

# Monetary Policy Rules and Financial Stress: Does Financial Instability Matter for Monetary Policy?

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## Abstract

We examine whether and how main central banks responded to episodes of financial stress over the last three decades. We employ a new methodology for monetary policy rules estimation, which allows for time-varying response coefficients as well as corrects for endogeneity. This flexible framework applied to the U.S., U.K., Australia, Canada and Sweden together with a new financial stress dataset developed by the International Monetary Fund allows not only testing whether the central banks responded to financial stress but also detects the periods and type of stress that were the most worrying for monetary authorities and to quantify the intensity of policy response. Our findings suggest that central banks often change policy rates: mainly decreasing it in the face of high financial stress. However, the size of a policy response varies substantially over time as well as across countries, with the 2008-2009 financial crisis being the period of the most severe and generalized response. With regards to the specific components of financial stress, most central banks seemed to respond to stock market stress and bank stress, while exchange rate stress is found to drive the reaction of central banks only in more open economies.

**JEL Classification:** E43, E52, E58.

**Keywords:** financial stress, Taylor rule, monetary policy, time-varying parameter model, endogenous regressors.

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## 1 Introduction

The recent financial crisis has intensified the interest in exploring the interactions between monetary policy and financial stability. Official interest rates were driven sharply to historic lows and many unconventional measures were used to pump liquidity into the international financial system. Central banks pursued monetary policy under high economic uncertainty coupled with large financial shocks in many countries. The financial crisis also raised new challenges for central bank policies, in particular how to operationalize the issues related to financial stability for monetary policy decision-making (Goodhart, 2006, Borio and Drehmann, 2009).

This paper seeks to analyze whether and how central banks reacted to the periods of financial instability, and in particular whether and how the interest-setting process evolved in response to financial instability over the last three decades. The monetary policy of central banks is likely to react to financial instability in a non-linear way (Goodhart et al., 2009). When a financial system is stable, the interest rate setting process largely reflects macroeconomic conditions and financial stability considerations enter the monetary policy discussions only to a limited degree. On the other hand, central banks may alter its monetary policy to reduce financial imbalances if these become severe. In this respect, Mishkin (2010) questions the traditional linear-quadratic framework<sup>1</sup> when financial markets are disrupted and puts forward the arguments for replacing it by nonlinear dynamics, describing the economy and the non-quadratic objective function resulting in the non-linear optimal policy.

To deal with the complexity of monetary policy and financial stability nexus as well as to evaluate monetary policy in a systematic manner, this paper employs the recently developed time-varying parameter estimation of monetary policy rules appropriately accounting for endogeneity in policy rules. This flexible framework, together with a new comprehensive financial stress dataset developed by the International Monetary Fund, will allow not only testing whether the central banks responded to financial stress but also the quantification of the magnitude of this response and the detection of the periods and types of stress that were the most worrying for monetary authorities.

Although theoretical studies disagree about the role of financial instability for central bank interest rate setting policy, our empirical estimates of time-varying monetary policy rules of the US Fed, the Bank of England (BoE), Reserve Bank of Australia (RBA), Bank of Canada (BoC)

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<sup>1</sup> Linear behavior of the economy and the quadratic objective function of monetary authority.

and Sveriges Riksbank (SR) shows that central banks often alter the course of its monetary policy in the face of high financial stress, mainly by decreasing their policy rates. However, the size of this response varies substantially over time as well as across countries. There is a certain across country and time heterogeneity as well when we look at central banks' consideration of specific types of financial stress: Most of them seemed to respond to stock market stress and bank stress, and exchange rate stress drives central bank reactions only in more open economies

The paper is organized as follows: Section 2 discusses related literature. Section 3 describes our data and empirical methodology. Section 4 presents our results. Section 5 concludes. An appendix with a detailed description of the methodology and additional results follows.

## **2 Related Literature**

First, this section gives a brief overview of the theory as well as empirical evidence on the relationship between monetary policy (rules) and financial instability. Second, it provides a short summary of various measures of financial stress.

### **2.1 Monetary policy (rules) and financial instability – some theories**

Financial frictions, such as an unequal access to credits or debt collateralization, were recognized to have important consequences for monetary policy transmission and Fisher (1933) has already presented the idea that adverse credit-market conditions can cause significant macroeconomic disequilibria.

During the last two decades, the effects of monetary policy have been studied mainly within New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) models, which assume the existence of nominal rigidities. The common approach to incorporate financial market friction within the DSGE framework is to introduce the financial accelerator mechanism (Bernanke et al., 1996, 1999), implying that endogenous developments in credit markets work to amplify and propagate shocks to the macroeconomy. Tovar (2009) emphasizes that the major weakness of the financial accelerator mechanism is that it only deals with one of many possible financial frictions. Goodhart et al. (2009) notes that many NK DSGE models lack the financial sector completely or modeled it in a rather embryonic way. Consequently, more recent contributions within this stream of literature examined other aspects of financial frictions such as the balance sheets in the banking sector (Choi and Cook, 2004), portfolio choice issue with complete (Engel or

Matsumoto, 2009) or incomplete markets (Devereux and Sutherland, 2007) or collateral constraints (Iacovello and Neri, 2010).<sup>2</sup>

A few studies focus more specifically on the relationship between the monetary policy stance (or the monetary policy rule) and financial stability. However, they do not arrive at a unanimous view on whether a monetary policy rule should include some measure of financial stability. Brousseau and Detken (2001) present an NK model where a conflict arises between short-term price stability and financial stability due to a self-fulfilling belief linking the stability of inflation to the smoothness of the interest rate path and suggests that monetary policy should react to financial instability. Akram et al. (2007) investigate the macroeconomic implications of pursuing financial stability within a flexible inflation-targeting framework. Their model using policy rule, augmented with financial stability indicators, shows that the gains of such an augmented rule vis-à-vis the rule without financial stability indicators highly depends on the nature of the shocks. Akram and Eitrheim (2009) build on the previous framework, finding some evidence that the policy response to housing prices, equity prices or credit growth can cause high interest rate volatility and actually lower financial stability in terms of indicators that are sensitive to interest rates. Cecchetti and Li (2008) show in a static and dynamic setting that a potential conflict between monetary policy and financial supervision can be avoided if the interest rate rule takes (procyclical) capital adequacy requirements into account, in particular that the policy interest rates are lowered when financial stress is high. Bauducco et al. (2008) extends the current benchmark NK model to include financial systems and firms that require external financing. Their simulations show that if a central bank responds to financial instability by policy easing it achieves better inflation and output stabilization in the short term at the cost of greater inflation and output volatility in the long term and vice versa. For the US Fed Taylor (2008) proposes a modification of a standard Taylor rule to incorporate adjustments to credit spreads. Teranishi (2009) derives a Taylor rule augmented by the response to credit spreads as an optimal policy under heterogeneous loan interest rate contracts. He finds that the policy response to a credit spread can be both positive and negative depending on the financial structure. However, he also puts forward that when nominal policy rates are close to zero a commitment rather than discretionary policy response is the key for reducing the credit spreads. Christiano et al. (2008) suggest augmenting the Taylor rule with aggregate private credit and find that such a policy would raise welfare by reducing the magnitude of the output fluctuations. Cúrdia and Woodford (2010) develop an NK DSGE model with credit frictions to evaluate the performance of alternative policy rules that are

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<sup>2</sup> The survey of this literature is provided by Tovar (2009).

augmented by a response to credit spreads and to aggregate the volume of private credit in the face of different shocks. They argue that the response to credit spreads can be welfare improving, but the optimal size of such a response is likely rather small. Like Teranishi (2009), they find little support for augmenting a Taylor rule by the credit volume given — that the size and even the sign of the desired response is sensitive to the sources of shocks and their persistence — which is information that is not always available during operational policy making.

The related stream of literature focuses on a somewhat narrower issue of whether or not monetary policy should respond to asset prices. Bernanke and Gertler (1999, 2001) argue that the stabilization of inflation and output provides a substantial contribution to financial stability and there are little if any gains to responding to asset prices. Faia and Monacelli (2007) extend the model developed by Bernanke and Gertler (2001) by a robust welfare metric confirming that strict inflation stabilization offers the best solution. Cecchetti et al. (2000) takes the opposite stand arguing that developments in asset markets can have a significant impact on both inflation and real economic activity, and central banks might achieve better outcomes considering the asset prices provided they are able to detect their misalignments. Borio and Lowe (2002) support this view claiming that financial imbalances can build up even in a low inflation environment, which is normally favorable to financial stability. The side effect of low inflation is that excess demand pressures may first appear in credit aggregates and asset prices rather than consumer prices, which are normally considered by the policy makers. Gruen et al. (2005) argues that responding to an asset bubble is feasible only when the monetary authority is able to make a correct judgment about the process driving the bubble. Roubini (2006) and Posen (2006) provide the summary of this debate from a policy perspective.

## 2.2 Monetary policy (rules) and financial instability – empirical evidence

The empirical evidence on central banks' reaction to financial instability is rather scant. Following the ongoing debate about whether central banks should respond to asset price volatility (e.g. Bernanke and Gertler, 1999, 2001; Cecchetti et al., 2000; Bordo and Jeanne, 2002), some studies tested the response of monetary policy to different asset prices, most commonly to stock prices (Rigobon and Sack, 2003; Siklos and Bohl, 2008; Fuhrer and Tootel, 2008). They find some evidence that asset prices either entered the policy information set (because they contain information about future inflation) or that some central banks were directly trying to offset its

disequilibria.<sup>3</sup> All these papers estimate time-invariant policy rules, which means that they test a permanent response to these variables. However, it seems more plausible that if central banks respond to asset prices, they do it only when their misalignments are substantial, in other words their response is asymmetric. There are two additional controversies related to the effects of asset prices on monetary policy decisions: (i) The first concerns the measure, in particular whether the stock market index that is typically employed is sufficiently representative or whether some other assets, in particular the housing prices, should be considered as well, and (ii) the second issue is related to the (even ex-post) identification of the asset price misalignment. Finally, it is likely that the perception of misalignments is influenced by general economic conditions and that a possible response could evolve over time. Detken and Smets (2004) summarize some stylized facts on macroeconomic and monetary policy developments during asset price booms. Overall they find that monetary policy was significantly looser during the high-cost booms that were marked by the investment and real estate prices crash in the post-boom periods.

A few empirical studies measure monetary policy response using broader measures of financial imbalances. Borio and Lowe (2004) estimate the response of four central banks (Reserve Bank of Australia, Bundesbank, Bank of Japan and the US Fed) to imbalances proxied by the ratio of private sector credit to GDP, inflation-adjusted equity prices and their composite. They find either negative or ambiguous evidence for all countries except for the USA confirming that the Fed responded to financial imbalances in an asymmetric and reactive way, i.e. that the federal fund rate was disproportionately lowered in the face of imbalance unwinding but it was not tightened beyond normal as imbalances built up. Cecchetti and Li (2008) estimate a Taylor rule augmented by a measure of banking stress, in particular a deviation of leverage ratios (total loans to the sum of equity and subordinated debt; total assets to the sum of bank capital and reserves) from its Hodrick-Prescott trend. They find some evidence that the Fed adjusted the interest rate in order to counteract the procyclical impact of a bank's capital requirements, while the Bundesbank and the Bank of Japan did not. Bulíř and Čihák (2008) estimate the monetary policy response to seven alternative measures of financial sector vulnerability (crisis probability, time to crisis, distance to default or credit default swap spreads) in a panel of 28 countries. Their empirical framework is different in the sense that the monetary policy stance is proxied along the short-term interest rate by measures of domestic liquidity and external shocks are controlled for. In the panel setting, they find a statistically significant negative response to many variables representing vulnerability (policy easing) but surprisingly not in country-level regressions. Belke

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<sup>3</sup> A similar but somewhat less polemic debate applies to the role of the exchange rate, especially for small open economies (Taylor, 2001).

and Klose (2010) investigate the factors behind the interest rate decision of the ECB and the Fed during the current crisis. They conclude that the estimated policy rule was significantly altered only for the Fed and they put forward that the ECB gave greater weight on inflation stabilization at the cost of some output loss.

### 2.3 Measures of financial stress

The incidence and determinants of different types of crises have been typically traced in the literature by a means of narrative evidence (expert judgment). This was sometimes complemented with selected indicators (the exchange rate devaluation, the state of foreign reserves) that point to historical regularities (e.g. Eichengreen and Bordo, 2002; Kaminsky and Reinhart, 1999; Reinhart and Rogoff, 2009; Laeven and Valencia, 2008). The empirical studies (e.g. Goldstein et al., 2000) used binary variables that were constructed based on these narratives.

Consequently, some contributions strived to provide more data-driven measures of financial stress. Most of the existing stress indices are based on high-frequency data but they differ in the selected variables (bank capitalization, credit ratings, credit growth, interest rate spreads or volatility of different asset classes), country coverage and the aggregation method. An important advantage of continuous stress indicators is that it may reveal periods of small-scale stress that did not result in full-blown crisis and were neglected in studies based on binary crisis variables.

The Bank Credit Analyst (BCA) reports a monthly financial stress index (FSI) for the USA that is based on the performance of banking shares as compared to whole stock market, credit spreads and the slope of the yield curve, and the new issues of stocks, bonds and consumer confidence. JP Morgan calculates a Liquidity, Credit and Volatility Index (LCVI) based on seven variables: the US Treasury curve error (standard deviation of the spread between on-the-run and off-the-run US Treasury bills and bonds along the entire maturity curve), the 10-year US swap spread, US high-yield spreads, JP Morgan's Emerging Markets Bond Index, foreign exchange volatility (weighted average of 12-month implied volatilities of several currencies), the Chicago Board of Exchange equity volatility index VIX, and the JP Morgan Global Risk Appetite Index.

Illing and Liu (2006) develop a comprehensive FSI for Canada. Their underlying data covers equity, bond and foreign exchange markets as well as the banking sector. They use a standard measure and refined measure of each stress component, where the former refers to the variables and their transformations that are commonly found in the literature, while the latter incorporates

the adjustments that allow for better extraction of the information about stressful periods. They explore different weighting schemes to aggregate the individual series (factor analysis, size of a corresponding market on total credit in economy, variance-equal weighting). At last, they perform an expert survey to identify periods that were perceived as especially stressful, confirming that the FSI matches these episodes very well.

Carlson et al. (2008) propose for the Fed Board of Governors a framework similar to the option pricing model (Merton, 1974) that aims to provide a distance-to-default of the financial system, the so-called Index of Financial Health. The method uses the difference between the market value of a firm's assets and liabilities and the volatility of the asset's value in order to measure the proximity of a firm's assets being exceeded by its liabilities. They apply this measure to 25 of the largest US financial institutions, confirming its impact on capital investments in the US economy. The FED of Kansas City developed the Kansas City Financial Stress Index (Hakkio and Keeton, 2009) that is published monthly and is based on eleven variables (seven spreads between different bond classes by issuers, risk profiles and maturities, correlations between returns on stocks and Treasury bonds, expected volatility of overall stock prices, volatility of bank stock prices and a cross-section dispersion of bank stock returns) that are aggregated by principal component analysis.

Finally, the International Monetary Fund (IMF) recently published financial stress indices for various countries. Cardarelli et al. (2009) propose a comprehensive index based on high-frequency data where the price changes are measured with respect to its previous levels or trend value. The underlying variables are standardized and aggregated into a single index (FSI) using variance-equal weighting for each country and period. The FSI has three subcomponents: the banking sector (the slope of the yield curve, TED spread, the beta of banking sector stock), securities markets (corporate bonds spread, stock market returns and time-varying volatility of stock returns) and exchange rate (time-varying volatility of NEER changes). Balaskrishnan et al. (2009) modify the previous index to account for specific conditions of emerging economies; on one hand including the measure of exchange rate pressures (currency depreciation and decline in foreign reserves) and sovereign debt spread, on the other hand downplaying the banking sector measures (slope of the yield curve and TED spread).<sup>4</sup> We will use the former index given its comprehensiveness as well as its availability for different countries (see more details below).

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<sup>4</sup> The IMF Financial Stress Index has been recently applied by Melvin and Taylor (2009) to analyze the exchange rate crises.



## 3 Data and Empirical Methodology

### 3.1 The dataset

We use monthly data (quarterly for Sweden and Canada, more details below). The sample period slightly varies due to data availability (the US 1981:1 M – 2009:6M; the UK 1981:1M -2009:3M; Australia 1983:3M – 2009:5M; Canada 1981:1Q – 2008:4Q; Sweden 1984:2Q – 2009:1Q).

The dependent variable is typically the interest rate closely related to the official (censored) policy rate, in particular the federal fund rate (3M) for the USA, the discount rate (3-month treasury bills) for the UK, Canada and Sweden, and the 3-month RBA accepted bills rate for Australia. It is evident that policy rate is not necessarily the only instrument that the central bank uses, especially during the 2008-2009 global financial crisis when many unconventional measures were implemented (see Borio and Disyatat, 2009; Reis, 2010). So as to address this issue in terms of estimated policy rules, for robustness check we use the interbank interest rate (at a maturity of 3 months). While both rates are used in empirical papers on the monetary policy rules estimation without great controversy, the selection of the interest rate turns more delicate during financial stress periods (Taylor, 2008). While the former is more directly affected by genuine monetary policy decisions (carried by open market operations), the latter additionally includes liquidity conditions on the interbank markets and as such can be affected by some unconventional policies, though these are usually insulated (often intentionally) from policy interest rates.<sup>5</sup> This represents a drawback but also a potential advantage of this alternative dependent variable. On the one hand, the changes in official policy rate may not fully pass through into interbank interest rates, in particular when the perceived counterparty risk is too high and the credit spreads widen (see Taylor and Williams, 2009). On the other hand the interbank rate may also incorporate the impact of policy actions such as quantitative easing aimed to supply additional liquidity into the system.<sup>6</sup>

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<sup>5</sup> Borio and Disyatat (2009) characterize the unconventional policies as policies that affect the central bank's balance sheet size and composition and that can be insulated from the interest rate policy (so-called "decoupling principle"). One common example of such a policy (not necessarily used during the time of crisis) is a sterilized exchange rate intervention. Given that we aim not for a single episode of stress but rather want to identify whether monetary authorities deviated from its systematic pattern (the policy rule) during these periods (by responding to indicators of financial stress), we need to use a consistent measure of policy actions that are adjusted during the periods of financial stress, though other measures can be in place as well. Therefore, we assume that the monetary policy stance is fully reflected in the interest rate, and we are aware that it might be subject to a downward bias on the financial stress coefficient. The reader may want to interpret our results on the importance of financial stress on interest rate setting as a conservative estimate.

<sup>6</sup> There are other policy measures that can be used as a reactive or pre-emptive response to financial stress such as regulatory or administrative measures, although their effects are likely to appear only in the longer term and cannot be reasonably included in our empirical analysis.

The inflation is measured as a year-on-year change of CPI, apart from the United States where we use the personal consumption expenditures price index (PCE) and Sweden where the underlying inflation CPIX (excludes households' mortgage interest expenditure and the direct effects of changes in indirect taxes and subsidies from the CPI) is used.<sup>7</sup> The output gap is proxied by the gap of the seasonally adjusted industrial production index derived by the Hodrick-Prescott filter with smoothing parameter set to 14400. For Sweden and Canada, where we use quarterly data, the output gap was taken as reported in the OECD Economic Outlook (production function method based on NAWRU — non-accelerating wages rate of unemployment).

We proxy the financial stress by means of the FSI provided recently by the IMF (Cardarelli et al., 2009), which is a consistent measure for a wide range of countries but at the same time is comprehensive enough to track stress of a different nature. It includes the main components of financial stress in an economy and is available for a reasonably long period to be used for our empirical analysis (see Figure 1). We use both the overall index, which is a sum of seven components, as well as each sub-index and component separately:

- (i) Banking-related sub-index components: the inverted term spread (the difference between short-term and long-term government bonds), TED spread (the difference between interbank rates and the yield on treasury bills), banking beta (12-month rolling beta, which is a measure of the correlation of banking stock returns to total returns in line with the CAPM);
- (ii) Securities-markets related sub-index components: corporate bond spread (the difference between corporate bonds and long-term government bond yields), stock markets returns (monthly returns multiplied by -1), time-varying stock return volatility from the GARCH(1,1) model, and
- (iii) Foreign exchange related sub-index: the time-varying volatility of monthly changes in NEER, from the GARCH (1,1) model.

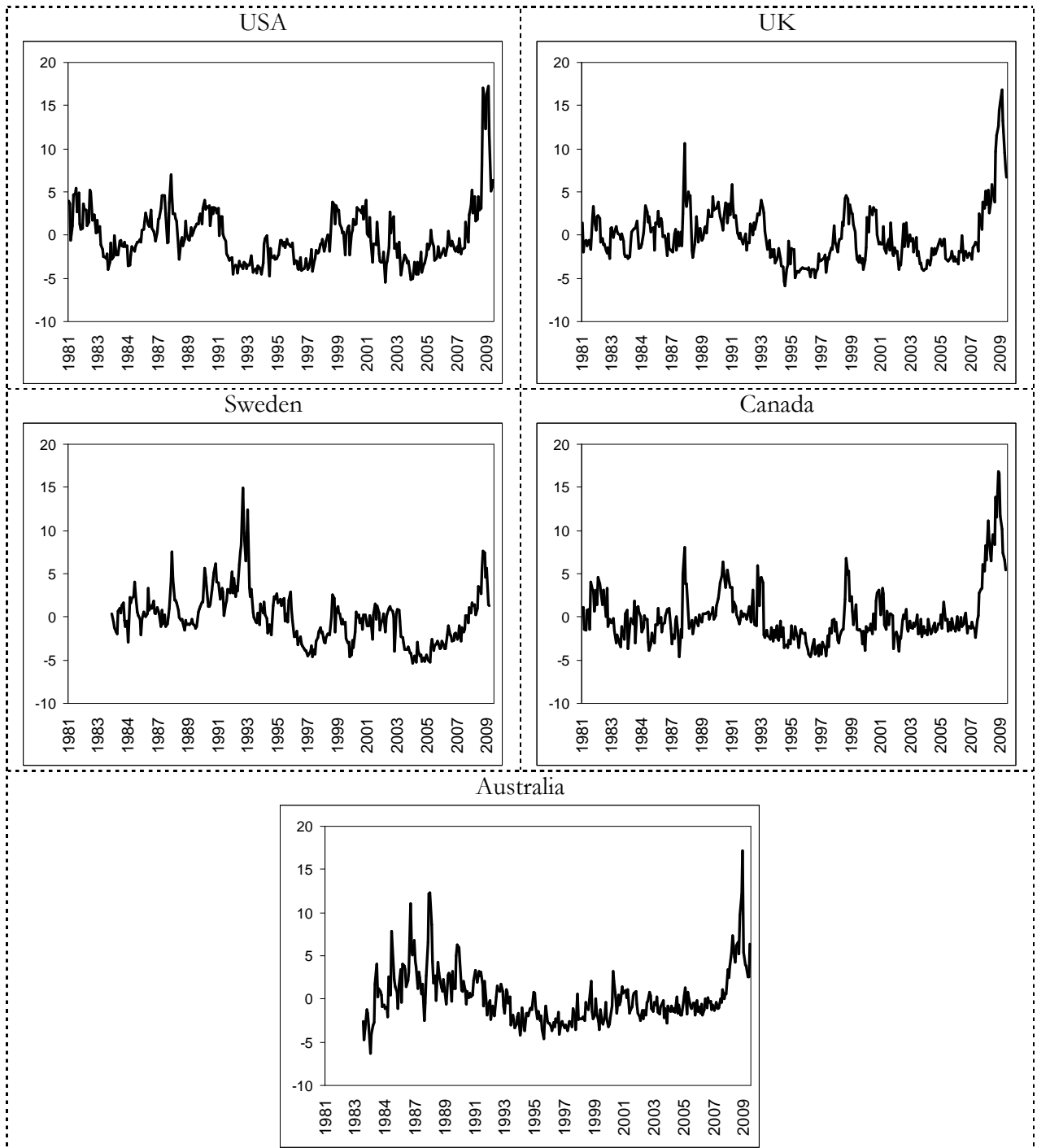
We have examined the various alternative methods of aggregating the components: simple sum, variance-equal weighting, and PCA weighting, but failed to uncover any systematic differences among these in terms of the values of the overall index and consecutively in the empirical results.

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<sup>7</sup> For Australia, the monthly CPI is not available because both the Reserve Bank of Australia and the Australian Bureau of Statistics only publish quarterly data. The monthly series was obtained using a linear interpolation of the CPI index.

The use of a composite index has a number of benefits. First, it approximates the evolution of financial stress caused by different factors and thus it is not limited to one specific type of instability. Second, the inclusion of additional variables into the stress index does not affect the evolution of the indicator markedly (Cardarelli et al., 2009). Third, the composition of the indicator allows breaking down the reactions of the central bank with respect to different stress sub-components. Nevertheless, one has to be cautious about the interpretation. The composite indicator might suggest a misleading interpretation as long as the stress is caused by variables not included within the FSI but rather are highly correlated with some sub-component. An example is the case of Sweden during the ERM crisis. At the time of the crisis, Sweden maintained a fixed exchange rate and Riksbank sharply increased interest rates in order to sustain the parity. However, this is not captured by the exchange rate sub-component of the FSI, which measures the exchange rate volatility, because the volatility was actually close to zero. A closer look at the data shows that this period of stress is captured by the inverted term structure; hence it is incorrectly attributed to bank stress. A similar pattern can be observed for the UK, where the FSI increases after the announcement of the withdrawal from the ERM.

Figure 1 – IMF Financial Stress Indicator



Note: The figure presents the evolution of the IMF stress index over time. Higher numbers indicate more stress (see Cardarelli et al., 2009).

### 3.2 The empirical model

Following Clarida et al. (1998, 2000), most empirical studies assume that the central bank sets the nominal interest rate in line with the state of the economy typically in a forward-looking manner:

$$r_t^* = \bar{r} + \beta \left( E \left[ \pi_{t+i} | \Omega_t \right] - \pi_{t+i}^* \right) + \gamma E \left[ y_{t+j} | \Omega_t \right] \quad (1)$$

where  $r_t^*$  denotes the targeted interest rate,  $\bar{r}$  is the policy neutral rate<sup>8</sup>,  $\pi_{t+i}$  stands for the central bank forecast of the yearly inflation rate  $i$  indicates periods ahead based on an information set  $\Omega_t$  used for interest rate decision available at time  $t$ , and  $\pi_{t+i}^*$  is the central bank's inflation target.<sup>9</sup>  $y_{t+j}$  represents a measure of the output gap.

Nevertheless, Eq. (1) was found to be too restrictive to provide a reasonable description of actual interest rate setting. Notably it does not account for the interest rate smoothing of central banks, in particular the practice when the central bank adjusts the interest rate sluggishly to the targeted value. This is in empirical studies tracked by the simple partial-adjustment mechanism:

$$r_t = \rho r_{t-1} + (1 - \rho) r_t^* \quad (2)$$

where  $\rho \in [0,1]$  is the smoothing parameter. There is an ongoing controversy as to whether this parameter represents genuine policy inertia or reflects empirical problems related to omitted variables, dynamics or shocks (see e.g. Rudebusch, 2006). The linear policy rule in Eq. (1) can be obtained as the optimal monetary policy rule in the LQ framework where the central bank aims only at price stability and economic activity. Bauducco et al. (2008) propose an NK model with a financial system where the monetary policy has privileged information (given its supervisory function) on the health of the financial sector. In such a setting, the common policy rule represented by Eq. (1) shall be augmented by variables representing the health of the financial sector. Following this contribution we consider the forward-looking rule where central banks may respond to a comprehensive measure of financial stress rather than stress in a particular segment (Bulíř and Čihák, 2008). Therefore, we substitute Eq. (2) into Eq. (1), eliminate unobserved forecast variables, pass the inflation forecast to the generic intercept  $\alpha$  and include measures of the financial stress described above, which results in Eq. (3):

$$r_t = (1 - \rho) \left[ \alpha + \beta \pi_{t+i} + \gamma y_{t+j} \right] + \rho r_{t-1} + \delta x_{t+k} + \varepsilon_t \quad (3)$$

While in Eq. (1) the term  $\alpha$  coincides with the policy neutral rate  $\bar{r}$ , its interpretation is not straightforward in our case. First, it is time varying as it encompass both changes in equilibrium real interest rate and inflation target. Second, the empirical model is augmented by an additional variable, the measure of financial stress. Note that the financial stress index  $x_{t+k}$  does not appear within the square brackets because it is not a variable that determines the target interest rate  $r_t^*$

<sup>8</sup> A policy-neutral rate is typically defined as the sum of the real equilibrium rate and expected inflation.

<sup>9</sup> An explicit definition of an inflation target exists only for countries with an inflation targeting (IT) regime. Most empirical studies assume, in line with Taylor (1993), that this target does not vary in time and can be omitted in the empirical model.

but it is rather a factor such as the lagged interest rate, i.e. it may explain why the actual interest rate  $r_t$  deviates from the target. Moreover, placing it in the regression on the same level as a lagged interest rate, we can directly test whether this variable representing ad-hoc policy decisions decreases the interest rate inertia  $\rho$  as suggested by Mishkin (2009). The common logic also suggest that the coefficients  $\rho$  and  $\delta$  shall move in the opposite direction because the central bank either smoothes the interest rate changes or adjusts the rates in the face of financial stress. In the latter case, the response is likely to be quick and substantial. We set  $i$  equal to 2,  $j$  equal to 0 and  $k$  equal to -1.<sup>10</sup> Consequently, the disturbance term  $\varepsilon_t$  is a combination of forecast errors and is thus orthogonal to all information available at time  $t$  ( $\Omega_t$ ).

The empirical studies on monetary policy rules have moved from using time-invariant estimates (Clarida et al., 1998) through sub-sample analysis (Taylor, 1999, Clarida et al., 2000) towards more complex methods that allow an assessment of the evolution in the conduct of monetary policy. There are two alternative methods to modeling structural changes in monetary policy rules that occur on an unknown date: (i) regime switching models, in particular the state-dependent Markov switching models (Valente, 2003; Assenmacher-Wesche, 2006; Sims and Zha 2006) and (ii) state-space models, where the changes are characterized by smooth transitions rather than abrupt switches (Boivin, 2006; Elkhoury, 2006; Kim and Nelson, 2006; Trecrocci and Vasalli, 2009). As argued in Baxa et al. (2010), we consider the second approach as preferable for the estimation of policy rules given that it is more flexible and allows the incorporation of a simple correction of endogeneity (Kim, 2006; Kim and Nelson, 2006), which is a major issue in forward-looking policy rules estimated from ex-post data.<sup>11</sup> The state-space approach or time-varying coefficient model seems also suitable when one wants to evaluate the effect of factors such as financial stress that can, for a limited length of time, alter (rather than permanently change) the monetary policy conduct.

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<sup>10</sup> Although the targeting horizon of central banks is usually longer (4-8 quarters), we prefer to proxy inflation expectations by inflation in  $t+2$  for the following reasons: First, the endogeneity correction requires a strong correlation between the endogenous regressor and its instruments. Second, the prediction error logically increases in longer horizons. In case of the output gap, we instead assume a backward-looking reaction. The reason is that in the absence of real time data we have to rely on the output gap construction of statistical methods. It is arguable that besides the prediction error there is also a construction error that both might be magnified if an unobserved forecast is substituted by the output gap estimate for future periods. At last, we assume that central bankers' response (if any) to financial stress is rather immediate (see Mishkin, 2009). Therefore, we use one lag of the FSI and its subcomponents in the benchmark case. However, as a robustness check we allow for different lags and leads, allowing the central bankers' response to be preemptive rather than reactive.

<sup>11</sup> The time-varying parameter model with the specific treatment of endogeneity is still relevant when real-time data are used (Orphanides, 2001). When the real-time forecast is not derived under the assumption that nominal interest rates will remain constant within the forecasting horizon (Boivin, 2006) or in the case of measurement error and heteroscedasticity (Kim et al., 2006).

The state-space models are commonly estimated by means of a maximum likelihood estimator via the Kalman filter or smoother. Unfortunately, this approach has several limitations that can turn problematic in applied work. First, the results are somewhat sensitive to the initial values of the parameters, which are usually unknown, especially in the case of variables whose impact on the dependent variable is not permanent and whose size is unknown, which is the case of financial stress and its effect on interest rates. Second, the log likelihood function is highly nonlinear and in some cases, optimization algorithms fail to minimize the negative of the log likelihood. In particular, it can either fail to calculate the Hessian matrix throughout the iterations process or, when the likelihood function is approximated to facilitate computations, covariance matrix of observation vector can get singular for provided starting values. The alternative is a moment-based estimator proposed by Schlicht (1981, 2005) and Schlicht and Ludsteck (2006), which is employed in our paper and briefly described below. This framework is flexible enough so as to incorporate the endogeneity correction proposed by Kim (2006).

Kim (2006) shows that the conventional time-varying parameter model delivers inconsistent estimates when explanatory variables are correlated with the disturbance term and proposes an estimator of the time-varying coefficient model with endogenous regressors. The endogeneity may arise not only in forward-looking policy rules based on ex-post data (Kim and Nelson, 2006, Baxa et al., 2010), but also in the case of variables that have a two-sided relation with monetary policy. Financial stress unquestionably enters this category. Following Kim (2006) we rewrite Eq. 3 as follows:

$$r_t = (1 - \rho_t) [\alpha_t + \beta_t \pi_{t+i} + \gamma_t y_{t+j}] + \rho_t r_{t-1} + \delta_t x_{t+k} + \varepsilon_t \quad (4)$$

$$\alpha_t = \alpha_{t-1} + \vartheta_{1,t}, \vartheta_{1,t} \sim i.i.d.N(0, \sigma_{\vartheta_1}^2) \quad (5)$$

$$\beta_t = \beta_{t-1} + \vartheta_{2,t}, \vartheta_{2,t} \sim i.i.d.N(0, \sigma_{\vartheta_2}^2) \quad (6)$$

$$\gamma_t = \gamma_{t-1} + \vartheta_{3,t}, \vartheta_{3,t} \sim i.i.d.N(0, \sigma_{\vartheta_3}^2) \quad (7)$$

$$\delta_t = \delta_{t-1} + \vartheta_{4,t}, \vartheta_{4,t} \sim i.i.d.N(0, \sigma_{\vartheta_4}^2) \quad (8)$$

$$\rho_t = \rho_{t-1} + \vartheta_{5,t}, \vartheta_{5,t} \sim i.i.d.N(0, \sigma_{\vartheta_5}^2) \quad (9)$$

$$\pi_{t+i} = Z'_{t-m} \xi + \sigma_{\varphi} \varphi_t, \varphi_t \sim i.i.d.N(0, 1) \quad (10)$$

$$y_{t+j} = Z'_{t-m} \psi + \sigma_v v_t, v_t \sim i.i.d.N(0, 1) \quad (11)$$

$$x_{t+k} = Z'_{t-m} \theta + \sigma_l l_t, l_t \sim i.i.d.N(0, 1) \quad (12)$$

The measurement Eq. (4) of the state-space representation is the monetary policy rule. The transitions in Eqs. (5)-(9) describes the time-varying coefficients as a random walk process without drift.<sup>12</sup> Eqs. (10)-(12) track the relationship between the potentially endogenous regressors ( $\pi_{t+i}$ ,  $y_{t+j}$  and  $x_{t+k}$ ) and their instruments,  $Z_t$ . We use the following instruments:  $\pi_{t-1}$ ,  $\pi_{t-12}$  ( $\pi_{t-4}$  for CAN and SWE),  $y_{t-1}$ ,  $y_{t-2}$ ,  $r_{t-1}$ , and when  $k \geq 0$  also  $x_{t-1}$  and  $x_{t-2}$ ). Following Kim (2006), we assume that the parameters in Eqs. (10)-(12) are time-invariant. The correlation between the standardized residuals  $\varphi_t$ ,  $\nu_t$  and  $\zeta_t$  and the error term  $\varepsilon_t$  is  $\kappa_{\varphi,\varepsilon}$ ,  $\kappa_{\nu,\varepsilon}$  and  $\kappa_{\zeta,\varepsilon}$  respectively (note that  $\sigma_\varphi$ ,  $\sigma_\nu$ , and  $\sigma_\zeta$  are the standard errors of  $\varphi_t$ ,  $\nu_t$  and  $\zeta_t$ , respectively). The consistent estimates of the coefficients in Eq. (4) are obtained in two steps. In the first step, we estimate Eqs. (10)-(12) and save the standardized residuals  $\varphi_t$ ,  $\nu_t$  and  $\zeta_t$ . In the second step, we estimate Eq. (13) below along with Eqs. (5)-(9). Note that Eq. (13) now includes bias correction terms, i.e. (standardized) residuals from Eqs. (10)-(12), to address the aforementioned endogeneity of the regressors. Consequently, the estimated parameters in Eq. (13) are consistent, as  $e_t$  is uncorrelated with the regressors.

$$r_t = (1 - \rho_t) [\alpha_t + \beta_t \pi_{t+2} + \gamma_t y_{t-1}] + \rho_t r_{t-1} + \delta_t x_{t-1} + \kappa_{\zeta,\varepsilon} \sigma_{\varepsilon,t} \zeta_t + \kappa_{\nu,\varepsilon} \sigma_\varepsilon \nu_t + \kappa_{\varphi,\varepsilon} \sigma_\varepsilon \varphi_t + \zeta_t$$

$$, \quad \zeta_t \sim N(0, (1 - \kappa_{\nu,\varepsilon}^2 - \kappa_{\varphi,\varepsilon}^2 - \kappa_{\zeta,\varepsilon}^2) \sigma_{\varepsilon,t}^2)$$
(13)

As we noted before, instead of the standard framework for second-step estimation, the maximum likelihood estimator via the Kalman filter (Kim, 2006), we use an alternative estimation framework, the ‘‘varying coefficients’’ (VC) method (Schlicht, 1981; Schlicht, 2005; Schlicht and Ludsteck, 2006). This method is a generalization of the ordinary least squares approach that, instead of minimizing the sum of the squares of residuals  $\sum_{t=1}^T \varepsilon^2$ , uses the minimization of the weighted sum of squares:

$$\sum_{t=1}^T \zeta^2 + \theta_1 \sum_{t=1}^T \vartheta_1^2 + \theta_2 \sum_{t=1}^T \vartheta_2^2 + \dots + \theta_n \sum_{t=1}^T \vartheta_n^2$$
(14)

where the weights  $\theta_i$  are the inverse variance ratios of the regression residuals  $\zeta_t$  and the shocks in time-varying coefficients  $\vartheta_t$ , that is  $\theta_i = \sigma^2 / \sigma_i^2$ . This approach balances the fit of the model and the parameter stability. Additionally, the time averages of the regression coefficients, estimated by a weighted least squares estimator, are identical to their GLS estimates of the

<sup>12</sup> Note that while a typical time-invariant regression assumes that  $a_t = a_{t-1}$ , in this case it is assumed that  $E[a_t] = a_{t-1}$ .



corresponding regression with fixed coefficients, that is  $\frac{1}{T} \sum_{t=1}^T \hat{a}_t = \hat{a}_{GLS}$ .<sup>13</sup> The method is useful in our case because:

- (i) it does not require knowledge of initial values even for non-stationary variables prior to the estimation procedure. Instead, both the variance ratios and the coefficients are estimated simultaneously,
- (ii) the property of the estimator, that the time averages of estimated time-varying coefficients are equal to its time-invariant counterparts, permits the easy interpretation of the results in relation to time-invariant results,
- (iii) it coincides with the MLE estimator via the Kalman filter if the time series are sufficiently long and if the variance ratios are properly estimated.<sup>14</sup>

However, this method suffers certain limitations of its own. In particular: (a) it requires that the time-varying coefficients are described as random walks and (b) the shocks in time-varying coefficients  $\vartheta_t$  are minimized (see Eq. (14)). While this does not represent a major problem for the estimation of the coefficients of common variables such as inflation, where the monetary policy response is permanent, it can lead to a loss of some information about ad-hoc response factors in monetary policy-making that are considered by central bankers only infrequently but once they are in place the policy response can be substantial. A financial stress indicator  $x_{t+k}$  seems to be this kind of factor. The way to deal with this problem is the estimation-independent calibration of the variance ratios in Eq. (14) such that the estimated coefficient is consistent with economic logic, i.e. it is mostly insignificant and it can turn significant (with no prior restriction on its sign) during the periods of financial stress, i.e. when the financial stress indicator is different from zero. Therefore, we first estimate Eq. (13) using the VC method first and study whether the resulting coefficients at the FSI correspond to economic intuition, and especially whether the coefficient is not constant or slowly moving (a so-called pile-up problem, see Stock and Watson, 1998). When this problem occurs, we compare the results with models where  $\kappa$  belongs to  $(-2, -1, 0, 1, 2)$  and calibrates the variance ratios in Eq. (13) by the variance ratios

<sup>13</sup> See Schlicht and Ludsteck (2006) and Baxa et al. (2010) for more details.

<sup>14</sup> The Kalman filter as implemented in common econometric packages typically uses the diffusion of priors for its initiation but it still produces a lot of corner solutions and often it does not achieve convergence. Schlicht and Ludsteck (2006) compare the performance of the moment estimator and the Kalman smoother in terms of the mean squared error on simulated data and they conclude that the moment estimator outperforms the Kalman filter on small samples with a size of up to 100 observations. For comparison, we estimated Eq. (13) using the conventional Kalman filter in the GROCER software using the function `typ` (Dubois-Michaux, 2009). We parameterized the model by initial conditions taken from the OLS estimates of the parameters on the full sample and the initial forecast error covariance matrix set to 0. The matrix of the residuals of time-varying coefficients is assumed to be diagonal like in the VC method. The results were very similar to those obtained from the VC method when the estimated variances were the same in both methods.

estimated for the model with the largest variances in the FSI. This step was necessary for Australia and Sweden. The Taylor rule coefficients were compared with the initial estimates and they were consistent in both cases.<sup>15</sup>

The results of our empirical analysis should reveal whether central banks adjusted its interest rate policy in the face of financial stress. However, the time-varying framework also allows inferring whether any response to financial stress led to the temporal dismissal of other targets, in particular the inflation rate. Therefore, we are mainly interested in the evolution of the financial stress coefficient  $\delta_t$ . We expect it to be mostly insignificant or zero given that episodes of financial stress are rather infrequent and even if they occur the monetary authorities may not always respond to them. Moreover, the size of the estimated coefficient does not have any obvious interpretation since the FSI is a composite indicator normalized to have a zero mean. Consequently, we define the stress effect as a product of the estimated coefficient  $\delta_t$  and the value of IMF financial stress index  $x_{t+k}$ . The interpretations of the stress effect is straightforward: it shows the magnitude of interest rate reactions to financial stress in percentage points or, in other words, the deviation from the target interest rate as implied by the macroeconomic variables due to the response to financial stress.

## 4 Results

This section summarizes our results on the effect of financial stress on interest rate setting. First, the results on the effect of the overall measure of financial stress on interest rate setting are presented. Second, the effect of specific components of financial stress on monetary policy is examined. Third, we briefly comment on the monetary policy rule estimates that served as the input for the assessment of financial stress effects. Finally, we perform a series of robustness checks.

Figure 2 presents our results on the effect of financial stress on interest rate setting in all five countries (labeled as *financial stress effect* hereinafter). Although there is some heterogeneity across countries, some global trends on the effect of financial stress are apparent. While in good times, such as in the second half of the 1990s, financial stress has virtually no effect on interest rate

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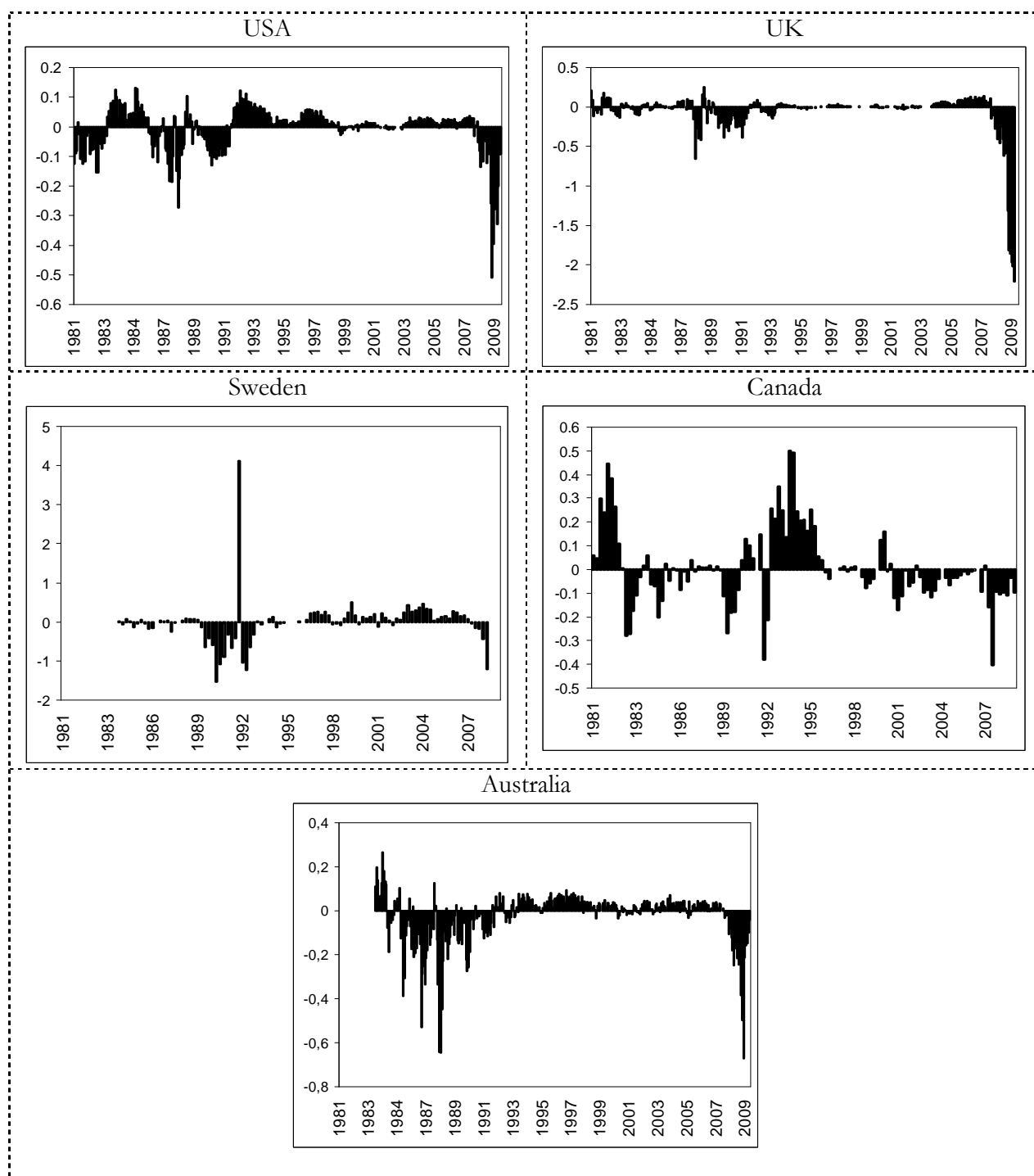
<sup>15</sup> Stock and Watson (1998) propose a medium unbiased estimator for variance in the time-varying parameter model but its application is straightforward only in the case of one time-varying coefficient and, more importantly, it requires the variables being stationary.

setting or it is slightly positive,<sup>16</sup> the reaction of monetary authorities to financial stress was highly negative during the 2008-2009 global financial crisis. While the previous evidence on the effect of financial stress on monetary policy is somewhat limited, our results broadly confirm the time-invariant findings of Cecchetti and Li (2008), which show that the US Fed adjusted the interest rates to the procyclical impact of bank capital requirements in 1989-2000. Similarly, Belke and Klose (2010) estimate the Taylor rule on two sub-samples (before and during the 2008-2009 global financial crisis) and find that the Fed reacted systematically not only to inflation and output gap, but to asset prices, credit and money as well.

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<sup>16</sup> Note that the positive effect of financial stress on interest rate setting is to some extent a consequence of scaling the financial stress indicator; its zero value corresponds to a long run average stress. Hence, we do not place much attention onto the positive values of stress unless caused by the temporarily positive and significant regression coefficient associated with the FSI.

Figure 2 – The Effect of Financial Stress on Interest Rate Setting



Notes: The figure depicts the evolution of the financial stress effect. The stress effect (y-axis) is defined as the product of the estimated coefficient on the financial stress indicator in monetary policy rule and the value of the IMF financial stress indicator. The stress effect shows the magnitude of the interest rate reaction to financial stress in percentage points.

The size of financial stress effects on interest rate setting during the recent financial crisis is somewhat heterogeneous with the strongest reaction found for the UK. The results suggest that all central banks, except the Bank of England, kept its policy rates by about 50-100 basis points

lower, as compared to the counterfactual of no reaction to financial stress. The size of this effect for the UK is assessed to be about three times stronger (i.e. 250 basis points). This implies that about 50 percent of the overall policy rate decreased during the recent financial crisis was motivated by the financial stability concerns in the UK (10-30 percent in the remaining sample countries), while the remaining half falls on unfavorable developments in domestic economic activity. This finding is interesting when confronted with the BoE's very low consideration of expected inflation over the last decade (found Baxa et al., 2010, using the time-varying model and in Taylor and Davradakis, 2006, in the context of the threshold model) that further decreased during the current crisis similarly as for the USA but less so for the other central banks. It is also evident that the magnitude of the response is unusual for all five central banks. Yet, the results for Australia, Canada and Sweden show that a similar magnitude of the response to financial stress recorded during the recent financial crisis was already seen in previous periods of high financial stress.

Given that the 2008-2009 global crisis occurred right at the end of our sample (there is a peak in the stress indicator of 5 standard deviations that has not returned to normal values yet), we have performed an additional check to avoid possible end-point bias. In particular, we have run our estimation excluding the observation from the period of 2008-2009 crisis: These results (are available upon request) confirmed the robustness of the reported findings. With regards to the effect of the current crisis, the largest uncertainty is associated with the results for Canada, for which the shortest data sample was available, and it ends in the fourth quarter of 2008. When the possibility of a preemptive reaction of the central bank to financial stress is considered, the effect of financial stress in the current crisis is somewhere at 1-2 percent (see Appendix 3). These additional results suggest the response of the Bank of Canada is rather underestimated.

The question of which components of financial stress influence interest rate setting is addressed in Figure 3. Some heterogeneity across countries is again apparent; although it seems that bank stress and stock market stress dominated the central bankers in less open economies. On the other hand, exchange rate stress matters in more open economies such as Canada and Sweden.

More specifically, the US Fed seemed to be worried about financial instability, especially during the 1980s. We can see that the main concern in the early 1980s was banking stress, which is arguably related to the Savings and Loans crisis. Another concern was that of stock market stress

in particular during the stock market crash of 1987 when interest rates were lower by 30 b.p. with respect to the benchmark case.

The Bank of England was, in general, much more perceptive to financial stress. We find its response mainly to stock market stress again notably in 1987. Interestingly, we find little response to exchange rate stress, not even during the 1992 ERM crisis. Nevertheless, it has to be emphasized that the interest rate reaction to speculative attack was subdued in comparison to, for example, the Riksbank (Buiters et al., 1998). The coefficient at the FSI remains constant until the devaluation of the pound sterling in September 1992. Since then the effect of financial stress on interest rate setting approaches zero from originally negative values. Besides this, the response of the Bank of England to inflation has decreased. From this perspective, it seems the pound sterling's withdrawal from the ERM allowed for both a more rule-based and less restrictive monetary policy.

The reaction of the Riksbank to the ERM crisis was different. First, after a series of speculative attacks on the Swedish krona in mid-September 1992, the Riksbank still tried to keep the current fixed exchange rate in place and the marginal interest rate jumped up 500 percent in order to offset the outflow of liquidity and other speculative attacks (see the large positive stress effect on the interest rate in 1992 in Figure 2). However, not even such an increase was sufficient and the fixed exchange rate had to be abandoned later in November.<sup>17</sup>

The Reserve Bank of Australia significantly loosened its policy during the 1980s, which can be attributed to the stress in the banking sector with an exception of the reaction to the stock market crash in 1987 (see Figure 3).

The exchange rate as well as bank stress seems to matter for interest rate considerations at the Bank of Canada. Interestingly, the results suggest that the Bank of Canada often responded to higher exchange rate stress by monetary tightening. A possible explanation for this finding could be that the Canadian central bank tightened the policy when the currency stabilized at the level that the monetary authority considered to be undervalued.

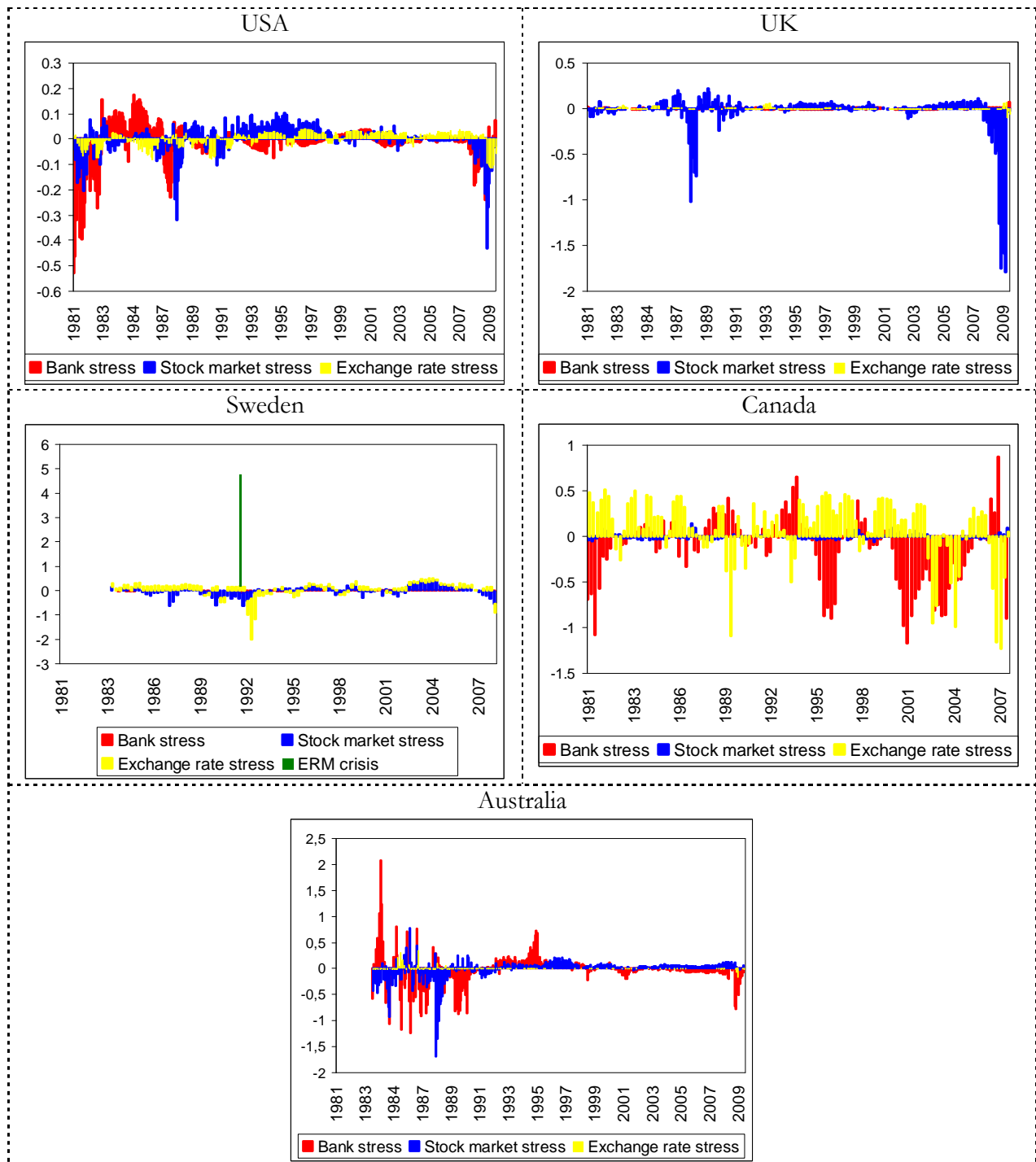
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<sup>17</sup> For Sweden, we add a dummy variable for the third quarter of 1992 (ERM crisis) to Eq. 13. At this time the Swedish central bank forced upward short-term interest rates in an effort to keep the krona within the ERM. From the perspective of our model, it was a case of a strong positive reaction to the actual stress that lasted only one period. When this dummy variable was not included, the model with a lagged value of the FSI was unable to show any link between stress and the interest and estimates of other coefficients were inconsistent with economic intuition.

We would like to highlight a comparison of Figures 2 and 3. First, it should be noted that the positive response to one stress subcomponent may cancel out against a negative response to another one, making the response to the overall stress negligible (as in the case of Canada). Second, the stress effects related to individual subcomponents need not necessarily sum up to the stress effect related to the entire FSI.

All in all, the results suggest that the central bank tends to react to financial stress and different components of financial stress matter in different time periods. The effect of financial stress on interest rate setting is found to be virtually zero in good times and economically sizable during the period of high financial stress.

**Figure 3 – The Effect of Financial Stress Components on Interest Rate Setting:  
Bank Stress, Exchange Rate Stress and Stock Market Stress**



Notes: The figure depicts the evolution of the components of the financial stress effect, namely bank stress effect, exchange rate stress effect and stock market stress effect. The stress effect (y-axis) is defined as the product of the estimated coefficient on the given component of the financial stress indicator in monetary policy rule and the value of the corresponding component of the IMF financial stress indicator. The stress effect shows the magnitude of the interest rate reaction to financial stress in percentage points.



Next, we briefly comment on our monetary policy rule estimates. The plot of the evolution of estimated parameters over time for all countries is available in Appendix 1. First, these results indicate that the interest rate smoothing is much lower than what time-invariant estimates of monetary policy rules typically suggest (see for example, Clarida et al., 1998, 2000). Our estimates of interest rate smoothing seem to be reasonable given the recent critique of Rudebush (2006), who argues that the degree of interest rate smoothing is rather low. Moreover, for some central banks such as the RBA and the BoE in 2010 or the Sveriges Riksbank in late 1980 we find support for Mishkin's (2009, 2010) argument that central banks are less inertial during the crisis.<sup>18</sup> Second, the response of interest rates on inflation is particularly strong during the periods when central bankers want to break the record of high inflation such as in the UK or in Australia at the beginning of 1980s and it becomes less aggressive in the low inflation environment with subdued shocks. Third, some central banks are also found to react to output gap developments with the estimated parameter to be slightly positive on average (see more detailed results in Baxa et al., 2010).

Finally, we perform a battery of robustness checks. First, following the argument put forward above, we use interbank interest rates as a dependent variable. These results are reported in Figures A.2.1-A.2.2. We can see that the overall stress effect on the interbank rate is larger for the US during the current crisis, where it explains 2 percent of the decrease of the interbank interest rate. For Sweden, we have found a strong positive effect of exchange rate volatility in the late 1980s; this might be linked to the aim of the central bank to keep the exchange rate fixed. In other cases, there is no substantial difference between the benchmark results and results obtained using this alternative dependent variable.

Second, in the benchmark model and all the results reported so far we use the first lag of the FSI in policy rule estimation. We stimulate this choice by the use of monthly data, the frequency of monetary policy meetings of most central bank boards and the assumption that the policy actions are likely to be implemented in a timely fashion. In addition, we employ different lags and leads, in the latter case allowing the policy to be preemptive rather than reactive. In this case, we use the future realized value of the FSI as a proxy of a central bank's expectation (in a similar manner as to how it is routinely executed for inflation expectations) and consequently treat the FSI as an endogenous variable (see Figure A.3.1 for the results). In order to get comparable results, we calibrate the variance ratios by the same values as in the baseline specification. Although we find

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<sup>18</sup> The correlation coefficient of the estimated time-varying coefficient of a lagged interest rate  $\rho$  and the financial stress index  $\delta$  is -0.79 for Australia, 0.21 for Canada, -0.20 for Sweden, -0.68 for the UK and 0.60 for the US

rather mixed evidence on preemptive policy actions, which can be also related to the inadequacy of proxying the expected values of financial stress by actual values of the financial stress indicator as well as the fact that a central bank might not react to the stress preemptively, the reaction to financial stress in the current crisis is strongly negative for both expected or observed stress.

Third, we further break down the FSI sub-indices to each underlying variable to evaluate their individual contribution.<sup>19</sup> The corresponding stress effects appear in Figures A.4.1-A.4.2. Breaking down stock-market related stress, we find that the US Fed and the BoC react to the corporate bond spread, whereas the BoE and Sveriges Riksbank are more concerned by stock returns and volatility. While the RBA seem to be concerned with both corporate bond spreads and stock market volatility in the 1980s, the role of stock-related stress had substantially decreased by then. As far as bank-related stress is concerned, the TED spread plays a major role in all countries apart from the UK where the largest proportion of the effect on the interest rate can be attributed to an inverted term structure.

Fourth, since the verifications related to our econometric framework to obvious alternatives such as, first, the use of a maximum likelihood estimator via the Kalman filter instead of the moment-based time-varying coefficient framework of Schlicht and, second, the use of a Markov-switching model instead of a state-space model were provided in Baxa et al. (2010), we estimate simple time-invariant monetary policy rules for each country by the generalized method of moments, including various subsamples. This simple evidence reaffirms that the analyzed central banks seem to pay attention to overall financial stress in the economy. The FSI is statistically significant, with a negative sign of a magnitude between 0.05-0.20 for all countries. On the other hand, the coefficient of its sub-components often are not, and the exchange rate subcomponent in some cases has a positive sign. These results, which are available upon request, confirm that to understand the interest rate adjustment to financial stress, one should rely on a model allowing a differential response across time.

## 5 Concluding Remarks

The 2008-2009 global financial crisis awoke a significant interest in exploring the interactions between monetary policy and financial stability. This paper aimed to examine in a systematic manner whether and how the monetary policy of selected main central banks (US Fed, the Bank

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<sup>19</sup> This applies only to the banking and the stock market sub-components because the foreign exchange sub-component is represented by a single variable.

of England, Reserve Bank of Australia, Bank of Canada and Sveriges Riksbank) responded to episodes of financial stress over the last three decades. Instead of using individual alternative measures of financial stress in different markets, we employed the comprehensive indicator of financial stress recently developed by the International Monetary Fund, which tracks overall financial stress as well as its main subcomponents, in particular banking stress, stock market stress and exchange rate stress.

Unlike a few existing empirical contributions that aim to evaluate the impact of financial stability concerns on monetary policymaking, we adopt a more flexible methodology that allows for the response to financial stress (and other macroeconomic variables) to change over time as well as deals with potential endogeneity (Kim and Nelson, 2006). The main advantage of this framework is that it does not only enable testing whether the central banks responded to financial stress at all, but it also detects the periods and types of stress that were the most worrying for monetary authorities. Our results indicate that central banks truly change their policy stance in the face of financial stress, but that the magnitude of such responses varies substantially over time. As expected, the impact of financial stress on interest rate setting is essentially zero most of the time when the levels of stress are very moderate. However, most central banks loosen monetary policy when the economy faces high financial stress. There is a certain cross-country and time heterogeneity when we look at central banks' considerations of specific types of financial stress. While most central banks seem to respond to stock market stress and bank stress, exchange rate stress is found to drive the reaction of central banks only in more open economies

Consistently with our expectations, the results indicate that a sizeable fraction of monetary policy easing during the 2008-2009 financial crisis can be explained by a direct response to the financial stress above what could be attributed to a decline in inflation expectation and output below its potential. Although, the size of the financial stress effect differs by country. The result suggests that all central banks, except the Bank of England, kept their policy rates at 50 basis points lower on average solely due to financial stress present in the economy. Interestingly, the size of this effect for the UK is assessed at about five times stronger (i.e. 250 basis points). This implies that about 50 percent of the overall policy rate decrease during the recent financial crisis was motivated by financial stability concerns in the UK (10-30 percent in the remaining sample countries), while the remaining half falls on unfavorable developments in domestic economic activity. For the US Fed, the macroeconomic developments themselves (a low-inflation environment and an output substantially below its potential) explain the major fraction of the

policy interest rate decreases during the crisis, leaving the further response to financial stress to be constrained by zero interest rate bound.

All in all, our results point to the usefulness of augmenting the standard version of monetary policy rule by some measure of financial conditions to get a better understanding of the interest rate setting process, especially when financial markets are not stable. The empirical results suggest that the main central banks considered in this study altered the course of their monetary policy in the face of financial stress. The recent crisis seems truly to be an exceptional period in the sense that the response to financial instability was substantial and coincided in all analyzed countries, which is evidently related to intentional policy coordination absent in previous decades. However, we have also seen that previous idiosyncratic episodes of financial distress were, at least in some countries, followed by monetary policy responses of similar if not higher magnitude.

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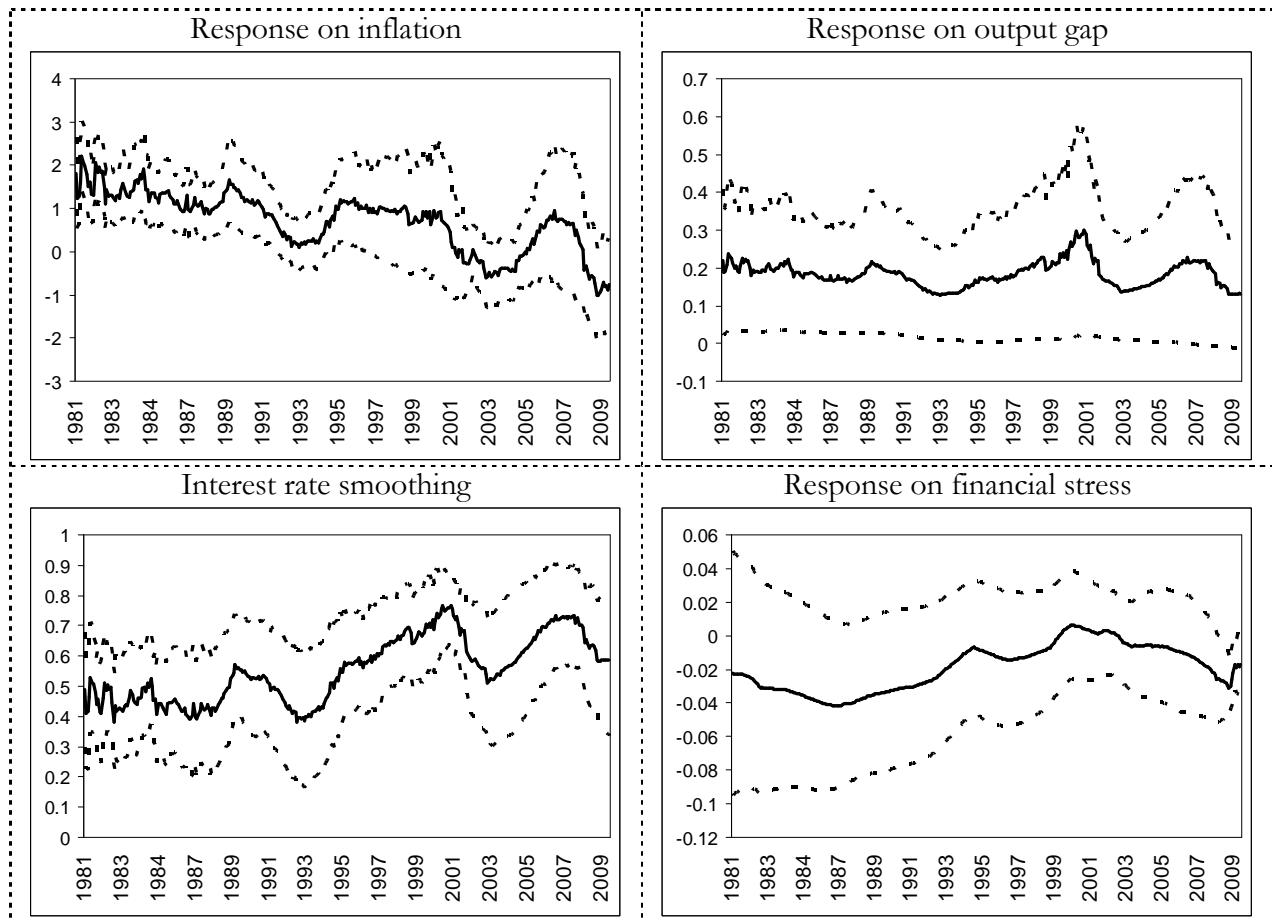
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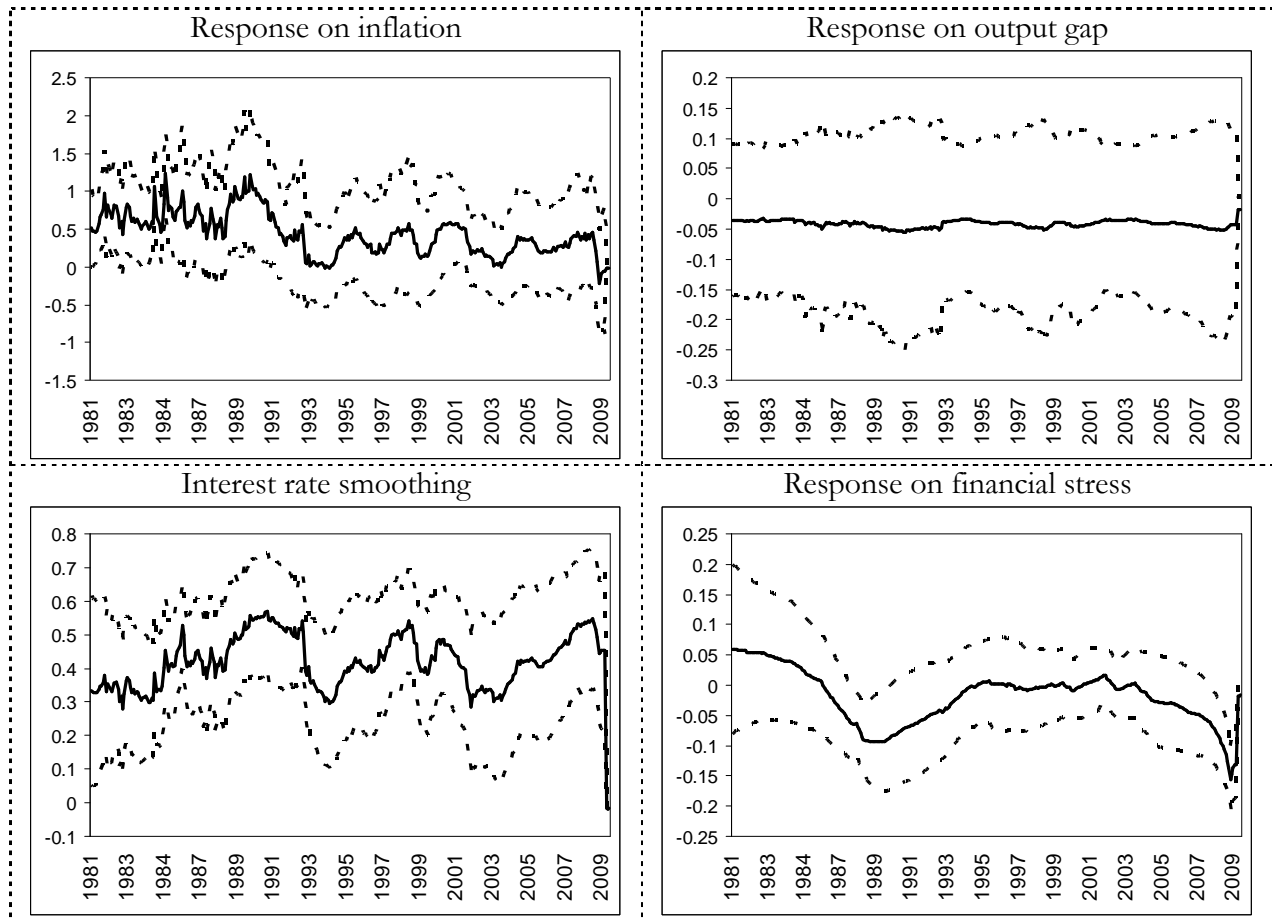
# Appendix 1

Figure A.1.1 – Time-Varying Monetary Policy Rules: U.S.



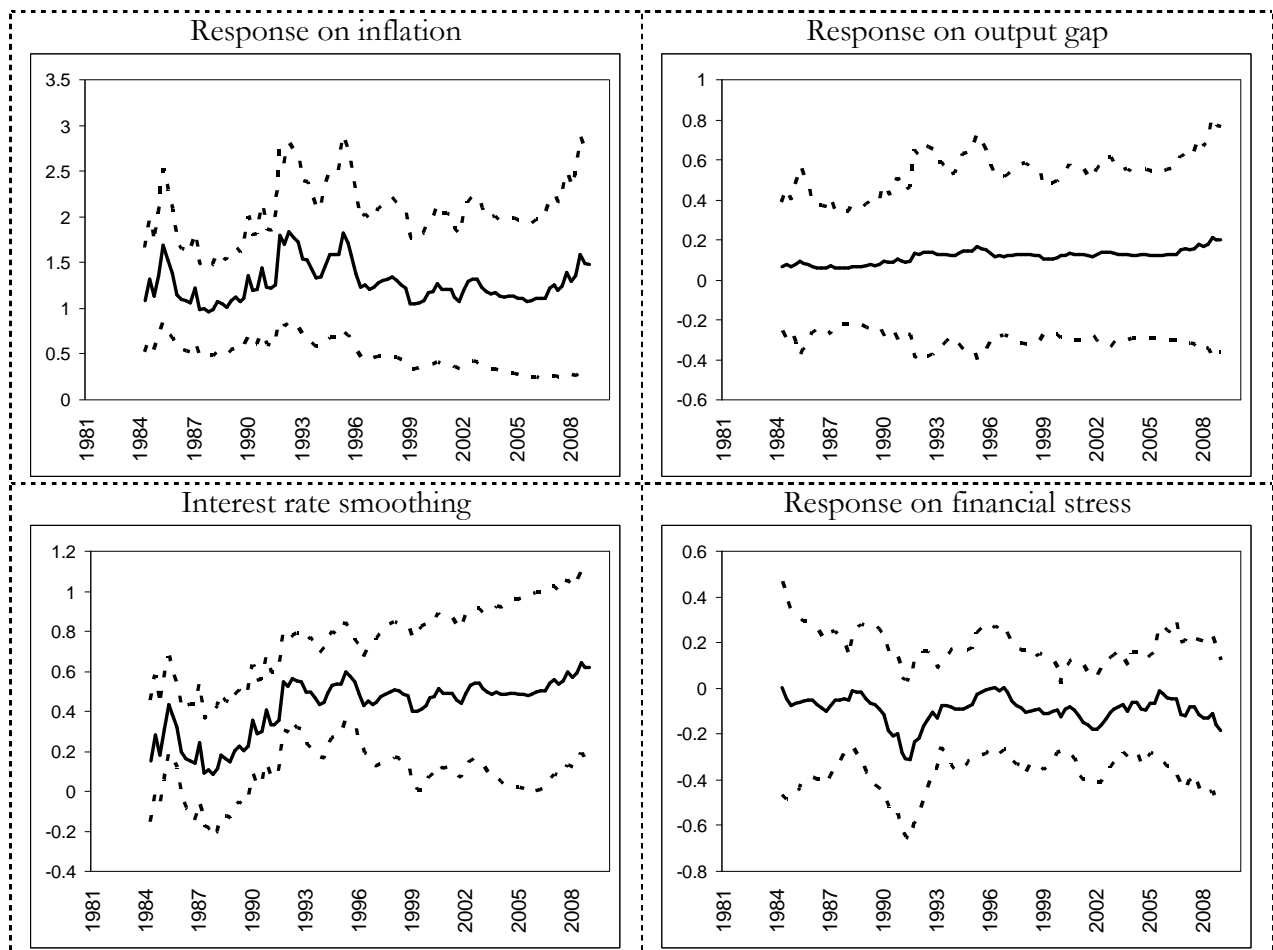
Note: The estimated coefficients of time-varying monetary policy rule are depicted with a 95% confidence interval.

Figure A.1.2 – Time-Varying Monetary Policy Rules: U.K.



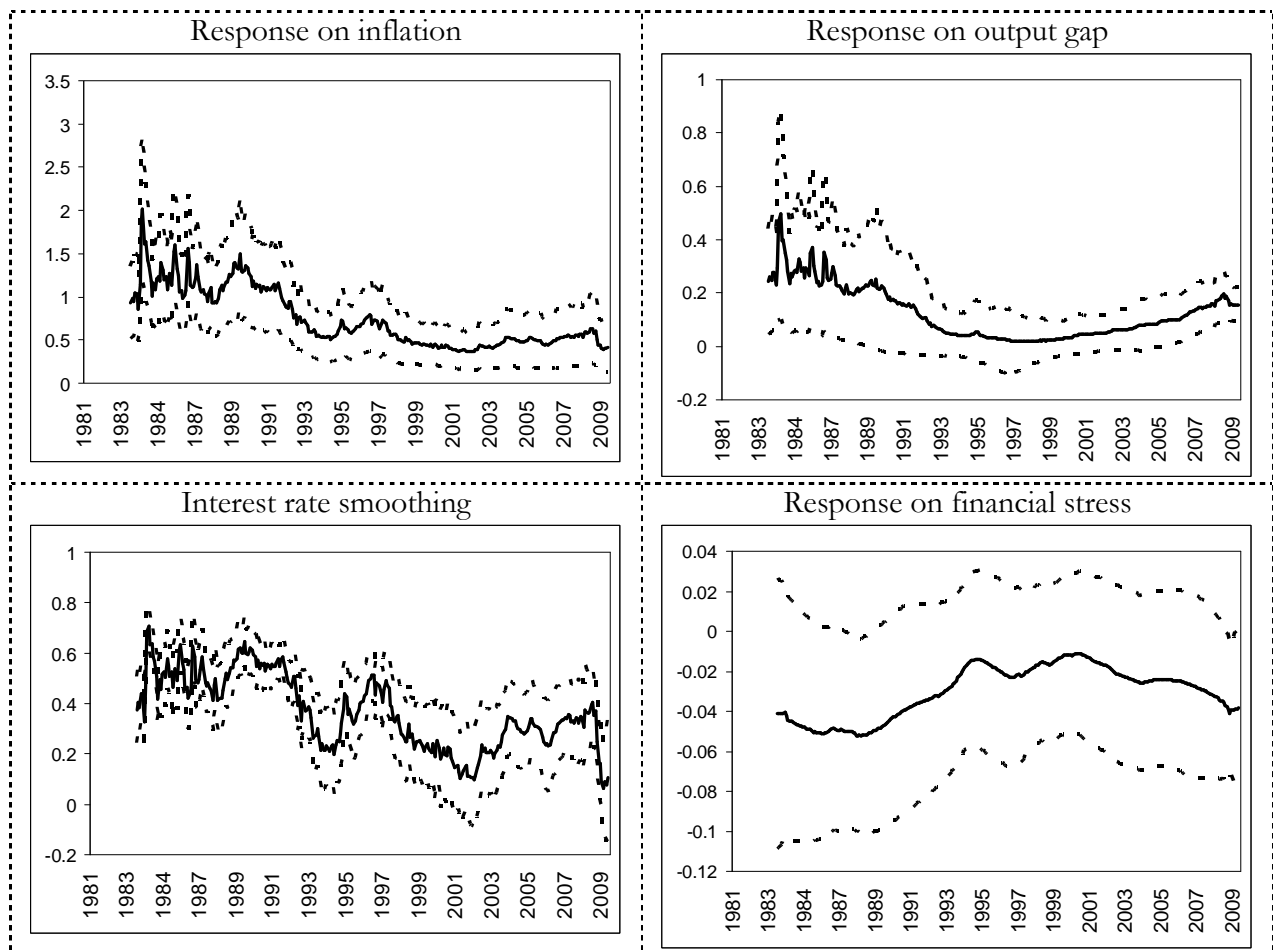
Note: The estimated coefficients of time-varying monetary policy rule are depicted with a 95% confidence interval.

**Figure A.1.3 – Time-Varying Monetary Policy Rules: Sweden**



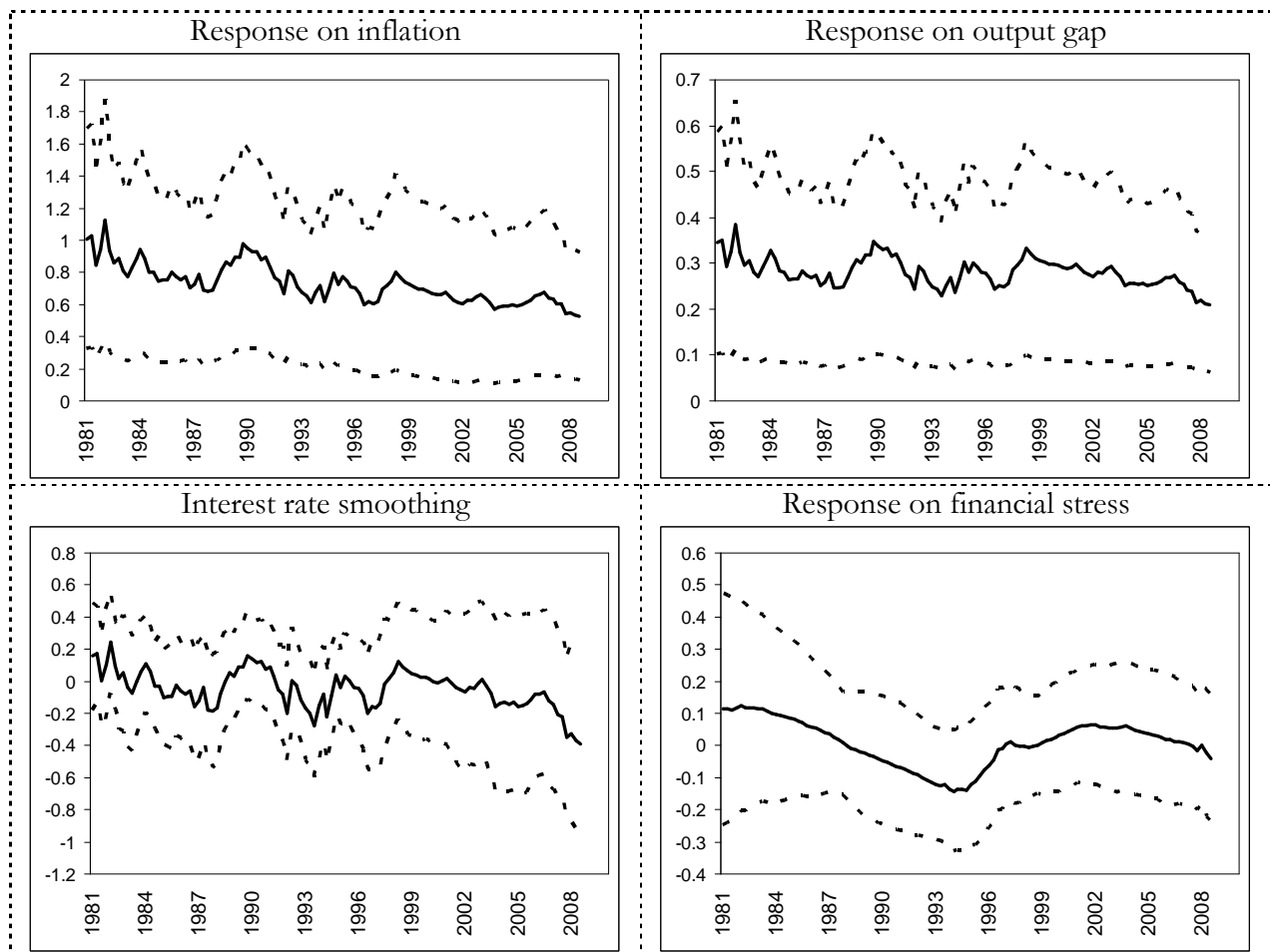
Note: The estimated coefficients of time-varying monetary policy rule are depicted with a 95% confidence interval.

Figure A.1.4 – Time-Varying Monetary Policy Rules: Australia



Note: The estimated coefficients of time-varying monetary policy rule are depicted with a 95% confidence interval.

**Figure A.1.5 – Time-Varying Monetary Policy Rules: Canada**

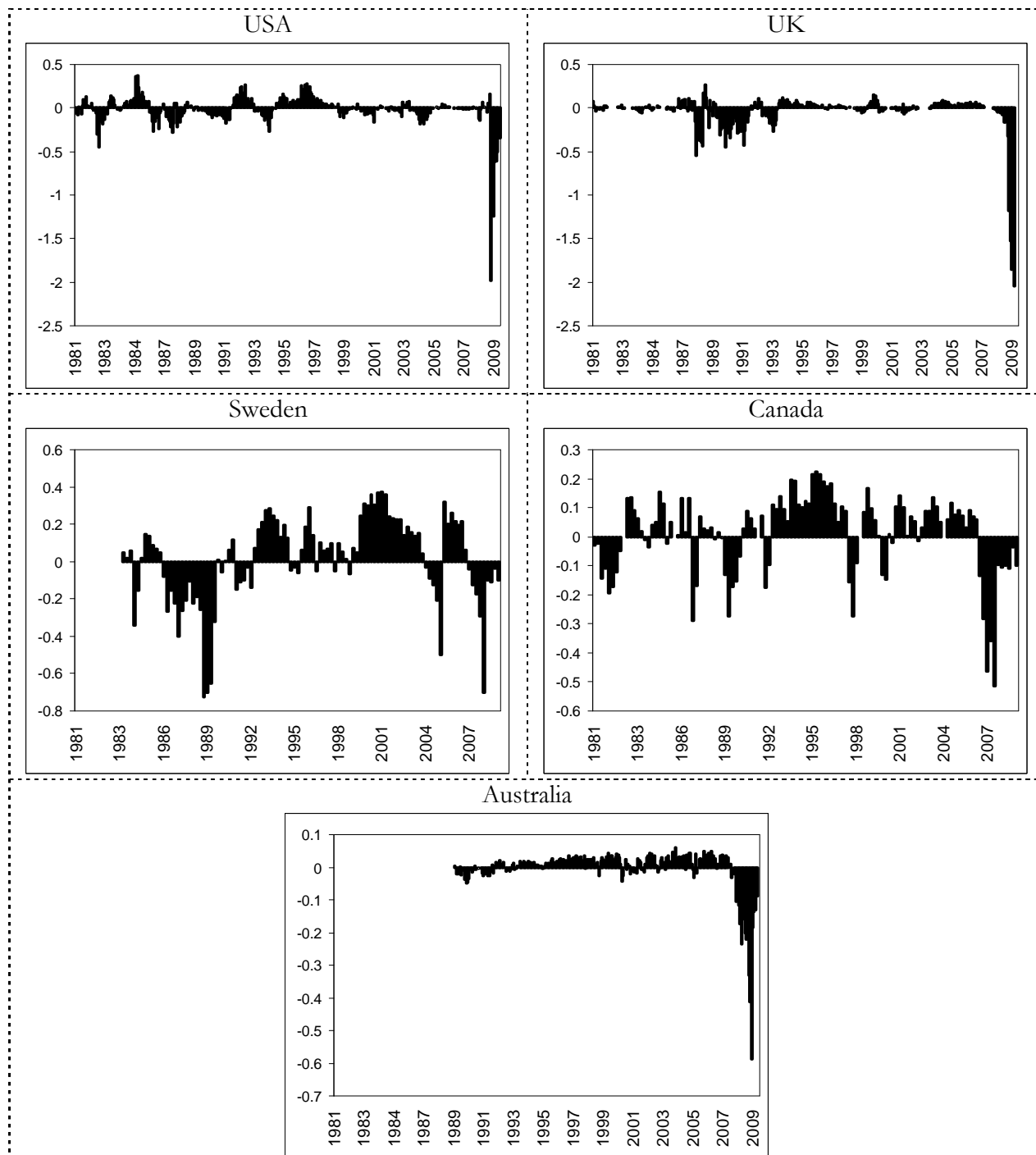


Note: The estimated coefficients of time-varying monetary policy rule are depicted with a 95% confidence interval.

## Appendix 2

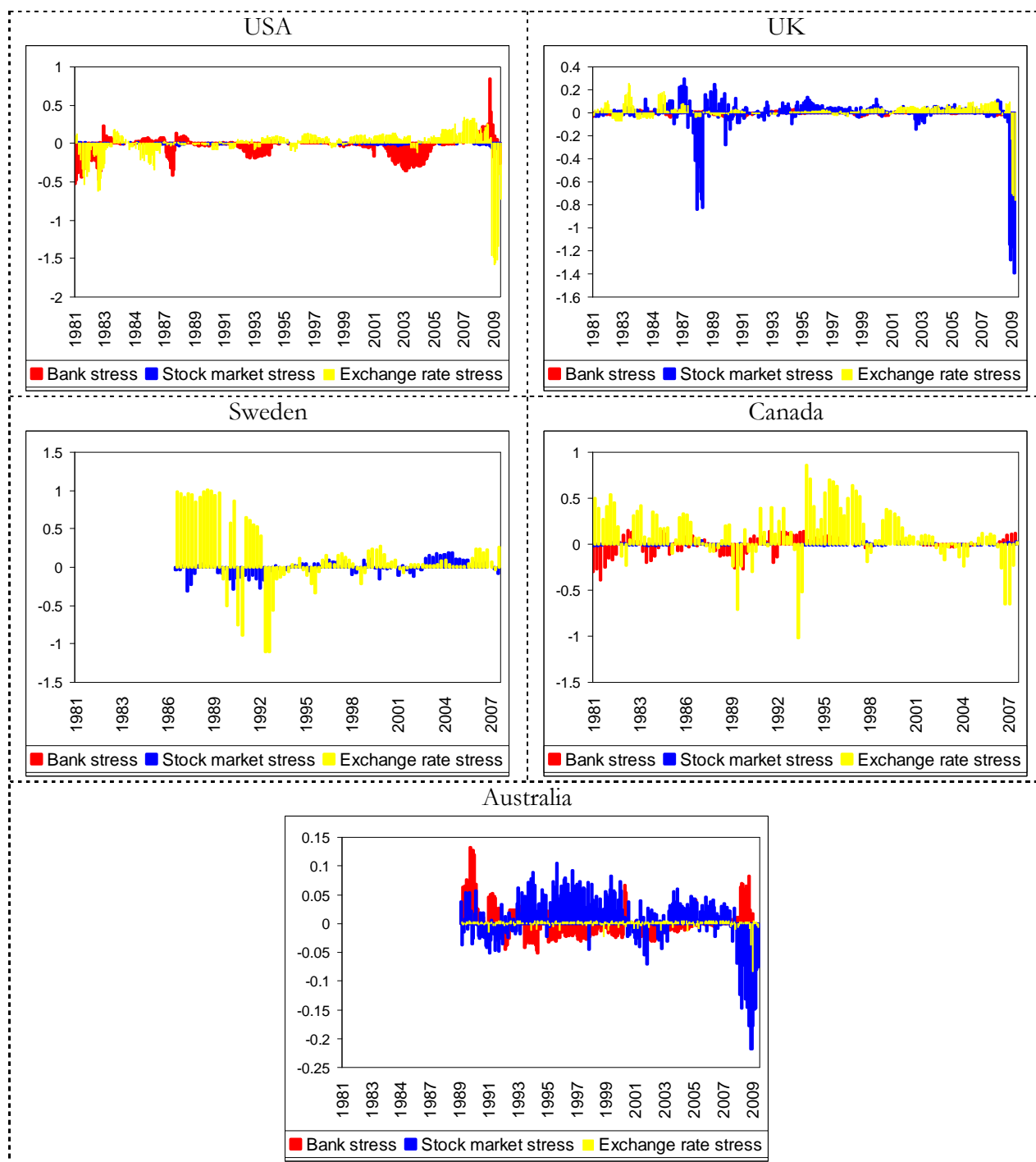
### The Results with the Interbank Rate as the Dependent Variable in the Policy Rule

Figure A2.1 – The Effect of Financial Stress on Interest Rate Setting



Notes: The figure depicts the evolution of the financial stress effect. The stress effect (y-axis) is defined as the product of the estimated coefficient on the financial stress indicator in monetary policy rule and the value of the IMF financial stress indicator. The stress effect shows the magnitude of the interest rate reaction to financial stress in percentage points.

**Figure A2.2 – The Effect of Financial Stress Components on Interest Rate Setting:  
Bank Stress, Exchange Rate Stress and Stock Market Stress**



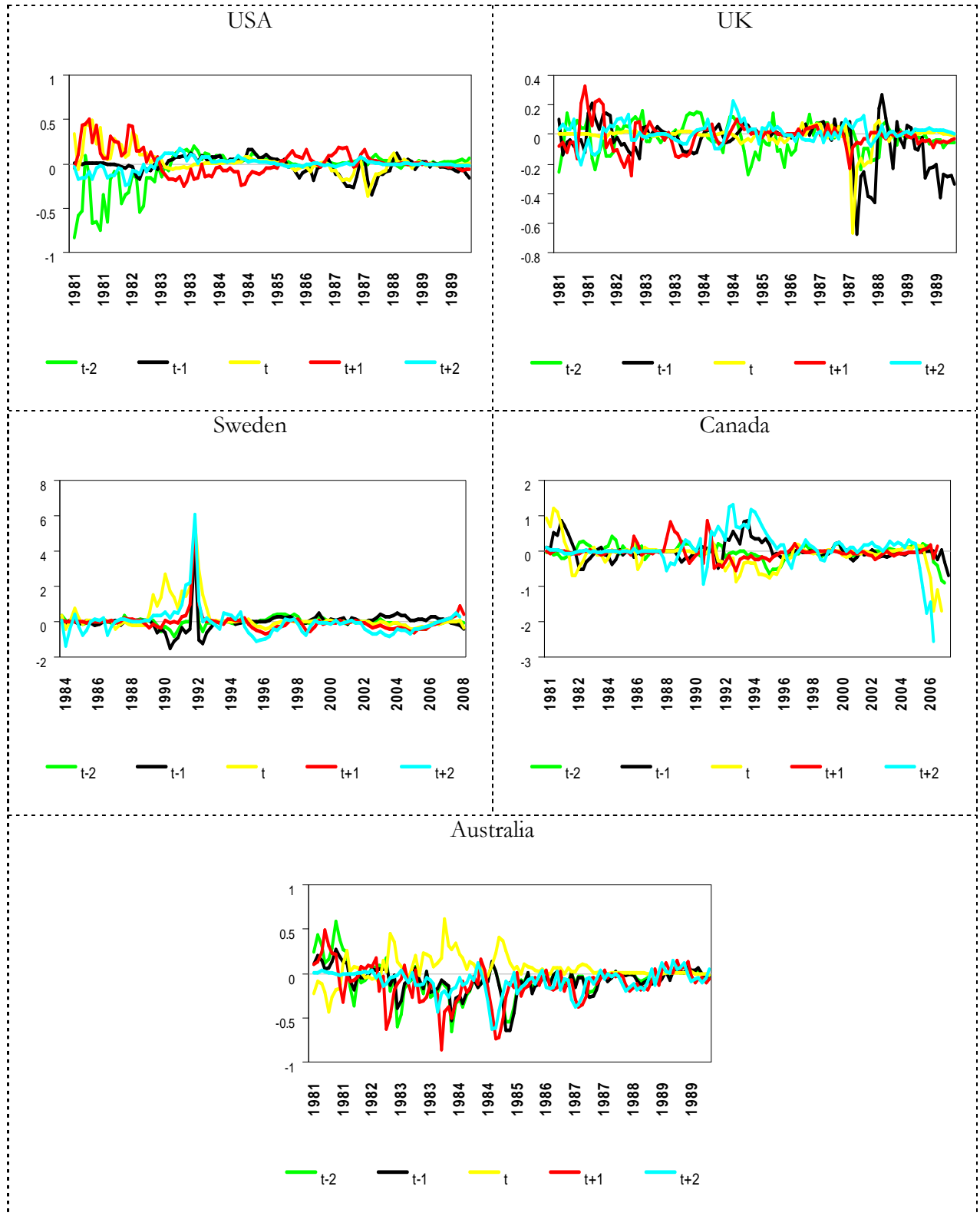
Notes: The figure depicts the evolution of the components of the financial stress effect, namely bank stress effect, exchange rate stress effect and stock market stress effect. The stress effect (y-axis) is defined as the product of the estimated coefficient on the given component of the financial stress indicator in monetary policy rule and the value of the corresponding component of the IMF financial stress indicator. The stress effect shows the magnitude of the interest rate reaction to financial stress in percentage points.



# Appendix 3

## The Results with Different Leads and Lag of the FSI

Figure A3.1 – The Effect of Financial Stress (t-1 vs. t-2, t, t+1, t+2) on Interest Rate Setting



# Appendix 4

## The Results with Individual Variables of Bank Stress and Stock Market Stress

Figure A4.1 – The Effect of Bank Stress on Interest Rate Setting

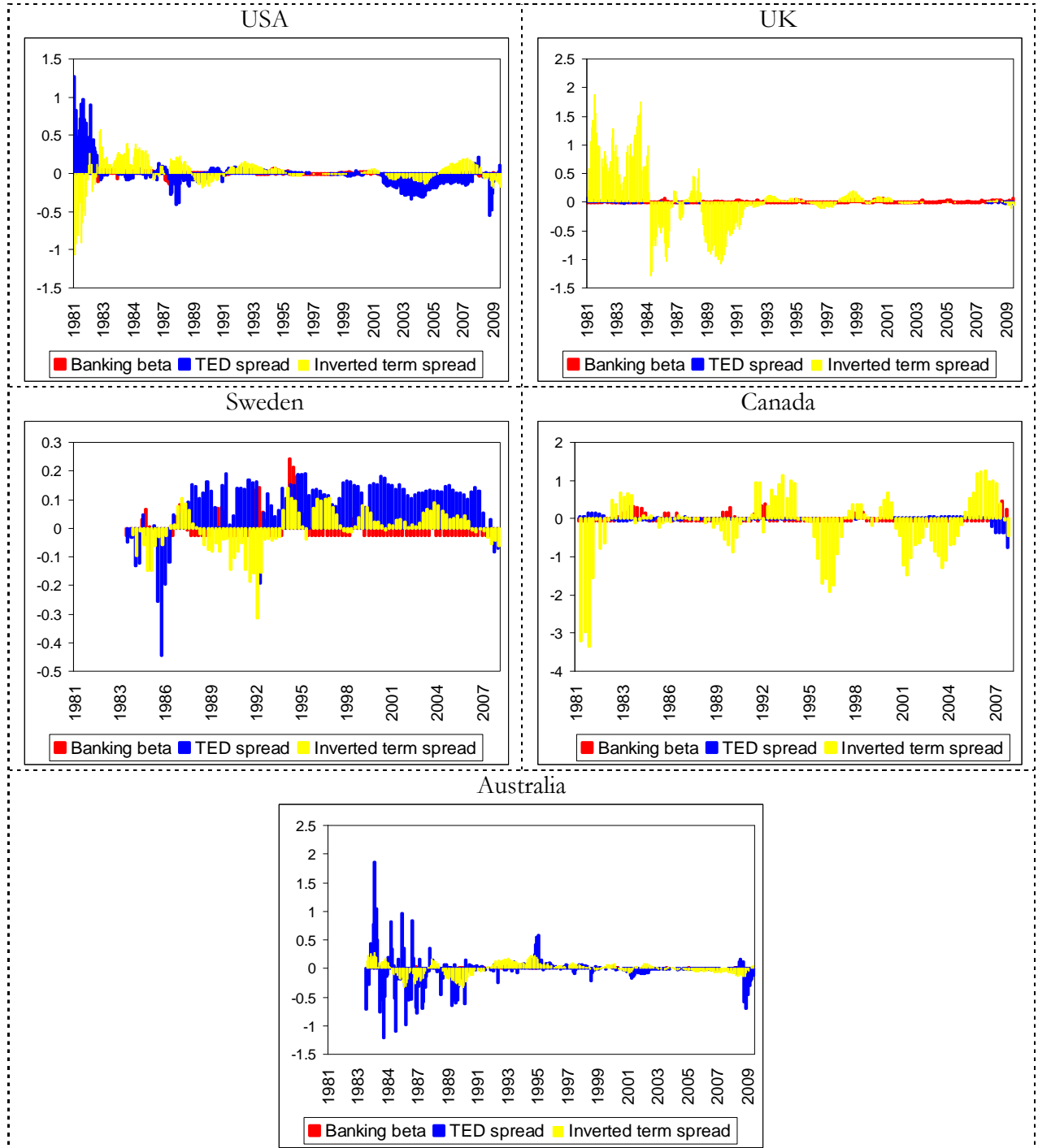


Figure A4.2 – The Effect of Stock Market Stress on Interest Rate Setting

