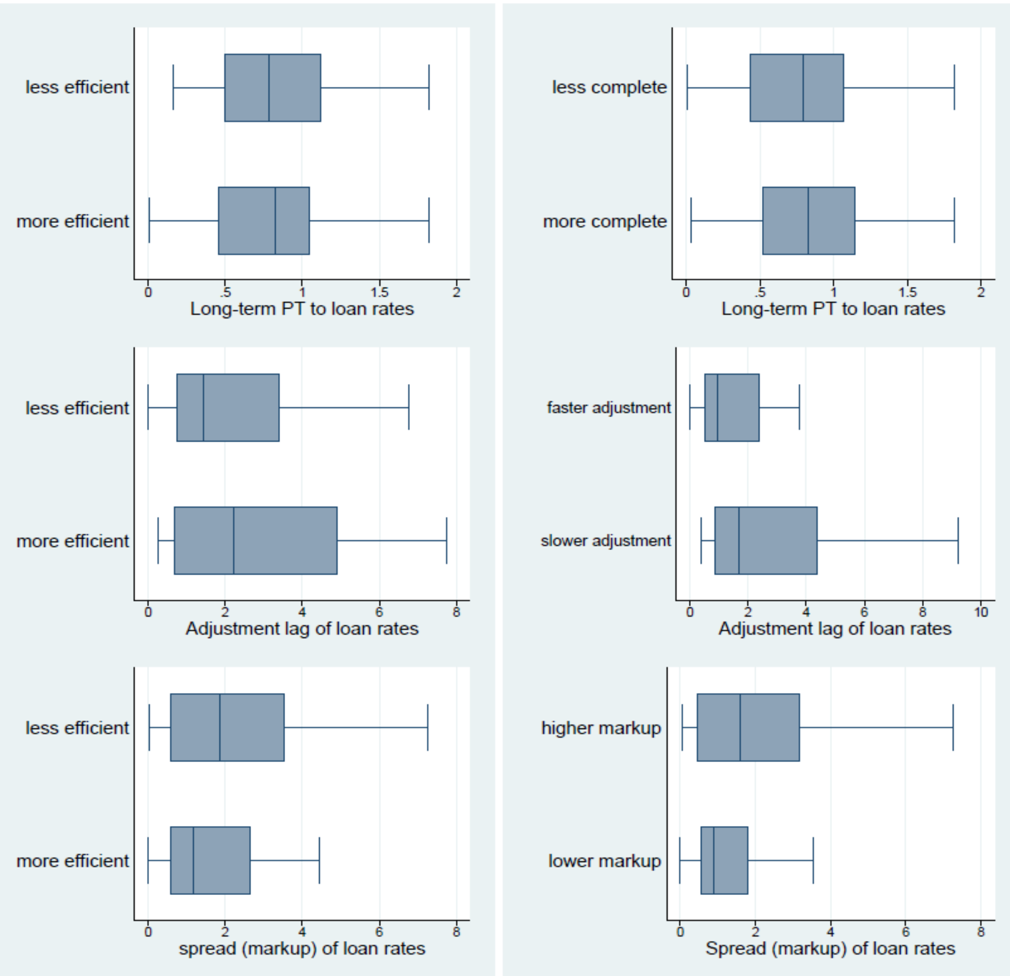
Figure 2 visualizes the relationships between the interest rate pass-through coefficients for loan products and the bank-level characteristics that we focus on in this paper. The left-hand panel of the figure shows the impact of banks' cost efficiency on the strength of the long-term pass-through (the first panel from the top), the adjustment lag between the short and the long term (middle panel), and the spread between bank loan rates and the corresponding market rates (bottom panel). We divide the banks in our sample into two groups according to efficiency scores computed using stochastic frontier analysis: the banks with scores below the median score are labeled "less efficient" and the banks with scores above the median value as "more efficient." Concerning the long-term pass-through coefficients, we observe that the distribution is approximately the same for both less and more efficient banks. In other words, banks' cost efficiency does not matter for the strength of long-term interest rate pass-through.

In contrast, banks' cost efficiency seems to matter for the mean adjustment lag. Although both efficient and inefficient banks sometimes display fast adjustment between the short-run response and the long-run equilibrium, large values of the adjustment lag are much more often associated with more efficient banks. In addition, the mean adjustment lag for more efficient banks is about twice as large as the mean lag for banks that are less efficient. More efficient banks tend to react to changes in financial market interest rates more slowly, thus smoothing loan rates for their clients. Concerning the spread between the bank and market rates, the bottom-left panel of the figure suggests that less efficient banks usually charge higher markups. This finding is intuitive, because banks operating more efficiently can afford to lower the rates they charge in an effort to reap a larger share of the market. So far, our preliminary results for the relation between cost efficiency and pass-through coefficients are fully in line with Schlüter *et al.* (2012), who use German product-level data.

The right-hand part of Figure 2 contains evidence of the relation between the passthrough coefficients for loan products and the pass-through coefficients for deposits for individual banks. Because deposits serve as a source of financing for loans provided by banks, we hypothesize that the pass-through mechanism for loans should be associated with that for deposits: more complete long-term pass-through from market rates to deposit rates should translate to more complete long-term pass-through for loans, longer adjustment lags for deposits should be associated with longer lags for loans, and banks that provide high spreads on deposits with respect to the corresponding financial market rate should charge higher markups on loan products. In each panel we divide banks into two groups according to their pass-through behavior for deposits. For example, in the top panel there are two groups: banks with long-term pass-through smaller than median long-term pass-through and banks with long-term pass-through exceeding the median. Nevertheless, we observe little relation between the equilibrium strength of pass-through for deposits and loans.

Figure 2

Selected determinants of pass-through to loan rates



Notes: IRPT = interest rate pass-through. Banks are divided to two groups by comparing their corresponding values to the median. The variables on the horizontal axes are winsorized using the 5% threshold for both tails.

The mean adjustment lag, on the other hand, seems to be often similar for loan and deposit products. Values of the adjustment lag for loan products larger than four months only occur for banks that also display slow adjustment of deposit rates to changes in the market rate. While there are some exceptions,[1] the mean adjustment lag corresponding to loan products is about twice as large for banks displaying slow adjustment of deposit rates than for banks with fast adjustment of deposit rates. Finally, the bottom panel of the figure shows that high spreads for deposit rates are associated with high markups for loan rates, which might suggest that banks engaged in risky lending behavior tend to offer attractive rates for depositors (CNB, 2014).

[1] For example, slow adjustment for deposits sometimes occurs simultaneously with fast transmission for loans.

The problem with Figure 2 is that the displayed relationships do not control for other potential determinants of heterogeneity in bank pricing policies, such as liquidity position, capital adequacy, or bank size (de Graeve *et al.*, 2007). To take this issue into account and investigate the aforementioned relationships more formally, we present a regression analysis of the determinants of the three pass-through coefficients in Table 6

Table 6

Determinants of interest rate pass-through, SFA used

Response variable:	Long-term PT		Adjustment lag		Spread (markup)	
Efficiency (SFA)	0.177	(2.229)	26.84***	(8.274)	2.302	(5.762)
Liquidity	-3.478*	(1.737)	-58.60***	(15.85)	9.791	(8.593)
Capital adequacy	4.345**	(1.653)	27.77	(17.35)	-7.327	(5.910)
Credit risk	1.372	(1.747)	-25.70*	(13.21)	2.642	(5.511)
Bank size	0.0255	(0.0373)	0.743***	(0.236)	0.0332	(0.120)
Deposits	3.422***	(0.573)	29.47***	(7.511)	-4.602	(2.940)
Post-crisis	-0.964**	(0.457)	-10.90***	(2.943)	2.714**	(1.240)
Deposits LTPT	-0.486	(0.326)				
Deposits adj. lag			0.00378	(0.0336)		
Deposits spread					3.466***	(0.507)
Mortgages	-0.399	(0.299)	2.720	(2.374)	-1.190	(1.018)
Large loans, fixed	-0.0796	(0.211)	0.542	(3.196)	-0.734	(0.811)
Large loans, floating	0.190	(0.251)	-4.666*	(2.542)	0.415	(0.779)
Small loans, fixed	0.338	(0.213)	0.233	(4.250)	1.413	(1.356)
Constant	-1.821	(2.052)	-1.712	(15.68)	1.155	(6.394)
R^2	0.85		0.88		0.67	
Observations	83		83		84	

Notes: Standard errors, reported in parentheses, are clustered at the bank level. The regressions are estimated using weighted least squares, with the precision of the pass-through estimates (the inverse of the estimates' standard errors) taken as the weight. The dependent variable is winsorized using the 5% threshold for both tails. SFA = stochastic frontier analysis. LTPT = long-term pass-through. * denotes statistical significance at the 10% level, ** at the 5% level, and ***at the 1% level.

(where efficiency scores are estimated using stochastic frontier analysis) and Table 7 (efficiency scores estimated using data envelopment analysis). Some of the estimated pass-through coefficients are implausible, due to the relatively small number of observations available for some banks.[1] Instead of removing these outliers or using a robust regression technique that does not allow for clustering of standard errors, such as in Horvath & Podpiera (2012), we winsorize the observations at 5% from each tail: in other words, we replace the values of the smallest 5% of the observations with the value of the 5% percentile in the data and the values of the largest 5% of the observations with the value of the 95% percentile in the data (a similar approach is used in the weighted-leastsquares setting by Havranek et al., 2015). Table A3 and Table A4 in Appendix A show that changing the threshold level to 1% does not alter our main results.

[1] While such imprecise estimates get less weight in the weighted-least-squares setting that we use, they are still substantial outliers. The estimated regression coefficients become significantly less precise when such outliers are not tackled; when simple OLS is used (that is, without weighting), the estimates get even more imprecise.

Table 7

Determinants of interest rate pass-through, DEA used

Response variable:	Long-term PT		Adjustment lag		Spread (markup)	
Efficiency (DEA)	6.918	(4.944)	97.43**	(38.20)	-23.81	(18.47)
Liquidity	-3.581**	(1.555)	-51.22***	(17.20)	8.890	(6.722)
Capital adequacy	4.253***	(1.286)	6.422	(13.62)	-8.627*	(4.411)
Credit risk	1.728	(1.519)	-25.40*	(13.90)	-0.114	(4.720)
Bank size	0.0519**	(0.0209)	0.677**	(0.265)	-0.107	(0.103)
Deposits	4.017***	(0.509)	29.68***	(9.262)	-6.568**	(2.456)
Post-crisis	-1.008***	(0.305)	-9.703***	(2.528)	2.707***	(0.769)
Deposits LTPT	-0.440	(0.321)				
Deposits adj. lag			0.0249	(0.0337)		
Deposits spread					3.842***	(0.498)
Mortgages	-0.106	(0.270)	4.483	(3.079)	-1.798*	(1.014)
Large loans, fixed	0.0545	(0.208)	-0.519	(3.497)	-1.164	(0.975)
Large loans, floating	0.296	(0.235)	-4.103	(2.723)	0.311	(0.791)
Small loans, fixed	0.587**	(0.261)	1.794	(4.401)	0.609	(1.184)
Constant	-7.751*	(4.467)	-64.29	(40.18)	24.10	(16.42)
R^2	0.86		0.87		0.70	
Observations	83		83		84	

Notes: Standard errors, reported in parentheses, are clustered at the bank level. The regressions are estimated using weighted least squares, with the precision of the pass-through estimates (the inverse of the estimates' standard errors) taken as the weight. The dependent variable is winsorized using the 5% threshold for both tails. DEA = data envelopment analysis. LTPT = long-term pass-through. * denotes statistical significance at the 10% level, ** at the 5% level, and ***at the 1% level.

Our results corroborate profound changes in the interest rate pass-through mechanism during the crisis, which we have already discussed in Section 4. The dummy variable corresponding to the post-crisis period is statistically significant in all specifications at the 5% level. The pass-through of financial market rates to bank loan rates weakens dramatically: when bank-level characteristics are controlled for, the estimated change in the long-term pass-through coefficient approaches one, which would translate an almost complete pass-through before the crisis to no significant pass-through after the crisis for an average loan product.[1] Moreover, adjustment lags shorten after the crisis, which suggests that although the long-term relationship between market and bank rates gets weaker, the adjustment between the short- and long-run reaction gets faster: banks change their rates more frequently. Spreads (markups) increase after the crisis, which reflects elevated risk aversion of individual banks.

Our findings concerning the impact of the financial crisis contrast with the results of Illes & Lombardi (2013), who find little change in the interest rate pass-through for major economies. Hristov *et al.* (2014), on the other hand, using fresher data, show that the pass-through has become significantly distorted in the euro area since 2008, which is consistent with our results for the same period and Czech data. Hansen & Welz (2011) examine Swedish data and report

[1] The crisis-induced changes estimated in this section are substantially larger than the ones reported previously for bank-level pass-through estimation. Here we use a different methodology and control for several bank-level characteristics. The qualitative finding that the crisis changed pass-through deeply is robust throughout the methods we use in the manuscript.

results in between those of Illes & Lombardi (2013) and Hristov *et al.* (2014): in Sweden the crisis has not affected interest rate pass-through for products with short maturities, but has distorted pass-through to lending rates at longer maturities.

Concerning the effect of banks' cost efficiency, we fail to confirm the intuition and observation from Figure 2 that more efficient banks tend to charge lower markups. The relationship does not hold when other bank-specific characteristics are controlled for, and it does not matter for the results whether efficiency scores are computed using stochastic frontier analysis or data envelopment analysis. Our results also show no relation between cost efficiency and long-term pass-through. In contrast, the regression analysis confirms the notion that more efficient banks tend to exhibit longer adjustment lags, changing rates less frequently, and thus smoothing the rates for their clients. The result, which holds for both stochastic frontier analysis and data envelopment analysis, is in line with the findings of Schlüter *et al.* (2012), the only other study (to our knowledge) that examines determinants of pricing policies using non-simplified measures of cost efficiency.

Our results show that the pass-through mechanism for deposits at the bank level is important for loan rate markups, but not for the adjustment lag or the strength of long-term pass-through. Higher spreads for deposit rates are associated with higher markups for loan rates, which suggests that banks offering generous deposit products tend to engage in risky lending behavior. Concerning our control variables, we find that more liquid banks tend to exhibit weaker and faster interest rate pass-through, which is consistent with the results of de Graeve *et al.* (2007) for the Belgian banking sector. In contrast to de Graeve *et al.* (2007), however, we find that banks with excess capital usually show stronger long-term pass-through. Moreover, our results suggest that larger banks exhibit longer adjustment lags on average: it seems to be easier for large banks not to react to changes in market rates so often and to smooth loan rates for their clients. Finally, consistent with Horvath & Podpiera (2012) and Gambacorta (2008), we find that banks with a greater degree of relationship banking (proxied by the share of deposits in total liabilities) is associated with smoother setting of loan rates.

2.7. Concluding Remarks

We explore the interest rate pass-through mechanism in the Czech banking sector using product-level data for both before and after the financial crisis. We find strong longterm pass-through from financial market rates to the rates that banks charge their clients before the crisis, but document a substantial deterioration of pass-through after the crisis (except mortgage rates). This result is consistent with the findings of Hristov *et al.* (2014) for the euro area, who show that the pass-through mechanism has become significantly distorted after 2008. Next, we find a relationship between bank pricing policies for deposits and loans: banks that offer large spreads between the deposit rate and the corresponding money market rate tend to charge high loan markups to their clients. The results are in line with anecdotal evidence, as banks offering generous deposit rates tend to be involved in the riskier segment of the loan market. Finally, our results suggest that banks' cost efficiency is not significantly related to loan markups, which contrasts with the results of Schlüter *et al.* (2012) for German banks. Similarly to Schlüter *et al.*(2012), however, we find that more cost-efficient banks tend to smooth loan rates.

The two most closely related studies to ours are Horvath & Podpiera (2012), who study the interest rate pass-through using Czech data, and Schlüter *et al.* (2012), who, to our knowledge, present the only available analysis that relates the strength and speed of pass-through to properly computed efficiency scores. In contrast to Schlüter *et al.* (2012), we use statistical techniques suited for heterogeneous panels: the mean group estimator (Pesaran & Smith, 1995) and the pooled mean group estimator (Pesaran *et al.*, 1999), and employ both stochastic frontier analysis and data envelopment analysis to compute efficiency scores. In contrast to Horvath & Podpiera (2012), we use efficiency scores instead of simple accounting ratios as a proxy for cost efficiency and cluster standard errors at the bank level when examining the determinants of pricing policies. Due to data limitations and omission of clustering, Horvath & Podpiera (2012) effectively work with less than 15 degrees of freedom in their main analysis, but report standard errors corresponding to about 40 degrees of freedom, which is likely to exaggerate the statistical significance of their results (they do not cluster standard errors). Indeed, our results differ from theirs to a large extent. In contrast to both papers, we examine pass-through both before and after the crisis and use weighted least squares estimation in which the precision of the bank-level pass-through coefficients is taken as the weight.

Concerning the policy implications of our results, it seems likely that the significant deterioration in the long-term interest rate pass-through that we identify in the postcrisis sample signals complications for monetary transmission in the future. We use data for the Czech Republic, whose central bank, similarly to many other central banks, has reached the zero lower bound of its main policy rate and currently uses the exchange rate as an additional monetary policy easing tool. Our results suggest that the transmission of the eventual liftoff of the policy rate to the rates that banks charge their clients might be weaker than what was the case during the last tightening cycle. The reason is that since the crisis banks have become substantially more risk-averse, significantly increasing their markups, which mutes their response to changes in the market rates. However, further research on more recent data should be done in order to verify how the interest rate pass-through from financial market rates to rates on banks loan products was affected by the exchange rate commitment used by the Czech National Bank from November 2013 to April 2017 and also in the following period of monetary policy tightening.

The situation is further complicated by the fact that we identify strong asymmetry of pass-through coefficients across banks related to bank characteristics. Cost-efficient banks tend to smooth loan rates for their clients, which nevertheless means that they react to changes in the policy rate with a lag. Larger banks also display delayed reactions to the development of the market interest rates, which is important given that the Czech banking sector is dominated by three large banks. Finally, the markups that banks charge depend on the spread between the market rate and the rate they offer on deposits. Banks offering more generous deposit rates charge higher loan markups, which further reduces their relative exposure to the policy rate.

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Appendix A: Robustness Checks

In this appendix we provide robustness checks for the baseline results presented in the main text. The first set of results, shown in Table A1 and Table A2, is related to the estimation of pass-through parameters. In the main text we estimate and interpret the pass-through mechanism based on the pooled mean group estimator, because it is in our case more efficient. Nevertheless, the alternative mean group estimator is more flexible by allowing all coefficients to differ across banks, and thus serves as a natural robustness check. It can be seen from the tables that the results are very similar to the baseline. Next, Table A3 and Table A4 show the consequences of altering the threshold level for winsorizing when we examine heterogeneity in pass-through. The threshold level used in the baseline analysis is 5%; we show that changing the threshold to 1% does not alter our main results.

Table A1

Interest rate pass-through before the crisis, mean group estimator

	Firm rates				Households	Deposit rates	
	Small loans, floating	Small loans, fixed	Large loans, floating	Large loans, fixed	Mortgages	Overnight deposits	Term deposits
Long-term PT	0.774***	1.103	1.199***	0.793***	0.637***	0.196***	0.642***
	(0.137)	(0.703)	(0.464)	(0.25)	(0.0895)	(0.0712)	(0.0823)
Error corr.	-0.821***	-0.552***	-0.646***	-0.896**	-0.432***	-0.529***	-0.397***
	(0.102)	(0.111)	(0.0752)	(0.369)	(0.0881)	(0.0869)	(0.0466)
Short-term PT	0.103	0.855	0.908**	-3.593**	0.0491	0.161***	0.258***
	(0.39)	(0.677)	(0.46)	(1.569)	(0.0502)	(0.0571)	(0.0445)
Persistence	-0.0435	-0.156**	-0.0843*	-0.0898	0.0741	-0.0353	-0.0751**
	(0.0452)	(0.0718)	(0.0456)	(0.296)	(0.0611)	(0.039)	(0.0363)
Spread	2.435***	2.074**	1.322***	1.661*	1.060***	0.269	0.00727
	(0.713)	(1.03)	(0.362)	(0.995)	(0.296)	(0.168)	(0.0673)
Adjustment lag	0.8	0.4	0.5	4.9	1.4	0.1	1
Observations	849	427	693	48	888	1623	1551

Notes: Estimated for the period 2004:01-2008:08 by the mean group estimator (Pesaran & Smith, 1995); standard errors are shown in parentheses. The mean adjustment lag is computed as (short-term PT minus long-term PT)/(error correction) and is denominated in months. PT stands for pass-through. * denotes statistical significance at the 10% level, ** at the 5% level, and ***at the 1% level.

Table A2

Interest rate pass-through after the crisis, mean group estimator

	Firm rates				Households	Deposit rates	
	Small loans, floating	Small loans, fixed	Large loans, floating	Large loans, fixed	Mortgages	Overnight deposits	Term deposits
Long-term PT	0.795***	0.516**	0.707***	0.506	0.504***	0.187***	0.348***
	(0.0603)	(0.223)	(0.266)	(0.377)	(0.122)	(0.0444)	(0.0641)
Error corr.	-0.635***	-0.915***	-0.824***	-1.439***	-0.152***	-0.318***	-0.153***
	(0.103)	(0.133)	(0.131)	(0.137)	(0.0363)	(0.0541)	(0.0235)
Short-term PT	0.205	0.225	-0.111	0.604	0.0349	0.111**	0.294***
	(0.384)	(0.512)	(0.919)	(0.602)	(0.0316)	(0.0487)	(0.0505)
Persistence	-0.183***	0.045	-0.0627	-0.0865	0.0137	-0.121***	-0.0285
	(0.0533)	(0.0636)	(0.0442)	(0.157)	(0.0592)	(0.0289)	(0.0585)
Spread	1.772***	5.526***	2.579***	7.048***	0.387***	0.112***	0.0975**
	(0.301)	(1.296)	(0.539)	(2.595)	(0.0987)	(0.0417)	(0.0478)
Adjustment lag	0.9	0.3	1	-0.1	3.1	0.2	0.4
Observations	930	354	742	44	1081	1966	1869

Notes: Estimated for the period 2008:09-2013:12 by the mean group estimator (Pesaran & Smith, 1995); standard errors are shown in parentheses. The mean adjustment lag is computed as (short-term PT minus long-term PT)/(error correction) and is denominated in months. PT stands for pass-through. * denotes statistical significance at the 10% level, ** at the 5% level, and ***at the 1% level.

Table A3

Determinants of interest rate pass-through, SFA used, winsorized at 1%

Response variable:	Long-term PT		Adjustment lag		Spread (markup)	
Efficiency (SFA)	2.145	(6.554)	32.07**	(11.58)	0.798	(8.962)
Liquidity	-11.97**	(5.467)	-93.50***	(27.69)	17.86	(12.72)
Capital adequacy	13.31**	(4.975)	34.54	(24.57)	-15.43	(10.42)
Credit risk	1.354	(4.724)	-46.31*	(23.81)	4.392	(7.333)
Bank size	0.0234	(0.110)	0.700**	(0.299)	-0.000758	(0.205)
Deposits	11.40***	(1.915)	46.08***	(11.66)	-7.615	(4.822)
Post-crisis	-2.297	(1.418)	-14.96***	(4.478)	5.605**	(2.341)
Deposits LTPT	-2.449*	(1.192)				
Deposits adj. lag			0.0546	(0.0526)		
Deposits spread					3.997***	(0.723)
Mortgages	-0.529	(0.830)	2.688	(3.432)	-1.733	(1.223)
Large loans, fixed	1.164*	(0.643)	2.154	(4.249)	-0.844	(1.024)
Large loans, floating	1.016	(0.847)	-6.736*	(3.838)	0.310	(0.868)
Small loans, fixed	1.023	(0.634)	1.166	(7.510)	1.500	(1.578)
Constant	-6.462	(5.806)	6.441	(26.13)	1.526	(9.284)
R^2	0.89		0.90		0.66	
Observations	83		83		84	

Notes: Standard errors, reported in parentheses, are clustered at the bank level. The regressions are estimated using weighted least squares, with the precision of the pass-through estimates (the inverse of the estimates' standard errors) taken as the weight. The dependent variable is winsorized using the 1% threshold for both tails. SFA = stochastic frontier analysis. LTPT = long-term pass-through. * denotes statistical significance at the 10% level, ** at the 5% level, and ***at the 1% level.

Table A4

Determinants of interest rate pass-through, DEA used, winsorized at 1%

Response variable:	Long-term PT		Adjustment lag		Spread (markup)	
Efficiency (DEA)	22.10	(14.44)	129.5**	(48.54)	-40.95	(27.92)
Liquidity	-12.06**	(4.879)	-83.80***	(29.48)	15.41	(9.206)
Capital adequacy	12.29***	(3.938)	11.92	(18.39)	-16.05**	(7.118)
Credit risk	1.975	(4.122)	-44.05*	(23.60)	0.254	(6.010)
Bank size	0.0807	(0.0585)	0.693**	(0.296)	-0.191	(0.161)
Deposits	12.98***	(1.805)	48.04***	(14.47)	-10.16**	(4.007)
Post-crisis	-2.320**	(0.982)	-13.88***	(3.793)	5.390***	(1.431)
Deposits LTPT	-2.274*	(1.156)				
Deposits adj. lag			0.0777	(0.0523)		
Deposits spread					4.442***	(0.735)
Mortgages	0.261	(0.751)	5.184	(4.249)	-2.539**	(1.220)
Large loans, fixed	1.519**	(0.610)	0.945	(4.729)	-1.427	(1.271)
Large loans, floating	1.274	(0.845)	-6.245	(4.229)	0.129	(0.895)
Small loans, fixed	1.739**	(0.779)	3.579	(7.594)	0.279	(1.341)
Constant	-24.19*	(12.83)	-81.45	(55.87)	38.77	(24.46)
R^2	0.90		0.90		0.71	
Observations	83		83		84	

Notes: Standard errors, reported in parentheses, are clustered at the bank level. The regressions are estimated using weighted least squares, with the precision of the pass-through estimates (the inverse of the estimates' standard errors) taken as the weight. The dependent variable is winsorized using the 1% threshold for both tails. DEA = data envelopment analysis. LTPT = long-term pass-through. * denotes statistical significance at the 10% level, ** at the 5% level, and ***at the 1% level.

Appendix B: Details of Efficiency Analysis

Here we provide additional material relevant for the estimation of efficiency scores. First, Table B1 shows the summary statistics of the variables used to estimate the stochastic frontier. The detailed results of all models, including all estimated parameters for the translog cost function, are presented in Table B2. Next, Table B3 shows the summary statistics of the variables used to estimate the deterministic efficiency scores of different banks: the data set is different from the stochastic frontier estimation because the deterministic frontier requires balanced panel data. Table B4 presents correlations of the stochastic efficiency measure, deterministic efficiency measure, and simplified measures based on accounting ratios. Finally, Figure B1 and Figure B2 show the evolution of efficiency scores in time and their distribution.

Table B1

Summary statistics of variables for stochastic frontier efficiency estimation

Variable	Label	Description	Obs.	Mean	SD	Min	Max
inputs	x_1	fixed assets = tangible and intangible assets	4,508	1,231	3,346	0	19,600
	x_2	borrowed funds = total interest-bearing financial liabilities	4,459	89,200	158,000	0	855,000
	x_3	number of full time employees	4,540	1,009	2,293	2	11,197
input prices	w_1	price of fixed assets = depreciation on fixed assets and other administrative expenses divided by fixed assets	4,508	5	12	0	301
	w_2	price of borrowed funds = interest expenses divided by borrowed funds	4,343	0.02	0.01	0	0.15
	w_3	price of labor = personnel expenses divided by number of full time employees	4,538	1.18	0.88	0	19.17
outputs	y_1	commercial loans	4,348	49,600	82,500	0	457,000
	y_2	interbank loans	4,348	24,000	46,200	1	314,000
	y_3	investment assets	4,085	26,500	62,900	0	403,000
heterogeneity	cov	expected inefficiency covariates captured in Section 3					
	z	equity capital	4,549	7,708	16,000	-488	96,100

Notes: All variables except for x_3, w_1, and w_2 in CZK millions; w_1 and w_2 in %. Reported variables are annualized. Unbalanced panel of 52 banks over the period of 2003–2013.

Table B2

Stochastic frontier estimation

	CS TL Cond.	CS TL Mean-cond.	Panel CD	Panel TL	Panel TL Cond.
$\ln y_1$	-2.578^{**}	-1.869^{**}	0.458^{**}	-0.678^{**}	-0.649^{**}
	(-16.21)	(-15.01)	(46.07)	(-5.35)	(-3.92)
$\ln y_2$	-0.458^{**}	-1.213^{**}	0.0883^{**}	0.722^{**}	0.663^{**}
	(-3.23)	(-9.96)	(19.80)	(10.64)	(11.02)
$\ln y_3$	1.376^{**}	1.395^{**}	0.0488^{**}	-0.0135	-0.111^{*}
	(15.18)	(14.52)	(13.57)	(-0.24)	(-2.27)
$\ln(w_2/w_1)$	2.286^{**}	1.542^{**}	0.502^{**}	3.580^{**}	3.754^{**}
	(8.51)	(5.90)	(67.52)	(28.51)	(30.15)
$\ln(w_3/w_1)$	-2.027^{**}	-1.233^{**}	0.337^{**}	-2.282^{**}	-2.670^{**}
	(-6.60)	(-4.30)	(37.67)	(-15.10)	(-19.28)
$\ln y_1 \ln y_2$	-0.0281^{**}	-0.0248^{**}		-0.0556^{**}	-0.0266^{**}
	(-4.74)	(-4.64)		(-16.51)	(-8.45)
$\ln y_1 \ln y_3$	-0.0255^{**}	-0.0331^{**}		-0.0222^{**}	-0.0115^{**}
	(-6.88)	(-10.40)		(-10.42)	(-5.40)
$\ln y_2 \ln y_3$	-0.0168^{**}	-0.0095^{*}		-0.0002	-0.0001
	(-4.13)	(-2.49)		(-0.11)	(-0.08)
$1/2 \ln y_1^2$	0.164^{**}	0.145^{**}		0.0910^{**}	0.0595^{**}
	(12.98)	(12.68)		(11.54)	(6.26)
$1/2 \ln y_2^2$	0.0382^{**}	0.0389^{**}		0.0362^{**}	0.0199^{**}
	(8.87)	(8.09)		(14.85)	(9.81)
$1/2 \ln y_3^2$	0.0472^{**}	0.0661^{**}		0.0337^{**}	0.0243^{**}
	(18.95)	(33.37)		(20.30)	(16.42)
$\ln(w_2/w_1)\ln(w_3/w_1)$	-0.0634^{*}	0.0211		-0.162^{**}	-0.225^{**}
	(-2.34)	(0.88)		(-18.59)	(-20.14)
$1/2 \ln(w_2/w_1)^2$	0.0877^{**}	-0.0553^{*}		0.185^{**}	0.274^{**}
	(3.20)	(-2.18)		(25.00)	(22.28)
$1/2 \ln(w_3/w_1)^2$	0.0651^{*}	0.0234		0.158^{**}	0.208^{**}
	(1.99)	(0.83)		(15.02)	(17.27)
$\ln y_1 \ln(w_2/w_1)$	-0.106^{**}	-0.0816^{**}		-0.0842^{**}	-0.0705^{**}
	(-8.86)	(-7.40)		(-16.86)	(-10.75)
$\ln y_2 \ln(w_2/w_1)$	-0.0836^{**}	-0.151^{**}		0.0121^{**}	0.0360^{**}
	(-7.12)	(-13.89)		(2.92)	(7.46)
$\ln y_3 \ln(w_2/w_1)$	0.142^{**}	0.162^{**}		0.0104^{**}	0.0067^{*}
	(19.59)	(20.81)		(3.35)	(2.11)
$\ln y_1 \ln(w_3/w_1)$	0.132^{**}	0.0876^{**}		0.0637^{**}	0.0725^{**}
	(9.21)	(7.16)		(9.53)	(10.21)
$\ln y_2 \ln(w_3/w_1)$	0.0686^{**}	0.115^{**}		-0.0232^{**}	-0.0459^{**}
	(5.17)	(9.86)		(-4.26)	(-8.82)
$\ln y_3 \ln(w_3/w_1)$	-0.105^{**}	-0.123^{**}		0.0043	$0.007^{\dagger}$
	(-12.73)	(-14.70)		(1.01)	(1.78)
time trend	-0.0045^{**}			0.0033^{**}	0.00275^{**}
	(-6.03)			(11.41)	(7.59)
time trend squared	0.00002^{*}				
	(2.54)				
equity over assets	-1.146^{**}				-0.197
	(-5.89)				(-1.38)
return on assets	-0.0250^{*}				0.0265^{**}
	(-2.04)				(3.70)
return on equity	-0.0036^{**}				-0.00247^{**}
	(-3.77)				(-5.90)
quick to total assets	0.0052^{**}				0.00527^{**}
	(7.24)				(14.69)
capital adequacy ratio	0.0007				0.00171^{**}
	(0.74)				(3.05)
credit risk to total assets	0.0045^{*}				
	(2.38)				
risk-weighted to total assets	0.0021				-0.0006
	(1.18)				(-1.40)
equity			-0.0168^{*}		
			(-2.51)		
constant	31.31^{**}	27.45^{**}	3.125^{**}	23.02^{**}	25.13^{**}
	(16.52)	(17.87)	(19.05)	(15.71)	(14.97)

time trend		-0.0172^{**} (−5.77)			
time trend squared		0.0001^{**} (2.76)			
equity over assets		1.023^{**} (3.26)			
return on assets		0.336^{**} (9.98)			
return on equity		-0.0509^{**} (−13.62)			
quick to total assets		-0.0073^{**} (−3.51)			
constant (μ)		1.037^{**} (9.44)	1.140^{**} (6.87)	0.851^{**} (6.03)	0.993^{**} (8.80)
inverse logit of γ		3.765^{**} (20.83)	2.720^{**} (8.12)	2.704^{**} (7.76)	3.020^{**} (8.99)
$\ln \sigma^2$		-0.971^{**} (−10.18)	$-0.557^{\dagger}$ (−1.78)	-1.037^{**} (−3.19)	-1.321^{**} (-4.14)
η			0.0001 (1.02)	0.0025^{**} (10.75)	0.0027^{**} (10.91)
$\ln \sigma_u^2$	-1.595^{**} (−28.36)				
$\ln \sigma_v^2$	-3.720^{**} (−36.38)				
σ_u	0.450	0.608	0.733	0.576	0.504
σ_v	0.156	0.093	0.188	0.149	0.111
$\sigma^2 = \sigma_u^2 + \sigma_v^2$			0.573	0.354	0.267
$\gamma = \sigma_u^2/\sigma^2$			0.938	0.937	0.953
Observations	2, 507	2, 507	3, 174	3, 208	2,507

Note: Dependent variable $\ln(\text{cost}/w_1)$. Cross-sectional (CS) normal/truncated-normal models and panel time-varying decay models using Cobb-Douglas (CD) and translog (TL) functional form with and without bank-specific terms inside the production function and the function of μ. The highlighted column is the preferred model chosen for computation of SFA efficiency. Maximum-likelihood computed using heteroscedasticity robust z-statistics (in parentheses). * denotes statistical significance at the 10% level, ** at the 5% level, and ***at the 1% level.

Figure B1

Development of the estimated frontier efficiencies during 2004–2013

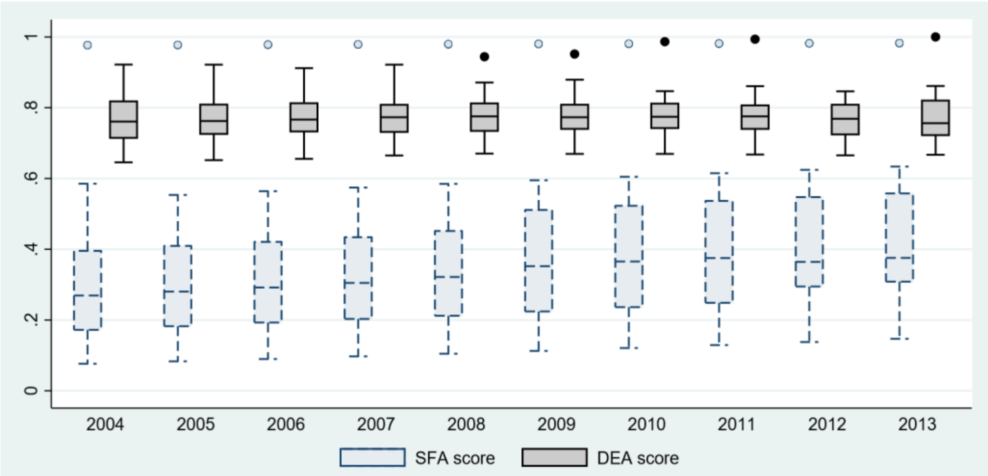

Figure B2

Kernel density function of the estimated frontier efficiencies

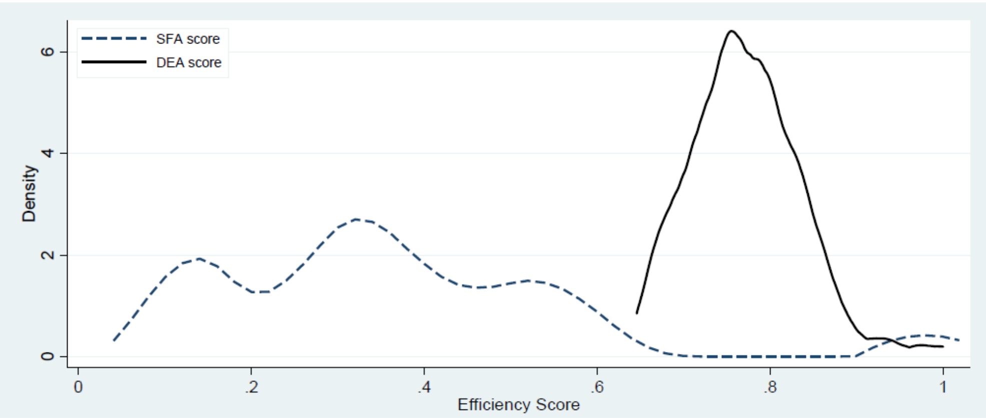

Table B3

Summary statistics of variables for deterministic frontier efficiency estimation

Variable	Label	Description	Obs.	Mean	SD	Min	Max
costs	C	total operating costs	300	4,715	6,850	50	33,900
inputs	x_1	fixed assets = tangible and intangible assets	300	1,595	3,815	0	18,900
	x_2	borrowed funds = total interest-bearing financial liabilities	300	114,000	176,000	336	817,000
	x_3	number of full time employees	300	1,310	2,581	13	11,187
input costs	c_1	expenditures on fixed assets = depreciation on fixed assets and other administrative expenses	300	1,609	2,713	0	13,600
	c_2	expenditures on borrowed funds = interest expenses	300	1,865	2,374	3	16,800
	c_3	expenditures on labor = personnel expenses	300	1,242	2,243	14	14,700
outputs	y_1	commercial loans	300	63,400	93,600	157	457,000
	y_2	interbank loans	300	27,900	46,800	10	282,000
	y_3	investment assets	300	32,000	70,500	0	394,000

Note: All variables except for x_3 in CZK millions. Reported variables are annualized. Balanced panel of 30 banks over the period of 2004–2013.

Table B4

Correlations between frontier efficiencies and traditional efficiency measures

	SFA	DEA	CIR	CAR	ROA	ROE
Pearson correlation						
SFA efficiency	1					
DEA efficiency	0.86	1				
Cost-to-income ratio	0.02	-0.04	1			
Cost-to-assets ratio	-0.06	-0.08	0.65	1		
Return on assets	-0.34	-0.29	-0.69	-0.32	1	
Return on equity	-0.37	-0.31	-0.41	-0.34	0.70	1
Spearman correlation						
SFA efficiency	1					
DEA efficiency	0.90	1				
Cost-to-income ratio	0.12	0.13	1			
Cost-to-assets ratio	-0.07	-0.05	0.47	1		
Return on assets	-0.50	-0.43	-0.40	-0.10	1	
Return on equity	-0.41	-0.36	-0.18	-0.20	0.75	1

Note: Pearson simple correlation and Spearman rank-order correlation between different measures of cost efficiency

3. Does Greater Capital Hamper the Cost Efficiency of Banks? A Bi-Causal Analysis

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Does Greater Capital Hamper the Cost Efficiency of Banks?

A Bi-Causal Analysis

Abstract

The aim of our research is to analyze the relation between capital and bank efficiency by considering both directions of the Granger causality for the Czech banking industry. We use an exhaustive dataset of Czech banks from 2002 to 2013. We measure the cost efficiency of banks using stochastic frontier analysis. We perform Granger-causality tests to check the sign and significance of the causal relation between capital and efficiency. We embed Granger-causality estimations in the GMM dynamic panel estimator. We find no relation between capital and efficiency, as neither the effect of capital on efficiency, nor the effect of efficiency on capital is significant. The financial crisis does not influence the relation between capital and efficiency. Our findings suggest that tighter capital requirements like those under Basel III do not affect financial stability through the efficiency channel. Policies favoring capital levels and efficiency of the banking industry can therefore be designed separately.

Keywords: bank capital, efficiency, transition countries

JEL Codes: G21, G28

3.1. Introduction

The new capital rules commonly known as the Basel III reforms have led to a wide debate about their overall impact on the financial sector and the real economy. These reforms, which include tighter capital requirements, are aimed at improving the resilience of the banking industry. However, there are also concerns about their potential negative impacts, particularly about their contribution to a reduction of bank lending and, in turn, to slower economic growth. A couple of studies have thus analyzed how bank lending and then output will be affected by the Basel III reforms (e.g., BCBS, 2009; Angelini et al., 2011). Horvath, Seidler, and Weill (2014) also contribute to this debate by showing that higher capital levels worsen liquidity creation by banks in the context of the Czech banking industry.

What is striking, however, is that the vast majority of studies looking at the effects of tighter capital requirements ignore the possibility of an impact on bank performance and hence on financial stability. This lack of interest is surprising both for a theoretical and for an empirical reason. The theoretical reason is that the agency costs literature has clearly shown that conflicts of interest between categories of agents (managers, shareholders, debtholders) which are related to the level of capital in the total balance sheet create agency costs which worsen firm performance (Jensen and Meckling, 1976).

The empirical reason is that bank performance, specifically the cost efficiency of banks, has been shown to influence financial stability. Podpiera and Weill (2008) have shown that deteriorations in cost efficiency precede increases in non-performing loans in a study of Czech banks. By also using cost efficiency scores for the Czech banking industry, Pruteanu-Podpiera and Podpiera (2008) have found that cost inefficient management predicts bank failures. Thus, if capital exerts an impact on financial stability through bank efficiency, it is of utmost interest to consider the influence of capital on bank efficiency to have a broad view of the consequences of capital requirements for financial stability.

A few studies have analyzed this question. Berger and Bonaccorsi di Patti (2006) analyze the impact of capital on profit efficiency in the US banking industry for the period 1990–1995. They find that higher capital ratios are associated with lower efficiency. Fiordelisi, Marques-Ibanez, and Molyneux (2011) provide a broader perspective by considering the intertemporal relationships between capital, risk, and efficiency for a sample of European banks between 1995 and 2007. They find a positive bi-directional relation between capital and efficiency, while these results are just derivative findings of their estimations. Pessarossi and Weill (2015) examine the effect of capital on efficiency for Chinese banks by considering the first implementation of capital requirements in China in 2004. They also show a positive impact of capital on cost efficiency.

The aim of our research is to analyze the impact of Basel III on Czech banks, specifically the impact of tighter capital requirements on the cost efficiency of Czech banks, which is directly connected to the financial stability issue. The findings of this paper are therefore of major interest for regulators. If capital reduces (increases) cost efficiency, capital requirements can potentially have negative (positive) consequences for financial stability through the cost efficiency channel.

The contribution of this paper to the literature is threefold. First, our paper analyzes the relation between capital and bank efficiency by considering both directions of the Granger causality. Previous studies only consider the impact of capital on efficiency, even though there are theoretical reasons why efficiency can influence capital. The exception is the study by Fiordelisi, Marques-Ibanez, and Molyneux (2011), although they do not test hypotheses on this relation and consider a broader issue. Consequently, we assume in our study that tighter capital requirements can influence efficiency, which, in turn, affects capital, thereby creating a virtuous or vicious circle.

Second, we provide new evidence on the implications of tighter capital requirements for Czech banks. The relation between capital and efficiency has only been investigated in the context of large countries such as the US and China or advanced economies such as Western European countries. We can question this relation in the context of small emerging countries with their specific features, such as the importance of financial stability, given the occurrence of bank failures in these countries in both of the last two decades and the major market share of foreign-owned banks.

Third, we analyze how this impact might have been influenced by the recent financial crisis. This crisis may have influenced the relation between capital and efficiency, notably through a higher capital ratio, which has not been chosen strictly voluntarily by banks but under pressure from regulators and other bank stakeholders. The actual introduction of Basel III in 2014[1] led to a decrease in capital surplus as banks use part of their capital surplus to cover the increase in the regulatory requirements, however, most banks remained compliant with these requirements by a sufficient margin on an individual basis (Malovaná, 2017).

To investigate this issue, we use an exhaustive dataset of Czech banks from 2002 to 2013 provided by the Czech National Bank. We measure cost efficiency using stochastic frontier analysis. We then perform Granger-causality tests to check the sign and significance of the causal relation between capital and efficiency. We embed Granger-causality estimations in the GMM dynamic panel estimator to address the econometric issues resulting from the use of lagged dependent variables.

The paper is organized as follows. Section 2 presents the hypotheses, while Section 3 describes the evolution of the Czech banking sector. Section 4 outlines the methodology and presents the data. Section 5 displays the results. Section 6 concludes.

3.2. Hypotheses on the relation between capital and efficiency

In this paper we investigate the relation between capital and efficiency at the bank level. We start by presenting the hypotheses proposed by the literature for each direction of the causality.

[1] In the European Union, Basel III was introduced via regulatory package so-called CRR/CRD IV.

- **From capital to efficiency**

The hypotheses on the impact of capital on cost efficiency come from the agency costs literature, which demonstrates the existence of conflicts of interest between firm stakeholders, as mentioned by Jensen and Meckling (1976). These authors identify two types of conflicts, which have different implications leading to opposite hypotheses on the link between capital and cost efficiency.

Agency costs can arise from conflicts of interest between shareholders and managers. Here, the main problem is the moral hazard behavior of managers, who may minimize their effort or waste firm resources instead of increasing firm value. Higher debt financing, and therefore a lower equity-to-assets ratio, raises the pressure on managers to perform, as it reduces the "free cashflow" at the disposal of managers (Jensen, 1986), as debt implies interest payment obligations, and as managers want to avoid the personal costs of bankruptcy (Grossman and Hart, 1982). So a higher equity-to-assets ratio should have a negative impact on efficiency (the "*agency costs shareholders-managers hypothesis*").

However, agency costs also arise from conflicts of interest between shareholders and debtholders, as shareholders have incentives to take actions that benefit themselves at the expense of debtholders and consequently do not necessarily maximize firm value. They have incentives to invest in riskier projects than those preferred by debtholders ("asset substitution," as suggested by Jensen and Meckling, 1976). These conflicts can also lead to underinvestment, as demonstrated by Myers (1977). Since these agency costs are related to the importance of debtholders, they are associated with greater debt financing. In other words, a higher equity-to-assets ratio would reduce these agency costs and would thus be positively related to efficiency (the "*agency costs shareholders-debtholders hypothesis*").

Both types of agency costs can emerge in the banking industry. However, the agency costs resulting from the relation between shareholders and debtholders are of particular interest in the context of this industry, in which regulation has to take care of the potential conflicts of interest between shareholders and depositors to protect this latter category. Nonetheless, we cannot ignore the possibility of conflicts of interest between shareholders and managers for Czech banks. Most of these institutions are foreign-owned and several studies have pointed out that foreign banks might be more difficult to monitor from a distance by shareholders (e.g., Berger et al., 2000). Monitoring by a foreign shareholder might be even more challenging if the shareholder owns several banks in different countries (i.e., the case of large international banking groups). On the other hand, many Czech banks have concentrated ownership, which can contribute to reducing the agency problem between shareholders and managers. All these arguments lead to the particular interest in analyzing this issue specifically for Czech banks.

Basel III can influence both hypotheses by resulting in greater and stricter requirements regarding capital from shareholders. It will contribute to increasing the moral hazard behavior of managers, but will reduce the moral hazard behavior of shareholders. The latter consequence is a key motivation behind this regulation, but it is important to check whether it is outweighed by the former. Hence, we have to empirically test for the sign of the relation between capital and efficiency.

- **From efficiency to capital**

The causality might also run from cost efficiency to capital. Berger and Bonaccorsi di Patti (2006) have proposed two conflicting hypotheses for this sense of causality. The *"efficiency-risk hypothesis"* suggests that greater efficiency is associated with lower capital, as it reduces the costs of financial distress for bank managers. Indeed, more efficient firms are less likely to fail and are therefore more willing to use debt. We should thus expect a negative impact of cost efficiency on capital.

The *"franchise value hypothesis"* considers that a more efficient bank is more willing to use capital to protect the economic rents or franchise value resulting from its efficiency from the threat of liquidation. So, this hypothesis predicts a positive role of cost efficiency in capital.

The financial crisis might have played a role in the relation between cost efficiency and capital. For instance, the crisis might have exacerbated the threat of liquidation for efficient banks suggested by the *"franchise value hypothesis"* and might therefore have fostered a positive impact of cost efficiency on capital.

So, there are opposite theoretical predictions for both senses of the causality, which may furthermore have been influenced by the financial crisis.

3.3. Developments in the Czech banking sector

The Czech financial system is a banking-based system, in the sense that the banking industry is the main source of funding for the real economy. Like its peers in Central and Eastern Europe, the Czech banking industry is still of a reasonable size; its assets represented roughly 130% of GDP in 2013. Also, the banking business in the Czech Republic is of a conservative nature, based mainly on collecting deposits and providing loans to the real economy. In addition to that, banks hold investment assets, the majority of which are domestic government bonds.

In the late 1990s, the Czech banking system experienced a banking crisis. This was followed in the early 2000s by a clean-up of bank balance sheets and by acquisitions of major banks by foreign investors. As a result, the quasi-totality of the assets of the banking industry is currently controlled by foreign owners. Also, large European banking groups such as Erste Group, Société Générale, KBC, UniCredit Group, and Raiffeisen Group are present in the Czech Republic. Their subsidiaries in the Czech Republic rank among the largest domestic banks, with a market share of around 60% in terms of assets. Over the last decade, the number of banks has varied between 40 and 44. Several banks have been converted into branches of foreign banks operating in the Czech Republic under the EU single passport. The Czech banking sector consisted of 18 banks, 21 foreign bank branches, and 5 special-purpose building societies as of 2013.

In comparison to the 1990s crisis, Czech banks came through the recent financial crisis relatively unscathed thanks to their good capital position and conservative business models. They did not receive any government capital support during the crisis, unlike some of their foreign parent banks, and performed well overall (Frait, Geršl, and Seidler, 2011). The aggregate capital adequacy of Czech banks in fact increased during the crisis and totaled 17% in 2013. The banking sector's resilience to the crisis was also positively influenced by the responsible lending policy of domestic banks in the pre-crisis period, with almost no use of innovative instruments such as CDS and no material dependence on financing from interbank markets.

The Czech banking system exhibits favorable values of key prudential indicators on the aggregate level and was even able to maintain its profitability during the crisis, which, in turn, helped banks improve their capitalization using retained earnings. The profitability of the Czech banking sector in the crisis period was positively influenced by its large and stable deposit base on the liability side. Domestic banks benefit from the conservative preferences of households, who favor bank deposits over alternative forms of financial assets. The significant overhang of deposits over loans in the sector (a deposit-to-loan ratio of about 130%) contributed to the ability of banks to lower interest rates paid on deposits, hence effectively reducing financing costs on the sector level.

On the asset side, credit risk materialized and non-performing loans increased in the initial years of the crisis. Increased provisioning for bad loans and some write-offs of junk foreign government bonds negatively impacted banks' net profits. However, non-performing loans stabilized in 2010 at the reasonable level of around 6%, which has led to a lower need to create significant additional provisions since then.

Although the key prudential indicators exhibit favorable values on the sector level, there are differences across banks in the Czech banking sector in terms of both riskiness, profitability, and capital position and their approach to the banking business.

The stability of Czech banks and the way they operate have been influenced by the regulatory environment in the Czech Republic, which has undergone important changes over time. In mid-2007 the Basel II rules were implemented into local law, and as early as 2007 some banks, mainly the largest ones, started to use the internal rating-based approach, an advanced and more sophisticated method for calculating capital requirements. Smaller banks kept the standardized approach for calculating capital requirements they were using under Basel I. The Basel III approach was implemented in the EU in mid-2013 via CRR/CRD IV, which took effect at the beginning of 2014. Basel III therefore influenced the 2009–2013 period only indirectly, as banks had been expecting stricter regulation to be introduced in reaction to the global financial crisis even though the final shape of CRR/CRD IV had not yet been finalized.

3.4. Model specification and methodological issues

This section is devoted to the presentation of the methodology used to obtain the results. We first present the data we used in our investigation. The empirical analysis is based on two building blocks, namely, the calculation of efficiency scores and Granger-causality testing of the relationship between the capital and efficiency of banks. Hence, we explain how we estimate the efficiency scores before describing how we study the relation between capital and efficiency.

- **Data**

As the source of the data for the empirical analysis, we use the internal regulatory database of the Czech National Bank (CNB) to obtain data of a financial and regulatory nature. Despite the monthly frequency of the data reported to the CNB, we opt for the use of quarterly data for our analysis for two reasons. Firstly, quarterly data might be of higher quality than monthly data, as banks also publish their financial results on a quarterly basis. Secondly, it is reasonable to believe that it potentially takes longer than a few months, and even several quarters, for capital to influence efficiency. As a result, monthly data might introduce additional noise into the analysis instead of additional informative value. It might also be reasonable to do the analysis on yearly data. However, this would lead to a significant decrease in the number of available observations, potentially to a level insufficient for reliable statistical testing, as the number of cross sections (banks in the Czech Republic excluding branches of foreign banks) is also not very large.

The data used comprise bank balance sheet and income statement items. The dataset covers 29 banks operating during the period 2002–2013, thus capturing pre-crisis and crisis effects. The dataset is unbalanced, as some banks came into being or stopped operating as standalone banks during the period.[1] As of 2013 there were 21 active banks in the sample, excluding two state-owned banks.[2] Branches of foreign banks were excluded from the dataset, as they are not independent of their parent banks, do not have registered capital, and therefore are not subject to capital regulation on a standalone basis.

- **Estimation of efficiency scores**

Bank efficiency is measured using frontier efficiency techniques, which are the standard way to measure bank performance in empirical banking studies (e.g. Bonin, Hasan, and Wachtel, 2005; Podpiera and Weill, 2008). We consider cost efficiency as defined by the ability of a bank to produce a given product with the minimum of costs. Frontier efficiency techniques provide sophisticated measures of performance–efficiency scores, which have two major advantages over other measures. First, they are synthetic measures of performance: efficiency scores allow several input and output dimensions to be included in the evaluation of performance. Second, they are relative measures of performance. A cost frontier is estimated, allowing each bank to be compared with the best-practice bank. Thus, the cost efficiency scores assess how close a bank is to what its optimal cost would be for producing the same bundle of outputs.

[1] These banks either closed down, changed their status to a branch of a foreign bank, or merged with another bank in the domestic banking system. As only two closures occurred at the beginning of the period analyzed, we do not consider any significant survival bias in our results. If a significant merger occurred in the system, i.e., a merger which resulted in an increase of more than 50% in the total assets of the acquiring bank, the banks concerned were treated as two separate entities (i.e., the bank before the merger and the bank after the merger) in the dataset used for the empirical investigation, as the way of doing business might also have changed as a result of the merger.

[2] Banks owned by the Czech state were excluded from the dataset, as the principles and incentives under which they operate are different from those of standard commercial banks.

We use the stochastic frontier approach to estimate efficiency scores. This technique is commonly applied in studies of bank efficiency (Bonin, Hasan, and Wachtel, 2005; Karas, Schoors, and Weill, 2010). It disentangles the distance from the efficiency frontier into an inefficiency term and a random error, which represent random disturbances reflecting luck or measurement errors.[1] To do so, we assume a normal distribution for the random error and a half-normal distribution for the inefficiency term. Following Jondrow et al. (1982), bank-specific estimates of inefficiency terms can then be calculated using the distribution of the inefficiency term conditional on the estimate of the composite error term (i.e., the sum of the inefficiency term and the random error).

Following Fries and Taci (2005) and Weill (2009), among others, we follow the intermediation approach for the specification of banking inputs and outputs. This approach assumes that the bank collects deposits to transform them into loans with capital and labor. We consider two outputs in the cost function: loans and investment assets.[2] Loans comprise loans provided to households, non-financial corporations, government, and the central bank.[3] Investment assets consist of debt securities and shares held by banks. We also employ three input prices. The price of funds is calculated as the interest rate paid on borrowed funds, the price of labor is defined as labor costs divided by the number of bank employees, and the price of capital is calculated as the costs incurred by banks for fixed assets such as buildings, equipment, and software relative to the value of those assets. All the costs are measured on an annual basis. Total cost is then simply the sum of the costs incurred for funds, labor, and capital. Following Bonin, Hasan, and Wachtel (2005) and Karas, Schoors, and Weill (2010), we employ a translog form to model the cost frontier of banks. The cost frontier is then the following one:

$$\ln\left(\frac{TC}{w_3}\right) = \beta_0 + \sum_m \alpha_m \ln y_m + \sum_n \beta_n \ln\left(\frac{w_n}{w_3}\right) + \frac{1}{2}\sum_m\sum_j \alpha_{mj} \ln y_m \ln y_j$$
$$+ \frac{1}{2}\sum_n\sum_k \beta_{nk} \ln\left(\frac{w_n}{w_3}\right)\ln\left(\frac{w_k}{w_3}\right) + \sum_n\sum_m \gamma_{nm} \ln\left(\frac{w_n}{w_3}\right)\ln y_m + \varepsilon \quad (1)$$

where TC is total cost, y_m is the m^{th} bank's output (m=1,2), w_n is the n^{th} input price (n=1,2), and w_3 is the price of borrowed funds. For simplicity of presentation, the indices for each bank have been dropped.

[1] The alternative approach to measuring bank efficiency is data envelopment analysis (DEA). However, unlike the stochastic frontier approach, it does not allow inefficiency to be disentangled from random shocks. As a consequence, the total distance between the cost frontier and the bank's effective total cost is viewed as inefficiency. This tends to overestimate the inefficiency and explains why the stochastic frontier approach is more commonly used in the context of transition countries (e.g., Bonin, Hasan, and Wachtel, 2005; Karas, Schoors, and Weill, 2010).

[2] We do not consider off-balance sheet items because we want to stick to a standard definition of banking inputs and outputs in our approach and because they represent a relatively small activity for Czech banks.

[3] Loans are measured net of loan loss provisions, hence the actual loan quality is taken into account. However, if a bank starts to provide risky loans, which will default with a certain time lag in future, the inefficiency resulting from the provision of these risky loans will also be captured with a time lag.

The model estimates one common cost frontier over the period, with dummy variables for each year to control for the specifics of individual years and dummy variables for each quarter to take into account the potential end-of-quarter effect and especially end-of-year effect in the case of the dummy variable for each fourth quarter. We also include a dummy variable for building societies due to the specifics of their business model (excluding them from the dataset would be costly in terms of the number of observations lost).

- **The relation between capital and efficiency**

The efficiency scores obtained from the stochastic frontier analysis are then used in the Granger-causality framework to test our hypotheses regarding the relationship between capital and efficiency in both directions: from capital to efficiency and from efficiency to capital. Since Granger causality is based on examining the lags of both efficiency and capital on the dependent variable efficiency/capital, we face a dynamic panel. The dynamic panel is estimated via the General Method of Moments (GMM), which, unlike the standard estimation method via fixed effects, is not liable to dynamic panel bias and handles the potential problem of endogeneity via the use of valid instruments.

Specifically, we use the two-step GMM system developed by Arellano and Bover (1995) and Blundell and Bond (1998). In comparison to the difference GMM framework, the GMM system should be more appropriate when the variables examined are relatively persistent, which is the case with both capital and efficiency, as both of them are dependent on their past values given their nature. In addition to the differenced equation being instrumented with instruments in levels (as in the difference GMM), the GMM system uses instruments in differences for the level equation, which might be more relevant when the variables are rather persistent.

The capital used for testing the Granger causality between efficiency and capital is simply the accounting capital represented by own funds. The capital ratio is calculated as the share of own funds in the balance sheet of the bank. In addition to the accounting definition, the capital ratio is alternatively defined with regulatory capital and is then calculated as the share of regulatory capital in the balance sheet of the bank. The reason for this alternative definition of capital is that the aim of this paper is to assess the potential impact of the higher regulatory capital requirements resulting from the Basel III framework on the efficiency of Czech banks. We do not consider risk-weighted assets when measuring our capital variable, because the theoretical arguments regarding the relation between capital and efficiency are all based on the relative importance of equity in comparison to total debt in the total balance sheet. It is therefore not relevant from this perspective to consider the ratio of capital to risk-weighted assets.

We perform Granger-causality tests to check the sign and causality of the relationship between capital and cost efficiency. We embed Granger-causality estimations in the GMM dynamic panel estimator to address the econometric issues induced by the use of lagged dependent variables. We then follow recent empirical studies on banking that similarly investigate Granger causality in various banking issues, such as the relationship between non-performing loans and efficiency (e.g., Berger and DeYoung, 1997; Podpiera and Weill, 2008), the link between competition and efficiency (e.g., Pruteanu-Podpiera, Weill, and Schobert, 2008; Casu and Girardone, 2009), and the relationship between capital and liquidity creation (Horvath, Seidler, and Weill, 2014).

We thus estimate the following equations to examine the relationships between bank capital and cost efficiency:

$$Efficiency_{i,t} = f(Capital_{i,lag}, Efficiency_{i,lag}, Z_{i,t}) + e_{i,t} \quad (2)$$

$$Capital_{i,t} = f(Efficiency_{i,lag}, Capital_{i,lag}, Z_{i,t}) + e_{i,t} \quad (3)$$

where the subscript t denotes the time dimension, i represents the cross-sectional dimension across banks, Z are the control variables, and $e_{i,t}$ is the error term. *Efficiency* is the cost efficiency score. *Capital* is the ratio of bank equity to total assets.

Equation (2) tests if changes in capital temporally precede variations in efficiency, while equation (3) evaluates if changes in efficiency temporally precede variations in capital.

We use four lags based on quarterly frequency. We consider this choice to be reasonable given the time needed to exert an influence and given the frequency of our data. In their analyses of the causal relation between non-performing loans and bank efficiency, Podpiera and Weill (2008) use three lags and Fiordelisi, Marques-Ibanez, and Molyneux (2011) use two, but both studies use yearly data.

We then estimate an AR(4) process in which the Granger causality is tested by a joint test in which the sum of all the lagged coefficients of the explained variable in question is significantly different from zero. Podpiera and Weill (2008), Fiordelisi, Marques-Ibanez, and Molyneux (2011) and Horvath, Seidler, and Weill (2014) use similar frameworks.

We add two control variables in the estimations. First, we consider *Size*, as measured by the log of total assets, as bank size can influence the relation between capital and efficiency. Second, we include *GDP*, representing GDP growth, to take into account the macroeconomic environment. The source of the data is the Czech Statistical Office.

Table 1 displays the summary statistics for all of the variables used in the estimations. Figure 1 shows the *Efficiency–Capital* scatter plot (see Appendix).

Table 1
Descriptive statistics

Variable name	N	Mean	S.D.	Min	Max
Loans (CZK billions)	888	110.86	144.65	2.33	617.97
Investment assets (CZK billions)	888	43.11	76.62	0.05	402.81
Price of labor (CZK thousands)	888	836.88	267.91	394.10	2102.30
Price of physical capital	888	1.594	1.749	0.214	14.271
Price of borrowed funds	888	0.021	0.009	0.004	0.052
Total cost (CZK billions)	888	5.410	7.025	0.109	30.987
Efficiency (%)	888	69.41	18.92	10.81	98.07
Capital (as share of total assets, %)	888	8.11	4.52	1.35	27.25
Regulatory capital (as share of total assets, %)	888	7.49	4.12	1.86	26.14
GDP growth (%)	888	2.74	3.36	-5.47	7.59
Total assets (CZK billions)	888	163.03	224.80	2.39	921.15

3.5. Results

This section displays our results. We first present the main estimations of the relation between capital and efficiency. We then display some robustness checks.

- **Main estimations**

With respect to the first direction of the causality, from *Capital* to *Efficiency*, our results show that capital does not Granger-cause efficiency, as the sum of the coefficients of the lagged variable *Capital* is insignificantly negative when *Efficiency* is the dependent variable (Table 2).[1] This finding is inconsistent with both the “agency costs shareholders-managers hypothesis” that capital has a negative impact on efficiency and the “agency costs shareholders-debtholders hypothesis,” where the impact should be positive. This finding differs from the positive impact found by Fiordelisi, Marques-Ibanez, and Molyneux (2011) for European banks and by Pessarossi and Weill (2015) for Chinese banks, and from the negative influence pointed out by Berger and Bonaccorsi di Patti (2006) for US banks, but with profit efficiency.

We interpret our result in the following way. Both studies using cost efficiency like us (Fiordelisi, Marques-Ibanez, and Molyneux, 2011; Pessarossi and Weill, 2015) find a positive impact. They therefore support the key influence of agency costs between shareholders and debtholders. As we find no significant impact of capital, it means that the two types of agency costs offset each other in the context of the Czech banking industry. In other words, agency costs

[1] There is weak evidence that lower capitalization has a positive impact on efficiency after one quarter which, however, does not continue in the following quarters. A possible interpretation of this result is that if a decrease in capital is a result of an increase in deposit funding (which is an alternative to capital financing and which causes a bank additional cost paid for this funding), the bank might be more eager to provide loans to cover the additional costs connected with deposit financing which translates into increased efficiency in the following quarter. This effect, however, disappears over time.

between shareholders and managers exert a greater influence for Czech banks than they do for European or Chinese banks, as they are strong enough to offset the influence of agency costs between shareholders and debtholders for the impact of capital on efficiency. This may stem from the fact that the vast majority of Czech banks are owned by foreign investors and, as such, are more difficult to monitor from a distance by shareholders (as shown by Berger et al., 2000), which leads to greater agency costs between shareholders and managers.

For the reverse causality, we find that efficiency does not Granger-cause capital, because the sum of the coefficients of the lagged variable *Efficiency* is not significant when explaining *Capital*. In other words, efficiency does not influence capital (Table 2). From a theoretical perspective, this finding does not accord with the "efficiency-risk hypothesis," which predicts a negative influence of efficiency on capital, or with the "franchise value hypothesis," which expects a positive one. We therefore have a different finding for Czech banks than Fiordelisi, Marques-Ibanez, and Molyneux (2011) have for European banks, as they conclude that efficiency has a positive impact on capital. One interpretation of our findings could be that the "efficiency-risk hypothesis" and the "franchise value hypothesis" offset each other for Czech banks, or else both exert no influence in the context of the Czech banking industry.

In a nutshell, our estimations support the absence of any relation between capital and efficiency for Czech banks.

Table 2

Main estimations

	Efficiency		**Capital**	
Efficiency (t-1)	0.382***	(0.066)	0.00823	(0.017)
Efficiency (t-2)	0.153***	(0.042)	-0.0147	(0.010)
Efficiency (t-3)	0.0898*	(0.046)	-0.0123	(0.009)
Efficiency (t-4)	0.292***	(0.066)	0.0169*	(0.010)
Efficiency TOTAL	**0.917*** **	**(*p*=0.000)**	**-0.002**	**(*p*=0.960)**
Capital (t-1)	-1.248**	(0.592)	0.831***	(0.175)
Capital (t-2)	0.363	(0.347)	-0.0100	(0.070)
Capital (t-3)	-0.296	(0.408)	0.0308	(0.048)
Capital (t-4)	0.554	(0.347)	0.0755	(0.102)
Capital TOTAL	**-0.627**	**(*p*=0.402)**	**0.928*** **	**(*p*=0.000)**
GDP	-0.0400	(0.136)	-0.0234	(0.042)
Size	0.00590*	(0.003)	-0.000212	(0.002)
Constant	0.0832	(0.099)	0.00959	(0.037)
Number of observations	736		736	
Number of banks	26		26	
Hansen test	5.193	(*p*=0.268)	4.948	(*p*=0.293)
AB test AR(1)	-3.551***	(*p*=0.000)	-3.114***	(*p*=0.002)
AB test AR(2)	0.452	(*p*=0.651)	0.357	(*p*=0.721)

Granger-causality tests: the dependent variable is at the top of the column. We use the two-step system GMM estimator with Windmeijer (2005) corrected standard errors (reported in brackets). The Hansen test of overidentifying restrictions with the null hypothesis that the instruments used are not correlated with the residuals and the overidentifying restrictions are valid is reported. The Arellano–Bond (AB) test for the first and second-order serial correlation applied to the differenced residuals has the null hypothesis of no serial correlation. The variables $Capital_{total}$ and $Efficiency_{total}$ are the estimated coefficients for the test that the sum of lagged terms (for capital and efficiency, respectively) is not different from zero. ***, **, and * indicate that p is less than 0.01, 0.05, and 0.1 respectively.

- **Robustness checks**

To check the robustness of our findings, we perform alternative specifications to our main estimations. First, we examine whether the results are the same if we consider a longer time for capital or efficiency to have an impact on one another. Specifically, we consider the potential influence over the previous two years instead of one year as in our main estimations. We then redo the estimations by considering eight lags for *Capital* and *Efficiency*, capturing the previous two years with quarterly data. The results with eight lags show a similar pattern in the relation between capital and efficiency (Table 3). The total effect of capital on efficiency is again insignificant, while we observe no significant influence of efficiency on capital. In other words, our findings are not influenced by the number of lags.

Second, we rerun all estimations without control variables (*Size*, *GDP*) to check whether their inclusion influences our results, for instance by changing the significance of the key variables. We again find that the sum of the coefficients of the lagged variable *Capital* when explaining *Efficiency* is insignificant, and the sum of the coefficients of the lagged variable *Efficiency* when explaining *Capital* is also insignificant (Table 4). In other words, we again find no evidence of Granger-causation in either direction.

Third, we use an alternative measure of the capital ratio in our estimations. We used the ratio of accounting capital represented by own funds to total assets as our measure of the capital ratio in the main estimations, following previous studies and the theoretical arguments regarding capital structure and performance and the conflicts between shareholders and other stakeholders (debtholders and managers). However, as the aim of this paper is to assess the potential effect of the new Basel III capital requirements, we replace accounting capital with regulatory capital and the capital ratio is then alternatively defined as the share of regulatory capital in the balance sheet of the bank. The results of the estimations with *Regulatory Capital* are in line with the main estimations (Table 5).

Fourth, we use an alternative measure of cost performance in our estimations. We consider a standard cost measure of performance to check if our results still stand. Specifically, one might wonder whether our results are influenced by the use of sophisticated cost efficiency measures and would survive the use of more basic cost measures. To this end, we create a measure *Cost* defined as the ratio of operating costs to total assets. Operating costs are the sum of costs incurred for labor and for fixed assets. The results of the estimations with *Cost* correspond with the main estimations using cost efficiency scores (Table 6).[1] We can therefore observe that the lack of evidence of Granger-causation is not a consequence of the cost efficiency scores obtained from the stochastic frontier approach.

Fifth, we examine whether the relationship between capital and efficiency has changed as a result of the recent global financial crisis. Financial troubles can affect the link between capital and efficiency, notably through regulators exerting pressure to enhance capital, but also by affecting the behavior of bank managers in terms of efficiency. To address this issue, we rerun our estimations by adding interaction terms between lagged values of *Capital* and *Efficiency* and *Crisis*, a dummy variable which is equal to one if the observation belongs to the years 2009–2013 (Table 7). We consider this period to be the crisis period, given that the main effects of the financial crisis were amplified in the Czech Republic in 2009 by a strong fall in GDP. We also alternatively tried other periods, such as 2008–2013, and obtained similar results.

We observe, however, that the sums of the interaction terms for *Capital* and *Efficiency* are insignificant. At the same time, the total impact of capital on efficiency is still insignificant, while the total impact of efficiency on capital is also insignificant. As a consequence, our findings are not influenced by the period of study, as the financial crisis did not influence the relation between capital and efficiency, which remains insignificant in both directions.

Although banks already knew in the crisis period that an implementation of a new regulation Basel III is coming, it was expected that the majority of Czech banks should fulfill stricter requirements without substantial problems (both the new capital and liquidity regulation) as they already had a significant excess of capital above the regulatory minimum in the pre-crisis and crisis period (Figure 2). So the situation was very different in the Czech Republic from that in China where the first regulation on capital adequacy requirements was implemented in 2004 which changed the industry from one in which less than 10% of the banks met the new capital adequacy requirements to one in which almost all of them comply with the regulatory requirements (Pessarossi and Weill, 2015). The fact that the capital requirements were not binding in the Czech Republic could also influence our results and explain why they are different from those by Pessarossi and Weill (2015).

Finally, as one of the specific features of the Czech banking sector is that most of the banks are (directly or indirectly) foreign-owned, we also examine whether different foreign owners behave in a different way depending on where they are coming from. We estimate our model excluding those banks whose end-owners come from outside of the EU as these owners might have potentially different incentives with respect to bank management (Table 8). The results are, however, broadly unchanged, so we conclude that our results are not influenced by the fact whether the end-owner comes from the EU or not.[2]

[1] We also redid our estimations by considering two alternative cost measures: the ratio of operating costs to income, and the ratio of total costs to total assets, with similar results.

[2] Additionally, we also examined whether the fact, how long the owners have been operating in the Czech market, matters. We dropped the first four years of data for each bank to capture only the long-term ownership. We did not find a significant change in our results.

3.6. Conclusion

This study investigates the relation between capital and efficiency in the Czech banking industry. This issue is of utmost interest for appraising the implications of tighter capital requirements such as those included in the Basel III rules. Namely increasing capital requirements can contribute to deteriorate financial stability if it hampers efficiency of banks. To this end, we perform Granger-causality tests on an exhaustive dataset of Czech banks from 2002 to 2013 to analyze the relation between capital and efficiency.

Our investigation to identify a link between capital and efficiency revealed no significant relation. Neither the effect of capital on efficiency, nor the effect of efficiency on capital is significant. These findings are robust to different specifications such as an alternative definition of cost performance or of capital, but also to the set of control variables and the number of lags considered in the estimations. In addition, the financial crisis does not influence the relation between capital and efficiency.

Our conclusion differs from the findings of former studies. However, our study differs by investigating the relation between capital and efficiency for a small emerging country characterized by a high presence of foreign-owned banks. In addition, it provides unique results on the relation between capital and efficiency by being the first study examining this question during the financial crisis.

From a normative perspective, our findings suggest that tighter capital requirements do not affect financial stability through the efficiency channel. The implementation of Basel III should not affect the efficiency of Czech banks. Our results also support the view that changes in efficiency do not influence capital.

Therefore this research provides policy recommendations for regulatory authorities. It first suggests that policies favoring capital levels and efficiency of the banking industry can be designed separately. Moreover it supports the view that the regulation on capital requirements does not appear from a tradeoff between bank efficiency and favoring the soundness of the banking industry. However, our results are drawn upon the situation when the capital requirements were not binding. If the capital requirements become strictly binding for Czech banks in the case of a really tough increase in these requirements, potentially combined with other micro- and macro-prudential regulations in the future, this relation might change. Hence, the impact of such policies should be analyzed again.

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Appendix

Table 3

Estimations with eight lags

Granger-causality tests: the dependent variable is at the top of the column. We use the two-step system GMM estimator with Windmeijer (2005) corrected standard errors (reported in brackets). The Hansen test of overidentifying restrictions with the null hypothesis that the instruments used are not correlated with the residuals and the overidentifying restrictions are valid is reported. The Arellano–Bond (AB) test for the first and second-order serial correlation applied to the differenced residuals has the null hypothesis of no serial correlation. The variables $Capital_{total}$ and $Efficiency_{total}$ are the estimated coefficients for the test that the sum of lagged terms (for capital and efficiency, respectively) is not different from zero. ***, **, and * indicate that p is less than 0.01, 0.05, and 0.1 respectively.

	Efficiency		Capital	
Efficiency (t-1)	0.287	(0.178)	0.0111	(0.021)
Efficiency (t-2)	0.201*	(0.109)	-0.0198	(0.013)
Efficiency (t-3)	0.0781	(0.086)	-0.00436	(0.011)
Efficiency (t-4)	0.184**	(0.085)	0.0125*	(0.008)
Efficiency (t-5)	-0.0385	(0.057)	-0.0120	(0.010)
Efficiency (t-6)	-0.0991	(0.082)	0.00539	(0.011)
Efficiency (t-7)	-0.117**	(0.056)	-0.00227	(0.006)
Efficiency (t-8)	0.177**	(0.076)	-0.00722	(0.009)
Efficiency TOTAL	**0.673***	**(*p*=0.051)**	**-0.017**	**(*p*=0.712)**
Capital (t-1)	-1.805	(1.203)	0.800***	(0.103)
Capital (t-2)	0.782	(0.723)	0.0484	(0.068)
Capital (t-3)	-0.146	(0.522)	0.0251	(0.055)
Capital (t-4)	0.233	(0.611)	0.144**	(0.063)
Capital (t-5)	-0.220	(0.230)	-0.127	(0.086)
Capital (t-6)	-0.0963	(0.713)	0.0940*	(0.050)
Capital (t-7)	-0.505	(0.583)	-0.0396	(0.088)
Capital (t-8)	0.332	(0.356)	0.0496	(0.108)
Capital TOTAL	**-1.426**	**(*p*=0.459)**	**0.995*****	**(*p*=0.000)**
GDP	-0.0710	(0.281)	-0.0179	(0.031)
Size	0.0171	(0.015)	0.000710	(0.002)
Constant	0.258	(0.326)	0.0101	(0.034)
Number of observations	616		616	
Number of banks	24		24	
Hansen test	7.640	(*p*=0.106)	5.288	(*p*=0.259)
AB test AR(1)	-2.796***	(*p*=0.005)	-2.992***	(*p*=0.003)
AB test AR(2)	-1.029	(*p*=0.304)	-0.0859	(*p*=0.932)

Table 4

Estimations without control variables

Granger-causality tests: the dependent variable is at the top of the column. We use the two-step system GMM estimator with Windmeijer (2005) corrected standard errors (reported in brackets). The Hansen test of overidentifying restrictions with the null hypothesis that the instruments used are not correlated with the residuals and the overidentifying restrictions are valid is reported. The Arellano–Bond (AB) test for the first and second-order serial correlation applied to the differenced residuals has the null hypothesis of no serial correlation. The variables $Capital_{total}$ and $Efficiency_{total}$ are the estimated coefficients for the test that the sum of lagged terms (for capital and efficiency, respectively) is not different from zero. ***, **, and * indicate that p is less than 0.01, 0.05, and 0.1 respectively.

	Efficiency		Capital	
Efficiency (t-1)	0.407***	(0.070)	0.0115	(0.016)
Efficiency (t-2)	0.159***	(0.046)	-0.0124	(0.009)
Efficiency (t-3)	0.103**	(0.050)	-0.0104	(0.009)
Efficiency (t-4)	0.300***	(0.072)	0.0191**	(0.009)
Efficiency TOTAL	**0.968*** **	**(*p*=0.000)**	**0.008**	**(*p*=0.812)**
Capital (t-1)	-1.019**	(0.421)	0.872***	(0.160)
Capital (t-2)	0.488	(0.388)	0.000602	(0.059)
Capital (t-3)	-0.274	(0.379)	0.0349	(0.046)
Capital (t-4)	0.490*	(0.284)	0.0853	(0.088)
Capital TOTAL	**-0.315**	**(*p*=0.643)**	**0.993*** **	**(*p*=0.000)**
Constant	0.0485	(0.133)	-0.00362	(0.035)
Number of observations	736		736	
Number of banks	26		26	
Hansen test	6.728	(*p*=0.151)	4.821	(*p*=0.306)
AB test AR(1)	-3.582***	(*p*=0.000)	-3.213***	(*p*=0.001)
AB test AR(2)	0.669	(*p*=0.504)	0.266	(*p*=0.791)

Table 5

Alternative definition of capital variable

Granger-causality tests: the dependent variable is at the top of the column. We use the two-step system GMM estimator with Windmeijer (2005) corrected standard errors (reported in brackets). The Hansen test of overidentifying restrictions with the null hypothesis that the instruments used are not correlated with the residuals and the overidentifying restrictions are valid is reported. The Arellano–Bond (AB) test for the first and second-order serial correlation applied to the differenced residuals has the null hypothesis of no serial correlation. The variables $Capital_{total}$ and $Efficiency_{total}$ are the estimated coefficients for the test that the sum of lagged terms (for capital and efficiency, respectively) is not different from zero. ***, **, and * indicate that p is less than 0.01, 0.05, and 0.1 respectively.

	Efficiency		Regulatory capital	
Efficiency (t-1)	0.435***	(0.059)	0.00769	(0.007)
Efficiency (t-2)	0.175***	(0.052)	-0.00302	(0.006)
Efficiency (t-3)	0.113**	(0.049)	0.000199	(0.006)
Efficiency (t-4)	0.311***	(0.077)	0.0134*	(0.007)
Efficiency TOTAL	**1.034*** **	**(*p*=0.000)**	**0.018**	**(*p*=0.181)**
Regulatory capital (t-1)	-0.758***	(0.276)	0.904***	(0.144)
Regulatory capital (t-2)	0.766**	(0.317)	0.0240	(0.066)
Regulatory capital (t-3)	-0.272	(0.239)	0.129**	(0.054)
Regulatory capital (t-4)	0.315	(0.238)	-0.00958	(0.063)
Regulatory capital TOTAL	**0.051**	**(*p*=0.930)**	**1.047*** **	**(*p*=0.000)**
GDP	0.0436	(0.107)	-0.00159	(0.027)
Size	0.00175	(0.004)	-0.000167	(0.001)
Constant	-0.0349	(0.105)	-0.0151	(0.022)
Number of observations	736		736	
Number of banks	26		26	
Hansen test	6.488	(*p*=0.166)	4.381	(*p*=0.357)
AB test AR(1)	-3.548***	(*p*=0.000)	-3.29***	(*p*=0.001)
AB test AR(2)	0.698	(*p*=0.485)	1.004	(*p*=0.315)

Table 6

Alternative definition of cost performance

Granger-causality tests: the dependent variable is at the top of the column. *Cost* is the ratio of operating costs (costs incurred for labor and for fixed assets) to total assets. We use the two-step system GMM estimator with Windmeijer (2005) corrected standard errors (reported in brackets). The Hansen test of overidentifying restrictions with the null hypothesis that the instruments used are not correlated with the residuals and the overidentifying restrictions are valid is reported. The Arellano–Bond (AB) test for the first and second-order serial correlation applied to the differenced residuals has the null hypothesis of no serial correlation. The variables $Capital_{total}$ and $Cost_{total}$ are the estimated coefficients for the test that the sum of lagged terms (for *Capital* and *Cost*, respectively) is not different from zero. ***, **, and * indicate that *p* is less than 0.01, 0.05, and 0.1 respectively.

	Cost		Capital	
Cost (t-1)	0.528**	(0.218)	-0.193	(0.210)
Cost (t-2)	0.348***	(0.083)	-0.206	(0.156)
Cost (t-3)	0.0517	(0.092)	0.0821	(0.134)
Cost (t-4)	0.342*	(0.201)	-0.121	(0.129)
Cost TOTAL	**1.269*** **	**(*p*=0.000)**	**-0.437**	**(*p*=0.243)**
Capital (t-1)	0.00799	(0.090)	0.829***	(0.258)
Capital (t-2)	-0.0546	(0.054)	-0.0114	(0.102)
Capital (t-3)	0.0494*	(0.027)	0.0791**	(0.038)
Capital (t-4)	-0.0714	(0.044)	0.0809	(0.078)
Capital TOTAL	**-0.069**	**(*p*=0.476)**	**0.978*** **	**(*p*=0.001)**
GDP	-0.0108	(0.025)	0.0112	(0.061)
Size	0.0000978	(0.001)	-0.000524	(0.001)
Constant	-0.000867	(0.007)	0.0134	(0.028)
Number of observations	734		734	
Number of banks	26		26	
Hansen test	3.252	(*p*=0.517)	3.943	(*p*=0.414)
AB test AR(1)	-2.092**	(*p*=0.036)	-2.860***	(*p*=0.004)
AB test AR(2)	1.125	(*p*=0.260)	1.045	(*p*=0.296)

Table 7

Results by periods

Granger-causality tests: the dependent variable is at the top of the column. We use the two-step system GMM estimator with Windmeijer (2005) corrected standard errors (reported in brackets). The Hansen test of overidentifying restrictions with the null hypothesis that the instruments used are not correlated with the residuals and the overidentifying restrictions are valid is reported. The Arellano–Bond (AB) test for the first and second-order serial correlation applied to the differenced residuals has the null hypothesis of no serial correlation. The variables $Capital_{total}$ and $Efficiency_{total}$ are the estimated coefficients for the test that the sum of lagged terms (for capital and efficiency, respectively) is not different from zero. ***, **, and * indicate that *p* is less than 0.01, 0.05, and 0.1 respectively.

	Efficiency		Capital	
Efficiency (t-1)	0.414***	(0.060)	-0.000221	(0.010)
Efficiency (t-2)	0.183***	(0.052)	-0.0249***	(0.009)
Efficiency (t-3)	0.0772	(0.048)	-0.0149	(0.009)
Efficiency (t-4)	0.313***	(0.078)	0.00887	(0.007)
Efficiency TOTAL	**0.987*** **	**(*p*=0.000)**	**-0.031**	**(*p*=0.154)**
Capital (t-1)	-1.422***	(0.453)	0.712***	(0.250)
Capital (t-2)	0.560	(0.416)	-0.0582	(0.060)
Capital (t-3)	-0.337	(0.480)	0.0199	(0.035)
Capital (t-4)	0.589*	(0.345)	-0.00719	(0.115)
Capital TOTAL	**-0.610**	**(*p*=0.274)**	**0.667*** **	**(*p*=0.001)**
Capital*Crisis (t-1)	0.506	(0.371)		
Capital*Crisis (t-2)	-0.296	(0.207)		
Capital*Crisis (t-3)	0.212	(0.167)		
Capital*Crisis (t-4)	-0.148	(0.159)		
Capital*Crisis TOTAL	**0.273**	**(*p*=0.229)**		
Efficiency*Crisis (t-1)			-0.0126	(0.012)
Efficiency*Crisis (t-2)			0.00769**	(0.004)
Efficiency*Crisis (t-3)			0.00119	(0.004)
Efficiency*Crisis (t-4)			0.00440	(0.006)
Efficiency*Crisis TOTAL			**0.001**	**(*p*=0.898)**
GDP	0.236	(0.169)	-0.0778	(0.076)
Size	0.00327	(0.003)	0.000794	(0.002)
Constant	0.0237	(0.105)	0.0464**	(0.024)
Number of observations	736		736	
Number of banks	26		26	
Hansen test	7.977	(*p*=0.240)	7.452	(*p*=0.281)
AB test AR(1)	-3.453***	(*p*=0.001)	-2.362**	(*p*=0.018)
AB test AR(2)	0.154	(*p*=0.878)	0.653	(*p*=0.514)

Table 8

Excluding banks with non-EU end-owners

Granger-causality tests: the dependent variable is at the top of the column. We use the two-step system GMM estimator with Windmeijer (2005) corrected standard errors (reported in brackets). The Hansen test of overidentifying restrictions with the null hypothesis that the instruments used are not correlated with the residuals and the overidentifying restrictions are valid is reported. The Arellano–Bond (AB) test for the first and second-order serial correlation applied to the differenced residuals has the null hypothesis of no serial correlation. The variables $Capital_{total}$ and $Efficiency_{total}$ are the estimated coefficients for the test that the sum of lagged terms (for capital and efficiency, respectively) is not different from zero. ***, **, and * indicate that p is less than 0.01, 0.05, and 0.1 respectively.

	Efficiency		**Capital**	
Efficiency (t-1)	0.404***	(0.082)	0.0165***	(0.006)
Efficiency (t-2)	0.150**	(0.067)	-0.0130	(0.011)
Efficiency (t-3)	0.0839	(0.060)	-0.00785	(0.006)
Efficiency (t-4)	0.311***	(0.081)	0.0187**	(0.008)
Efficiency TOTAL	**0.949*** **	**(*p*=0.000)**	**0.014**	**(*p*=0.359)**
Capital (t-1)	-1.158**	(0.505)	0.827***	(0.109)
Capital (t-2)	0.345	(0.395)	0.00633	(0.054)
Capital (t-3)	-0.0704	(0.304)	0.00903	(0.034)
Capital (t-4)	0.471*	(0.273)	0.0235	(0.062)
Capital TOTAL	**-0.411**	**(*p*=0.462)**	**0.865*** **	**(*p*=0.000)**
GDP	0.00523	(0.123)	-0.0224	(0.022)
Size	0.00467	(0.008)	0.000670	(0.001)
Constant	0.0474	(0.145)	-0.00252	(0.018)
Number of observations	678		678	
Number of banks	24		24	
Hansen test	4.494	(*p*=0.343)	6.679	(*p*=0.154)
AB test AR(1)	-3.370***	(*p*=0.001)	-3.389***	(*p*=0.001)
AB test AR(2)	0.0944	(*p*=0.925)	0.112	(*p*=0.911)

Figure 1

Efficiency-capital scatter plot

Efficiency is the cost efficiency score. Capital is the ratio of bank equity to total assets.

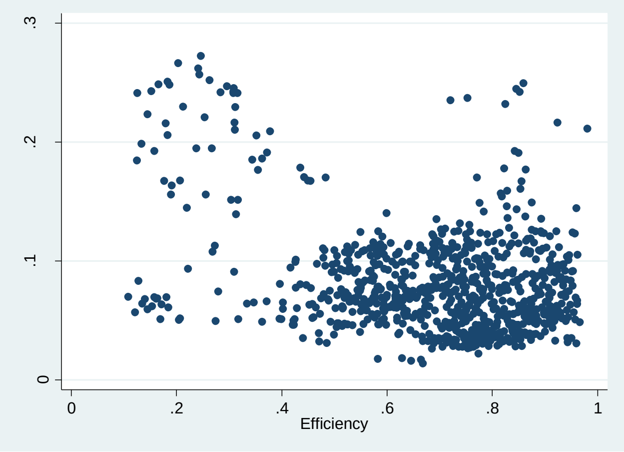
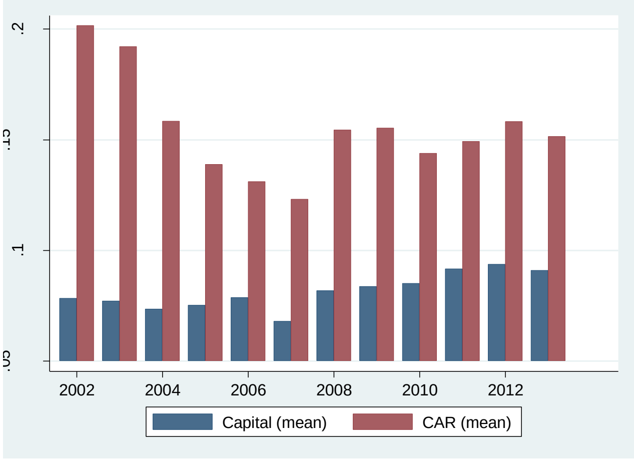


Figure 2

Capital vs. CAR

Capital is the ratio of bank equity to total assets. CAR is the capital adequacy ratio calculated according to Basel II regulation.



References to the Introduction

JENSEN, M. AND MECKLING, W. (1976): *Theory of the firm: managerial behavior, agency costs, and capital structure*. Journal of Financial Economics 3(4), 305-360.

Response to opponents

I would like to thank referees for their valuable comments that helped to improve my dissertation thesis. Here, I provide a report how I have incorporated individual comments into the thesis. They are ordered by essays.

The first essay

Response to Michael Brei

The results description may be expanded by explaining briefly the theoretical justifications of the findings (e.g. why higher provisions are associated with a higher risk premium).

I have extended the results description by the theoretical justification of our findings as suggested (chapter 1.6. Results, pp. 27-28).

While it is important to establish significance, there could be more discussion of the economic importance of the results.

I have extended the results description by the discussion of the relative importance of each explanatory variable based on the reported standardized posterior means and added the channels of influence (chapter 1.6. Results, pp. 30-31).

Future research could extend the analysis to other countries in Europe with similar characteristics (i.e. high presence of foreign bank branches and subsidiaries).

I have added a note into the chapter 1.7. Conclusion that we believe that the results of this analysis might be relevant also for other emerging European countries facing the liquidity surplus in the system and having significant foreign ownership of majority of banks (p. 33). I have also added a reference to a recent paper by Hryckiewicz (2017) on interbank markets in CEE and mentioned selected findings by this paper (chapter 1.6. Results, p. 32). Further, I have also mentioned in chapter 1.7. Conclusion that further research on the sources of the interbank risk premium in other countries in Europe with similar characteristics might be desirable (1.7. Conclusion, p. 33).

Response to Zuzana Fungáčová

Even if the Czech banks did not incur direct subprime-related losses, due to the fact that they are majority foreign-owned they might have been hit indirectly through their parent banks. As the foreign owners of the Czech banks are known, it would be interesting to check if the risks connected particularly to the parent banks' countries play more prominent role when explaining the risk premium than risks stemming from other countries' markets.

The following section was added on page 23: We also indirectly test for spillovers from other countries' risk via including the CDS spreads of parent banks. While it would have been interesting to test whether the risks related particularly to the parent banks' countries of domicile play a more prominent role than risks stemming from other countries' markets, we don't think that there are any strong channels through which such other countries would have had an effect on the Czech interbank market risk premium. Czech banks are neither significantly exposed on their assets side nor on their liabilities side to other countries than countries of their parent banks.

The study acknowledges that the Czech interbank market differs from markets in many other countries as it does not really serve as important source of funding for banks and the Czech banks only use it to balance their liquidity needs. The question arises if and how this special setting might have influenced the results of the study and to what extend the findings can be generalized e.g. for the other emerging European economies.
I have added a note into the chapter 1.7. Conclusion that we believe that the results of this analysis might be relevant also for other emerging European countries facing the liquidity surplus in the system and having significant foreign ownership of majority of banks (p. 33). I have also added a reference to a recent paper by Hryckiewicz (2017) on interbank markets in CEE and mentioned selected findings by this paper (chapter 1.6. Results, p. 32). Further, I have also mentioned in chapter 1.7. Conclusion that further research on the sources of the interbank risk premium in other countries in Europe with similar characteristics might be desirable (1.7. Conclusion, p. 33).

The risk premium between 2009 and 2011 seems to be higher in the Czech market in comparison with the Euro Interbank Markets (Figure 3) which was not the case before the crisis. Why is this the case and has similar development been observed in other European emerging markets?
I have added a discussion explaining the difference between the risk premium in the Czech interbank market and the Euro interbank market (chapter 1.3. The Czech Interbank Market and the Role of PRIBOR, p. 17).

It would be good to provide more details concerning possible policy implications that can be derived from the analysis in this paper.
I have added several policy implications into the chapter 1.7. Conclusion (p. 33).

Response to Michal Hlaváček
Article nicely illustrates the effects of the financial crisis on the money market. However, as the time span of the data used ends in 2012, the article is not able to document the latest developments. It would be interesting to see how the conclusions of the article change if we would take into account the unconventional monetary policy from last years. Quantitative easing and negative interest rates in Eurozone have definitely influenced the EURIBOR market strongly. Similarly, in the Czech case the hitting the zero-lower-bound on the central bank rates in the 2012 as well as the exchange rate commitment effective from November 2013 to April 2017 led to further increase of the liquidity surplus of the Czech banking sector and to unprecedented pricing of financial products (negative government

bond yields). Maybe that the thesis could comment on these developments. Or has the unconventional monetary policy replaced the interbank market completely?

I have added a discussion how the use of the exchange rate commitment by the Czech National Bank influenced the domestic banks and domestic interbank market (chapter 1.3. The Czech Interbank Market and the Role of PRIBOR, p. 19).

Article very shortly refers to the LIBOR manipulation scandal (page 19). Maybe that some more detailed information on this scandal would be welcomed together with comparison with the Czech PRIBOR case. Does author find some signs for this manipulation in the Czech case? What measures should be taken to avoid similar manipulations in future?

I have added more detailed information on the manipulation of LIBOR and EURIBOR submissions into the chapter 1.4. Hypotheses (p. 20). I have also mentioned that having these strategic manipulations in mind, we also test for strategic behavior potentially relevant for the Czech case. In addition to that, I have also mentioned there have already been measures taken to avoid similar manipulations in future–creation of new European regulation regarding benchmarks („BMR“) which entered into application on 1 January 2018 (pp. 20-21).

Czech banking sector currently shows good liquidity indicators (LCR, NSFR). Does this influence the interpretation of the results and comparison with the interbank markets in countries that report much worse liquidity measures?

The effect of good liquidity position of Czech banks and consequences of liquidity surplus in the banking sector are mentioned on p. 17 (chapter 1.3. The Czech Interbank Market and the Role of PRIBOR) and on p. 32 (chapter 1.6. Results).

When describing the Czech interbank market the article could add short notion that the interbank market does not capture interbank transfers of liquidity between banks that are related by ownership links. Typically, the bank could transfer or withdraw liquidity to/from its building society, there is strong funding relation between ČSOB and Hypoteční banka. Maybe that author could speculate how this could influence the interbank market and the results of the analysis.

A relevant footnote has been added on p. 14 (chapter 1.3. The Czech Interbank Market and the Role of PRIBOR).

Article analyses one channel of cross border contagion via inclusion of the proxies for the situation of the counterparty parent bank financial ratios. However, the article could comment also on more direct relation between EURIBOR and PRIBOR markets.

On p. 23, I have mentioned that the inclusion of the euro interbank risk premium also captures the potential contagion from the euro area interbank market to the Czech interbank market. Further, on p. 28, there is another comment on this issue – as there is a close interconnection between the Czech Republic and the Eurozone, the stress in the Eurozone interbank market is also transmitted to the Czech interbank market (i.e. contagion effect from abroad).

On the page 21 article argues that banks would not be able to calculate important variables related to their counterparty that are not publicly available. Article comments on the public availability mainly in relation to the CNB reporting. However, the individual banks most probably could get relevant information on their counterparty also from alternative sources ranging from their annual reports, reports for the stock exchange, reports by the independent institutions, alternative databases (Bankscope,…).

I have specified that the problem is particularly with the branches of foreign banks which do not usually publish their results on a monthly or quarterly basis on their webpage (1.5. Empirical Approach, footnote on p. 23).

The second essay

Response to Michael Brei

The chapter may have benefited from a discussion of the impact of market power on the pass-through of monetary policy on the bank-level. Even though bank size has been considered, a discussion of market power is not included. For example, the higher pass-through to mortgage rates could have been related to higher market power or concentration in this market segment and not just to higher risk aversion.

I have added a discussion regarding the role of competition on an example of the Czech mortgage market (chapter 2.4. Pass-Through Estimation, pp. 53-54).

Moreover, the discussion (and model specification) could have raised the issue of other monetary policy instruments that might have been used by the Czech National Bank to complement conventional interest rate policy, particularly following the global financial crisis.

I have added a recommendation that further research on more recent data should be done in order to verify how the interest rate pass-through from financial market rates to rates on banks loan products was affected by the exchange rate commitment used by the Czech National Bank from November 2013 to April 2017 and also in the following period of monetary policy tightening (chapter 2.7. Concluding Remarks, p. 65).

Response to Zuzana Fungáčová

The results indicate that financial crisis significantly influenced the pass through as the long-term pass through was close to complete for most of the products before the crisis but then weakened significantly after the crisis. This main result is in line with the other literature on the monetary policy transmission. The analysis however uncovers that in the Czech case this does not hold true for mortgage loans. It would be good to explain in more details why this is the case and what kind of policy implications this result might have.

I have explained that the competition contributed to the fact that the interest rate pass-through improved in case of mortgages in the post-crisis period (pp. 53-54). At the same, we explain that banks could have tried to increase their market share in the mortgage market also because of low delinquency rates in this segment (p. 54). From these two facts, I have derived suggested policy implications (p. 54, chapter 2.4. Pass-Through Estimation).

The findings provide evidence on tightening of banks' lending standards after the financial crisis but the question remains if these findings have been confirmed by similar studies on other countries as well.
I have added a footnote and a few references to existing studies on p. 54 which shows that banks' lending standards tightened after the financial crisis also in other countries (chapter 2.4. Pass-Through Estimation).

Response to Michal Hlaváček
The essay studies the pass-through to client rates of various loans categories separately in the period before the global financial crisis and afterwards. Nevertheless, the authors do not follow Brůha (2011) and do not distinguish between different fixation categories. Therefore the strength of the transmission mechanism could be distorted by changes on the yield curve slope, or the changes in the share of the different fixation categories on the different loan categories (e.g. recent increase of the share of the long term loans on the consumption loans that ceteris paribus pushes for higher client rates). Maybe that thesis should just shortly comment on this issue.
I have added a comment on this issue on p. 45 (chapter 2.3. Data).

Essay finds longterm pass-through from financial market rates to the client rates for the period before financial crisis and a substantial deterioration of pass-through after the crisis. As the data end in 2013, again it would be interesting to see whether the pass-through "renewed" during quantitative easing period.
I have added a recommendation that further research on more recent data should be done in order to verify how the interest rate pass-through from financial market rates to rates on banks loan products was affected by the exchange rate commitment used by the Czech National Bank from November 2013 to April 2017 and also in the following period of monetary policy tightening (chapter 2.7. Concluding Remarks, p. 65).

The rates on consumer loans are not found to be cointegrated with market rates in the panel of banks in the Czech Republic showing the limited pass-through. Nevertheless, this result (limited pass-through to consumer loans) could be due to the fact that consumer loans consist of quite heterogeneous types of loans ranging from "Xmas gifts" loans to car loans, or to housing related loans. Therefore the distribution of the loans matters here strongly. In our upcoming analysis (Brož and Hlaváček, 2018) we found that the limited size of pass through exists if we consider alternative measure of client rate.

I have added a comment on this issue and the reference to the article by Brož and Hlaváček (2018) in the footnote on p. 51 (chapter 2.4. Pass-Through Estimation).

It would be nice to mention also implications of different levels and changes of competition for individual loan types. Do the changes to competition influence the pricing of the loan products?
I have added a discussion regarding the role of competition on an example of the Czech mortgage market (chapter 2.4. Pass-Through Estimation, pp. 53-54).

The third essay

Response to Michael Brei
Graphical representations of the main variables of interest could have been included, such as a scatter plot of bank capital and efficiency or a graph showing efficiency and capital over time.
I have added the efficiency–capital scatter plot into the Appendix (Figure 1, p. 100) and also a reference to this scatter plot on p. 86 (chapter 3.4. Model specification and methodological issues).

There is weak evidence that higher capitalization has an impact on efficiency after one quarter (not over all quarters), which is a result that could have been discussed.
I have provided an explanation of the reaction of efficiency after one quarter in the footnote on p. 87 (chapter 3.5. Results).

Response to Zuzana Fungáčová
The non-significant results are not in line with the existing evidence for other countries and therefore it would be interesting to investigate more what exactly stands behind these results. As it is mentioned in the paper, the results on the causality going from capital to efficiency might come from the fact that majority of banks in the Czech Republic are foreign-owned which increases agency costs between shareholders and managers. Nevertheless, it might well be that different foreign owners behave in a different way depending on where they are coming from or how long they have been operating in the Czech market.
I have estimated our model excluding those banks whose end-owners come from outside of the EU as these owners might have potentially different incentives with respect to bank management (Table 8, Appendix, p. 99). The results are, however, broadly unchanged, so I conclude that our results are not influenced by the fact whether the end-owner comes from the EU or not (p. 90, chapter 3.5. Results) or how long they have been operating in the Czech market (footnote on p. 90).

In the second set of results it is shown that efficiency does not influence capital and it is explained that the results indicate that two hypotheses (efficiency-risk one and franchise value one) offset each other. This might well be but it would be good to confirm this by some additional tests.

I have somewhat weakened the interpretation of our findings as confirming that the two hypotheses cancelling each other (p. 88), as indeed, this would have to be ideally confirmed by additional tests which, however, go beyond the scope of this paper. At the same time, this is in our view the best interpretation we could find, as we have included five robustness checks of various types to check whether our results are robust in our paper, and they all confirm the initial findings.

It is also remarkable to observe that the crisis does not seem to influence the relationship between capital and efficiency. This result deserves more attention and detail explanation as well.
I have provided a more detailed discussion of our results with respect to the crisis period on p. 90 (chapter 3.5. Results).

Response to Michal Hlaváček
In relation to the main result on the non-existing relation of the capital and bank efficiency, it would be nice to discuss whether the results could differ according to the situations when the capital requirements are or are not binding. As the results of the article are drawn upon the situation when the capital requirements were not binding for the Czech banks, really tough increase of these requirements could have different implications.
I have added a discussion on the fact that the results are drawn upon the situation when the capital requirements were not binding for the Czech banks (p. 90, chapter 3.5. Results). I have also mentioned it in the chapter 3.6. Conclusion (p. 91).

Article could refer also to some newer articles related to similar questions. (e.g. Malovaná, 2017).
I have added the reference to the article by Malovaná (2017) on p. 79 (chapter 3.1. Introduction).

As the estimate or measure of the efficiency is based on comparing the inputs (capital and labor) and outputs (typically loan products) of given bank, the question arises, whether the measured output is adjusted for the loan quality. Generally, granting high volume of risky loans with slightly higher interest rate would be evaluated as "efficient" as far as stochastic frontier analysis concerned, however from the ex post view this is highly inefficient. Essay could shortly comment on this.
I have commented on this issue in the footnote on p. 84 (chapter 3.4. Model specification and methodological issues).