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Abstract

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Keywords: global financial crisis (GFC), monetary policy, Taylor rule, unconventional monetary policy

JEL Classification: E43, E52, E58

1. Introduction

The Taylor rule, a monetary policy rule proposed by Taylor (1993), not only receives central attention in monetary policy research but also tangibly impacts debates on monetary policy implementation at the Federal Open Market Committee (FOMC). Kahn (2012) carefully reviews the minutes of the discussions at the FOMC and reports that Janet Yellen first referred to the Taylor rule at the FOMC meeting held in January 1995, after the Carnegie-Rochester Conference in November 1992, where John Taylor presented his paper. The rule has been guiding not only the Federal Reserve but also central banks in other countries (Issing, 2012; Kahn, 2012; Ortiz, 2012; Yellen, 2012).

The great influence of the Taylor rule in both academia and the monetary policy circle is due to several reasons. For the monetary policy practice, especially in the United States (US), the Taylor rule has two primary terms, one for unemployment and the other for inflation, which is consistent with the Federal Reserve's dual mandates of maximum employment and price stability. Moreover, its fit to express the Federal Reserve's monetary policy in terms of setting the nominal federal funds rate (FFR) is reasonably high for the period from 1987 to 1992 (Taylor, 1993)—a period during which the US economy was in good shape in terms of both employment and price stability after the Great Inflation of the 1970s (Yellen, 2012). From a theoretical perspective, the rule satisfies the so-called Taylor principle that the central bank raises its policy rate by more than 1% when the inflation rate increases by 1% (Taylor, 1993) and is also consistent with the optimal monetary policy if some conditions hold (Woodford, 2001).

Two strands of modifications to the Taylor rule exist, namely, a forward-looking specification (Clarida et al., 1998) and the use of real-time data (Orphanides, 2001). The Taylor rule is also an indispensable component in New Keynesian monetary models. These developments in the Taylor rule literature further help the understanding of its usefulness and relevant caveats. Consequently, the FFRs derived from the original form of the Taylor rule, and some of its variations now form parts of regular materials prepared for the FOMC (Yellen, 2012).

The global financial crisis (GFC) from 2007 to 2009 had a two-fold implication on the value of guidance provided by the Taylor rule in monetary policy implementation—possibly proving its value in retrospect regarding a period leading up to the GFC as well as proving its limitation to judge monetary policy stance over maturities of yield curve far from the overnight, which the unconventional monetary policy (UMP)—unlike the conventional monetary policy—aimed to influence more directly.

During the period before the GFC, the actual FFR undershot the levels posted by the Taylor rule for a prolonged time. Taylor (2007) argued that the undershooting FFR implied an excessively eased monetary policy that resulted in a housing price boom, paving the road to the credit crisis.

The Federal Reserve continued to ease monetary policy in the wake of the GFC to prevent the deepening of the credit crisis and further worsening of economic conditions. As a result, the FFR declined to the effective lower bound (ELB), although the Federal Reserve's assessment of the economy called for a further monetary easing to set a more accommodative monetary condition for economic recovery. Without additional room for a reduction in the FFR, the Federal Reserve resorted to UMPs of quantitative easing and forward guidance. A notable feature of such a UMP was that the Federal Reserve intended to influence longer maturities directly, or at least more directly than it did with conventional monetary policy to influence the FFR.

The Taylor rule to determine the FFR gauges the monetary policy stance employing "Taylor rule deviation (TRD)," that is, the difference between the actual FFR and the rate derived from the rule, even when the FFR hits the ELB and the Taylor rule rate plunges into the negative territory. However, a policy stance gauge for longer maturities that the Federal Reserve tries to influence through UMPs, including forward guidance, is more desirable and appropriate. For example, when a policy action by the Federal Reserve aims to influence a maturity range longer than overnight, the impact of such a policy action is not reflected in the FFR, even if it has not yet hit its ELB.

To address the abovementioned issue, this paper proposes a methodology to gauge the monetary policy stance over maturities longer than overnight and up to 10-year ahead. This is an extension of the Taylor rule for the short-term policy rate to the points in time in the future horizon, corresponding to the original rule to yield curve. We call this the "Taylor rule yield curve." The methodology is useful to gauge the monetary policy stance when the monetary policy aims to achieve economic recovery from a recession employing policy tools to influence maturities considerably longer than overnight. The analysis provides empirical evidence on the effectiveness of deviations of market expected rates from the Taylor rule implied expected rates to assess the monetary policy stance.

The remainder of this paper is organized as follows. Section 2 provides a brief review of related literature. Section 3 describes the formal structure of the Taylor rule yield curve. Section 4 explains the data and estimation methodology. Section 5 reports the empirical results. Section 6 presents a theoretical analysis supporting the empirical findings. Section 7 concludes.

2. Literature review

A large body of literature has analyzed the Taylor rule. Kahn (2012) and Yellen (2012) provided a comprehensive survey of both theoretical and empirical findings related to the Taylor rule. Orphanides (2007) summarized the development of monetary policy rules and useful elements of monetary policy design gained from the generalization of the original Taylor rule proposed by Taylor (1993). All of them concluded that the Taylor rule has substantially contributed to both positive and normative analysis of monetary policy and implementation of monetary policy research outcomes in monetary policy practice. In this section, we focus on relevant literature on gauging monetary policy stance using the Taylor rule, especially in the context of the experience during the GFC and the post-crisis monetary policy in the US.

The Taylor rule has been well accepted as a systematic guide for monetary policy to respond to incoming information concerning economic conditions. According to the rule, when the TRD is zero, the monetary policy stance is judged neutral, while a positive (negative) TRD means tightening (loosening) the monetary policy stance. As mentioned above, in practice, the central banks across the world frequently refer to analyses based on the Taylor rule.

Taylor (1993) proved that the Taylor rule can describe the Federal Reserve's determination of the FFR for the period from 1987 to 1992 when the US economy was performing well in terms of both employment and price stability. Taylor (1999) extended the sample period to 1997 and derived the same result. Levin et al. (1999) showed that fully optimal rules for differently specified models yield only small macroeconomic stabilization benefits compared with simple policy rules such as the Taylor rule.

As for the housing boom in the US during the pre-GFC period, Taylor (2007) argued that the housing boom can be largely attributed to the monetary policy stance expressed by the TRD. He analyzed the housing market behavior with the FFR as an explanatory variable to demonstrate that a counterfactual path of higher FFRs that are more consistent with the Taylor rule—that is, a tighter monetary policy stance—could have curbed the housing boom and subsequent hikes in delinquency rates in mortgage markets. Ahrend et al. (2008) showed that the TRDs in the Organisation for Economic Co-operation and Development countries suggested a relatively loose monetary policy stance that may have amplified housing booms during the pre-GFC period. Moreover, the authors demonstrated that the TRDs could explain the cross-country variations in housing booms to a significant extent. These findings would reinforce the view that the Taylor rule is an effective guide to follow for monetary policy.

However, periods during and after the GFC, when the US economy experienced severe downturns, revealed a limitation of the guidance offered by the Taylor rule: the Taylor rule is solely for the FFR—the overnight interest rate—and cannot assess monetary policy stance over maturities of yield curve far from overnight, which the Federal Reserve aims to affect directly through UMPs when facing the ELB of the FFR.

Forward guidance is one of the UMP tools that has been proven to be an effective addition to central banks' policy toolkit (Bank for International Settlements, 2019). The Federal Reserve communicates its views on the future state of the economy and likely policy paths, thereby intending to influence longer maturities directly, or at least more directly than it does by controlling the FFR as conventional monetary policy. Therefore, it is desirable and appropriate if we have a policy stance gauge for the maturities that the Federal Reserve tries to influence through UMP means.

Inoue and Rossi (2018) proposed an approach to identify monetary policy shocks as exogenous shifts in the reaction function of government bond yield curves during both UMP and conventional monetary policy periods. In this study, we assess the monetary policy stance from a different viewpoint, gauging the stance by referring to a neutral degree following a certain principle based on the Taylor rule idea.[1]

Nakamura and Steinsson (2018) identified monetary policy and information shocks by measuring unanticipated changes in bond yields around the FOMC announcements using high-frequency data and discussed information content about a future course of monetary policy reflected in the bond yields.[2] Their novel approach focused on unanticipated disturbances in the Taylor rule, while the current study assesses the state of the cumulated sum of anticipated and unanticipated disturbances in the Taylor rule to measure the market expectations of monetary policy stance consequent to the FOMC announcements and market expectations on future courses of the economy and monetary policy.

From a different perspective, previous studies assessed the monetary policy stance when short-term policy rates hit ELBs using a shadow policy rate (e.g., Krippner, 2013;

[1] Empirical studies such as Swanson (2020) generally point to the effectiveness of forward guidance in reducing nominal interest rates over a yield curve (see also Bundick and Smith, 2018). The focus of such studies is UMP's impacts on interest rates, per se, for different maturities but they do not discuss monetary policy stance vis-à-vis a certain reference for the maturities.

[2] See also, for example, Hirose and Kurozumi (2017) for an estimation of anticipated component of monetary policy implied by the government bond yields.

Christensen and Rudebusch, 2015; Wu and Xia, 2016; Debortoli et al., 2020). The shadow policy rate is defined as a hypothetical short-term policy rate that can take negative values, summarizing rate changes in maturities of the entire yield curve. The deviation of the shadow policy rate from the FFR following the Taylor rule can be regarded as a measure of the monetary policy stance. However, as the shadow policy rate reflects all relevant information in a single hypothetical short-term rate, we cannot infer the impact of (unconventional) monetary policy measures on other specific maturities of the yield curve. Our study provides a novel method to examine the monetary policy stance at any maturity on the yield curve.

3. Taylor rule yield curve

We begin with a standard Taylor rule to describe the equation to determine the nominal FFR as the policy rate. It is usually formulated as:

$$i_t = r_t^* + \pi_t + \alpha(\pi_t - \pi^*) + \beta y_t + e_t,$$

where i_t is the FFR, r_t^* is the natural rate of interest, π_t is the inflation rate, π^* is the level of the inflation target, y_t is the output gap, and e_t is the residual. The residual is interpreted as a measure of the central bank's monetary policy stance. Taylor (1993) proposed the first idea of the Taylor rule with $\alpha = 0.5$ and $\beta = 0.5$, which we label as the "original" Taylor rule, hereafter. Later, Taylor (1999) argued that the Federal Reserve's monetary policy would follow a Taylor rule with more weight on the output gap, and proposed $\alpha = 0.5$ and $\beta = 1.0$. We label this modified version of the Taylor rule as the "balanced" rule.

We extend the idea of the Taylor rule to determine the future course of short-term policy rates. We denote the variables with the notation $t + h|t$ as the h-period ahead expectation at time t: $i_{t+h|t}$ is an expected short-term rate at time $t + h$ conditional on information available at time t, with $h > 0$, for example. We then propose the Taylor rule expected short-term rate as:

$$i_{t+h|t} = r_{t+h|t}^* + \pi_{t+h|t} + \alpha\left(\pi_{t+h|t} - \pi^*\right) + \beta y_{t+h|t} + e_{t+h|t},$$

Note that we assume that the coefficients (α, β) do not depend on the horizon h or time t.

To introduce the Taylor rule yield curve, let $y_t(m)$ denote the market yield for m-year maturity, which is decomposed into two components:

$$y_t(m) = y_t^e(m) + y_t^p(m),$$

where $y_t^e(m)$ is the expected short-term rate and $y_t^p(m)$ is the term premium. We approximate $y_t^e(m)$ by $i_{t+k|t}$, which is the k-year $(k = 1, \dots, m)$ ahead expected short-term rate. That is,

$$y_t^e(m) = \frac{1}{m}\int_0^m i_{t+h|t}\, dh \approx \frac{1}{m}\sum_{k=1}^{m} i_{t+k|t}$$

$$= \frac{1}{m}\sum_{k=1}^{m}\{r^*_{t+k|t} + \pi_{t+k|t} + \alpha(\pi_{t+k|t} - \pi^*) + \beta y_{t+k|t} + e_{t+k|t}\},$$

where the expected rate for maturity m is described by Taylor rule components expected at the k-year ahead horizon.

We define *the Taylor rule expected rate* by:

$$\tilde{y}_t^e(m) = \frac{1}{m}\sum_{k=1}^{m}\{r^*_{t+k|t} + \pi_{t+k|t} + \alpha(\pi_{t+k|t} - \pi^*) + \beta y_{t+k|t}\}.$$

The difference between the market expected rate and the Taylor rule expected rate is simply the average of the expected monetary policy stance from the current t to $t + m$, which we call the TRD:

$$y_t^e(m) - \tilde{y}_t^e(m) = \frac{1}{m}\sum_{k=1}^{m} e_{t+k|t}.$$

The Taylor rule was originally a device to interpret the monetary policy stance associated with the current short-term interest rate. We extend this idea to the yield dimension, that is, to time points in the future horizon, considering the expected path of the variables in the original Taylor rule. The deviation of the expected rates of short-term interest rate from the Taylor rule expected rates reflects the market expectations on the course of monetary policy stance—the expectations of market participants on how accommodative or tight would the monetary policy be m years ahead.

We often discuss the monetary policy stance by using the FFR gap, defined as the deviation of the FFR—the overnight short-term rate—from the Taylor rule short-term rate. In our analysis, for each sample point, the FFR gaps are not only estimated for contemporaneous short-term maturity but also for short-term interest rates in points of time in the future. We regard the TRD defined above as the FFR gap for a maturity longer than overnight maturity.

We only focus on the expected rates in the yield curve, putting the term premium component aside. The original Taylor rule formulates the short-term interest rate that is virtually unrelated to the term premium. While the term premium partly reflects the uncertainty of the future path of monetary policy, we believe that it is challenging to explicitly formulate its idea in our Taylor rule yield curve, leaving this issue as future work. For now, we can point to the possibility that the impact of the forward guidance may be conservative in this study's empirical analysis as we ignore the impact of the term premium; some existing studies show that the forward guidance would lead to downward pressure on the term premium by reducing the uncertainty of future path of policy rates (e.g., Bundick et al., 2017).

4. Data and estimation methodology

To estimate the Taylor rule yield curve, we need a data series of expectations on inflation rates and output gap for each point in time in the future. We obtain them from Consensus Economics, a widely used survey of professional forecasters. We use the mean forecasts of inflation rates and gross domestic product (GDP) growth rates for 1, 2, ..., 5 years ahead and the average of 6–10 years ahead, assuming constant GDP growth rates from 6 to 10 years ahead. We calculate forecasts of the output gap with the current potential output estimated by the Congressional Budget Office. In addition, we obtain the FFRs, current core Consumer Price Index inflation rates, and GDP growth rates from the Federal Reserve Economic Data. Regarding the natural rate of interest, we use estimates by Holston et al. (2017), which are available on the website of FRB New York, and assume it remains the same for the years ahead.

For the market expected rates, we use the OIS rates for 1, 2, ..., 5, and 10 years ahead obtained from Bloomberg. For 6 to 9 years ahead, we linearly interpolate the OIS rates using rates of 5 and 10 years ahead. While it can be argued that the OIS rates could contain a term premium to some extent for the long-year maturity, it is true that OIS rates are generally regarded as a good measure reflecting the expectations of overnight short-term rates and are widely used to gauge the expectations of future monetary policy courses (e.g., Gürkaynak et al., 2005; Ferrari et al., 2017; Altavilla et al., 2019; Jarociński and Karadi, 2020).

It has been well discussed that the Taylor rule with inertia in its time-series process fits actual policy rates better than the original Taylor rule. We use this inertial type to estimate the Taylor rule yield curve, namely:

$$i_{t+h|t} \ = \ \rho i_{t+h-1|t} + (1-\rho)\{r^*_{t+h|t} + \pi_{t+h|t} + \alpha(\pi_{t+h|t} - \pi^*) + \beta y_{t+h|t} + e_{t+h|t}\},$$

where ρ measures the persistence of short-term policy rates. We assume that $\rho = 0.85$ for quarterly series, which is usually assumed in the literature and also fits the data well. Note that we compute the Taylor rule yield curve at 1, 2, ..., 10 years maturity using the implied annual persistence as ρ^4 ($\fallingdotseq 0.522$). The expected natural rates of interest in the future horizons are assumed to be the same as the current ones, which is consistent with the random-walk assumption in Laubach and Williams (2003).

As for the coefficients in the Taylor rule, we examine two sets proposed by Taylor as mentioned above: the original Taylor rule with $(\alpha, \beta) = (0.5, 0.5)$ and the balanced Taylor rule with $(\alpha, \beta) = (0.5, 1.0)$. Given that the balanced rule is understood as reflecting the Federal Reserve's monetary policy strategy in recent years, we mainly discuss the estimation for the balanced rule as the baseline model and compare both to check the robustness of the results.

5. Empirical results

5.1 Taylor rule yield curve and deviation

Figure 1a presents the actual short-term interest rates and short-term rates implied by the Taylor rules with balanced and original coefficients from 2000/Q1 to 2018/Q4. Figure 1b illustrates the deviations of the actual rates from the Taylor rule. As discussed in the literature, the Taylor rule rates were higher than the actual short-term rates from 2004 to 2006 when the Federal Reserve hiked the policy rates (Taylor, 2007). After the onset of the GFC, the Federal Reserve cut the policy rates to almost zero, while the balanced Taylor rule rates sank to about −6% because of the severe downturn of the economy and stayed mostly below zero until late 2015, reflecting the slow economic recovery. The original Taylor rule rates were also in the negative territory, although around higher levels than the balanced rule rates, rising to above zero levels at roughly the same time as the balanced rule rates.

(Figure 1)

Figure 2 depicts the estimated Taylor rule expected rates based on the balanced rule and OIS-based market expected rates for each maturity from 1 to 10 years. Note that the OIS rates are available from 2002/Q1 in our dataset. After the onset of the GFC, the Taylor rule expected rates dropped completely below zero for maturities up to 10 years. The rates started picking up in 2009, reflecting the expectations of economic recovery. In 2010, only 1- and 2-year Taylor rule expected rates remained below zero.

(Figure 2)

Figure 3 shows the 2- and 10-year Taylor rule expected rates and market rates. Before the GFC, both the 2- and 10-year Taylor rule expected rates were generally higher than the market rates. During the recovery phase after the GFC, the 2-year Taylor rule expected rates were slightly below zero from 2010 to 2013 and rose to relatively higher levels than the market rates in 2014. Interestingly, the 10-year Taylor rule expected rates were higher than the market rates for most of the periods after 2010.

(Figure 3)

Figure 4 illustrates the Taylor rule expected rate curve and market rate curve at selected time points. During the phase of the severe downturn in 2008/Q4, the Taylor rule expected rate curve was substantially below the market rate curve: the deviations were approximately 2–3 percent points over the various maturities. The slope of the market rate curve reduced significantly for the mid- and long-term maturities and the curve flattened during the course of the Federal Reserve's policy rate cutting. In 2011/Q4, the market curve was even below the Taylor rule expected rate curve for maturities beyond 4 years. In 2013/Q4, the mid- and long-term market expected rates were aligned with the Taylor rule expected rates.

(Figure 4)

The reversal of relative positions of the market rate curve and the Taylor rule expected rate curve occurred during the course of the Federal Reserve's monetary policy tightening. In 2015/Q4, when the Federal Reserve hiked the policy rate for the first time after the GFC, while the Taylor rule short-term rate was still negative, the market rate curve almost perfectly matched the Taylor rule expected rate curve for maturities beyond one year. After the Federal Reserve's policy rate hike, in 2017/Q4, the Taylor rule expected rate curve was higher than the market rate curve by approximately 0.5–1 percent points. The relative position between the two curves in 2017/Q4 suggests that the monetary policy stance, implied by not only the policy rates but also the central bank communication and the quantitative easing in operation even sometime after the policy rate hike, was expansionary according to the monetary policy stance measure proposed in this paper.

The Taylor rule expected rate curve demonstrates that the Federal Reserve's policy was evidently bounded by the ELB of policy rates. For instance, in 2011/Q4, the Taylor rule expected rate curve dropped below zero for maturities up to three years, as shown in Figure 4, and its implied forward rate curve for maturities up to two years. According to the estimation results, the Taylor rule expected forward rate curve for maturities up to one year continued to be below zero until 2014/Q3, and so also the Taylor rule expected short-term rates until 2016/Q3.

In assessing the market expectations reflected by the OIS curve, a great advantage of the Taylor rule expected rate curve is that we can evaluate market expectations at each year of maturity. The entire curve of the Taylor rule expected rates indicates specific maturities where the difference between the market expectation and the Taylor rule implied rates are either wide or narrow. Previous studies employ two or three factors to summarize the shape of the yield curve and its changes (e.g., Gürkaynak et al., 2005; Altavilla et al., 2019; Swanson, 2020). Although the yield curve does not have as many different sources of variation as the years of maturities used for the Taylor rule expected rates in our analysis, it can be useful to assess market expectations when some specific maturities are abnormally altered as they cannot be captured by the traditional two or three factors.

Next, we investigate the determinants of changes in the TRDs over the sample period. Figure 5 depicts the TRDs for 2- and 10-year maturities in the form of bar charts and can be regarded as summarizing the narratives in Figure 3.

(Figure 5)

Figure 6 illustrates period-by-period first differences of TRDs for 2-year maturity and their components. The output gap component is the main determinant of changes in TRDs, while the inflation component has a considerably smaller contribution. The figure reflects a substantially volatile outlook on economic growth, especially around the time immediately preceding and succeeding the GFC.

(Figure 6)

Figure 7 shows the same set of figures as Figure 6 but for TRDs for 10-year maturity. The qualitative aspects of the figures remain unchanged from Figure 6. One noticeable difference is that the contribution of the inflation component to changes in the TRDs is even smaller for a 10-year maturity, reflecting smaller changes in inflation outlook on longer time horizons in general.

(Figure 7)

The changes in TRDs depicted in Figure 5 are largely consistent with the narratives of monetary policy in the US. The Federal Reserve began the first large-scale asset purchase program in November 2008 and communicated an expectation of low policy rates in the future, that is, forward guidance, with an expression of the low FFR "for some time" in the FOMC statement in December 2008. However, as Williams (2014) explains in detail, the public's conviction that the Federal Reserve would quickly raise policy rates again was firm. This was the case during the severity of the downturn in the economy and the Taylor rule expected rates generally dropped, which resulted in large TRDs around 2008. To counter the excessively tight expectations, the Federal Reserve implemented more explicit and forceful forward guidance: in August 2011, it included an expression "exceptionally low levels for the federal funds rate at least through mid-2013" in the FOMC statement. Since then, with the succession of strengthened forward guidance, the levels of the TRDs have been around zero for shorter maturities or in the negative territory, especially for longer maturities, with exceptional hikes during the so-called taper tantrum in 2013.

5.2 VAR analysis

In this section, we examine if and how the Taylor rule yield curve and its deviation from the OIS curve affect macroeconomic variables, thereby identifying their role in the implementation of monetary policy. We begin with a standard three-variable VAR model that consists of the output gap, inflation rate, and FFR gap. The FFR gap is the deviation of the FFR from the Taylor rule short-term rate calculated by the smoothed formulation. All the variables are the same as those used in the previous sections. As for the identification of monetary policy shocks in the context of VAR analysis, we consider the simplistic Cholesky decomposition strategy with the ordering of variables as listed above.

Figure 8a plots impulse responses (IRs) of the output gap and inflation rates to the FFR gap shock. For the sample period from 1971 to 2017, the output gap decreases significantly about one year after the shock. The inflation rate increases after the shock, which exhibits the well-known price puzzle. When we focus on more recent years, from 2002 to 2017, both the IRs of the output gap and inflation increase, which is contrary to the standard macroeconomic theory and typical empirical results from VAR analyses in preceding papers. This result arises presumably because the sample period includes the period of ELB for the FFR: the FFR hit its ELB and the Federal Reserve implemented the UMP such as forward guidance that could affect the output gap and inflation after the GFC, which the trajectory of FFR gap cannot capture in this VAR system.

(Figure 8)

Figure 8b exhibits the result of the same VAR exercise replacing the FFR with the shadow policy rate proposed by Wu and Xia (2016). As mentioned earlier, the shadow policy rate dropped below zero during the UMP period, reflecting the accommodative monetary policy stance. The pictures of the VAR results remain similar to the results with the FFR gap.

For the sample period from 2002 to 2017, Figure 9a plots IRs of the output gap and inflation to the TRDs for 2- and 10-year maturities. We replace the FFR gap with one of these TRDs in the VAR model. Both the output gap and inflation decrease in response to the TRD shock. We interpret this result as the usefulness of TRDs while considering monetary policy implementation even during the period when the FFR hits its ELB. In particular, the TRDs for a long maturity may succeed in capturing forward guidance, that is, monetary policy easing by a policy measure intending to affect expectations concerning the future course of the monetary policy stance.

(Figure 9)

Next, we examine whether OIS rate futures, that is, OIS for a longer maturity, per se, has a meaningful role in the VAR system, which will highlight the distinct role of TRD. Figure 9b plots IRs of the output gap and inflation to the OIS rates for 2- and 10-year maturities. The VAR model comprises four variables, namely, output gap, inflation rate, FFR, and OIS rates, for the period from 2002 to 2017. As in the benchmark case, the shock is identified by the Cholesky decomposition based on the ordering listed here. The responses of the output gap and inflation to the OIS shock are mostly muted. This implies that the OIS rates, per se, do not play a meaningful role in this VAR analysis for the sample period.

Furthermore, Table 1 reports the Granger causality test for the TRDs and OIS rates for 2- and 10-year maturities. The null hypothesis that the TRDs do not Granger-cause the OIS rates is rejected for both 2- and 10-year maturities, whereas its reverse causality is not rejected. In other words, the TRDs Granger-cause the OIS rates while the OIS rates do not Granger-cause the TRDs.

(Table 1)

We can summarize the results of the VAR model and Granger causality test in this section as follows: the TRD includes more useful information than the FFR gap and OIS rates, per se, in considering the relationship between monetary policy and economic performance.

5.3 TRD and risk appetite in financial markets

Monetary policy stance and expectations in the future would affect the risk appetite of players in financial markets. Coining the idea "risk-taking channel of monetary policy" seems to gain more support, especially after the GFC. Given this, we consider the relationship between the TRD and risk appetite in financial markets. We use the volatility index (VIX) as a measure of market risk appetite, as in previous studies.

Figure 10a plots the FFR gap and VIX in the same quarter as well as the TRDs for 2-, 5-, and 10-year maturities and VIX. The TRDs and VIX are positively correlated, which holds for all of those maturities, while the FFR gap and VIX are negatively correlated. The same relationship is observed between the current TRDs and the VIX at the four quarters ahead, as illustrated in Figure 10b. Figure 11 plots the 5-year TRD and VIX, where the samples are divided into the periods of ELB, from 2008/Q1 to 2015/Q3, and the other periods (no-ELB). Remarkably, the positive correlation between the TRDs and VIX is observed during both the ELB and no-ELB periods. These findings imply that the TRD can be useful as the series correlated with the broad measures of risk appetite in financial markets.

(Figure 10)

(Figure 11)

5.4 Robustness

In this section, we check the robustness of the results by replacing the Taylor rule yield curve based on the balanced rule with that based on the original rule. Figure 12 plots the Taylor rule expected rates for maturities ranging from 1 to 10 years based on the original rule. Compared with those based on the balanced rule in Figure 2, fluctuations in the original rule version are smaller. This reflects the smaller coefficient of the volatile output.

(Figure 12)

Figures 13 plots the Taylor rule expected rates and market OIS rates for 2- and 10-year maturities. Although the decrease in the Taylor rule expected rates after the GFC is smaller in the original rule than that in the balanced rule, the overall trajectories do not change significantly.

(Figure 13)

Figure 14 shows the Taylor rule expected rates and market OIS rates at selected time points. For 2008/Q4 and 2009/Q4, the original rule figures are similar to those of the balanced rule in Figure 4. By contrast, for 2011/Q4 and 2013/Q4, the Taylor rule expected rates using the original rule are all positive, while those using the balanced rule are negative from the 1-year up to around 3-year maturity, reflecting the difference in the coefficient of the output gap. The latter rule implies that the market OIS rate curve is still bounded by the ELB to reach the Taylor rule expected curve for these periods. For 2015/Q4 and 2017/Q4, both the rules suggest that the market expected rates are mostly consistent with the Taylor rule expected rates, except for the short-term.

(Figure 14)

6. Analysis of the theoretical model

In this section, we present the analysis that theoretically supports our empirical findings presented above. Specifically, we examine the effects of anticipated future shocks to the Taylor rule causing TRD in a stylized New Keynesian model. Such shocks can be interpreted as the so-called news shocks in the business cycle literature (Beaudry and Portier, 2006; Barsky and Sims, 2011). We analytically and numerically demonstrate that future shocks to the Taylor rule generate contemporaneous effects on nominal and real variables and they are qualitatively consistent with our empirical findings.

6.1 Analytical example of 1-period ahead shock

First, we analytically investigate the effects of future shocks in a stylized New Keynesian model. We consider a stylized New Keynesian model in which equilibrium dynamics are summarized in the Euler equation, the New Keynesian Phillips curve (NKPC), and the Taylor rule:

$$y_t = \mathbb{E}_t[y_{t+1}] - \frac{1}{\sigma}(i_t - \mathbb{E}_t[\pi_{t+1}]),$$

$$\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \kappa y_t,$$

$$i_t = \phi_\pi \pi_t + \epsilon_{1,t-1} + \epsilon_{0,t},$$

where y_t, π_t, and i_t are the output gap, inflation rate, and nominal interest rate, respectively. Each variable is the log-deviation from the deterministic steady state. σ is the relative risk aversion, β is the subjective discount factor, $\kappa = (\sigma + \eta)(1 - \xi)(1 - \beta\xi)/\xi$ is the slope of the NKPC—where ξ and η denote the Calvo-probability and the Frisch labor supply elasticity, respectively—and ϕ_π is the responsiveness to the inflation rate in the Taylor rule. The derivation of these equilibrium conditions is provided by Gali (2015), for example.

This model embeds an anticipated future shock to the Taylor rule. Following Laséen and Svensson (2011) and Del Negro et al. (2012), $\epsilon_{h,t}$ denotes a shock to the h-period ahead Taylor rule that is known at time t. We assume $\epsilon_{h,t} \sim N(0, \sigma_h^2)$. In this analysis, we focus on the one-period ahead shock, $\epsilon_{1,t-1}$, as well as the standard contemporaneous shock, $\epsilon_{0,t}$, for simplicity. To observe the effect of future shock, it is convenient to iterate the Taylor rule forward and take the conditional expectation at time t:

$$\mathbb{E}_t[i_{t+1}] = \phi_\pi \mathbb{E}_t[\pi_{t+1}] + \epsilon_{1,t}.$$

We derive a solution to the model by using the undetermined coefficient method. Given that the model is linear and the shocks to the Taylor rule are the only state variables, the solution is conjectured to be given by:

$$y_t = c_{1,y}\epsilon_{1,t} + c_{0,y}\epsilon_{0,t} + c_{-1,y}\epsilon_{1,t-1},$$

$$\pi_t = c_{1,\pi}\epsilon_{1,t} + c_{0,\pi}\epsilon_{0,t} + c_{-1,\pi}\epsilon_{1,t-1},$$

where $c_{j,x}$ denotes the undetermined coefficients for $j = \{-1,0,1\}$, and $x = \{y, \pi\}$. Notice that i_t can be obtained according to the Taylor rule once π_t is determined. It follows that:

$$\mathbb{E}_t[y_{t+1}] = c_{-1,y}\epsilon_{1,t},$$

$$\mathbb{E}_t[\pi_{t+1}] = c_{-1,\pi}\epsilon_{1,t}.$$

Substituting the equations above into the equilibrium conditions pins down the coefficients $c_{j,x}$:

$$c_{1,y} = -\frac{\sigma-\kappa(\beta\phi_\pi-1)}{(\sigma+\phi_\pi\kappa)^2},\ c_{0,y} = c_{-1,y} = -\frac{1}{\sigma+\phi_\pi\kappa},$$

$$c_{1,\pi} = -\frac{\kappa\{\sigma(1+\beta)+\kappa\}}{(\sigma+\phi_\pi\kappa)^2},\ c_{0,\pi} = c_{-1,\pi} = -\frac{\kappa}{\sigma+\phi_\pi\kappa}.$$

Several points are noteworthy regarding the model solution. First, the impact upon realization is identical for the future and contemporaneous shocks, that is, $c_{0,y} = c_{-1,y}$ and $c_{0,\pi} = c_{-1,\pi}$. It is straightforward to note that $\epsilon_{1,t-1}$ and $\epsilon_{0,t}$ appear equivalently in the Taylor rule, and therefore, have identical effects once they are realized.

Second, under reasonable parameter values, the future shock has contemporaneous effects upon announcement with the same sign as the contemporaneous shock, that is, $c_{1,y} < 0$ if $\phi_\pi < (1+\sigma/\kappa)/\beta$, and $c_{1,\pi} < 0$. This is due to the forward-looking nature of the model. To be precise, when the future expansionary monetary policy shock is known ($\epsilon_{1,t} < 0$), agents expect that the shock will generate expansionary effects in the next period (i.e., $\mathbb{E}_t[y_{t+1}] > 0$ and $\mathbb{E}_t[\pi_{t+1}] > 0$), as described above. In turn, they lead to expansionary effects in the current period because of consumption smoothing in the Euler equation and the forward-looking pricing in the NKPC (i.e., $y_t > 0$, and $\pi_t > 0$).

Third, under reasonable parameter values, the impact of the future shock is larger than that of the contemporaneous shock for the inflation rate, whereas it is smaller for the output gap, that is, $|c_{1,y}| < |c_{0,y}|$ if $\phi_\pi > 1/(1+\beta)$ and $|c_{1,\pi}| > |c_{0,\pi}|$ if $\phi_\pi < 1+\beta\sigma/\kappa$. The inflation rate is determined by the sum of the current and future output gap in the NKPC. Therefore, the future shock, which has both contemporaneous and future effects, leads to a larger impact than the contemporaneous shock on the inflation rate. By contrast, the model suggests a smaller response of the output gap because a higher inflation rate on the future shock leads to a rise in the nominal interest rate due to the endogenous feedback of the Taylor rule, which partly offsets the expansionary effect of the shock.

6.2 Numerical analysis

6.2.1 Theoretical IRs in a stylized model

Next, we derive the theoretical IRs to future shocks to the Taylor rule in the stylized New Keynesian model.[3] For the theoretical IR analysis, the model is extended to accommodate future shocks at different horizons:

$$i_t = \phi_\pi \pi_t + \sum_{h=0}^{H} \epsilon_{h,t-h},$$

while the other parts of the model remain identical to the one employed in Section 6.1. The parameters are set to standard values in the literature: $\beta = 0.995, \sigma = 1.0, \eta = 1.0, \xi = 0.85\ (\kappa = 0.027)$, and $\phi_\pi = 1.5$.[4]

Figure 15 displays theoretical IRs of each variable to the 1-, 4-, and 8-period ahead shocks as well as the contemporaneous shock to the Taylor rule. Consistent with the analytical results obtained in Section 6.1, future shocks have contemporaneous effects on the output gap and inflation rate. The magnitude of the effects is also consistent with the analytical example.

(Figure 15)

6.2.2 Theoretical IRs in a model with inertia

As an extension, we include inertia in the model to attain a better fit to the data. Specifically, we add (i) internal habit formation in consumption, (ii) backward-looking firms, and (iii) interest rate smoothing. We also consider the response to the output gap in the Taylor rule. All these elements are fairly standard in the literature. The equilibrium conditions are modified to:

$$\lambda_t = \mathbb{E}_t[\lambda_{t+1}] + (i_t - \mathbb{E}_t[\pi_{t+1}]),$$

$$\lambda_t = -\frac{\sigma}{(1-h)(1-\beta h)}\{(y_t - \beta h y_{t-1}) - \beta h(\mathbb{E}_t[y_{t+1}] - \beta h y_t)\},$$

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f \mathbb{E}_t[\pi_{t+1}] + \frac{\tilde{\kappa}}{(\sigma + 1/\eta)} mc_t,$$

[3] Note that the future shocks can be easily implemented by using Dynare. See, for example, Johannes Pfeifer's website: https://sites.google.com/site/pfeiferecon/dynare.

[4] One thing to note is that the Calvo-probability ξ is set slightly higher than the value implied by the frequency of price changes in micro data to capture stable inflation rates in recent years.

$$mc_t = \frac{1}{\eta} y_t - \lambda_t,$$

$$i_t = \rho_i i_{t-1} + (1-\rho_i)(\phi_\pi \pi_t + \phi_y y_t) + \sum_{h=0}^{H} \epsilon_{h,t-h},$$

where $\gamma_b = \frac{\omega}{\Theta}, \gamma_f = \frac{\beta\xi}{\Theta}$, and $\tilde{\kappa} = \frac{\left(\sigma + \frac{1}{\eta}\right)(1-\omega)(1-\xi)(1-\beta\xi)}{\Theta}$, with $\Theta = \xi + \omega\{1 - \xi(1-\beta)\}$, h is the degree of habit formation, ω is the share of backward-looking firms, and ρ_i is the degree of interest rate smoothing. Notice that the model is reduced to the stylized one if $h = \omega = \rho_i = 0$. Additional parameters are set to $h = 0.70, \omega = 0.25$ ($\tilde{\kappa} = 0.032$), $\phi_y = 0.125$, and $\rho_i = 0.7$.

Figure 16 shows the theoretical IRs in the model with inertia. Compared with the case of the stylized model, the responses of the output gap and the inflation rate are hump-shaped and persistent in the presence of inertia. In addition, the initial response of the output gap is less mitigated in the longer horizon compared with the case without inertia.

(Figure 16)

6.2.3 IRs on simulated data

One potential concern is whether the effects of anticipated future shocks to the Taylor rule, implied by the theoretical model above, can be captured by our empirical framework using the VAR. To address this concern, Figure 17 presents IRs computed based on the simulated data of the model with inertia. To construct the IR, we suppose that an econometrician, who does not know the data-generating process, estimates the VAR from the observed data to recover the responses to structural shocks. More specifically, we simulate the model economy for 200 periods (50 years), estimate a three-variable VAR with the output gap, inflation rate, and interest rate measure using the simulated data, and then compute the IR to a monetary policy shock based on the estimated coefficients. For the choice of the interest rate measure, we consider three cases: (i) future interest rate, $FI_t = 1/H \sum_{h=1}^{H} \mathbb{E}_t[i_{t+h}]$, (ii) current interest rate deviation, $\epsilon_{0,t}$, and (iii) (H-period) TRD, $TRD_t = 1/H \sum_{h=1}^{H} \epsilon_{h,t}$. A monetary policy shock is identified by the Cholesky decomposition with the ordering of the variables described above. The lag length of the VAR is set to one. For parameter values, σ_h is set to 0.0025 for $h = 0,1,\ldots,H$, and the horizon is truncated at $H = 8$, corresponding to 2 years.

(Figure 17)

The top, middle, and bottom panels of Figure 17 show IRs on simulated data, where each of the interest rate measures, FI_t, $\epsilon_{0,t}$, and TRD_t, is included in the VAR, respectively. The figure indicates that the responses of the output gap and the inflation rate to the monetary policy shock identified from FI_t exhibit the opposite sign to the structural model, presumably capturing the reverse causality. Moreover, the responses based on ϵ_t have the intended sign, but are not statistically significant. These results imply that the effects of future shocks in the structural model are not well captured in these empirical settings because the future shocks are not materialized in the current nominal interest rate by construction. It is also notable that though the size of the shock is normalized to 1% in the annual rate, finding such large fluctuations in the short-term interest rate would be challenging in practice when the short-term rate is constrained at the ELB. By contrast, when TRD_t is included in the VAR, the identified monetary policy shock generates statistically significant effects with the intended sign. The analysis implies that $TRD_t$is a valid measure that represents monetary policy stance.

7. Conclusion

This paper proposed the Taylor rule yield curve, which is an extension of the Taylor rule for the short-term policy rate to the points in time in the future horizon. The estimated Taylor rule expected rates are useful for considering the monetary policy stance reflected in the entire yield curve, which is valid even during the periods when the FFR hits its ELB. The analyses demonstrated that the TRDs for maturities much longer than overnight could influence the output gap and inflation rates in the US even in the sample period when the FFR hit the ELB for a considerable duration and the Federal Reserve resorted to UMP. A stylized New Keynesian model with news shocks qualitatively supported our empirical estimation results. Moreover, the TRDs for long maturities can be regarded as a measure of risk appetite in financial markets.

Several issues can be highlighted for future work. We examined the TRDs only for the US, while it is of interest for other major countries, in particular, those that experienced prolonged periods of ELB for policy rates. Our methodology in this study can be directly applied for analysis in other countries, as long as data on professional forecasters' forecasts of output and inflation are available. Besides, cross-border correlations of TRDs for various maturities would be informative for the investigation of potential spillovers of monetary policy stances in the global context. A sample period of strong research interest will be the period when advanced economies introduced UMPs following the GFC (e.g., Diebold and Li, 2006; Ahrend et al., 2008). We leave these issues as future work.

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Table 1: Granger causality test for TRD and OIS rates

(a) 2-year maturity

Null Hypothesis	Obs.	F-Stat	P-value
TRD 2Y does not Granger Cause OIS 2Y	62	4.579	0.014**
OIS 2Y does not Granger Cause TRD 2Y		0.999	0.375

(b) 10-year maturity

Null Hypothesis	Obs.	F-Stat	P-value
TRD 10Y does not Granger Cause OIS 10Y	62	7.734	0.001**
OIS 10Y does not Granger Cause TRD 10Y		0.843	0.436

Note: ** indicates 5% statistical significance.

Figure 1a: Short-term interest rates and Taylor rule rates

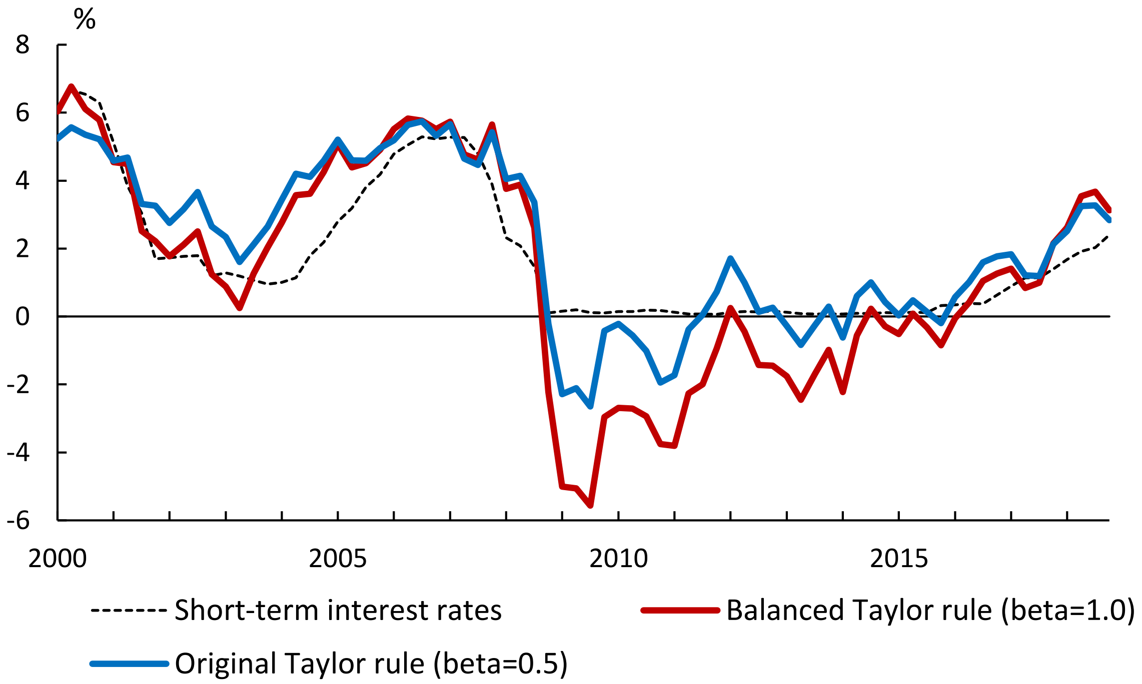


Figure 1b: Deviations of short-term interest rates from the (balanced) Taylor rule rates

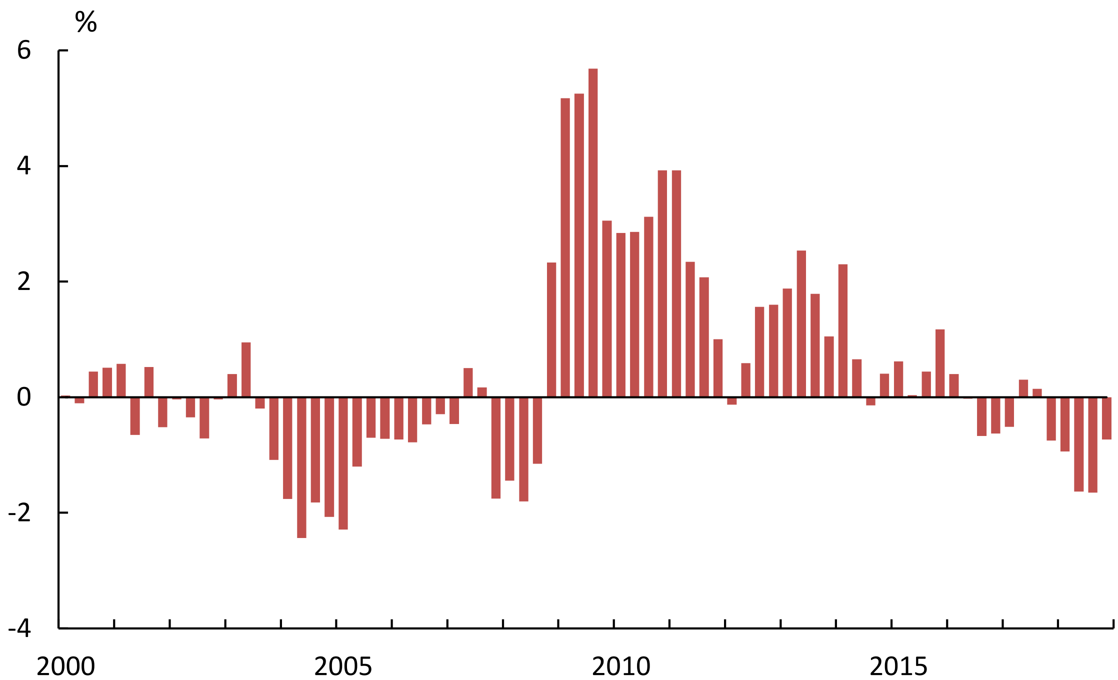


Figure 2: Taylor rule expected rates based on the balanced rule (top) and market expected rates (bottom) for various maturities

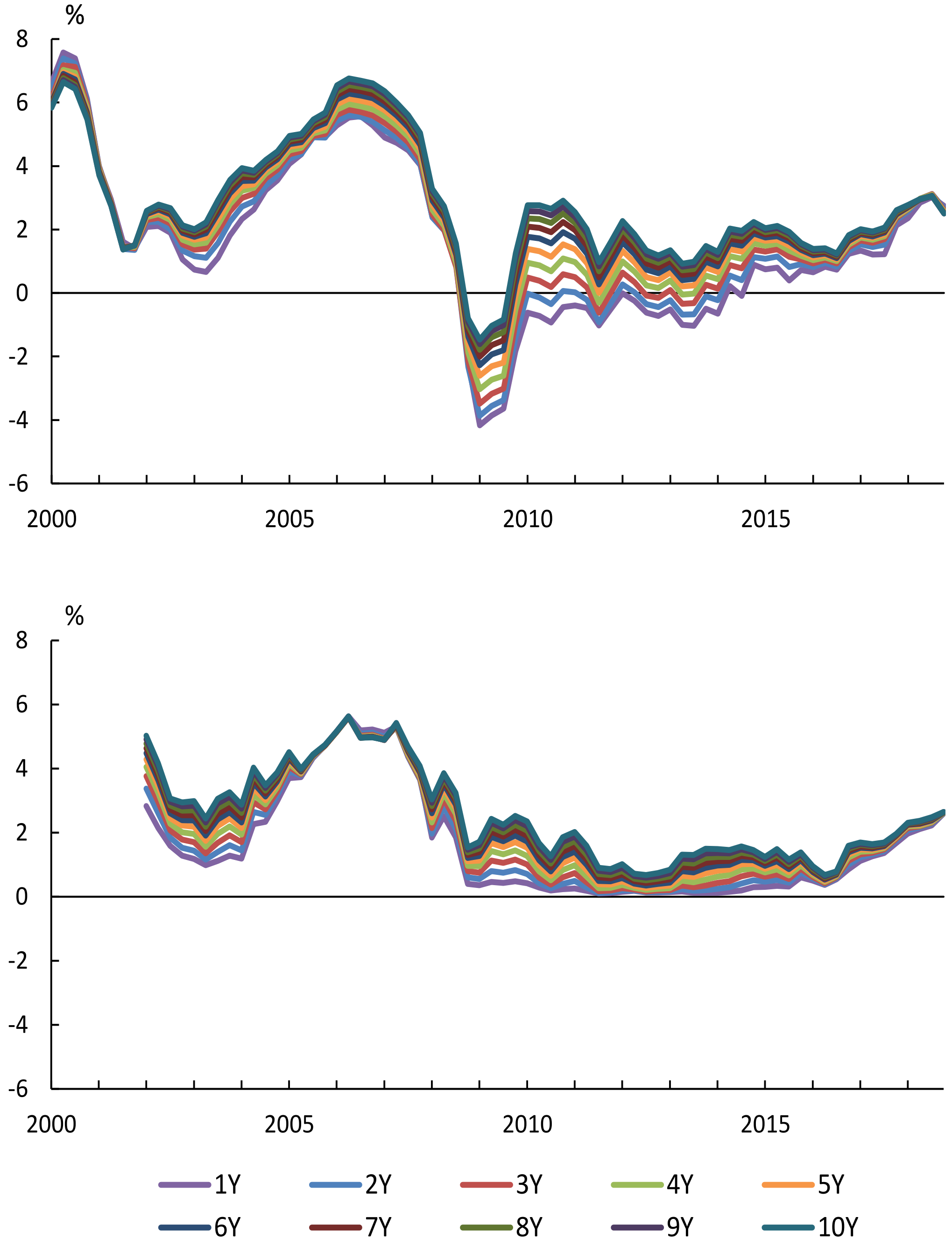


Figure 3: Taylor rule expected rates based on the balanced rule and market rates for 2-year (top) and 10-year (bottom) maturities

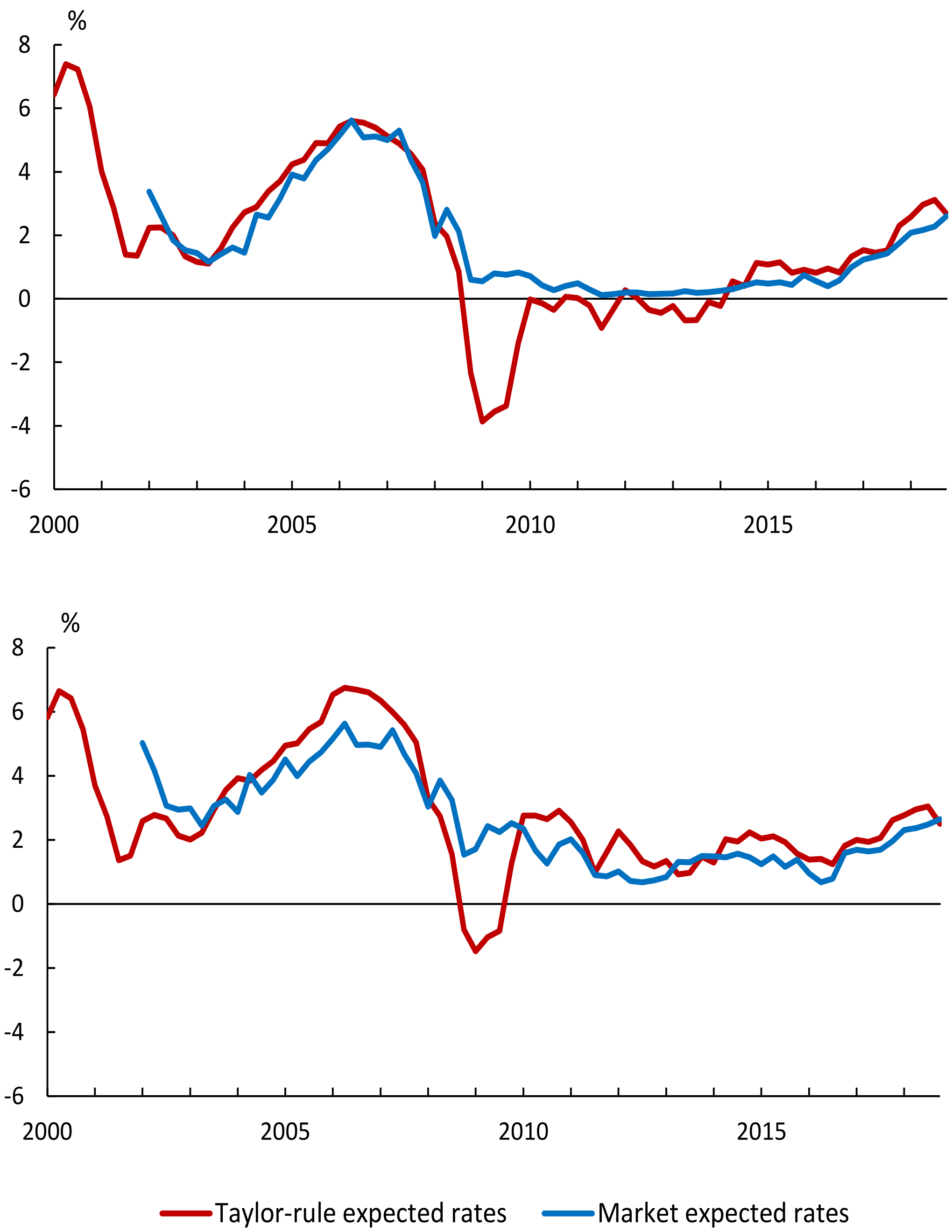


Figure 4: Taylor rule expected rates based on the balanced rule and market rates at selected points in time

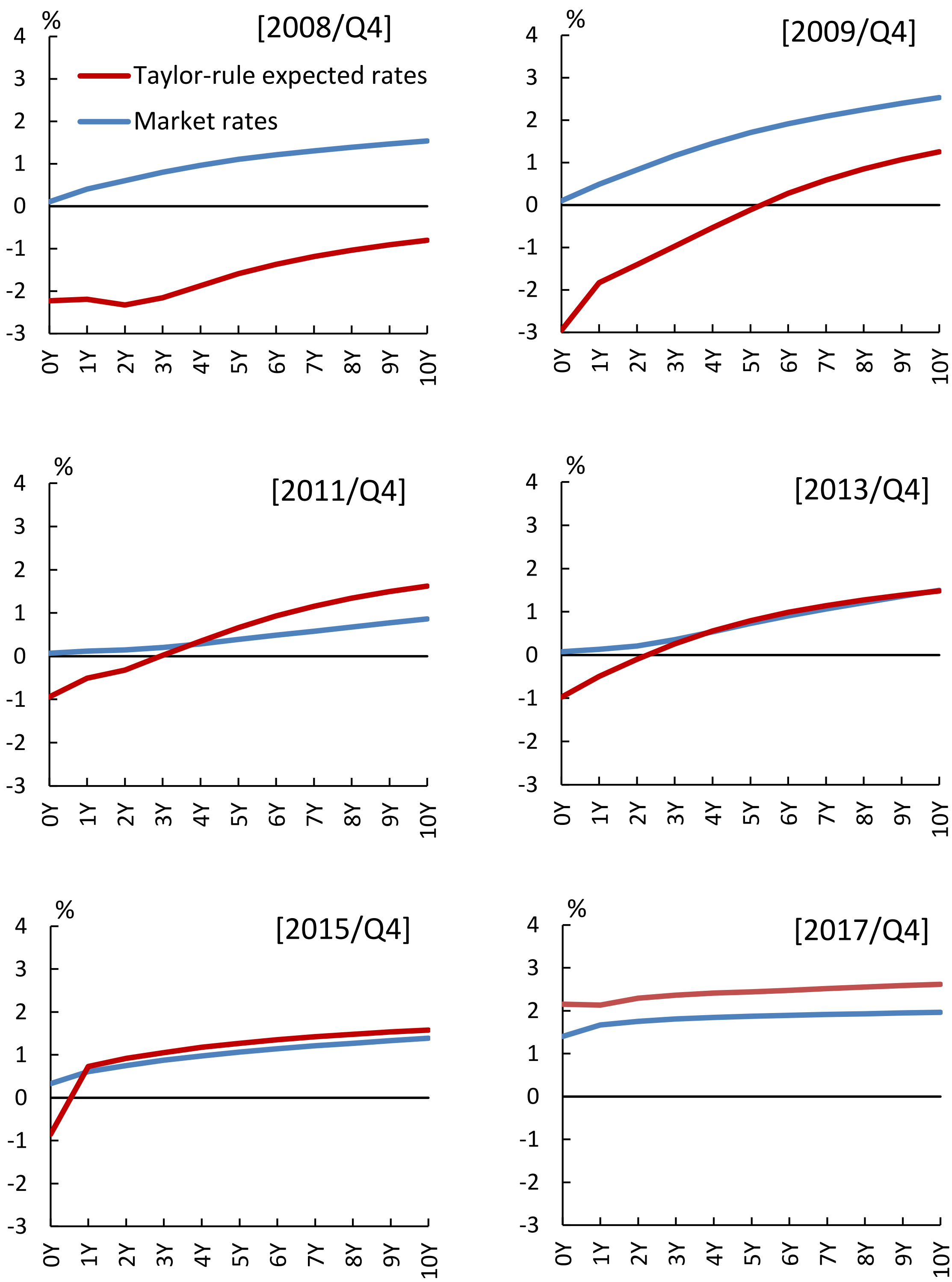
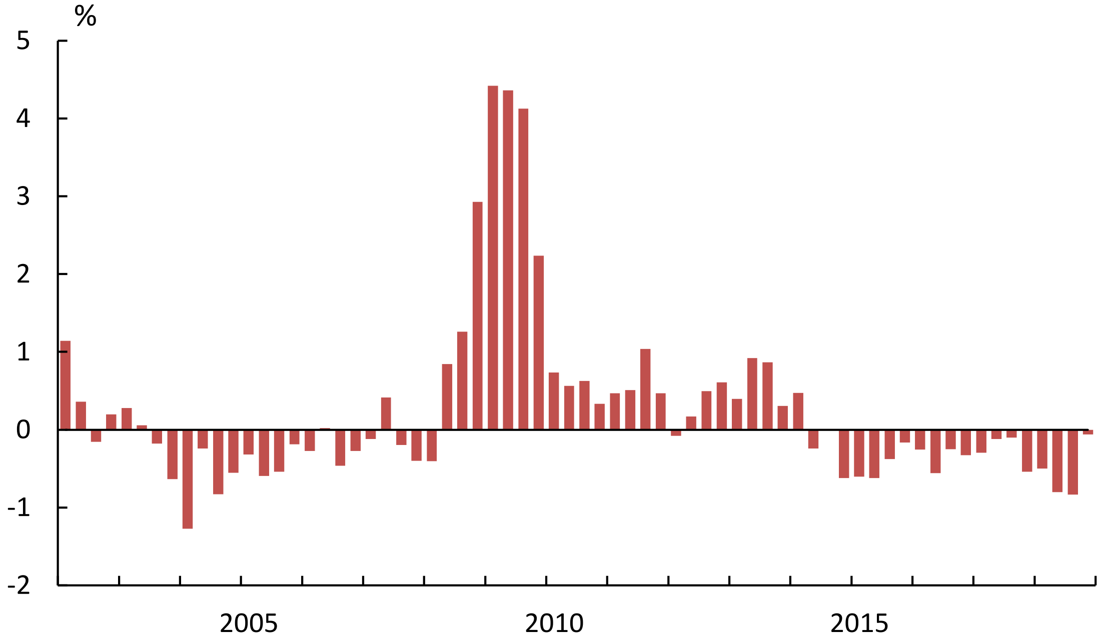


Figure 5: TRDs for 2-year (top) and 10-year (bottom) maturities



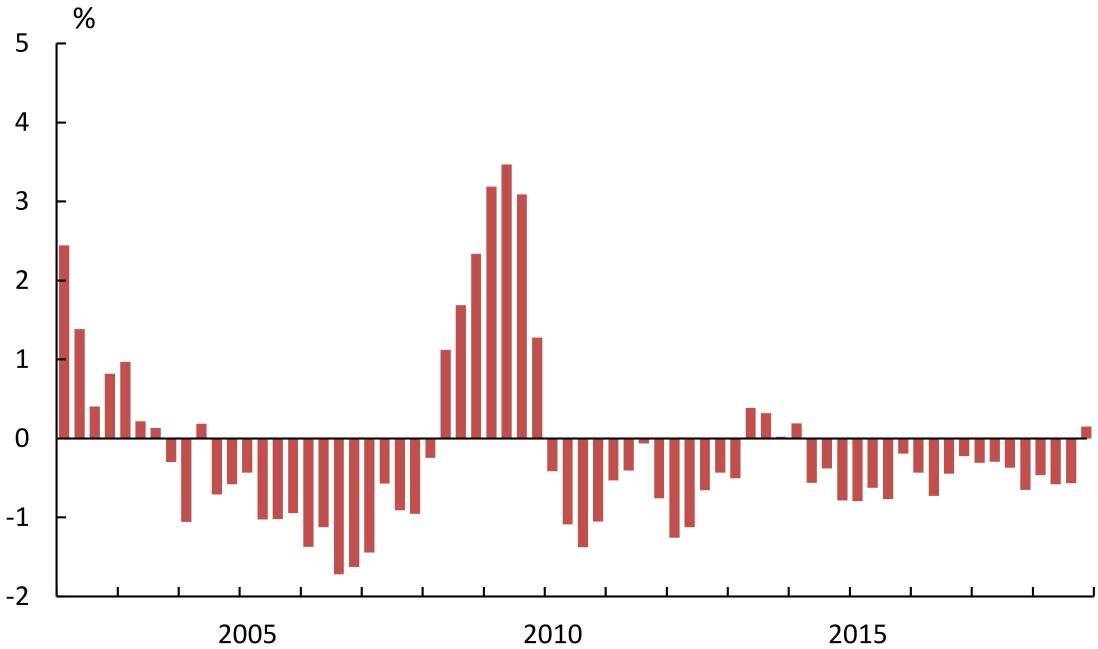
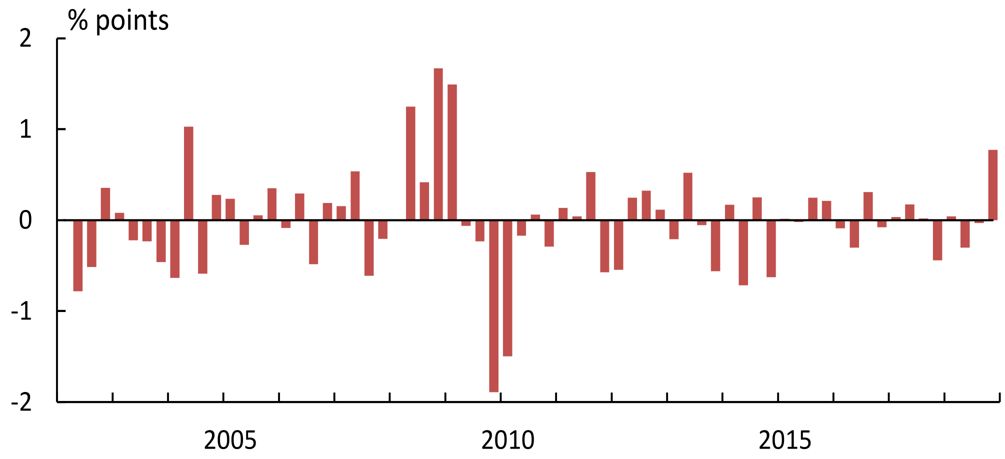
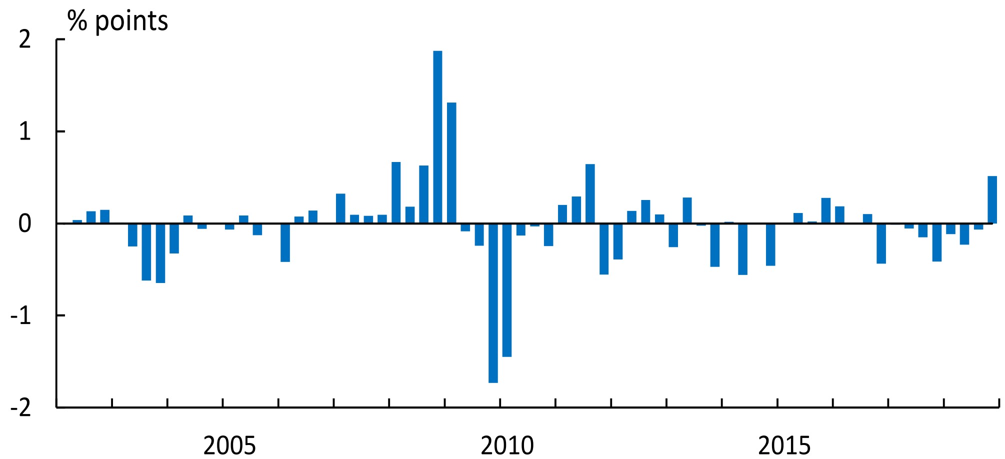


Figure 6: TRDs and their components for 2-year maturity

(a) TRDs (first difference)



(b) Contribution of the output gap (first difference)



(c) Contribution of inflation (first difference)

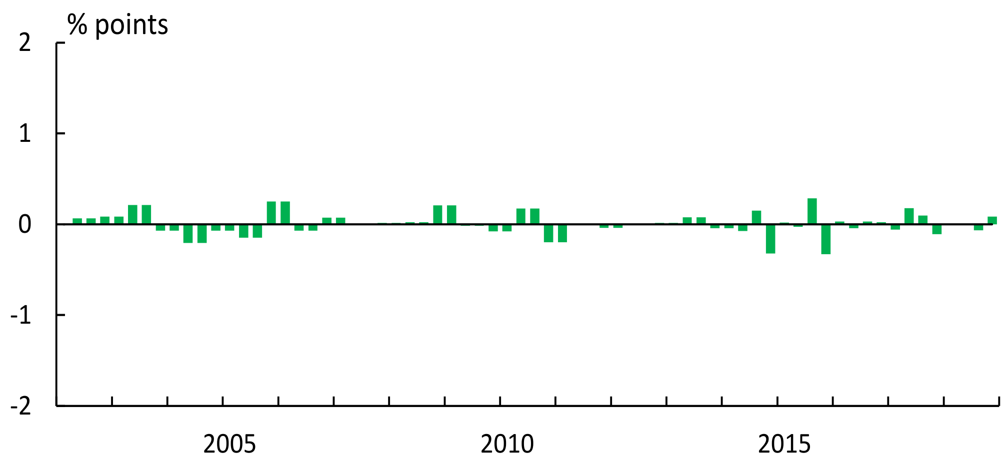
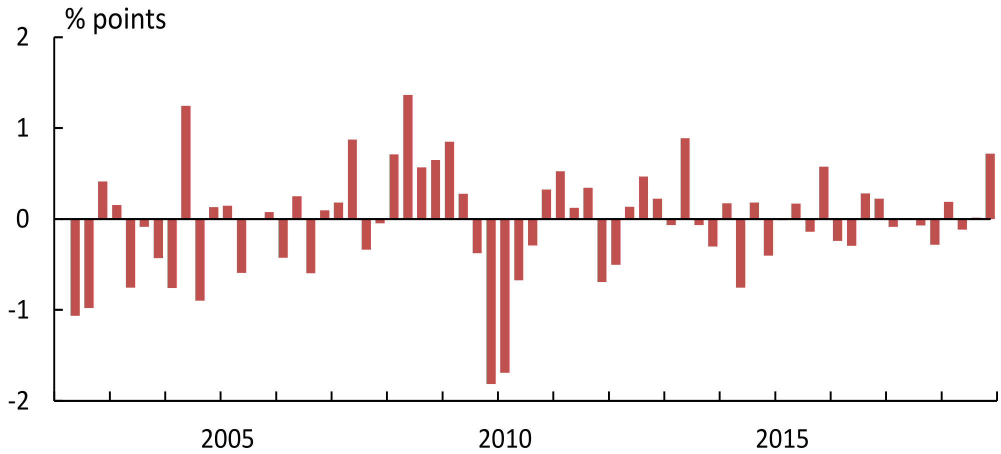
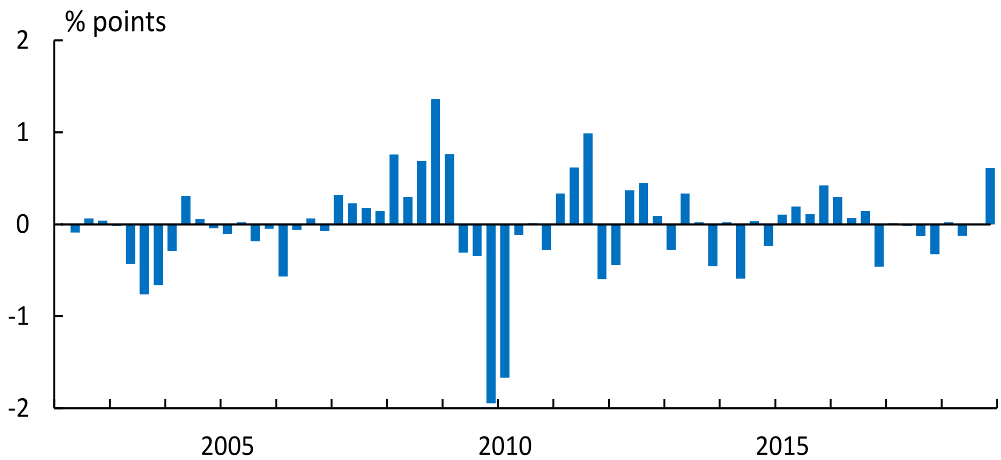


Figure 7: TRDs and their components for a 10-year maturity

(a) TRDs (first difference)



(b) Contribution of the output gap (first difference)



(c) Contribution of inflation (first difference)

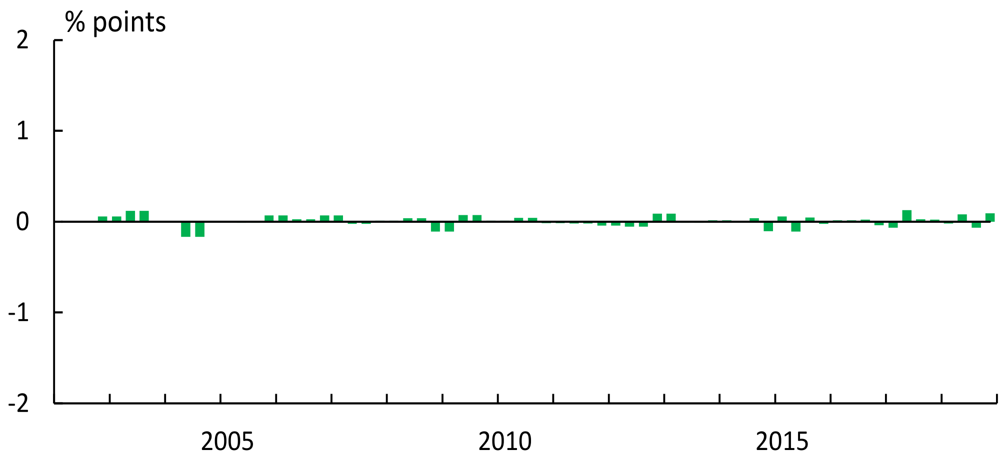
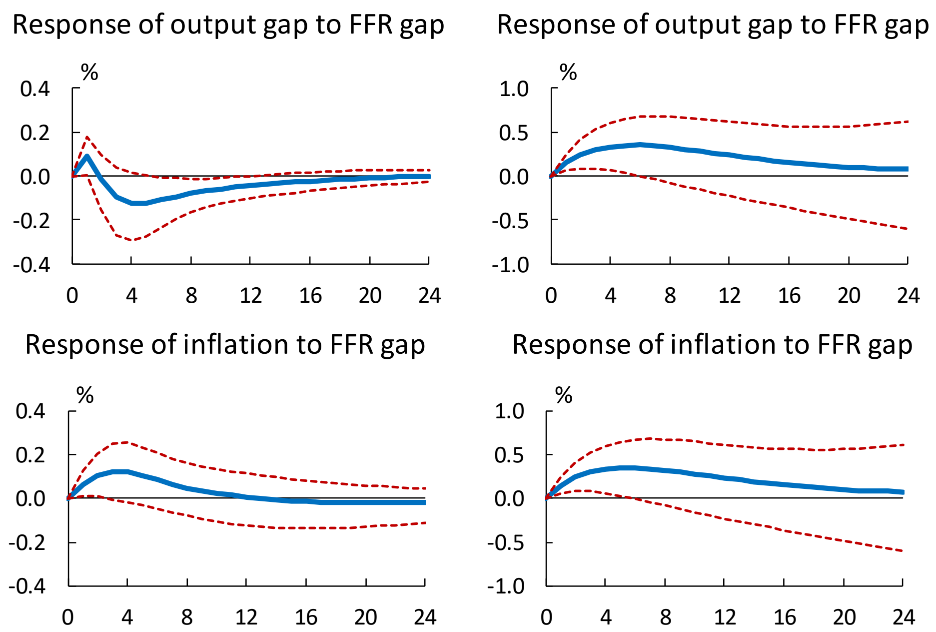


Figure 8: IRs of the output gap and inflation rates to the (a) FFR gap and (b) shadow policy rate gap

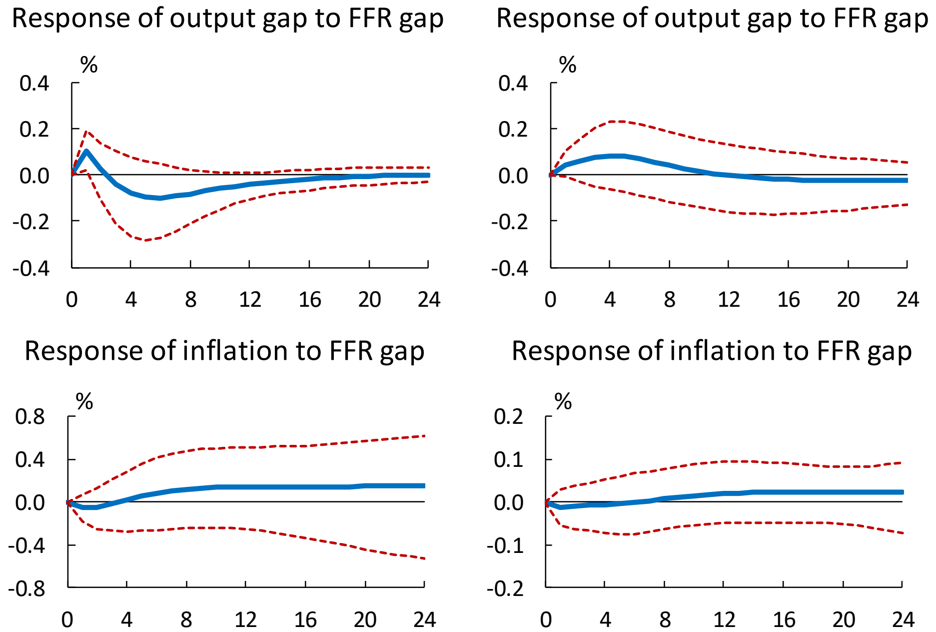
(a) Responses to the FFR gap

(1971–2017) (2002–2017)



(b) Responses to the FFR gap with shadow policy rate replacing FFR

(1971–2017) (2002–2017)

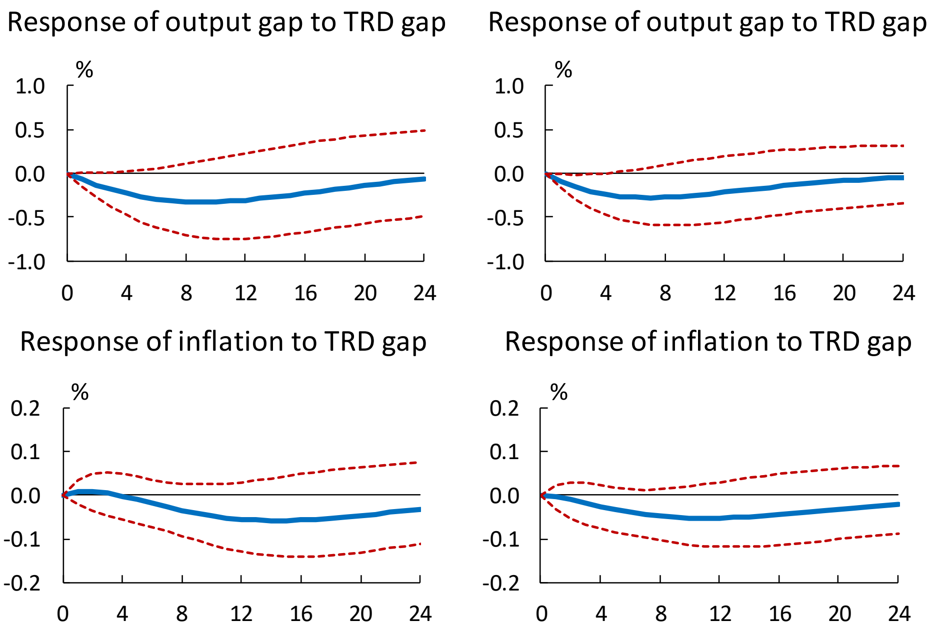


Note: The dashed lines indicate 95% confidence intervals.

Figure 9: IRs of the output gap and inflation rates to (a) TRDs and (b) OIS rates

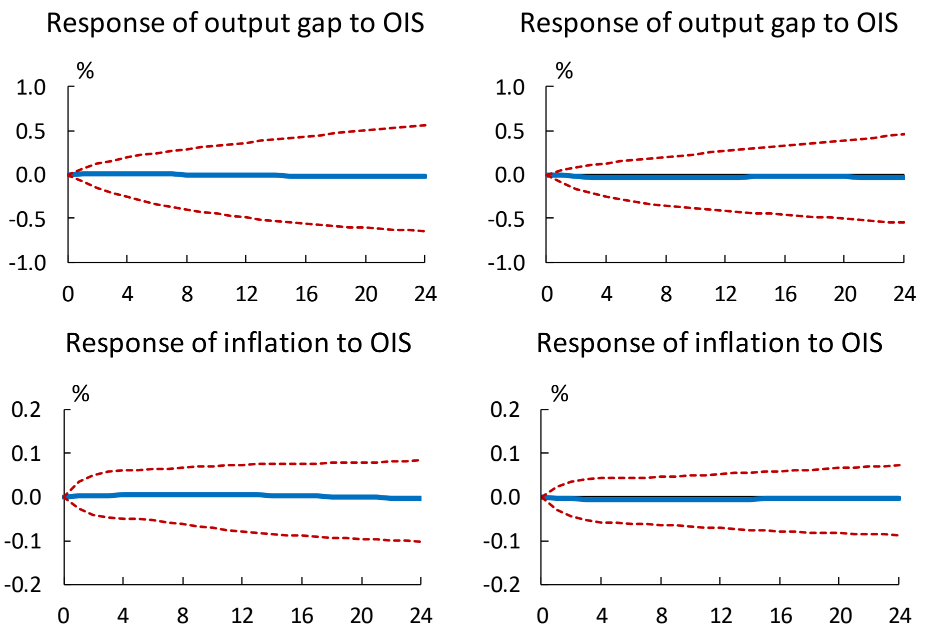
(a) Responses to TRDs

2-year TRD (2002–2017) 10-year TRD (2002–2017)



(b) Responses to the OIS rates

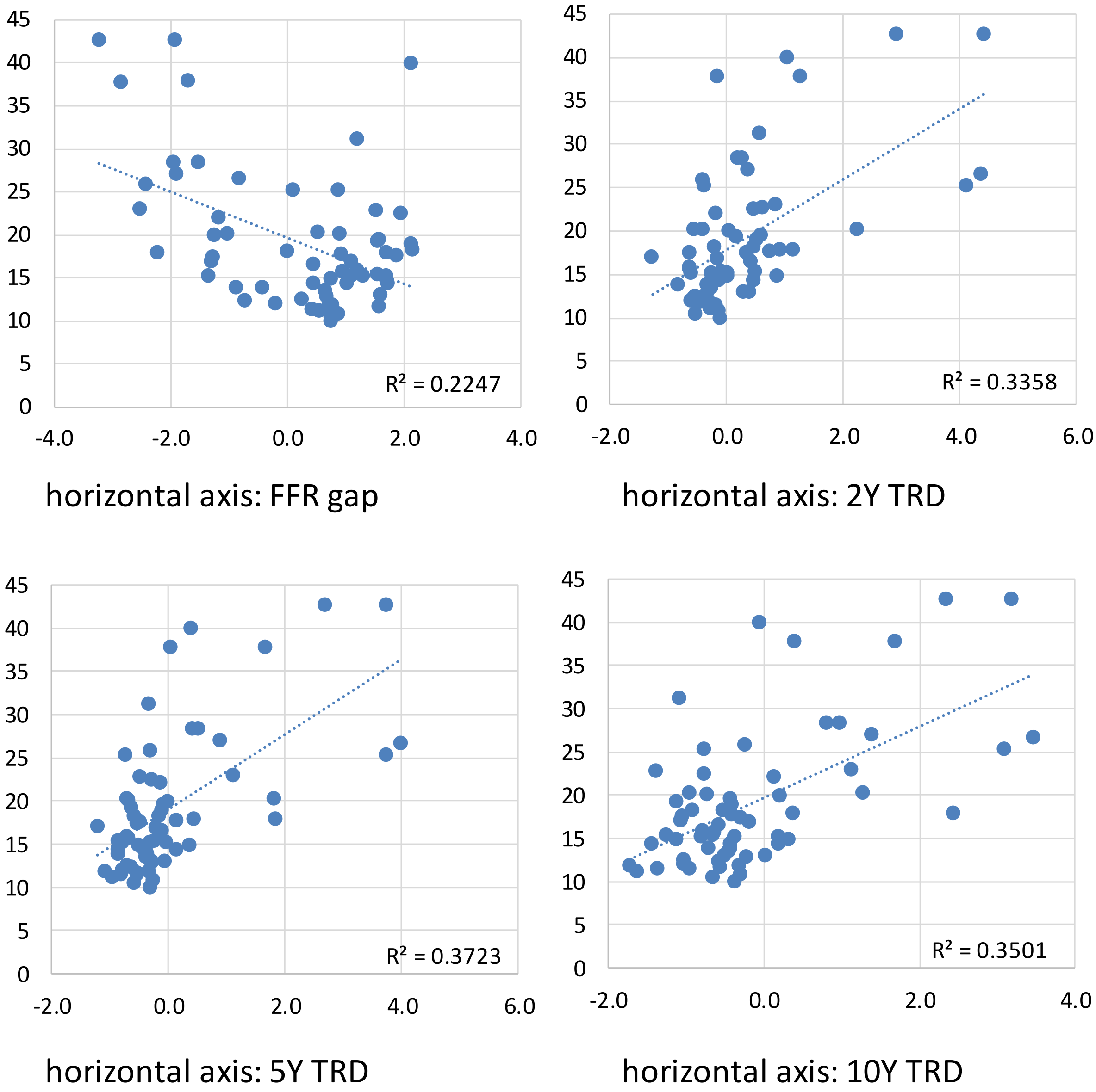
2-year OIS (2002–2017) 10-year OIS (2002–2017)



Note: The dashed lines indicate 95% confidence intervals.

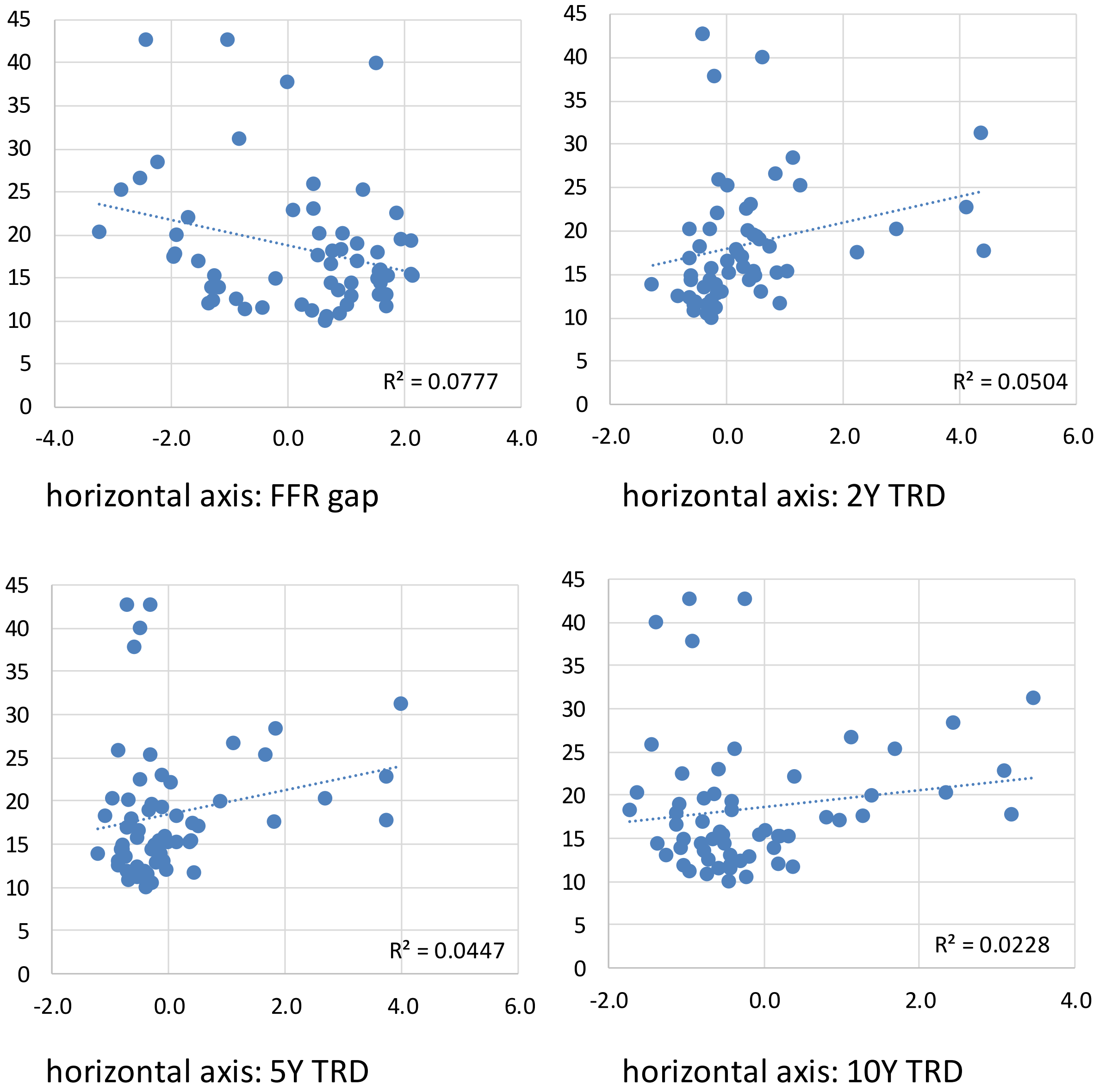
Figure 10: TRDs (horizontal axis) and VIX (vertical axis)

(a) In the same quarter



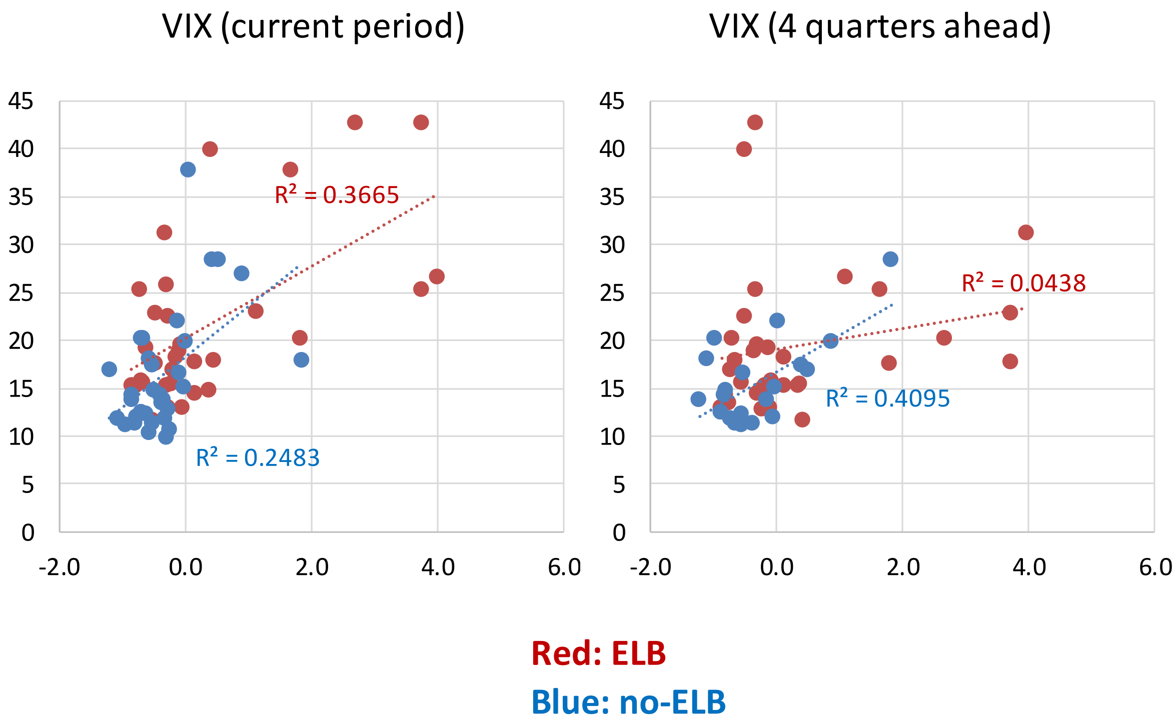
Note: The sample period is from 2002/Q1 to 2017/Q4.

(b) Current TRD and VIX at the four quarters ahead



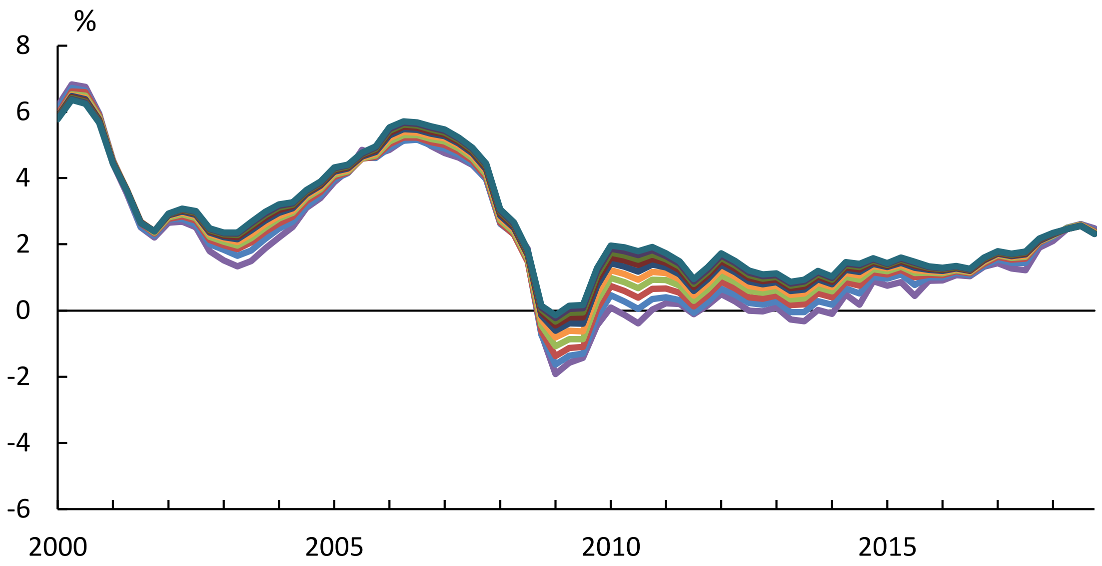
Note: The sample period is from 2002/Q1 to 2017/Q4.

Figure 11: TRDs (5-year, horizontal axis) and term premium (vertical axis)



Note: The sample period is from 2002/Q1 to 2017/Q4. The ELB period ranges from 2008/Q1 to 2015/Q3.

Figure 12: Taylor rule expected rates based on the original rule (top) and market expected rates (bottom) for various maturities



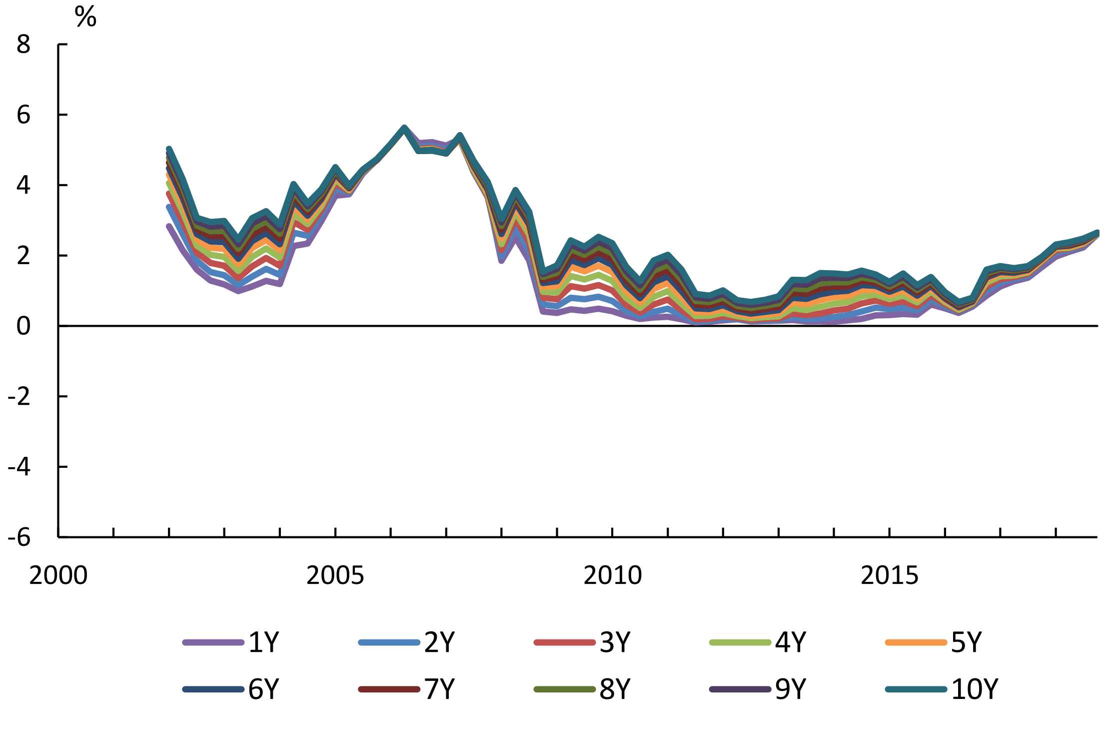


Figure 13: Taylor rule expected rates based on the original rule and market rates for 2-year (top) and 10-year (bottom) maturities

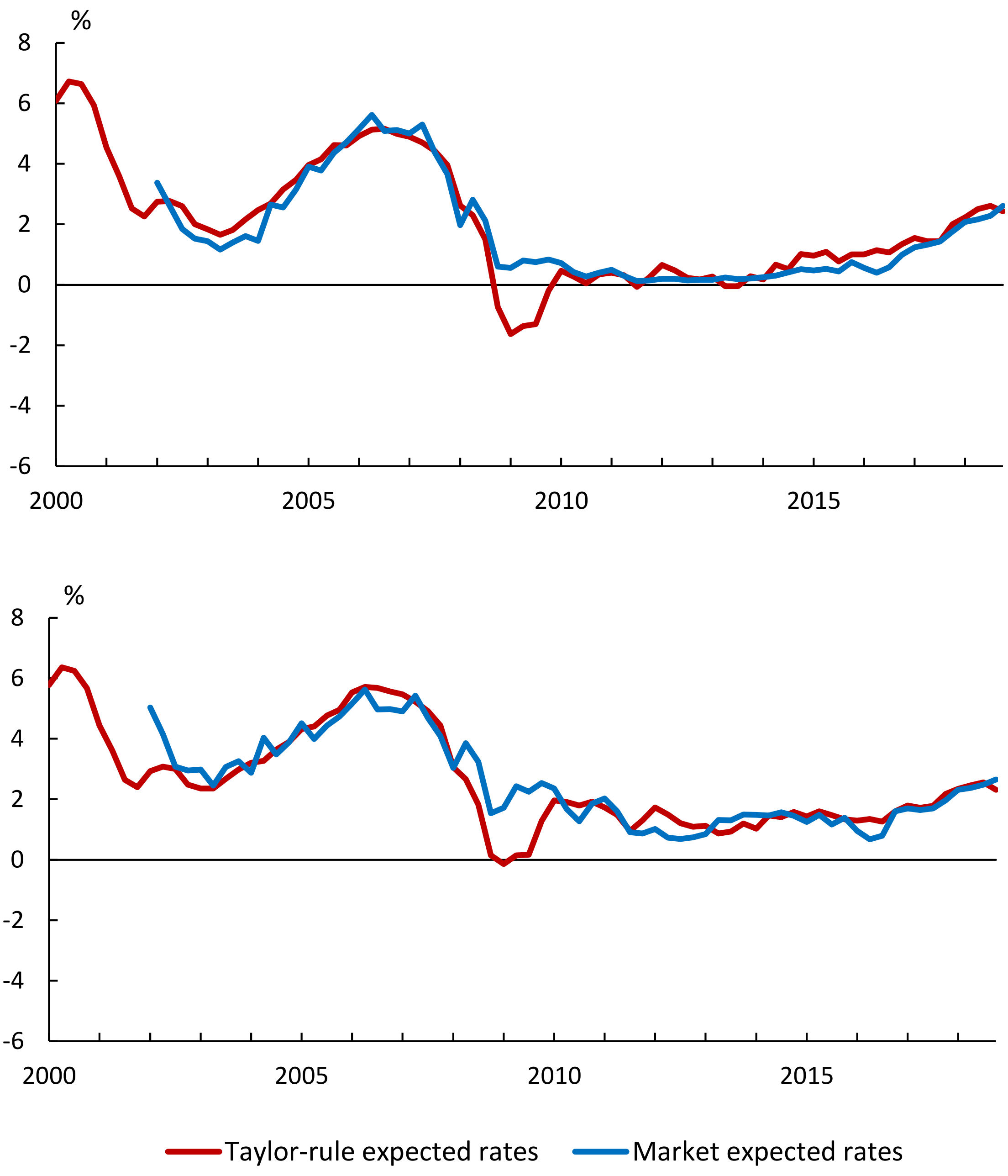


Figure 14: Taylor rule expected rates based on the original rule and market rates at selected points in time

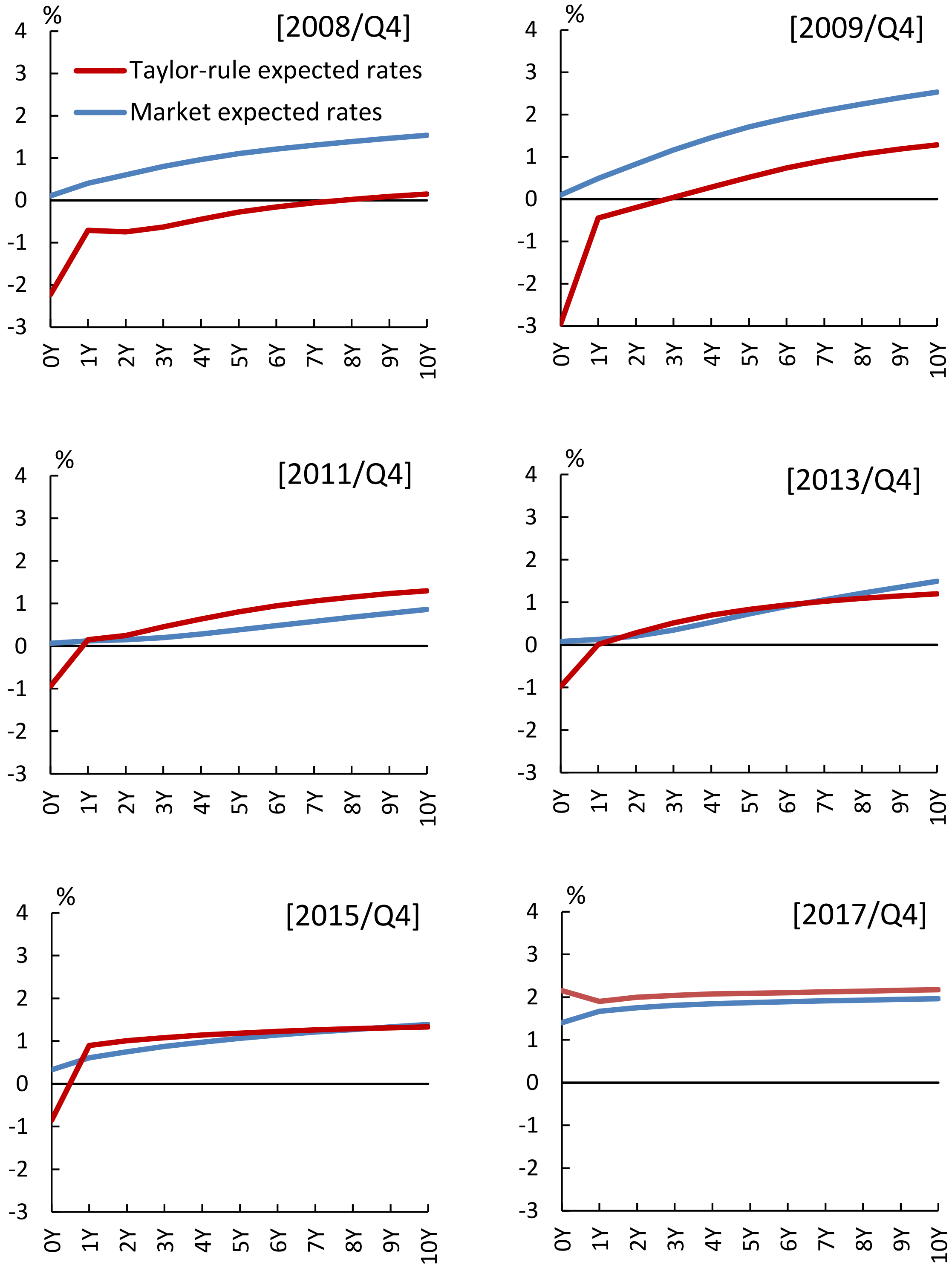
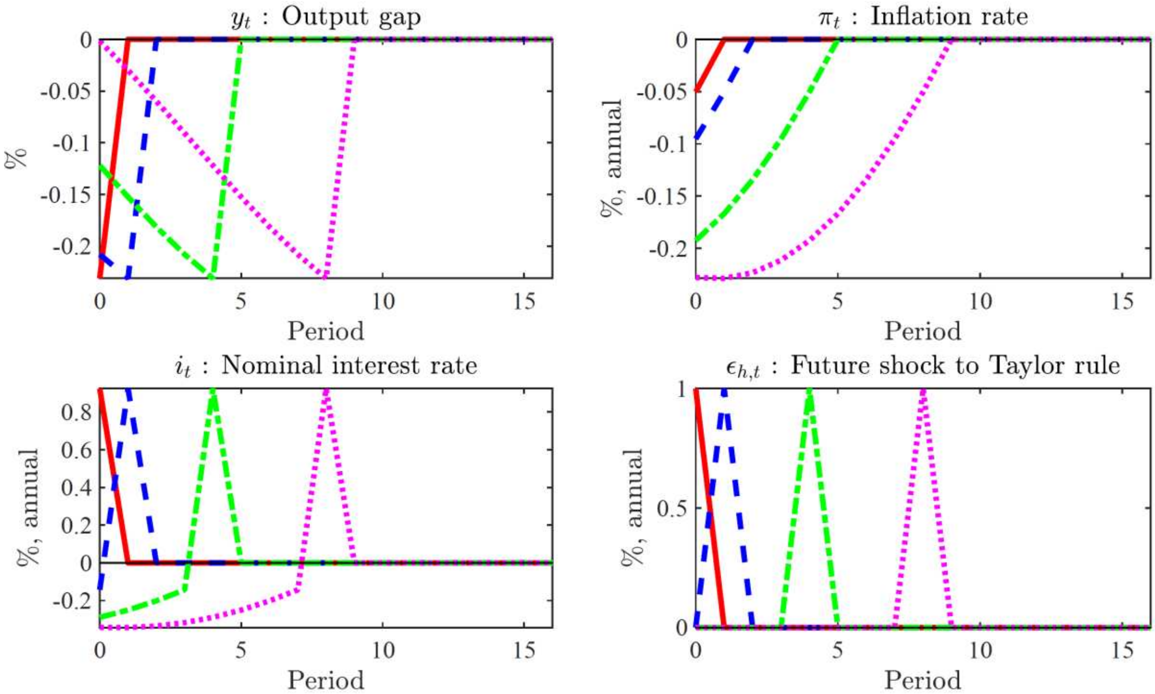
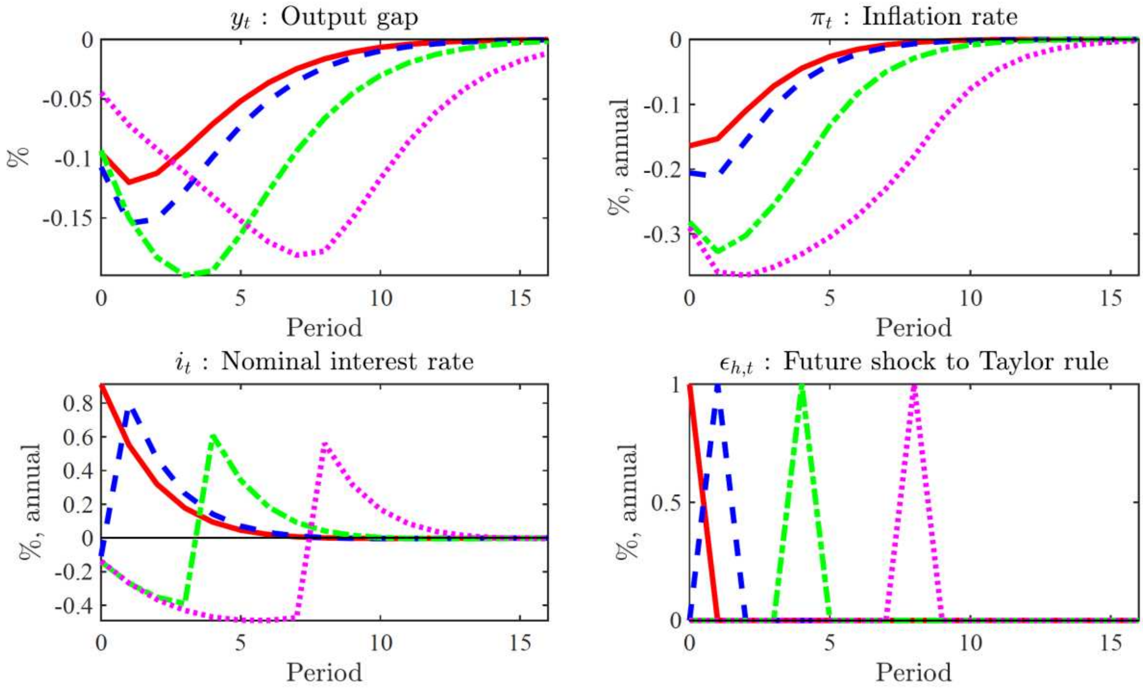


Figure 15: Theoretical IRs to future shocks in a stylized model



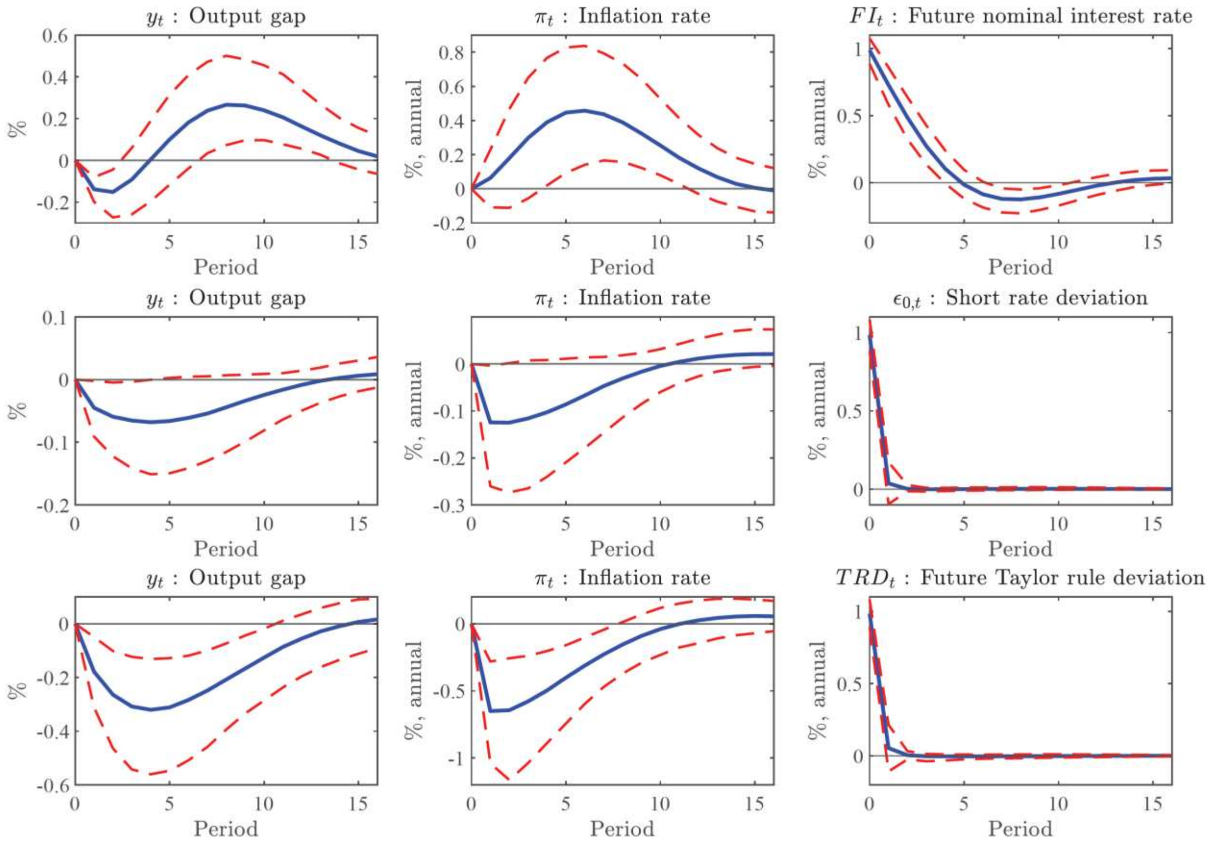
Note: Each shock is known at period 0. The size of the shock is normalized to 1% in the annual rate.

Figure 16: Theoretical IRs to future shocks in model with inertia



Note: Each shock is known at period 0. The size of the shock is normalized to 1% in the annual rate.

Figure 17: IRs on simulated data



Note: Each response is computed based on a three-variable VAR with the output gap, inflation rate, and interest rate measure with the simulated data of the model with inertia. The interest rate measure is the future interest rate (FI_t) in the upper panels, the current interest rate deviation ($\epsilon_{0,t}$) in the middle panels, and the (H-period) Taylor rule deviation (TRD_t) in the bottom panels. H is set to 8. The red dashed lines are the 95% confidence intervals computed by the bootstrap method.