RE-EXPLORING THE NEXUS BETWEEN MONETARY POLICY AND BANKS' RISK-TAKING

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Abstract

In this paper, we analyse the link between monetary policy and banks' risk-taking behaviour. Some theoretical and empirical studies show that monetary easing is increasing banks' appetite for risk related to asset valuation and the search for higher yields. However, the low interest rate environment that began in 2010 is casting doubt on these findings. Our study adds to analyses of the monetary risk-taking channel considering non-linearity, especially testing threshold effects in this channel. Using a dataset of US banks, we find that the impact of low interest rates on banks' risk behaviour depends on the previous monetary regime, that is on the deviation of monetary rates from the Taylor rule.

JEL Classification : E44, E58, G21.

Keywords: Monetary policy, financial stability, bank risk-taking, non-dynamic panel threshold model

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1 Introduction

The 2008 crisis revealed the excessive risk-taking of financial agents. As Galati and Moessner (2013) point out, they had become dependent on a fairly serene financial market climate, and had increased both their risk tolerance thresholds and their reliance on the robustness of the financial system. An accommodative monetary policy is considered to be one of the main drivers of this perverse behaviour. By pursuing the objectives of price stability and increased macroeconomic development, the monetary policy in place conditioned the behaviour of financial agents: any shrinkage or expansion of the money supply (in the main through interest rate changes) modifies agents' net worth , inducing changes to investment behaviours, that is, changes to risk taking decisions. The literature identifies two main channels through which monetary policy can affect the risk-taking behaviour of financial agents.

The first is (borrowers' and banks') balance sheets (Bernanke and Gertler 1989, 1995; Bernanke et al., 1996; Kiyotaki and Moore, 1997; Rajan, 2005; Adrian and Shin, 2009; De Nicolo et al. 2010). In this case, on the one hand, low interest rates translate into increased asset prices and borrower net worth. For the same amount of assets used as collateral, borrowers can access a larger amount of financing. As the borrowers' overall solvency ("fictitiously") improves, the supply of credit increases and the costs of financing reduce (Bernanke and Gertler, 1989). On the other hand, monetary softening implies that following a decline in the monetary interest rate, the returns on banks' risk-free assets decline. Banks substitute risky assets for risk-free assets (De Nicolo et al., 2010). The second channel is liquidity (Diamond and Rajan, 2006). In the event of an expansionary monetary policy, banks tend to finance more long-term projects. Thus, banks' illiquidity increases due to the fictitious liquidity ensured by an accommodative monetary policy.

In this paper, we provide an empirical analysis of the monetary risk-taking channel and address the following main question: do low interest rates necessarily have harmful effects on bank soundness? We do so by investigating three sub-questions: how do low interest rate levels whet banks' appetite for risk? Do banks' risks increase as monetary policy softens? Is there a threshold to the impact of monetary policy rates on banks?

There are many reasons why we should continue to be concerned about the risk-taking induced by monetary policy. The principal one is the influence that low interest rates have on banks' risk-taking behaviour. It is generally acknowledged that a low interest environment has a negative effect on the determinants of agents' risk behaviour, risk perception and risk tolerance (Adrian and Shin, 2009; Borio and Zhu, 2012). In addition, some empirical works show that banks' risk-taking behaviour is exacerbated by a low interest rate environment (Ioannidou et al., 2007; Jimenez et al., 2008; Gambacorta, 2009; Dell'Ariccia et al., 2010; Altunbas et al., 2010). However, this view has been challenged by several works that show that low interest rates can be beneficial for banks and do not trigger more risky behaviour (Kane, 1989; Smith, 2002; Gan, 2004; Agénor and Da Silva, 2011; Agur and Demertzis, 2012; Korinek and Simsek, 2016; Brunnermeier and Koby, 2016). Instead, these studies show that a higher interest rate can jeopardize rather than bolster the banking system. For example, Gan (2004) shows that higher interest rates can reduce banks' franchise value, which leads to more risk-taking. Also, Agur and Demertzis (2012) show that raising interest rates increases the banks' opportunity costs (cost of holding cash) and makes alternatives more attractive. Moreover, the low interest rate environment since 2010, casts doubt on such common knowledge. Despite the fact that interest rates have been low for a long period, the banking system seems sound.

Risk-taking is a complex concept. It can be understood as an action or a decision that induces high asset volatility and depreciates bank soundness. Risk-taking can induce reduced capital requirements (even if the banks comply with the regulation), degradation of leverage ratios, excessive lending or softening of credit standards, deterioration of loan quality, and decreased liquidity. Banks' risk-taking behaviour is a major factor in financial fragility, which results from a decline in the robustness or resilience of the financial system. The robustness of the system refers to the system's ability to resist negative shocks. The system is said to be resilient in relation to its capacity "to adapt in response to both short-term shocks and long-term changes in economic, social, and ecological conditions while continuing to fullfil its functions in serving the real economy" (Berry et al., 2015, p.10).

We propose further analysis of the hot topic of the risk-taking channel of monetary policy. The results of previous comparative analysis, lead to a reconsideration of the relation between monetary shocks and banks' risk-taking. Our aim is to investigate the non-linearity in this relationship by employing a non-linear model. The panel threshold model developed by Hansen (1999) appears appropriate since it allows linear and non-linear relations to be tested in the same regression. In other words, this model should allow us to identify different marginal effects of monetary shocks on banks' risk behaviour using a threshold variable.

However, there are two major challenges associated to measuring banks' risk-taking behaviour and the monetary policy stance.

The choice of a good measure of risk-taking behaviour is not obvious. Altunbas et al. (2010) and Gambacorta (2009) use the change in the Expected Default Frequency (ΔEDF) to proxy for bank risk-taking behaviour. This variable is derived from Moody's KMV and measures the probability that a firm will default over a given time period. According to Moody's KMV, a default occurs when the market value of the assets falls below the liabilities payable. So, the EDF can be considered as forward-looking indicator of credit risk. Bank risk-taking is captured by the change in the EDF (Gambacorta, 2009; Altunbas et al., 2010). Using this change to proxy for bank-risk taking behaviour is a weak assumption since the change could stem from the credit demand side rather than the bank's appetite for risk. To handle this, Ioannidou et al. (2007), Maddaloni et al. (2008) and Jimenez et al. (2008) assess bank risk-taking behaviour using the softening of credit standards obtained from the credit register of the central banks of the countries observed. However, this measure suffers from two main drawbacks. On the one hand, credit registers are available only for those countries that maintain them. On the other hand, this measure considers only one element of bank risk. There is a need for a wider measure of risk.

Therefore, we use the Z-score [1] to proxy of bank risk. The Z-score or its log is used commonly to measure banks' financial soundness or insolvency (Roy, 1952; Boyd et al. 2006; Lepetit et al. 2008; Lepetit and Strobel, 2013; Delis et al., 2014; Lepetit and Strobel, 2015). The Z-score is inversely related to the probability the bank will become insolvent. The lower the bank's Z-score the higher its risk of insolvency. The advantage of using the Z-score to measure risk is that it is derived from bank decision taking. In this sense, it is a more accurate measure of risk-taking behaviour than the measures referred to above. Furthermore, Z-score is less data demanding (it requires only accounting data) and, also, gathers essential financial information. In fact, the Z-score gives information on bank capitalization (capital to asset ratio) and investment decision quality (given by the Return on Assets (*roa*) and the volatility of *roa*). However, since *roa* is rarely normally distributed, the Z-score is bias. Our objective is to analyse the potential impact of monetary shocks on banks' risk, not to provide an accurate assessment of banks' risk. Therefore, we consider the traditional z-score is suited to our goal.

After controlling for macroeconomic shocks and the impact of some bank-specific factors, we can consider that any change in the Z-score refers mostly to the bank's risk-taking behaviour.

The second issue is assessment of the monetary policy stance, which we derive from the deviation of the fed main refinancing rate from the Taylor rule rate. The Taylor rule rate is estimated following Taylor (1993) [2] and is used as our threshold variable. We understand a negative Taylor gap as an accommodative monetary policy, and a positive Taylor gap as a restrictive monetary policy.

[1] Z-score = $\frac{Car+ROA}{\sigma_{roa}}$ Where *roa* is profits after tax/total assets, *car* is equity capital/total assets and σ_{roa} is the standard deviation of*roa*. The underlying idea of the Z-score is that since bank is supposed to become insolvent when its current losses exhaust capital, $car+roa \leq 0$, we can easily estimate the likelihood of insolvency by assuming that this likelihood refers to the probability that $roa \leq -car$ (or $car < \pi$), with car the bank's capital to asset ratio, roa its return on asset ratio (Lepetit and Strobel, 2015), and π its losses.

[2] Following Taylor (1993): $i = r + \pi + 0.5(\pi - \pi^{*}) + 0.5y$ where r is the natural interest rate (set at 2%), π^{*} is the inflation target set at 2% and y is the output gap. As quarterly data have short frequency and don't allow to smooth fluctuation in price level, Taylor (1993) suggest that π should be estimated as the moving average of the inflation on the 4 last quarters.

Using quarterly data for 194 US banks from 1998q1 to 2015q4 (72 quarters), we study the risk-taking channel of monetary policy through non-dynamic panel threshold model. we study the risk-taking channel of monetary policy, using a non-dynamic panel threshold model. The analysis tests the threshold to the impact of changes to the monetary rate on banks' risk-taking behaviour depending on its deviation from a Taylor rule rate.

The analysis proves that there is a threshold value in the Taylor gap. This means that there is a point in the deviation of the monetary rate from the Taylor rule at which the effects of the monetary rate on the bank's risk-taking behaviour reverse. The results show that when the monetary policy is far below the Taylor rule, a decrease in the interest rate has a negative effect on the bank's fragility. This can translate into more risk-taking behaviour following an interest rate cut. However, this effect turns positive for lower negative deviations or for positive deviations from the Taylor rule, meaning that monetary easing will foster bank soundness when the monetary rate is close to or greater than the Taylor rule.

Our results allow for some recommendations about monetary policy. In light of our findings, monetary policy authorities should take account of the monetary rate regime (positive or negative deviation of the interest rate from the Taylor rule) when setting their monetary policy. Our work reopens the debate on the need for Central Banks to include financial stability in their objectives. It supports arguments that favour an augmented Taylor rule to take account of financial stability concerns. As a result of our study, the Taylor rule (or the Taylor gap) could be used by monetary authorities to identify the potential effects of monetary shocks on banking system fragility when setting interest rates.

The remaining paper is organized as follows. Section 2 provides a review of the literature on the risk-taking channel of monetary policy and Section 3 describes the data and the empirical approach adopted to assess it . Section 4 presents the results and Section 5 concludes the paper.

2 Literature review

Common knowledge on the risk-taking channel of monetary policy establishes that a low interest environment has a negative effect on the determinants of agents' risk behaviour, risk perception and risk tolerance (Adrian and Shin, 2009; Borio and Zhu, 2012). Also, low interest rates trigger the softening of credit conditions and reduce banks' screening efforts (Ioannidou et al., 2007; Jimenez et al., 2008; Dell'Ariccia et al., 2010). There is a stream of empirical work on monetary risk-taking channel that supports this common view. It shows that monetary easing whets the bank's appetite for risk taking and that this negative impact of a lower interest rate is amplified by a sustained period of low interest rates (Maddaloni et al., 2008; Gambacorta, 2009; Altunbas et al., 2010). These studies also analyse non-linearity, but use the interaction between the explanatory variables or squared variables.

In an analysis of the quality of borrowers in Europe, Jimenez et al. (2008) find that low interest rates can lead to an increased credit supply and a high probability of allocating more credit to risky borrowers. They also identify a positive (short-term) relationship between interest rates and bank portfolio risk. An interest rate cut reduces the default risk of borrowers, since it reduces their interest expenses, which improves their repayment capabilities and reduces their and the bank's default probabilities. However, if interest rates remain low for a prolonged period, banks are likely to take more risks as their revenues reduce. This leads to a search for yield as Rajan (2005) shows. Jimenez et al. (2008) find also that in a lower interest rate environment, well-capitalized banks take more risks than poorly capitalized banks. Ioannidou et al. (2007) find that an expansionary shock to the Fed interest rate softened lending conditions among banks in Bolivia. Ioannidou et al. (2007) show that liquid banks (with low levels of liquidity constraints) are more likely to take risks than those facing strong liquidity constraints.

However, a low interest rate reduces the bank's opportunity cost (cost of hoarding liquidity) and, therefore, its risk incentive (Smith, 2002). Higher interest rates may reduce the bank's franchise value and lead to more risk-taking (Gan, 2004). For instance, Kane (1989) found that higher interest rates cause a decrease in the bank's net worth and lead to "gambling for resurrection" as risky strategies become more attractive. Agur and Demertzis (2012) find that a rise in interest rates, by increasing the bank's cost of financing, reduces the bank's profits. To compensate for this loss, the bank will choose riskier (more profitable) assets. Agur and Demertzis (2012) shows that raising rates increases the bank's opportunity costs (cost of holding cash). Constrained by the fall in net wealth, risky alternatives and gambling for resurrection become attractive.

Brunnermeier and Koby (2016, p.1) establish the existence of a reversal interest rate, which they define as "the rate at which accommodative monetary policy "reverses" its intended effect and becomes contractionary for lending. It occurs when recapitalization gain from the duration mismatch are offset by decreases in net interest margins, lowering banks' net worth and tightening its capital constraint". In other words, monetary easing can lead banks to reduce their risk since their capital constraints become more binding. While numerous studies link monetary softening to a credit boom and financial fragility, Agénor and Da Silva (2011) find the reverse is true. According to them, in a middle-economy, an increase in the monetary rate to alleviate inflationary pressure, translates into capital inflow and a credit boom. In other words, both monetary contraction and monetary easing can induce risk-taking and, hence, financial fragility. Therefore, we can expect an ambiguous relationship between monetary policy and bank risk-taking. Both an increase and a decrease in interest rates can lead to expansion of bank credit and an increase in bank risk.

Finally, it is clear that banks' behaviour will depend on the gains or losses they experience due to lower interest rates. There will be a level of interest rate reduction that will not lead the banks to increase their risk because the loss it incurs in their lending operations is offset by the benefit derived from lower financing costs.

Due to these contrasting results, we re-explore the risk-taking channel to achieve a better understanding of the relationship between monetary policy and banks' risk-taking behaviour. We rely on a non-linear model, specifically, the panel threshold model developed by Hansen (1999), to detect threshold values in the risk-taking channel. To our knowledge, this is the first study to investigate the existence of a threshold in the risk-taking channel using a panel threshold model. We control for macroeconomic conditions, the specific characteristics of the banks, the house price boom-bust cycle and excessive lending growth, to isolate the effects of monetary policy on banks' risk.

3 Data and measure of bank risk-taking behaviour

3.1 Model and data

3.1.1 Data description

We use quarterly data from Bloomberg, on 194 American banks over the period 1998q1 to 2015q4. This long period allows a better assessment of the changes in banks' risk taking behaviours since it includes periods of both economic expansion and economic downturn, and periods of high and low interest rates. Our sample is heterogeneous in terms of bank size (assets), efficiency (income-to-cost ratio), asset quality and liquidity (see Appendix Table 4).

Bank risk variable

An essential element in our analysis is the variable for bank risk. We use the traditional Z-score to proxy for bank risk, using actual *car* and *ROA*, and standard deviation of *roa* estimated on the entire sample following Hesse and Cihak (2007) and Niu (2012):

$$\text{Z-score} = \frac{Car_t + ROA_t}{\sigma_{roa}}$$

where *ROA* is profits after tax/total assets, *Car* is equity capital/total assets and σ_{roa} is the standard deviation of *ROA* on the entire sample.

The idea underlying the Z-score is that since a bank is supposed to become insolvent if its current losses exhaust its capital, $car + roa \leq 0$, we can estimate the likelihood of insolvency by assuming that the likelihood refers to the probability that $roa \leq -car$ (or $car < \pi$), where *car* is the bank's capital to asset ratio, *roa* is the bank's return on asset ratio (Lepetit and Strobel, 2015), and π is the bank's losses. The Z-score or its log is used widely to measure bank financial soundness or bank insolvency (Roy, 1952; Boyd et al. 2006; Lepetit et al 2008; Lepetit et Strobel, 2013; Delis et al., 2014; Lepetit et Strobel, 2015) and is inversely related to the probability the bank will become insolvent. The lower the bank's Z-score, the higher the risk of insolvency.

This calculation of the Z-score has some limits. On the one hand, Delis et al. (2014) note that using the entire sample to calculate σ_{roa} does not reflect short-term fluctuation of bank risk. Certain method of calculating the Z-score have been applied to deal with this issue:

- using actual *car* and *roa*, and standard deviation of *roa* estimated over a rolling window of 5 periods (Chortareas et al., 2012);
- using actual *car* and *roa*, and instantaneous standard deviation of *roa* ($roa_t - \mu_{roa}$), where μ_{roa} is the average *roa* estimated on the entire sample (Boyd et al., 2006);
- using the means of *car* and *roa*, and the standard deviation of *roa*, all estimated over a rolling window of 4 or 8 periods (Boyd et al., 2006; De Haan and Poghosyan, 2012; Anolli et al., 2014);
- using actual *car* and estimating the mean and standard deviation of *roa* over a rolling window of 4 or 5 periods (Yeyati and Micco, 2007; Anginer et al., 2014).

However, the time frame used to estimate σ_{roa} (and mean *roa*) is important. Delis et al. (2014) note that if a long-time frame is used, the risk will increase earlier, but the magnitude of the risk will be smaller. For example, if the period is reduced to eight quarters, the risk will increase later and will be a larger increase. It is easily understood that the assumption about the number of periods to include to construct the variance component will affect the results significantly.

On the other hand, the Z-score is computed assuming that *ROA* is normally distributed. Unfortunately, this assumption is rarely validated. *ROA* is skewed and has excess kurtosis, which can lead to misestimation of the bank's default probability. To deal with this issue, some authors use the logarithm of the traditional Z-score (Demirgüç-Kunt et al., 2008; Leaven and Levine, 2009; Lepetit and Strobel, 2015). Also, Lapteacru (2016) proposes a more flexible distribution function to make the Z-score consistent and preserve its original concept of risk.

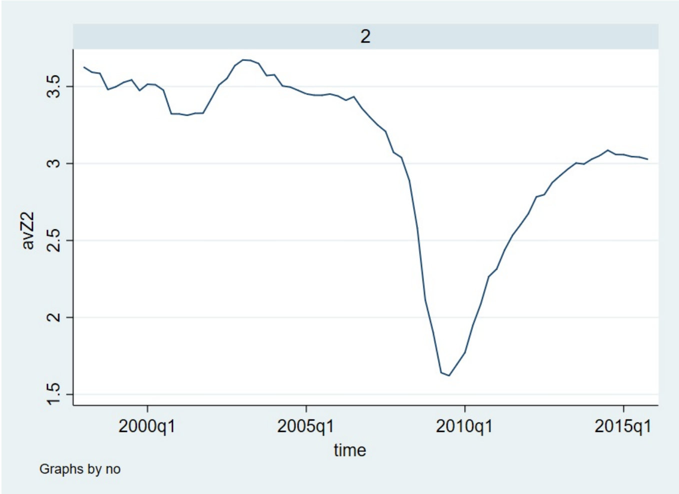
Despite these drawbacks to the Z-score (the under- or over-estimation bias in the default probability due to the non-normality of the distribution of *roa*), and regardless of the "true" distribution of *roa*, the Z-score is a good proxy for bank risk since a decreasing Z-score translates to increasing bank fragility. In addition, we can rely on the Z-score since our aim is to assess the impact of monetary shock on banks' risk behaviour, not to provide a better estimate of banks' default probability.

Since bank risk is appreciated only when it materializes, bank risk-taking behaviour cannot assessed at time. Therefore, the Z-score can be used to account for banks' risk behaviour through their capitalization, profitability and asset volatility. We would expect the bank's risk behaviour to affect its level of capitalization, profitability and asset volatility, since the bank's financial decisions are related to capital structure and investment projects. Another advantage of the Z-score is that it is less data demanding and is easy to calculate since it requires only accounting data.

The identification strategy applied in this work is as follows: the risk-taking channel would suggest that bank risk increases (Z-score decreases) with a decrease in the Fed effective rate, and this mechanism is amplified by an accommodative monetary policy, that is, when the Taylor gaps are negative.

Figure 1 shows how well the Z-score represents the various shocks in the financial system. The American banking sector was sound from 1998 to 2006 on average, apart from some shocks hitting the financial system during the 2001 dot-com bubble and the market reaction to the 2001 terrorist attacks. Bank solvency weakened during the financial crisis (2007-2009) and began a slow recovery process in 2010.

Figure 1: Average Z over the period



To perform our regression analysis, we need to include some key monetary, macroeconomic and bank variables that explain the variation in banks' Z-scores.

Monetary variables

Monetary variables gather short-term (changes in the effective Fed rate, ΔMP) and long-term (Change in the slope of the yield curve, 10 year bonds yield curve minus 2 year bonds yield curve) to account for the short- and long-run relation between monetary policy and bank's risk. To account for an accommodative or restrictive monetary policy, we estimate the Taylor gap (TGap) following Gambacorta (2009) and Altunbas et al. (2010). The Taylor Gap is the deviation of the monetary rate from the Taylor rule based rate. We estimate the Taylor rule rate following Taylor (1993):

$$i = r + \pi + 0.5(\pi - \pi^*) + 0.5y$$

where r is the natural interest rate (set at 2%), π^* is the inflation target set at 2% and y is the output gap. Since quarterly data have short frequency and do not smoothing of fluctuations in price levels, Taylor (1993) suggest that π should be estimated as the moving average of the inflation on the 4 last quarters. We use the Gross Domestic Product (GDP) deflator as the inflation rate, expressed as the annual rate of change. Figures 2 and 3 (appendix A) provide an overview of the effective Fed interest rate, the Taylor rule interest rate, and the Taylor gap, over the whole period.

To isolate the impact of conventional monetary policy shock on bank risk, from the potential influence of unconventional measures, we introduce a dummy *UNC*, which takes the value 1 from 2009q1 to 2015q4. This dummy refers to the period when the Fed introduced unconventional measures such as quantitative easing (purchase of 10 year mortgage backed securities, 10 year treasury securities, federal debts securities, etc.).

Macroeconomic variables

It is important to control for macroeconomic variables. Firms' principal fund providers are banks. So, the banks' financial position depends (at least partly) on the financial state of firms. Using GDP growth, we can control for the effect of business on bank soundness. That is, GDP growth captures the part of the change in the Z-score that stems from the credit demand side. Moreover, banks operate in financial systems that, often, are subject to stress, which, in turn, could influence their soundness. Thus, we use the financial Stress Index (FSI) to capture the impact that system stress might have on bank soundness. Housing prices can affect banks' risk behaviour through their decision-making. Therefore, we control for housing price fluctuations based on changes to the Shiller national House Price (HP) index. Banks operate in stock markets and are affected by asset price changes; we account for Stock Market (SM) returns via changes in the S&P index returns. However, banks' overall risk can be affected also by unforeseen changes to the riskiness of its assets (risks occurring after their acquisition that are largely beyond the banks' control). We enter the macroeconomic variables in the regressions at both current values and one-quarter lag values to account for their impact on the banks' risk-taking (at time of decision-making, i.e., at period $t-1$) and soundness (i.e., at time t).

To handle stationary concerns, with the exception of the Shiller national HP index, which is double differentiated, monetary and macroeconomic variables are first differentiated.

Bank specific variables

Since our database is composed of banks with different characteristics, we need to control for bank heterogeneity. First, we need to control for possible scale economies. Due to moral hazard and agency costs, larger banks have access to better sources of liquidity and are likely to hold less capital and less liquidity. However, larger banks' balance sheets are complex and are subject to more stringent regulation. Thus, bank size affects the Z-score via its effects on bank equity. We account for bank size using the log of total assets since banks vary in size. Second, banks evolve in a competitive environment and employ different production technologies, which trigger differential technical efficiency. We include bank efficiency (EFF measured as total income to total cost ratio) to control for differences in technical efficiency (Delis and Kouretas, 2011; Boyd et al., 2006). We also include bank liquidity (LIQ: net loan to deposits and short-term funding ratio), since this appears to be relevant for banks' risk behaviour (Altunbas et al., 2010). Also, banks that finance their assets mostly with short-term liabilities (maturity transformers) are more exposed to refinancing problems (illiquidity) in the event of an economic downturn. A high value of LIQ indicates an illiquid bank. Considering that banks' primary activity is lending, we expect large lenders to encounter increased assets and a decrease in their Z-score. We include excessive lending expansion (EXLEND), as in Altunbas et al. (2010), to control for excessive lending growth. Third, it is clear that well-capitalized banks can cope with credit losses. However, bank capital is highly correlated to our measure of risk since bank capital is a component of its determination. Therefore, we exclude bank capital from our regression. To address potential endogeneity problems, all bank-level variables enter with a one-quarter lag.

Since bank risk could be subject to seasonal changes, we include seasonal dummies (SD).

Appendix B, Tables4 and 5 present the statistical description and correlation matrix of our variables.

3.2 Econometric analysis

Existing empirical studies try to assess risk-taking using a linear General Method of Moment (GMM) model.

The objective of the present study is to deepen preceding analysis by testing non-linearity in the risk-taking channel of monetary policy. We do so by regressing the Z-score on monetary, macroeconomic and bank-specific variables, using the non-dynamic panel threshold model developed by Hansen (1999). This model appears appropriate to identify the existence of structural changes in the impact of monetary policy on banks' risk-taking behaviour.

3.2.1 Non-dynamic panel threshold model

Framework and setup

In this section, we describe the general econometric framework developed by Hansen (1999) that supports our empirical work. Following Hansen (1999), we consider a panel dataset $\{y_{it}, q_{it}, x_{it} : 1 \leq \text{i} \leq \text{n}, 1 \leq \text{t} \leq \text{T}\}$, where y_{it} is the dependent variable of interest; q_{it} is the threshold variable; and x_{it} is a matrix including the control variables. The single threshold model can be written as follows:

$$y_{i,t} = \mu_i + \lambda_1 x_{i,t} I(q_{i,t} \leq \gamma) + \lambda_2 x_{i,t} I(\lambda < q_{i,t}) + \varepsilon_{i,t}$$

This is a compact form. Intuitively, it can be written as two regressions:

$$\begin{cases} y_{i,t} &= \mu_i + \lambda_1 x_{i,t} + \varepsilon_{i,t} \quad \text{if } q_{i,t} \leq \gamma \\ y_{i,t} &= \mu_i + \lambda_2 x_{i,t} + \varepsilon_{i,t} \quad \text{if } q_{i,t} > \gamma \end{cases}$$

In this expression, the sample is divided into two regimes distinguished by different regression slopes λ_1 and λ_2; I(.) is the indicator function defining the sample split. The term μ_i is a permanent but unobserved fixed effect. It captures cross-sectional unobserved heterogeneity due to differences between individual and all other determinants of the variability in y_{it} not already controlled for in x_{it}. There are several reasons why, at this point, we assume the presence of fixed effect. First, the validity of the econometrics of the threshold panel rely on the assumption of fixed effects. Second, we argue that fixed effects is more plausible than random effects, since the latter implies a zero correlation ($Cov(x_{it}, \mu_i) = 0$) between the unobserved effect μ_i and the variable on the right-hand side of the regression. Altunbas et al. (2010) and many other researchers have shown empirically that banks' risk-taking behaviour is affected by several factors such as competition, technology, power bargaining between manager, shareholder and stakeholders, and monetary policy expectations. Since we cannot capture these factors, they are assumed to be included in the unobserved fixed effects.

The model idiosyncratic errors are denoted $\varepsilon_{i,t}$ with the usual assumption that they are independent and identically distributed normal. Equation (1) can be extended to allow for the presence of multiple thresholds. In the case of m thresholds, the model will have $m+1$ regimes or regression functions or regime dependent slopes.

Estimation

After eliminating the individual effect μ_i, based on the assumption discussed above, the endogenous threshold γ is estimated by employing a concentrated least squares estimation (Hansen, 1999), which consists of minimizing the sum of the squared error function:

$$\hat{\gamma} = \underbrace{argmin}_{\gamma} S_1(\hat{\gamma}) = \hat{\varepsilon}_{it}(\hat{\gamma})' * \hat{\varepsilon}_{it}(\hat{\gamma})$$

The grid search approach to implementing this minimization problem and estimation of the parameters, is accomplished in the following steps:

1. The lowest and highest $\eta\%$ values on the threshold variable q_{it} are eliminated and, among the remaining values, we look for the optimal value of γ.
2. After removing individual effects, we estimate a regression for each of the remaining values. The optimal threshold is the value of γ which yields the smallest Sum of the Squared Errors (SSE).

3. The data are split according to γ, and OLS is employed to estimate the regression parameters..

Empirically, for large panel data, the optimization search can be exponentially huge, making the estimation computationally costly. Hansen (1999) proposes that, rather than searching over the entire threshold variable values, restricting the search to specific quantiles between η% and (1 - η)%, a shortcut that provides identical results.

Testing and inference

After estimating the endogenous threshold γ, we need to test for the statistical significance of the threshold effect (Hansen, 1999). The null hypothesis of this test is written as $H_0 : \lambda_1 = \lambda_2$. The statistic for this test is:

$$LR_0(\gamma) = \frac{(S_0 - S_1(\hat{\gamma}))}{\hat{\sigma}^2}$$

$$\text{with } \hat{\sigma} = \frac{1}{(n(T-1))} S_1(\hat{\gamma})$$

Because of the non-classic distribution of this statistic under the null, In order to obtain p-values that are asymptotically valid, construction of the p-value of this test is recommended using the bootstrap procedure. As suggested in Hansen (1999, 2000), due to the panel nature of our data, the most straightforward approach to constructing the bootstrap sample is to treat all the explanatory variables as constant and to treat the banks as clusters.

The bootstrap likelihood ratios are computed by repeating this procedure multiple times. Then, the bootstrap p-value of the test of the threshold effect is computed as the percentage of draws for which the simulated statistic exceeds the actual. As proposed in Hansen (1999), we use the likelihood ratio test to form the confidence intervals for γ with the no rejection region of the test $H_0 : \gamma_0 = \gamma_1$:

$$LR_1(\gamma) = \frac{(S_1 - S_1(\hat{\gamma}))}{\hat{\sigma}^2}$$

Hansen (1999, 2000) proposes an asymptotic distribution of the threshold parameter, showing that under the null hypothesis, the test statistics LR1(γ) converge to a random variable ξ with distribution:

$$P(\xi \leq x) = \left(1 - exp\left(\frac{x^2}{2}\right)\right)^2$$

The asymptotic p-value for the significance of the threshold estimated is:

$$P_n = 1 - \left(1 - exp\left(-\frac{LR_1(\gamma_0)^2}{2}\right)\right)^2$$

Graphically the associated no rejection region is the value of γ such $LR_1(\gamma) \leq c(\alpha) = -2\log(1-\sqrt{1-\alpha})$

where $c(\alpha) = -\log(1-\sqrt{1-\alpha})$ with (1 - α) the desired confidence level.

A test $H_0 : \gamma_0 = \gamma_1$ rejects at the asymptotic level α if $LR_1(\gamma)$ exceeds $c(\alpha)$.

3.2.2 Looking for threshold effects in the monetary policy risk-taking channel

There are more examples of threshold models. In economics, Durlauf and Johnson (1995) argue that cross-country growth models with multiple equilibria can exhibit threshold effects. In addition, Khan and Senhadji (2001) examine the existence of threshold effects in the relationship between inflation and growth. In empirical finance studies, Pesaran and Pick (2007) argue that the effect of financial contagion can be described as a discontinuous threshold effect, hence testing for threshold effects implies testing for the presence of financial contagion.

Some studies try to analyse the risk-taking channel through non-linearity (see Altunbas et al., 2010; Gambacorta, 2009) using the interactions between variables or squared variables. These studies are effective for identifying and explaining the non-linear relationship between the interest rate and banks' risk-taking behaviour. We explore this non-linearity further through a threshold regression. This is a novel approach to empirically testing the existence of a threshold to the monetary policy risk-taking channel.

The data generating process for the threshold analysis can be written as follow:

$$Z_{i,t} = \lambda_i + \delta' f(\Delta MP_{t-1}, TGAP_{t-2}) + \sum_{j=0}^{1} \beta_j \Delta X_{1,t-j} + \phi X_{2i,t-1} + UNC + \sum_{j=1}^{4} \eta_j SD_t + \varepsilon_{i,t}$$

where f represents a nonlinear function between the Fed rate and the threshold variable $TGAP_{t-2}$ with :

$$\delta' f(\Delta MP_{t-1}, TGAP_{t-2}) = {\delta_1}' \Delta MP_{t-1} * I(TGAP_{t-2} \leq \gamma) + {\delta_2}' \Delta MP_{t-1} * I(TGAP_{t-2} > \gamma)$$

in the case of a single threshold model,

$X_{1,t}$ and $X_{2i,t}$ are respectively macroeconomic variables and bank-specific variables, *UNC* is a dummy referring to period of unconventional measures (2009q1 to 2015q4), and SD are seasonal dummies.

The variable submitted to the threshold test is the deviation of the monetary rate from the Taylor rule (TGap). The choice of this variable is motivated by the fact it has been identified as amplifying the negative effect of monetary easing on bank risk-taking. Gambacorta (2009) and Altunbas et al. (2010) find that the impact of changes to the monetary rate on bank risk, is amplified by the Taylor gap. However, their study assumes an identical effect of the Taylor gap on the risk-taking channel.

It would seem useful to analyse non-linearity in the effect of monetary shock on bank risk using threshold analysis to account for a possible change in its effect, depending on the threshold value. The regime dependent variable is change in the Fed rate. The choice of this variable is motivated by the unclear effect of monetary rates on banks' risk-taking, observed in our previous regression analysis, and the likely existence of a reverse interest rate. The results in Lamers et al. (2016) show that monetary easing increases bank profitability and, thus, reduces the banks' incentives to take more risk. An accommodative monetary policy is beneficial for banks that rely on debt financing, since it lowers interest charges and increases their profit. It is obvious that banks' behaviour will depend on the gains or losses due to lower interest rates. Thus, there will be a degree of interest rate reduction that will not lead to more risk-taking by the banks because the losses incurred in their lending operations are offset by their lower financing costs.

We use the lag of monetary rate as the regime-dependent variable, and the Taylor gap enters the regression at its period $t-2$ value. This specification allows consideration of the effect of the change in monetary rates (at the moment of decision-making $t-1$) on banks' soundness, depending on the monetary policy stance in the preceding quarter $(t-2)$. The aim is to determine how banks behave, overall, regarding monetary policy.

4 Results and discussion of the threshold analysis

In this section, we present and discuss the results of our threshold analysis and check the robustness of our estimations.

4.1 Panel threshold results

Table 1 presents the results of the threshold analysis.

An interesting result is that the impact of monetary policy on banks' soundness effectively depends on the previous monetary policy. Table 1 shows that our analysis provides evidence of a threshold value of -0.1898, implying a change in the impact of monetary shocks if the monetary rate is 18.98 basis points below the Taylor rule. However, there are differences in the magnitude of the effects. Below this threshold value, any interest rate cut increases bank fragility since a 1% decrease in the monetary rate when the Taylor gap is -18.98 basis points or lower, induces around a 0.19 unit decrease in the bank's Z-score. This decrease in bank soundness could be explained by the bank's excessive risk-taking. Conversely, a 1% interest rate reduction when the Taylor gap is greater than -18.98 basis points, increases bank soundness by some 0.08 units.

This result shows that a Central Bank that adheres to the Taylor rule (Taylor gap 0) should decrease its interest rates to avoid jeopardizing its banking system.

The threshold analysis provides an overview of the threshold values in the Taylor gap. Our findings confirm the existence of points in the deviation of the monetary rate from the Taylor rule, at which the effects of the monetary rate on bank fragility changes. Our results show, also, that the effect of changes to monetary policy on bank soundness depends on the monetary cycle.

Our results question the existence of a monetary policy risk-taking channel. So far, interest rate cuts have been considered to drive banks' risk-taking behaviour. Our findings tend to reconcile the idea of monetary easing and its opponents. We show that the effects of monetary policy on bank risk, change after the Taylor gap threshold value. Thus, when the monetary rate is, to a certain extent, already below the Taylor rate, monetary easing is undesirable. In a low interest rate environment, banks already suffer from a spread cut, and a further decrease in the interest rate will depress their profit, making riskier alternatives more attractive. This is consistent with the "search for yield" notion developed by Rajan (2005) and supports the notion of a monetary policy risk-taking channel.

Table 1: Threshold analysis on the Taylor gap

The dependent variable is the the Z-score (Z_t)

EXPLANATORY VARIABLES	(1)
Threshold variable $q_{i,t}$	$TGAP_{t-2}$
Threshold value γ	**-0.1898***
ΔGDP_{t-1}	0.0368***
	(0.00485)
ΔGDP_t	0.0343***
	(0.00494)
ΔSM_{t-1}	-0.220*
	(0.130)
ΔSM_t	-0.0450
	(0.133)
$\Delta^2 HP_{t-1}$	-0.00621
	(0.00546)
$\Delta^2 HP_{t-1}$	0.00735
	(0.00545)
$\Delta Slope_{t-1}$	-0.0148
	(0.0257)
$\Delta Slope_t$	0.0287
	(0.0278)
ΔFSI_{t-1}	0.199***
	(0.0249)
ΔFSI_t	-0.0138
	(0.0217)
LIQ_{t-1}	-0.146
	(0.184)
EFF_{t-1}	1.276***
	(0.104)
$Size_{t-1}$	-0.0569
	(0.0590)
$EXLEND_{t-1}$	-0.134
	(0.131)
$EXLEND^2_{t-1}$	-0.0541
	(0.0539)
UNC	-0.322***
	(0.0543)
ΔMP_{t-1} if $TGAP_{t-2} \leq \gamma$	**0.189*** **
	(0.0338)
ΔMP_{t-1} if $TGAP_{t-2} > \gamma$	**-0.0763***
	(0.0306)
Constant	2.896***
	(0.463)
Observations	13,580
Number of Banks	194

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The Taylor gap (TGap) is the deviation of the monetary rate from the Taylor rule based rate. The Taylor rule rate is estimated following Taylor (1993) $i = r + \pi + 0.5(\pi - \pi^*) + 0.5y$,where r is the natural interest rate (set at 2%), π^* is the inflation target set at 2% and y is the output gap.

The dummy variable "UNC" take the value 1 between 2009q1 and 2015q4, and 0 otherwise and refers to a period of unconventional monetary policy measures.

However, when the interest rate is not far below the Taylor rule or is above it, the negative impact of monetary policy on bank soundness diminishes. In this type of regime, an interest rate cut is beneficial to the bank and, therefore, increasing the interest rate is undesirable. An interest rate cut, rather than triggering bank fragility, fosters bank soundness if the interest rate is already close to the Taylor rule or if there is in place a restrictive monetary policy (positive Taylor gap). In the case of a restrictive monetary policy, banks will have to bear higher refinancing costs. A decrease in the interest rate will allow the banks to benefit from a cost reduction, to the extent that they do not face spread contraction. This is consistent with the findings in Smith (2002) that low interest rates are beneficial to banks and reduce their incentive for risk, since their opportunity costs decrease. Alternatively, the negative effects of a restrictive monetary policy might dry up liquidity, and reduce investments and future profits. Also, as Gan (2004) shows, a higher interest rate may reduce the bank's franchise value and lead to more risk-taking. This is consistent with "gambling for resurrection" behaviour (Kane, 1989). A higher interest rate entails a decrease in the banks' net worth and leads to "gambling for resurrection", since risky strategies become more attractive. Our results also support the findings in Agur and Demertzis (2012) that a rise in interest rates, by increasing the cost of bank financing, reduces bank profits. To compensate for this loss, banks turn to riskier (more profitable) assets.

Our findings are consistent with the Deutsche Bundesbank (2018, p.27) statement that: *"The net interest margins generated by banks, which constitute a significant part of their profitability, can come under pressure in prolonged periods of accommodative monetary policy and low interest rates. At the same time, low interest rates can also have a positive impact on profitability, e.g. in the form of reduced loan loss provisions; however, these effects may not be strong enough to compensate for decreasing net interest margins"*.

There are two important implications of our study. First, it reopens the debate on the necessity for the triptych price stability/output stability/financial stability in Central Banks' objectives. It offers support to those in favour of including financial stability issues in Central Banks' objectives, since monetary rates influence financial agents' behaviours. The second implication, which follows from the first one, is related to use of the Taylor rule as an indicator of the risk of financial weakening. An augmented Taylor rule that accounts for financial stability is appropriate for this. Further work is needed along the lines of an augmented Taylor rule. The main underlying idea is that risk-taking and crisis prevention should be the tasks of both the regulatory and the monetary authorities. Central Banks should not only make "repairs" but also should take account of financial stability concerns when setting interest rates. Our conclusions support the proactive view of monetary policy (Borio and White, 2004; Woodford, 2012) and reject the conventional or reactive view upheld by Bernanke (2002).

Regardless of the threshold analysis, the threshold-independent variables exhibit diverse effects on bank risk. GDP growth has a positive impact on bank soundness: economic expansion tends to ameliorate banks' and their customers' balance sheets, triggering a reduction of risk. Also, economic expansion increases the volume of safe projects, leading the banks to reduce their risk (Jimenez et al., 2008).

There is a significant positive relation between bank soundness and changes in the previous period financial stress index. This positive relation explains why when the financial system is negatively affected, banks tend to behave well to withstand this negative shock. However, there is a negative (non-significant) relation between the financial stress index and bank soundness, which might suggest that when the financial system receives a negative hit, this negative shock is transmitted to the banks.

Our results show that banks were impacted negatively by the period of unconventional policy measures: the coefficient of the dummy *UNC* is negative and significant. This result is consistent with the findings in Plescau and Cocris (2016) that banks' risk-taking increases with Central Banks' use of unconventional instruments.

Looking at the bank variables, our results indicate that operational efficiency has a positive impact on bank soundness. This is consistent with Fiordelisi et al.'s (2010) findings that a decrease in bank efficiency is associated to an increase in the bank's future risk (see also Nitoi and Spulbar 2016). Our result could be explained by the fact that efficient banks, compared to less efficient ones, may have more possibilities to reduce their operational costs. They then can increase their profits, which increases their soundness.

Also, credit expansion negatively affects bank soundness, but the impact appears not to be significant.

Our results have some important implications; therefore, we need to test their robustness.

4.2 Robustness check

4.2.1 Controlling for potential influence of macroeconomic and banks specific variables

We test various specification to check the robustness of our estimations. Use of different specifications is aimed at checking whether the threshold effect is subject to influence from some of the variables included in the regression.

We regress the bank Z-score on the lagged values of the macroeconomic and bank-specific variables (model 2) to check that our threshold effect does not depend on the economic condition prevailing at time t. We estimate model 3 to check whether the threshold still holds if we remove only the bank-specific variables. The final specification (model 4) is our baseline model plus one additional variable. To test the impact of monetary policy shocks during the period of unconventional policy, we include an interaction between the dummy *UNC* and the monetary variable. This is mainly to check whether our threshold effect remains robust to the potential impact of a period of unconventional policy.

Table 2 presents the results of the robustness tests.

All three additional specifications confirm the existence of a threshold value in the deviation from the Taylor rule at $t-2$. Our results appear robust to any changes to the regression and show the existence of a threshold effect in the impact of monetary policy. Although the threshold value (-1.2300) in model 4 is lower than in models 1, 2 and 3 (-0.1898), the reverse marginal effects of monetary policy are still at play. Monetary expansion in a regime of already low interest rates, weakens bank soundness, inducing more risk-taking. However, an interest cut is beneficial to the banks in a monetary policy regime that is fairly restrictive. Hence, the positive and negative impacts of monetary expansion have mutually superior marginal effects depending on the monetary regime in the previous quarter.

The results of model 4 indicate that the impact of a monetary shock is more important during a period of unconventional policy. In this specification, the effects of monetary policy are more important during a period of unconventional policy than in normal times. In a low monetary regime ($TGAP_{t-2} \leq \gamma$), the impact of monetary shock on bank soundness is twice that in normal times and, in a high monetary regime ($TGAP_{t-2} > \gamma$), it is 50 times higher than in a normal period. This is because the unconventional period corresponds to the post-crisis period, which is also a period of recovery. Hence, banks are likely to be more sensitive to monetary shocks during this period since their recovery is not complete. Bank soundness becomes more sensitive to a monetary shock during an unconventional period combined with a restrictive policy. The differential of bank Z-score sensitivity to a monetary shock during an unconventional period relative to a normal period, triples for a high monetary regime compared to a low monetary regime. This result suggests that the monetary authorities need to be more vigilant when introducing unconventional policy measures since they could amplify reversal of the desired effect.

Table 2: Robustness check of the threshold analysis

The dependent variable is the Z-score (Z_t)

EXPLANATORY VARIABLES	(2)	(3)	(4)
Threshold variable $q_{i,t}$	$TGAP_{t-2}$	$TGAP_{t-2}$	$TGAP_{t-2}$
Threshold value $\boldsymbol{\gamma}$	**-0.1898****	**-0.1898*****	**-1.2300****
ΔGDP_{t-1}	0.0412***	0.0567***	0.0339***
	(0.00507)	(0.00553)	(0.00472)
ΔGDP_t		0.0572***	0.0357***
		(0.00519)	(0.00502)
ΔSM_{t-1}	0.00192	-0.700***	-0.551***
	(0.0991)	(0.141)	(0.141)
ΔSM_t		-0.118	-0.160
		(0.148)	(0.143)
$\Delta^2 HP_{t-1}$	-0.0134**	-0.00656	-0.00672
	(0.00564)	(0.00551)	(0.00515)
$\Delta^2 HP_t$		0.0272***	0.0197***
		(0.00648)	(0.00550)
$\Delta Slope_{t-1}$	-0.00797	-0.0438*	-0.0328
	(0.0292)	(0.0264)	(0.0264)
$\Delta Slope_t$		0.0237	0.149***
		(0.0312)	(0.0323)
ΔFSI_{t-1}	0.175***	0.265***	0.265***
	(0.0208)	(0.0290)	(0.0342)
ΔFSI_t		-0.00880	-0.00834
		(0.0249)	(0.0202)
LIQ_{t-1}	-0.222		-0.0237
	(0.184)		(0.184)
EFF_{t-1}	1.301***		1.330***
	(0.104)		(0.104)
$Size_{t-1}$	-0.110**		-0.244***
	(0.0557)		(0.0539)
$EXLEND_{t-1}$	-0.137		-0.122
	(0.131)		(0.136)
$EXLEND^2_{t-1}$	-0.0521		-0.0745
	(0.0536)		(0.0540)
UNC	-0.298***	-0.623***	
	(0.0507)	(0.0541)	
$\boldsymbol{\Delta MP_{t-1}}$ **if** $\boldsymbol{TGAP_{t-2} \leq \gamma}$	**0.221*****	**0.329*****	**0.510*****
	(0.0342)	(0.0386)	(0.0707)
$\boldsymbol{\Delta MP_{t-1}}$ **if** $\boldsymbol{TGAP_{t-2} > \gamma}$	**-0.0495**	**-0.157*****	**-0.0618****
	(0.0300)	(0.0347)	(0.0247)
$\boldsymbol{\Delta MP_{t-1} * UNC}$ **if** $\boldsymbol{TGAP_{t-2} \leq \gamma}$			**1.009*****
			(0.220)
$\boldsymbol{\Delta MP_{t-1} * UNC}$ **if** $\boldsymbol{TGAP_{t-2} > \gamma}$			**-3.254*****
			(0.894)
Constant	3.423***	2.979***	4.072***
	(0.434)	(0.0354)	(0.457)
Observations	13,580	13,580	13,580
Number of Banks	194	194	194

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The dummy variable "UNC" take the value 1 between 2009q1 and 2015q4, and 0 otherwise and refers to a period of unconventional monetary policy measures.

The Taylor gap (TGap) is the deviation of the monetary rate from the Taylor rule rate. The Taylor rule rate is estimated following Taylor (1993) $i = r + \pi + 0.5(\pi - \pi^*) + 0.5y$,where r is the natural interest rate (set at 2%), π^* is the inflation target set at 2% and y is the output gap.

Ceteris paribus, economic expansion, the steepness of the yield curve and bank efficiency have a positive impact on bank soundness. Economic expansion and a more steeply sloped yield curve increase the number of save projects and decrease bank risk. Efficient banks are able to control their costs and, thus, increase their profits, and have fewer incentives to engage in risky projects.

When the system receives a negative hit, the banks tend to behave cautiously, leading to a reduction of their risk in the next period, shown by the positive relation between the change in the FSI at $t-1$ and the bank Z-score at time t.

Bank size has a negative effect on bank soundness, which highlights the potential perverse effect of an implied "too big to fail" policy on the risk-taking behaviour of large banks.

4.2.2 Alternative measures of monetary policy rate and stance

The threshold analysis, using the effective Fed interest rate and Taylor's (1993) rule to compute the Taylor gap, provides evidence of a threshold value in the Tgap at $t-2$ at which the impact of monetary policy on banks risk changes.

In this section, we provide some robustness tests, including two major changes to the Taylor gap estimation.

A first novelty is related to the monetary rate used to compute the Taylor gap. Since the effective Fed interest rate has a Zero Lower Bound (ZLB), it may fail to reflect the real monetary policy stance since some unconventional measures were introduced after 2009. To deal with this limitation, we check the robustness of our results using the shadow Fed Fund rate instead of the effective Fed interest rate to compute the Taylor gap. The advantage of using the shadow rate is that it is not constrained by the ZLB and takes account of unconventional measures not reflected in the main refinancing interest rate. We employ the shadow Fed Fund rate computed by Wu and Xia (2015) to estimate a new Taylor gap.

Second, we allow for another measure of the Taylor rule, which puts greater weight on output stability, following Taylor (1999). Use of Taylor's (1999) rule rather than the 1993 rule, has proven to better stabilize output and inflation and more closely match the Fed's optimal control of interest rates. Thus, the Taylor 1999 rule is preferred by most researchers. In this section we use the Taylor (1999) rule to compute the Taylor gap.

The Taylor 1999 rule is given by:

$$i = r + \pi + 0.5(\pi - \pi^*) + y$$

where r is the natural interest rate (set at 2%), π^* is the inflation target set at 2% and y is the output gap. Since quarterly data have short frequency and do not allow smoothing of the fluctuations in price levels, we estimate inflation π as the moving average of the GDP deflator on the last four quarters.

Figure 4 depicts the shadow Fed rate computed by WU and Xia (2015). Note that the shadow Fed rate deviates from the effective Fed rate, starting in 2009, and becomes negative at the end of 2015. That is, the Taylor gaps, using each of the interest rates (shadow and effective rate) remain stable up to 2009 and differ up to 2015 (see Figures 6 and 7).

We then estimates three additional Taylor gaps :

- The gap between the shadow Fed rate and the 1993 Taylor rule (model 5)
- The gap between the effective Fed rate and the 1999 Taylor rule (model 6)
- The gap between the shadow Fed rate and the 1999 Taylor rule (model 7)

Table 3 presents the regression results. Model 5 uses the Taylor gap estimated as the difference between the shadow Fed rate and the 1993 Taylor rule. Models 6 and 7 are tested using the gap between the 1999 Taylor rule and, respectively, the effective Fed rate and the shadow Fed rate. The results of these regressions confirm the existence of threshold values in the Taylor gap of -1.23%, -0.60% and -0.77%, leading the effects of monetary policy to reverse. The differential in threshold values stems from the changes in the variables included in the calculation of the Taylor gaps (effective/shadow Fed rates and Taylor 1993/1999 rules). The results indicate that the impacts of monetary shocks reverse when the effective Fed rate is -60.83 basis points below the Taylor 1999 rule. The results also suggest a reversal in the impact of monetary shocks when the shadow Fed rate is -123 basis points below the Taylor 1993 rule or -77 basis points below the Taylor 1999 rule.

Even in presence of unconventional monetary policy, the positive and negative marginal effects of monetary policy on bank risk still hold. We can conclude that the impact of monetary policy on bank soundness depends, effectively, on the previous “real” monetary stance.

Table 3: Threshold analysis on the Taylor gap

The dependent variable is the Z-score (Z_t)			
EXPLANATORY VARIABLES	(5)	(6)	(7)
Threshold variable $q_{i,t}$	$TGAP_{Shadow-Taylor93,t-2}$	$TGAP_{Fed-Taylor99,t-2}$	$TGAP_{Shadow-Taylor99,t-2}$
Threshold value γ	**-1.233****	**-0.6083 *****	**-0.7739 *****
ΔGDP_{t-1}	0.0356***	0.0375***	0.0373***
	(0.00488)	(0.00491)	(0.00491)
ΔGDP_t	0.0392***	0.0415***	0.0415***
	(0.00517)	(0.00522)	(0.00522)
ΔSM_{t-1}	-0.347***	-0.242*	-0.228*
	(0.132)	(0.129)	(0.129)
ΔSM_t	-0.338**	-0.406***	-0.407***
	(0.145)	(0.149)	(0.149)
$\Delta^2 HP_{t-1}$	-0.0026	-0.00131	-0.000595
	(0.0052)	(0.00517)	(0.00515)
$\Delta^2 HP_t$	0.0102**	0.00274	0.00296
	(0.0052)	(0.00511)	(0.00510)
$\Delta Slope_{t-1}$	-0.019	-0.0102	-0.00535
	(0.0264)	(0.0264)	(0.0263)
$\Delta Slope_t$	0.162***	0.157***	0.158***
	(0.0323)	(0.0324)	(0.0324)
ΔFSI_{t-1}	0.290***	0.301***	0.307***
	(0.0296)	(0.0315)	(0.0319)
ΔFSI_t	-0.0189	-0.00713	-0.00845
	(0.0198)	(0.0196)	(0.0196)
LIQ_{t-1}	-0.0319	-0.0319	-0.0354
	(0.184)	(0.184)	(0.184)
EFF_{t-1}	1.329***	1.333***	1.332***
	(0.104)	(0.105)	(0.105)
$Size_{t-1}$	-0.239***	-0.239***	-0.238***
	(0.0539)	(0.0539)	(0.0539)
$EXLEND_{t-1}$	-0.122	-0.121	-0.121
	(0.134)	(0.135)	(0.135)
$EXLEND^2_{t-1}$	-0.0739	-0.0750	-0.0751
	(0.0536)	(0.0535)	(0.0535)
ΔMP_{t-1} if $TGAP_{t-2} \leq \gamma$	**0.537*****	**0.507*****	**0.518*****
	(0.0699)	(0.0705)	(0.0716)
ΔMP_{t-1} if $TGAP_{t-2} > \gamma$	**-0.068*****	**-0.0620****	**-0.0621****
	(0.0246)	(0.0246)	(0.0246)
Constant	4.041***	4.028***	4.027***
	(0.458)	(0.458)	(0.458)
Observations	13,580	13,580	13,580
Number of Banks	194	194	194

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

$TGAP_{Shadow-Taylor93,t-2}$ is the deviation of the shadow Fed rate from the Taylor 1993 rule based rate at time t-2. The Taylor 1993 rule rate is estimated as follow $i = r + \pi + 0.5(\pi - \pi^*) + y$. $TGAP_{Fed-Taylor99,t-2}$ is the deviation of the effective Fed rate from the Taylor 1999 rule based rate at time t-2. $TGAP_{Shadow-Taylor99,t-2}$ is the deviation of the shadow Fed rate from the Taylor 1999 rule based rate at time t-2. The Taylor 1999 rule rate is estimated as follow $i = r + \pi + 0.5(\pi - \pi^*) + y$,where r is the natural interest rate (set at 2%), π^* is the inflation target set at 2%, π is the inflation rate and y is the output gap. The Fed shadow rate is computed by Wu and Xia (2015).

the results in Table 3 show that our robustness tests provide evidence of threshold values that are slightly lower than those obtained in the previous analysis (-0.1898). This implies that the impact of monetary policy shocks reverses when the effective Fed interest rate (the shadow Fed rate) is already below the Taylor rule. Below these threshold values, any interest rate cut increase bank fragility since a 1% decrease in the monetary rate in the low interest regime, induces around a 0.51 unit decrease in the bank Z-score. This decrease in bank soundness can be explained by excessive risk-taking by the banks. Conversely, a 1% interest rate reduction in the high interest regime, leads to a slight improvement (0.07 units) in bank soundness.

5 Conclusion

The objective of this paper was to contribute to empirical research on the monetary policy risk-taking channel. We fitted a panel threshold model that allowed us to identify different regimes where the effect of changes in the monetary rate might differ. Although much empirical research on the monetary policy risk taking channel has been conducted, our paper is the first to analyse this channel using a panel threshold model.

We found that the impact of monetary shocks on bank risk depends on the deviation of the monetary rate from the Taylor rule based interest rate. When the deviation is sufficiently below the Taylor rule, a cut in interest rates triggers bank fragility, due, possibly, to a greater appetite for risk. For small deviations below the Taylor rule or deviations above the Taylor rule, monetary easing is beneficial for the banks. This highlights the presence of positive and negative marginal effects of monetary policy on bank risk, and we show that these marginal effects are mutually greater depending on the previous monetary stance.

Our findings shed light on the non-linear impact of monetary policy on banks' risk-taking behaviour and have important implications for monetary and prudential policy. It reopens debate on the possibility of a financial stability side to Central Banks' objectives. On the one hand, our findings call for monetary authorities to pay more attention to financial stability when setting interest rates, and on the other hand they suggest that banking supervisors should consider the potential effects of monetary shocks depending on the interest rate regime (low or high) when conducting banking supervision. In sum, our results suggest that monetary authorities should not only consider the impact a change in monetary policy on banks' risk-taking behaviour but also should take account of deviations from the Taylor rule.

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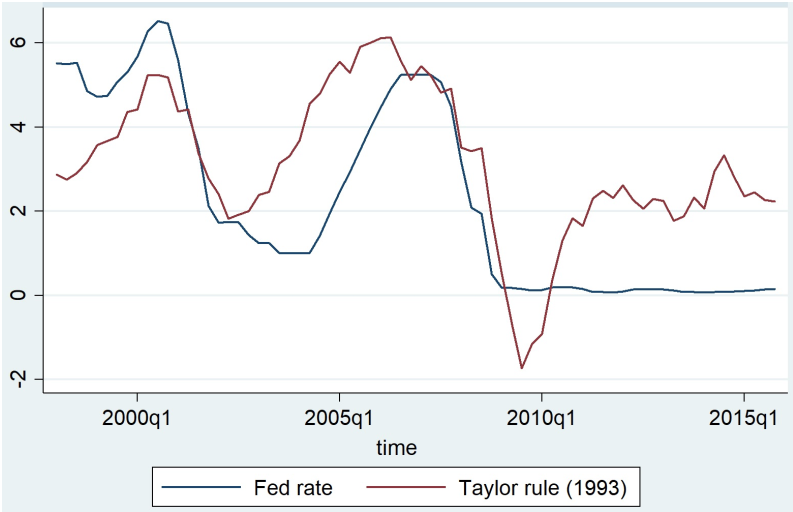
Appendices

Appendix A Estimation of monetary policy stance

Figure 2: Fed real interest rate and Taylor rule-based interest rate(1)



(1) The Taylor-rule rate is estimated following Taylor (1993): $i = r + \pi + 0.5(\pi - \pi^{*}) + 0.5y$ where π is the moving average of the inflation on the 4 last quarters and y is the output gap. And π^{*} is the inflation target set at 2%

Figure 3: Taylor gap(2)

(2) The Taylor gap is the difference between Fed interest rate and the Taylor-rule rate following Taylor (1993). Negative value indicates monetary softening.

Appendix B Summary statistics and correlation matrix

Table 4: Summary statistics of the variables used in the regressions (USA banks data, 1995q1-2015q4)

Variables	Obs	Mean	Std.Dev	Min	Max	1rst quartile	3rd quartile
Z	13,968	3.073	2.895	-4.692	20.97	1.113	4.431
ΔMP	13,968	-0.074	0.43	-1.43	0.59	-0.06	0.025
TGAP	13,968	-0.863	1.617	-3.559	2.751	-2.176	0.19
ΔGDP	13,968	2.20	2.58	-8.200	7.800	1	3.75
$\Delta^2 HP$	13,968	.0285	1.164	-3.58	3.81	-0.53	0.445
ΔFSI	13,968	-0.020	0.49	-1.439	2.934	-0.183	0.168
$\Delta Slope$	13,968	1.81	1.185	-0.63	3.61	0.77	2.73
ΔSM	13,968	2.14	10.5	-30	35.4	-2.21	7.43
Liq	13,968	0.813	0.172	0.18	2.934	0.715	0.912
Eff	13,968	0.494	0.494	-5.157	7.175	0.297	0.667
Size	13,968	7.808	1.721	2.55	14.76	2.55	14.74
Exlend	13,774	0	0.0905	-0.683	3.77	-0.0268	0.00948

$Z_{i,t}$: Individual bank Z-score at time t

ΔMP_t : Quarterly change in monetary interest rate at time t

$TGAP_t$: Gap between Fed interest rate and Taylor rule rate (Taylor rate is estimated following Taylor (1993))

ΔGDP_t : GDP growth at time t

$\Delta Slope_t$: Change in the slope of the yield curve (10-Year Treasury Const. Maturity Minus 2-Years Treasury Const. Maturity)

$\Delta^2 HP_t$: Quarterly pace of change in the housing price index at time t

ΔFSI_t : Change in financial stress index at time t

ΔSM_t : quarterly percentage change in the stock market index at time t

$Liq_{i,t}$: Liquidity ratio of bank i at time t (Net Loan/(Total deposits+Short-term debts))

$Eff_{i,t}$: Operational efficiency ratio of bank i at time t (Operational income to Operational cost ratio)

$Size_{i,t}$: Natural logarithm of total assets of bank i at time t

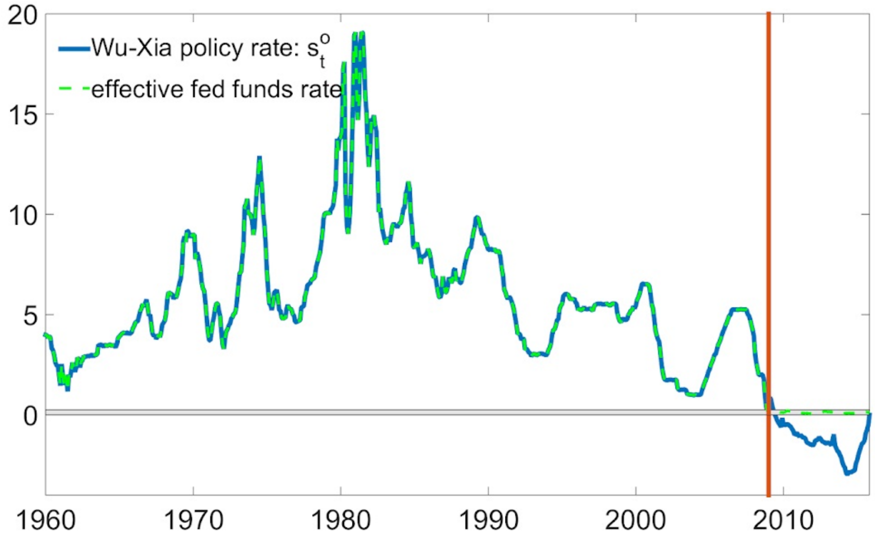
$Exlend_{i,t}$: Excessive lending growth (excess lending growth over average lending growth of other banks) of bank i at time t

Table 5: Correlation matrix between variables used in regressions

Variables	Z	ΔMP	$TGap$	ΔGDP	$\Delta^2 HP$	ΔFSI	$\Delta Slope$	ΔSM	Liq	Eff	$Size$	$Exlend$
Z	1											
ΔMP	0.0276	1										
$TGAP$	0.00420	-0.103	1									
ΔGDP	0.0747	0.450	0.0911	1								
$\Delta^2 HP$	-0.0307	0.0791	0.0142	0.0609	1							
ΔFSI	0.0324	-0.259	-0.0853	-0.148	-0.122	1						
$\Delta Slope$	-0.0206	-0.656	0.286	-0.346	-0.236	0.147	1					
ΔSM	-0.00610	0.02618	-0.0187	0.478	0.1488	-0.472	-0.0856	1				
Liq	-0.215	-0.0393	-0.0374	-0.0940	-0.116	0.0187	0.0298	-0.0500	1			
Eff	0.202	0.0346	0.0616	0.0773	0.131	0.0107	-0.0139	-0.00750	0.118	1		
$Size$	0.0625	0.0118	-0.148	-0.0686	-0.0887	-0.00590	-0.0198	0.0119	-0.0233	0.108	1	
$Exlend$	-0.0140	0	0	0	0	0	0	0	0.0359	0.0150	-0.00540	1

Appendix C Unconventional monetary policy and Taylor rule 1999

Figure 4: Wu and Xia shadow Fed Funds rate



Source: Cynthia Wu's website `https://sites.google.com/view/jingcynthiawu/shadow-rates`

Figure 5: Taylor rule 1999 Vs Taylor rule 1993

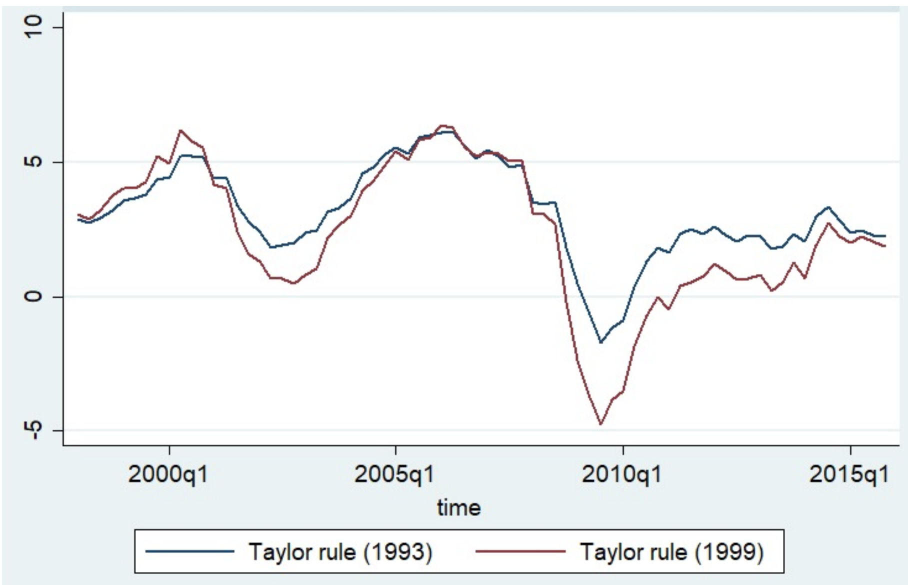


Figure 6: Taylor gap using Fed effective rate and the shadow Fed Funds rate compared to Taylor 1993

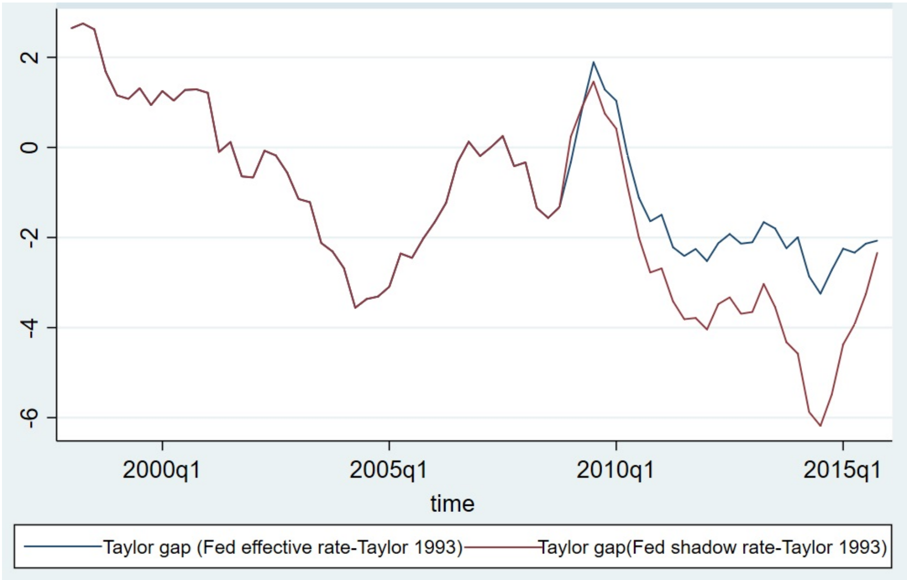


Figure 7: Taylor gap using Fed effective rate and the shadow Fed Funds rate compared to Taylor 1999