



Bank efficiency and interest rate pass-through: Evidence from Czech loan products[☆]



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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.

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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](#)

and [Lombardi, 2013](#)), some significant distortion in pass-through ([Hristov et al., 2014](#)), and some changes in transmission only for certain products ([Hansen and 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 and 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

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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 and 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. 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 and 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 and Gallo (2014) find more complete long-run pass-through for corporate loans than for household loans.

Holton and Rodriguez d'Aciri (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 and 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 and Kleimeier (2006), de Graeve et al. (2007), Gambacorta (2008), or more recent studies by Stanisławska (2014) and Holton and Rodriguez d'Aciri (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 (Stanisławska, 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 pass-through 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 and Podpiera, 2005; Podpiera et al., 2007; Irsova and Havranek, 2011) or deterministic frontiers (Havranek and 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 pass-through 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 and 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.

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 banks¹ 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 and 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 mortgages³ and consumer loans provided to households.⁴ 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 and 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 bank 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 sub-sample 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.

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.

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 and Smith, 1995), which allows each regression coefficient to vary across banks. Pesaran and 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:

$$\Delta \text{bank rate}_{i,t}^k = \alpha_i^k \Delta \text{market rate}_t^k + \beta_i^k \Delta \text{bank rate}_{i,t-1}^k + \gamma_i^k (\text{bank rate}_{i,t-1}^k - \delta_i^k \text{market rate}_{t-1}^k - \mu_i^k) + \epsilon_{i,t}^k, \quad (1)$$

where $\Delta \text{bank rate}_{i,t}^k = \text{bank rate}_{i,t}^k - \text{bank rate}_{i,t-1}^k$ stands for the change in bank i 's rate on product k between months $t-1$ and t ,⁵ $\Delta \text{market rate}_t^k$ 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 , $\Delta \text{bank rate}_{i,t-1}^k$ is the change in the bank rate in the previous month,

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 and 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.

⁵ Due to data limitations we use a maximum of one lag in all estimations of the pass-through mechanism.

Table 1
Categories of bank products.

<i>Firm rates</i>	
Small loans, floating	Commercial loans up to CZK 30 M, interest rate floating or fixed up to 1 year
Small loans, fixed	Commercial loans up to CZK 30 M, interest rate fixed more than 1 year
Large loans, floating	Commercial loans larger than CZK 30 M, interest rate floating or fixed up to 1 year
Large loans, fixed	Commercial loans larger than CZK 30 M, interest rate fixed more than 1 year
<i>Household rates</i>	
Mortgages	Loans for house or apartment purchase
Consumer loans	Loans for household spending on (mostly) durable goods
<i>Deposit rates</i>	
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

β_i^k captures persistence in bank rate changes, δ_i^k denotes the long-term equilibrium pass-through coefficient, μ_i^k is the mean markup (spread) over the market rate, γ_i^k denotes the speed of adjustment, and $\epsilon_{i,t}^k$ 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 estimators⁶ 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:

$$\Delta \text{bank rate}_{i,t}^k = \alpha_i^k \Delta \text{market rate}_t^k + \beta_i^k \Delta \text{bank rate}_{i,t-1}^k + \gamma_i^k (\text{bank rate}_{i,t-1}^k - \delta^k \text{market rate}_{t-1}^k - \mu^k) + \epsilon_{i,t}^k. \quad (2)$$

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.

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).

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 and 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

Table 2
Determinants of pricing policies.

Variable	Definition
Bank size	Assets of <i>i</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

⁶ The traditional estimators restrict all slope coefficients to be equal.

Table 3

Correlations between product rates and financial market rates.

	CZEONIA	1 M PRIBOR	3 M PRIBOR	6 M PRIBOR	1 Y PRIBOR	IRS1	IRS2	IRS3	IRS5	IRS10	YTM2	YTM5	YTM10
<i>Firm rates</i>													
Small loans, floating	0.517	0.537	0.541	0.544	0.542	0.529	0.518	0.509	0.493	0.479	0.527	0.517	0.472
Small loans, fixed	0.079	0.116	0.142	0.173	0.190	0.131	0.151	0.154	0.145	0.135	0.146	0.221	0.273
Large loans, floating	0.660	0.698	0.709	0.716	0.715	0.689	0.664	0.644	0.610	0.577	0.673	0.639	0.572
Large loans, fixed	0.199	0.208	0.216	0.223	0.227	0.208	0.218	0.226	0.230	0.235	0.218	0.257	0.276
<i>Household rates</i>													
Mortgages	0.280	0.295	0.300	0.305	0.309	0.297	0.310	0.323	0.332	0.341	0.316	0.367	0.379
Consumer loans	−0.018	−0.012	−0.010	−0.009	−0.010	−0.022	−0.023	−0.021	−0.017	−0.010	−0.018	−0.003	0.010
<i>Deposit rates</i>													
Overnight deposits	0.202	0.202	0.201	0.199	0.196	0.197	0.187	0.179	0.170	0.163	0.192	0.169	0.140
Term deposits	0.491	0.514	0.524	0.524	0.520	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.

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.⁷

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 pass-through 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-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.

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.⁸ 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 $(\text{short-term PT} - \text{long-term PT}) / (\text{error correction})$. 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.⁹ 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,

⁷ 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.

⁸ 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.

⁹ In Section 6 we will evaluate the statistical significance of this decrease.

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*** (0.0279)	1.343*** (0.152)	1.133*** (0.0359)	0.896* (0.543)	0.453*** (0.0423)	0.282*** (0.0207)	0.905*** (0.0123)
Error corr.	−0.653*** (0.0931)	−0.451*** (0.109)	−0.546*** (0.0745)	−0.889** (0.38)	−0.378*** (0.0831)	−0.317*** (0.0727)	−0.307*** (0.049)
Short-term PT	0.381** (0.194)	0.822 (0.585)	0.943** (0.412)	−3.716** (1.827)	0.0448 (0.0494)	0.168*** (0.0652)	0.282*** (0.0474)
Persistence	−0.116** (0.0474)	−0.193*** (0.0669)	−0.140*** (0.045)	−0.0926 (0.296)	0.0723 (0.0666)	−0.121*** (0.0415)	−0.0742* (0.0395)
Spread	1.319*** (0.193)	1.284*** (0.416)	0.573*** (0.156)	1.599*** (0.221)	1.161*** (0.281)	0.0957 (0.0817)	−0.105*** (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.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance at the 1% level.

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.

In general, our results are consistent with the notion that banks tightened their lending standards considerably after the financial crisis. 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).

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 and 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 pass-through. 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) and 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 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 and 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 and 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.¹⁰ Therefore, our preferred cost minimization model is defined following a transcendental logarithmic functional form as:

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

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

¹⁰ 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.

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*** (0.0371)	0.792*** (0.17)	0.870*** (0.0342)	0.696*** (0.259)	0.842*** (0.06)	0.0515*** (0.0073)	0.279*** (0.0295)
Error corr.	−0.541*** (0.0927)	−0.607*** (0.14)	−0.860*** (0.305)	−1.379*** (0.196)	−0.098*** (0.0374)	−0.178*** (0.0337)	−0.089*** (0.0125)
Short-term PT	0.216 (0.352)	0.32 (0.499)	−1.737 (2.762)	0.542 (1.132)	0.0334 (0.0299)	0.0589 (0.0447)	0.277*** (0.048)
Persistence	−0.227*** (0.0544)	−0.0407 (0.053)	−0.085 (0.0733)	−0.125 (0.217)	−0.00745 (0.0613)	−0.170*** (0.0351)	−0.0328 (0.0661)
Spread	1.463*** (0.238)	3.324*** (1.123)	2.294*** (0.854)	5.515*** (0.223)	0.105*** (0.0402)	0.0891*** (0.0213)	0.0693*** (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 2008:09–2013:12 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 1% level.

i -th bank at time t , $u_i \sim N^+(\mu, \sigma_u^2)$ truncated at 0 and $v_{it} \sim N(0, \sigma_v^2)$ 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 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):

$$\min \theta_i \quad (4)$$

$$\text{s.t.} \quad \sum_{i=1}^n \lambda_i x_{ki} - \theta_i x_{ki} \leq 0 \quad \forall k, \quad \sum_{i=1}^n \lambda_i y_{ji} - y_{ji} \geq 0 \quad \forall j, \quad \lambda_i \geq 0 \quad \forall i,$$

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 $\min \sum_{k=1}^m w_k x_{ki}^*$ for a technical efficiency program defined in Eq. (4), and economic efficiency would be defined as $\sum_{k=1}^m (w_k x_{ki}^*) / (w_k x_{ki})$.

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). Fig. 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 Fig. 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.

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.¹¹ The mean adjustment lag is not directly estimated by the mean group estimator;

¹¹ 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 and Irsova (2011).

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:

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

where SE_{ijk} denotes the standard error of the estimate of the long-term pass-through for bank i , period j , and product k .¹² 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.¹³ The corresponding dummy variable (*post-crisis*) controls for changes in the strength of the long-term pass-through since the crisis.¹⁴ 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.¹⁵ Finally, in Section 4 we estimate the pass-through coefficients separately for various loan products, so in Eq.(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:

$$\begin{aligned} \text{adjustment lag}_{ijk}/SE_{ijk} = & \alpha_0 + \alpha_1 \text{efficiency}_{ij}/SE_{ijk} + \alpha_2 \text{liquidity}_{ij}/SE_{ijk} \\ & + \alpha_3 \text{capital adequacy}_{ij}/SE_{ijk} + \alpha_4 \text{credit risk}_{ij}/SE_{ijk} \\ & + \alpha_5 \text{bank size}_{ij}/SE_{ijk} + \alpha_6 \text{deposits}_{ij}/SE_{ijk} \\ & + \alpha_7 \text{post-crisis}_j/SE_{ijk} + \alpha_8 \text{deposits adj. lag}_{ij}/SE_{ijk} \\ & + \sum_{k=1}^4 \alpha_9^k \text{product}_k + \epsilon_{ijk}, \end{aligned} \quad (6)$$

¹² 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 and Podpiera, 2012).

¹³ The occurrence of crisis is denoted by period j , which equals 0 for pre-crisis periods and 1 for post-crisis periods.

¹⁴ Due to the limited number of banks in our data set, we cannot estimate the determinants of pass-through separately before and after the crisis. Therefore, we impose the condition that the crisis did not change the slope coefficients in the regression.

¹⁵ 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.

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:

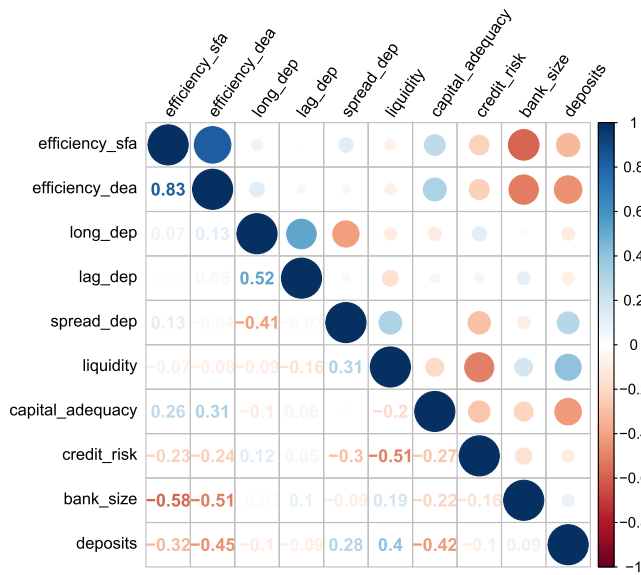
$$\begin{aligned} \text{spread (markup)}_{ijk}/SE_{ijk} = & \alpha_0 + \alpha_1 \text{efficiency}_{ij}/SE_{ijk} + \alpha_2 \text{liquidity}_{ij}/SE_{ijk} \\ & + \alpha_3 \text{cap. adequacy}_{ij}/SE_{ijk} + \alpha_4 \text{credit risk}_{ij}/SE_{ijk} \\ & + \alpha_5 \text{bank size}_{ij}/SE_{ijk} + \alpha_6 \text{deposits}_{ij}/SE_{ijk} \\ & + \alpha_7 \text{post-crisis}_j/SE_{ijk} + \alpha_8 \text{deposits spread}_{ij}/SE_{ijk} \\ & + \sum_{k=1}^4 \alpha_9^k \text{product}_k + \epsilon_{ijk}, \end{aligned} \quad (7)$$

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.

Fig. 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, Fig. 1 suggests that strong long-term pass-through for deposits is often associated with long mean adjustment lags and low spreads.

Fig. 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



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.

Fig. 1. Correlations between bank-level characteristics.

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 Fig. 2 contains evidence of the relation between the pass-through 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.

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,¹⁶ 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).

The problem with Fig. 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 (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.¹⁷ Instead of removing these outliers or using a robust regression technique that does not allow for clustering of standard errors, such as in Horvath and 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-least-squares 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.

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.¹⁸ 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.

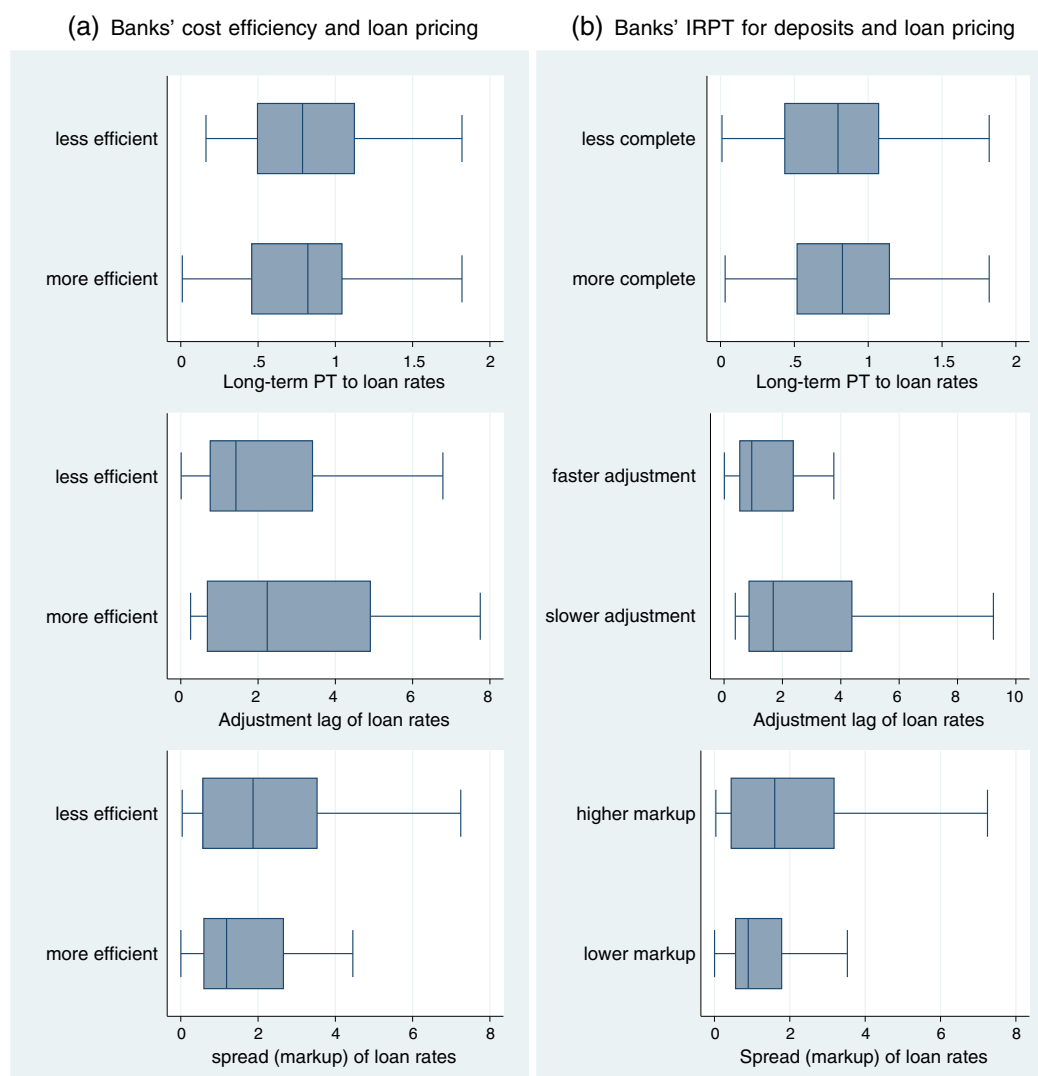
Our findings concerning the impact of the financial crisis contrast with the results of Illes and Lombardi (2013), who find little change in the interest rate pass-through for major economies. Hristov et al. (2014), on the other hand, using fresher data, show that the pass-through has become significantly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

¹⁶ For example, slow adjustment for deposits sometimes occurs simultaneously with fast transmission for loans.

¹⁷ 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.

¹⁸ 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.



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.

Fig. 2. Selected determinants of pass-through to loan rates.

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 and 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.

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 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 (except mortgage rates). This

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.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance at the 1% level.

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 and 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 and 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 and 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 and 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

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.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance at the 1% level.

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 post-crisis 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.

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.

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*** (0.137)	1.103 (0.703)	1.199*** (0.464)	0.793*** (0.25)	0.637*** (0.0895)	0.196*** (0.0712)	0.642*** (0.0823)
Error corr.	−0.821*** (0.102)	−0.552*** (0.111)	−0.646*** (0.0752)	−0.896*** (0.369)	−0.432*** (0.0881)	−0.529*** (0.0869)	−0.397*** (0.0466)
Short-term PT	0.103 (0.39)	0.855 (0.677)	0.908** (0.46)	−3.593** (1.569)	0.0491 (0.0502)	0.161*** (0.0571)	0.258*** (0.0445)
Persistence	−0.0435 (0.0452)	−0.156** (0.0718)	−0.0843* (0.0456)	−0.0898 (0.296)	0.0741 (0.0611)	−0.0353 (0.039)	−0.0751** (0.0363)
Spread	2.435*** (0.713)	2.074** (1.03)	1.322*** (0.362)	1.661* (0.995)	1.060*** (0.296)	0.269 (0.168)	0.00727 (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 and 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.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance 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*** (0.0603)	0.516** (0.223)	0.707*** (0.266)	0.506 (0.377)	0.504*** (0.122)	0.187*** (0.0444)	0.348*** (0.0641)
Error corr.	−0.635*** (0.103)	−0.915*** (0.133)	−0.824*** (0.131)	−1.439*** (0.137)	−0.152*** (0.0363)	−0.318*** (0.0541)	−0.153*** (0.0235)
Short-term PT	0.205 (0.384)	0.225 (0.512)	−0.111 (0.919)	0.604 (0.602)	0.0349 (0.0316)	0.111** (0.0487)	0.294*** (0.0505)
Persistence	−0.183*** (0.0533)	0.045 (0.0636)	−0.0627 (0.0442)	−0.0865 (0.157)	0.0137 (0.0592)	−0.121*** (0.0289)	−0.0285 (0.0585)
Spread	1.772*** (0.301)	5.526*** (1.296)	2.579*** (0.539)	7.048*** (2.595)	0.387*** (0.0987)	0.112*** (0.0417)	0.0975** (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 and 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 5% level.

*** Denotes statistical significance 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.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance 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.

** Denotes statistical significance at the 5% level.

*** Denotes statistical significance 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, [Fig. B1](#) and [Fig. 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	4508	1231	3346	0	19,600
	x_2	Borrowed funds = total interest-bearing financial liabilities	4459	89,200	158,000	0	855,000
Input prices	x_3	Number of full time employees	4540	1009	2293	2	11,197
	w_1	Price of fixed assets = depreciation on fixed assets and other administrative expenses divided by fixed assets	4508	5	12	0	301
	w_2	Price of borrowed funds = interest expenses divided by borrowed funds	4343	0.02	0.01	0	0.15
	w_3	Price of labor = personnel expenses divided by number of full time employees	4538	1.18	0.88	0	19.17
Outputs	y_1	Commercial loans	4348	49,600	82,500	0	457,000
	y_2	Interbank loans	4348	24,000	46,200	1	314,000
	y_3	Investment assets	4085	26,500	62,900	0	403,000
Heterogeneity	cov	Expected inefficiency covariates captured in Section 3					
	z	Equity capital	4549	7708	16,000	−488	96,100

Notes: All variables except for x_3 , w_1 , and w_2 are in CZK millions; w_1 and w_2 are 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** (−16.21)	−1.869** (−15.01)	0.458** (46.07)	−0.678** (−5.35)	−0.649** (−3.92)
$\ln y_2$	−0.458** (−3.23)	−1.213** (−9.96)	0.0883** (19.80)	0.722** (10.64)	0.663** (11.02)
$\ln y_3$	1.376** (15.18)	1.395** (14.52)	0.0488** (13.57)	−0.0135 (−0.24)	−0.111* (−2.27)
$\ln(w_2/w_1)$	2.286** (8.51)	1.542** (5.90)	0.502** (67.52)	3.580** (28.51)	3.754** (30.15)
$\ln(w_3/w_1)$	−2.027** (−6.60)	−1.233** (−4.30)	0.337** (37.67)	−2.282** (−15.10)	−2.670** (−19.28)
$\ln y_1 \ln y_2$	−0.0281** (−4.74)	−0.0248** (−4.64)		−0.0556* (−16.51)	−0.0266** (−8.45)
$\ln y_1 \ln y_3$	−0.0255** (−6.88)	−0.0331** (−10.40)		−0.0222* (−10.42)	−0.0115** (−5.40)
$\ln y_2 \ln y_3$	−0.0168** (−4.13)	−0.0095* (−2.49)		−0.0002 (−0.11)	−0.0001 (−0.08)
$1/2 \ln y_1^2$	0.164** (12.98)	0.145** (12.68)		0.0910** (11.54)	0.0595** (6.26)
$1/2 \ln y_2^2$	0.0382** (8.87)	0.0389** (8.09)		0.0362** (14.85)	0.0199** (9.81)
$1/2 \ln y_3^2$	0.0472** (18.95)	0.0661** (33.37)		0.0337** (20.30)	0.0243** (16.42)
$\ln(w_2/w_1) \ln(w_3/w_1)$	−0.0634* (−2.34)	0.0211 (0.88)		−0.162** (−18.59)	−0.225** (−20.14)
$1/2 \ln(w_2/w_1)^2$	0.0877** (3.20)	−0.0553* (−2.18)		0.185** (25.00)	0.274** (22.28)
$1/2 \ln(w_3/w_1)^2$	0.0651* (1.99)	0.0234 (0.83)		0.158** (15.02)	0.208** (17.27)
$\ln y_1 \ln(w_2/w_1)$	−0.106** (−8.86)	−0.0816** (−7.40)		−0.0842** (−16.86)	−0.0705** (−10.75)
$\ln y_2 \ln(w_2/w_1)$	−0.0836** (−7.12)	−0.151** (−13.89)		0.0121** (2.92)	0.0360** (7.46)
$\ln y_3 \ln(w_2/w_1)$	0.142** (19.59)	0.162** (20.81)		0.0104** (3.35)	0.0067* (2.11)
$\ln y_1 \ln(w_3/w_1)$	0.132** (9.21)	0.0876** (7.16)		0.0637** (9.53)	0.0725** (10.21)
$\ln y_2 \ln(w_3/w_1)$	0.0686** (5.17)	0.115** (9.86)		−0.0232** (−4.26)	−0.0459** (−8.82)
$\ln y_3 \ln(w_3/w_1)$	−0.105** (−12.73)	−0.123** (−14.70)		0.0043 (1.01)	0.007† (1.78)
Time trend	−0.0045** (−6.03)			0.0033** (11.41)	0.00275** (7.59)
Time trend squared	0.00002* (2.54)				

Table B2 (continued)

Equity over assets	–1.146** (–5.89)				–0.197 (–1.38)
Return on assets	–0.0250* (–2.04)				0.0265** (3.70)
Return on equity	–0.0036** (–3.77)				–0.00247** (–5.90)
Quick to total assets	0.0052** (7.24)				0.00527** (14.69)
Capital adequacy ratio	0.0007 (0.74)				0.00171** (3.05)
Credit risk to total assets	0.0045* (2.38)				
Risk-weighted to total assets	0.0021 (1.18)				–0.0006 (–1.40)
Equity			–0.0168* (–2.51)		
Constant	31.31** (16.52)	27.45** (17.87)	3.125** (19.05)	23.02** (15.71)	25.13** (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† (–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	2507	2507	3174	3208	2507

Note: Dependent variable $\ln(cost/w_1)$. 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).

† p | 0.10

* p | 0.05

** p | 0.01

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	4715	6850	50	33,900
Inputs	x_1	Fixed assets = tangible and intangible assets	300	1595	3815	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	1310	2581	13	11,187
Input costs	c_1	Expenditures on fixed assets = depreciation on fixed assets and other administrative expenses	300	1609	2713	0	13,600
	c_2	Expenditures on borrowed funds = interest expenses	300	1865	2374	3	16,800
	c_3	Expenditures on labor = personnel expenses	300	1242	2243	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

Notes: All variables except for x_3 are 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
<i>Pearson correlation</i>						
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
<i>Spearman correlation</i>						
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

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

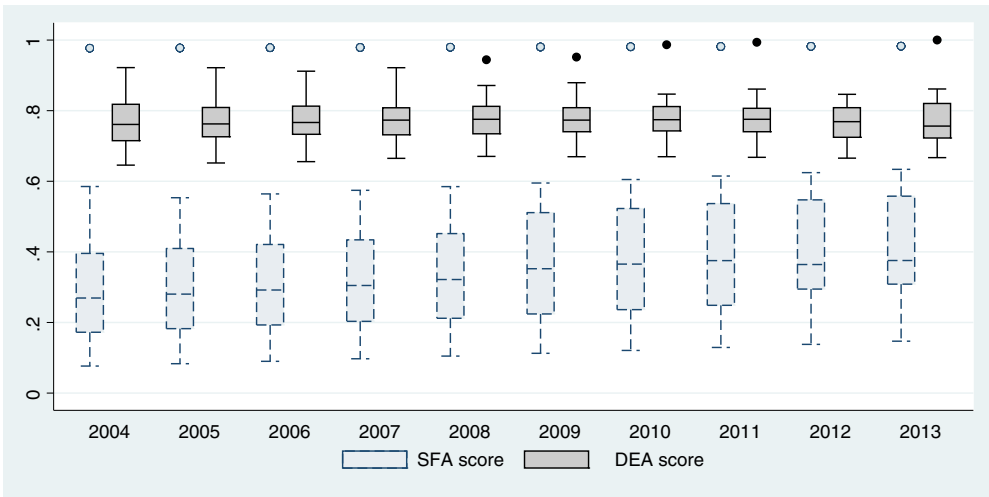


Fig. B1. Development of the estimated frontier efficiencies during 2004–2013.

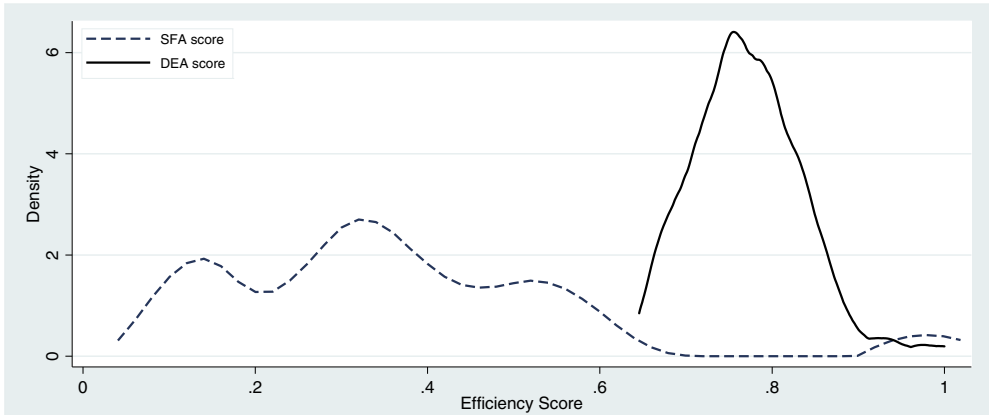


Fig. B2. Kernel density function of the estimated frontier efficiencies.

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