The Effects of Conventional and Unconventional Monetary Policy on Exchange Rates

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Abstract: What are the effects of monetary policy on exchange rates? And have unconventional monetary policies changed the way monetary policy is transmitted to international financial markets? According to conventional wisdom, expansionary monetary policy shocks in a country lead to that country's currency depreciation. We revisit the conventional wisdom during both conventional and unconventional monetary policy periods in the US by using a novel identification procedure that defines monetary policy shocks as changes in the whole yield curve due to unanticipated monetary policy moves. The new approach allows monetary policy shocks to differ depending on how they affect agents' expectations about the future path of interest rates as well as their perceived effects on the riskiness/uncertainty in the economy. Our empirical results show that: (i) a monetary policy easing leads to a depreciation of the country's spot nominal exchange rate in both conventional and unconventional periods; (ii) however, there is substantial heterogeneity in monetary policy shocks over time and their effects depend on the way they affect agents' expectations.

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1 Introduction

Central banks have recently been forced to rely on unconventional monetary policies due to the ineffectiveness of conventional policies at the zero lower bound. The unconventional policies include altering the size and composition of Central banks' balance sheets (i.e. Large Scale Asset Purchases programs, or LSAP) and/or issuing announcements about the future path of short-term interest rates (i.e. forward guidance). Have these new policies affected the way monetary policy shocks are transmitted to international financial markets, in particular exchange rates? And do the effects differ depending on how monetary policy affects agents' expectations regarding the future path of interest rates? Regarding the first question, several studies have found that conventional, expansionary monetary policies typically depreciate the exchange rate of the country implementing such policies (see e.g. Clarida and Gali, 1994, Eichenbaum and Evans, 1996, among others). However, during the recent decade, the implementation of unconventional monetary policy has become more and more frequent: whether the way monetary policy affects international financial markets has changed as well is an open question. Furthermore, regarding the second question, monetary policy shocks are typically identified in the literature as unexpected changes in short-term interest rates that are exogenous to the state of the economy (cfr. Eichenbaum and Evans, 1996). However, monetary policy may have other dimensions, both in the conventional and in the unconventional period, as its effects may depend on how it affects agents' perception of future expected monetary policy, riskiness and uncertainty in the economy. For example, Gürkaynak, Sack and Swanson (2005a) find that monetary policy announcements have important effects on the term structure of interest rates even if the short-term interest rate did not change.

To answer these questions, we use a new approach to the identification of monetary policy shocks based on Inoue and Rossi's (2017) Functional VARs, where shocks are defined as shifts in the entire term structure of interest rates on a day of a monetary policy announcement. Our framework differs from the traditional literature since it naturally captures alternative dimensions of monetary policy (such as forward guidance and asset purchases programs announcements) embedded in shifts of the whole term structure triggered by unexpected monetary policy moves.

By examining the exchange rates of the UK, Europe, Canada and Japan vis-a'-vis the US dollar, we find that *a country's monetary policy tightening in the conventional period generally leads to an appreciation of that country's nominal spot exchange rate*, a result consistent with Clarida and Gali (1994), Eichenbaum and Evans (1996) and Faust and Rogers (2003). *However, interestingly, the effects on exchange rates differ depending on how monetary policy affects agents' expectations as well as its perceived effects on the riskiness/uncertainty in the economy in specific episodes.* In particular, on average across episodes, the appreciation (depreciation) that follows a contractionary (expansionary) monetary policy shock is mostly due to changes in expectations in the short-run, although changes in medium to long-term expectations turn out to be important in selected episodes. The possibility that monetary policy might be multi-dimensional was first discussed and empirically investigated in the seminal work by Gürkaynak, Sack and Swanson (2005a). In this paper we take their analysis a step further: in fact, our approach can be viewed as a way to systematically capture all the various dimensions in which monetary policy affects international financial markets via changes in agents' expectations and perception of risk/uncertainty in the economy, and their time variation.

Since the definition of the monetary policy shock is the same no matter whether monetary policy is conventional or unconventional, we can consistently compare the effects of monetary policy in the two regimes. *The effects of unconventional monetary policy on spot exchange rates are qualitatively similar to those in conventional times; hence, monetary policy did not lose its effectiveness in unconventional times.* However, the exchange rate depreciation following an unconventional monetary policy easing is mostly due to changes in expectations in the medium- to long-run.

Our work is related to the vast literature that studies the effects of monetary policy on exchange rates. It is well-known that expansionary shocks typically lead to a depreciation of the currency – see Clarida and Gali, 1994; Eichenbaum and Evans, 1996; Faust and Rogers, 2003; Scholl and Uhlig, 2008; Bouakez and Normandin, 2010, among others. However, the latter papers focus on the conventional monetary policy period, where monetary policy shocks can be identified as exogenous changes in short-term interest rates; the effects of unconventional monetary policy shocks, instead, are relatively less studied. Recent papers that focus on the unconventional period are Rogers, Scotti and Wright (2014, 2016) and Glick and Leduc (2015). As unconventional monetary policies are a combination of asset purchases and forward guidance, they estimate monetary policy surprises in a short window of time around monetary policy announcements. Rogers, Scotti and Wright (2014) study the effects of monetary policy shocks identified in two principal components extracted from a cross-section of yields on bond yields, stock prices and exchange rates for the US, UK, Euro-area and Japan. Rogers, Scotti and Wright (2016) estimate the effects of unconventional monetary policy surprises on both excess returns on carry trade portfolios as well as a variety of macroeconomic variables (bond yields, exchange rates, employment, inflation and interest rate spreads) and foreign risk premia in a VAR with external instruments. Glick and Leduc (2015) distinguish between changes in the Fed Funds Rate (FFR) around monetary policy announcements; changes in the one-year ahead euro-dollar future rate (short-run path surprises); and changes in the first principal component from several long-term Treasury rate futures (long-run path surprises). They find that monetary policy is effective in both conventional and unconventional periods. Also, in the conventional period, the U.S. dollar depreciates in response to a short-term easing but not to a long-term one; on the contrary, in the unconventional period, the U.S. dollar depreciates in response to both short-term and long-term path surprises. Our paper differs from these contributions in several ways. A first difference is that, in the latter papers, the shock is the exogenous change in the principal component(s) extracted from a cross section of interest rates, while in our work the shock is the *shift in the entire term structure* due to an exogenous monetary policy move. It is the analysis of how the whole yield curve shifts over time that allows us to crucially differentiate our results from those existing in the literature. In fact, we use an alternative measure of monetary policy shocks that allows shocks to potentially differ in each monetary policy episode depending on how the shock is perceived by the agents at different horizons. A second, important difference is that Rogers, Scotti and Wright (2014) and Glick and Leduc (2015) use an event study approach which allows them to estimate the contemporaneous correlation between changes in the term structure due to monetary policy on specific dates and the exchange rate, but is otherwise silent on the dynamic effects; in contrast, our paper estimates the *whole dynamic impulse response.* Rogers, Scotti and Wright (2014, 2016) also complement their analyses with VARs either using a heteroskedasticity-based identification (as in Rogers, Scotti and Wright, 2014, and Wright, 2012), or external instruments (as in Rogers, Scotti and Wright, 2016) to trace out the effects of monetary policy shocks over time. Our approach instead relies on the *Functional VAR approach* (Inoue and Rossi, 2017), which provides the dynamic response to the shift in the whole term structure viewed as a function of maturity. Finally, our analysis naturally leads to *time-varying responses* of exchange rates that fundamentally depend on the ways in which monetary policy affects agents' expectations of current and future interest rates as well as the risk and uncertainty in the economy.

In a related paper, Gali (2018) analyzes the effectiveness of forward guidance in open economies. According to economic theory, under standard economic assumptions, the impact of an announcement of a future adjustment in interest rates on the current exchange rate either does not depend on the timing of the adjustment or it is larger the longer the horizon of implementation, depending on whether prices are assumed to be fixed or flexible. Empirically, however, Gali (2018) finds instead that expectations of interest rate differentials in the near (distant) future have larger (smaller) effects than implied by theory. Since the theory is inconsistent with the empirical results, he concludes that there is a forward guidance exchange rate puzzle. In this paper, instead, we focus on the overall response of exchange rates to a monetary policy "event", which is defined as the shift in the entire term structure around monetary policy announcement dates, as opposed to interest rate changes at different maturities.[1]

Our paper is also related to the literature that measures the effects of unconventional monetary policy on the yield curve, and more broadly the literature on the effects of monetary policy announcements using high-frequency identification, such as Kuttner (2001), Gürkaynak, Sack and Swanson (2005a, 2005b, 2007), Wright (2012) and Altavilla and Giannone (2014). While our work builds on these contributions, it substantially differs from them: unlike these papers, which focus only on the effects of monetary policy on yields at specific maturities, we use instead shifts in the whole yield curve to identify unconventional monetary policy shocks; furthermore, we study their effects on exchange rates by measuring the response of exchange rates to the whole shift in the term structure due to the policy itself.

The paper is structured as follows. Section 2 describes the data and Section 3 provides an overview of the methodology used in this paper. Section 4 presents the empirical results on the effects of monetary policy shocks on exchange rates in conventional times, while Section 5 discusses the results for the unconventional period. Section 6 provides empirical evidence on which expectations matter the most in different monetary policy regimes (whether they are short-run or long-run). Section 7 concludes.

[1] There are several other differences between our work and Gali (2018). One such difference is that Gali's (2018) results are unconditional, i.e. independent on which shocks affect agents' expectations of interest rates, whereas we condition on monetary policy announcements. Another difference is that our data are nominal, rather than real, although nominal and real exchange rates are highly correlated.

2 The Data

The term structure data are daily zero-coupon yields (mnemonics "SVENY") from Gürkaynak, Sack and Wright (2007) and include yields at 1 to 30 years maturities. The daily frequency is dictated by the availability of the data. The 3- and 6-month daily zero-coupon yields are from the Federal Reserve Board (Fed) H-15 release. The data are from January 1995 to June 2016. The sample starts in 1995 due to the fact that the Fed did not release statements of monetary policy decisions after its Federal Open Market Committee meetings before 1994. Note that the frequency of the data is daily. While one might be interested in investigating the identification at a higher frequency, Gürkaynak, Sack and Swanson (2007a) show that daily data are sufficient for extracting monetary policy shocks using a high-frequency identification if the sample is limited to post-1995 data, which is our case.

The nominal bilateral exchange rate data for the Euro, British pound, Canadian dollar and the Yen vis-a'-vis the U.S. dollar (respectively denoted by EURUS, GBPUS, CADUS and YENUS) are from Bloomberg. We calculate the daily exchange rate change (measured as foreign currency units for one US dollar) as the (log of the) value at the end of the day minus that at the end of the previous day.[2] The exchange rate data are in units of foreign currency for one US dollar (USD); thus, in this paper, an increase in the exchange rate denotes an appreciation of the US dollar relative to the foreign currency.

The dates of US conventional monetary policy announcements are from Nakamura and Steinsson (2017) and include Federal Open Market Committee (FOMC) meetings. The unconventional monetary policy announcement dates are instead from Wright (2012), although we updated them to the end of our sample. In particular, the unconventional monetary policy dates include the announcements of the start of LSAP-I on November 25, 2008; LSAP-II on August 10, 2010; and LSAP-III on September 13, 2012; as well as announcements of additional Treasury and bond purchases, among others. Inoue and Rossi (2017) and its Not-for-Publication Appendix (Inoue and Rossi, 2017b) provide more details on the announcement dates we use.

3 The Empirical Approach

This section describes Inoue and Rossi's (2017) approach to the identification of monetary policy shocks. In our analysis, we assume that, on days of a monetary policy announcement, a change in a yield curve is mainly caused by monetary policy shocks, which shift the entire yield curve. In fact, at the time of the monetary policy announcement, the term structure moves because of financial markets' changes in expectations about current interest rates as well as the entire path of medium- to long-term interest rates due to unexpected changes in monetary policy and their perceived effects on the riskiness/uncertainty in the economy. This "high-frequency" identification approach builds on Gürkaynak, Sack and Swanson (2005a,b, 2007), although it differs from them as we focus on the change in both the shape and the magnitude of the whole yield curve.

[2] The EUR/USD series starts on 1/1/2000.

Let $\mathcal{Y}_{\tau,t}$ denote the yield to maturity at time t, where τ is the maturity. We follow Inoue and Rossi (2017) and estimate monetary policy shocks as changes in the term structure during the day of a monetary policy announcement:

$$\varepsilon_t^m(\tau) = \Delta\mathcal{Y}_{\tau,t} \cdot d_t,$$

where $\Delta\mathcal{Y}_{\tau,t} \equiv \mathcal{Y}_{\tau,t} - \mathcal{Y}_{\tau,t-1}$ is the change in the yield curve as a function of maturity τ on any day t; d_t is a dummy variable equal to unity on a day of a monetary policy announcement, and zero otherwise. Each monetary policy shock can be potentially different: for example, it could be a parallel shift in the term structure; or it could shift its slope by affecting more (less) the short-term interest rates relative to long-term ones; or it could affect the curvature by affecting the medium-term rates more than the rest of the maturities – or, it could be a combination of all these. These different dimensions of monetary policy are embedded in changes in the yield curve resulting from monetary policy moves, which we estimate by $\varepsilon_t^m(\tau)$. In fact, note that the monetary policy shock depends on the maturity, τ.

Measuring monetary policy shocks as shifts in the term structure in a short window of time around a monetary policy announcement allows us to identify the exogenous variation in monetary policy under the assumption that any other shocks that affect the economy during the same period of time have only minor effects. This assumption is credible in our context since the window of time we rely upon is one day. The approach is convenient since it captures only monetary policy changes that are fully unexpected by financial markets. At the same time, monetary policy shocks that are intended by the policymaker to be expansionary may actually be contractionary if they are not as expansionary as financial markets expect. Similarly to the traditional high frequency identification approach in Gürkaynak, Sack and Swanson (2005a,b), such shocks will be contractionary in our framework.

In addition, the identification requires that monetary policy announcements carry information about monetary policy changes, as opposed to new information about the state of the economy. The possibility that monetary policy announcements affect agents' beliefs about other economic fundamentals and not only about monetary policy has been proposed by Nakamura and Steinsson (2017), and is referred to as "the information channel". Whether the information channel is empirically relevant is an open question that has attracted interest in the literature. The information channel is plausible only if the Central bank has superior information about the state of the economy relative to market participants. On the one hand, Romer and Romer (2000) and Nakamura and Steinsson (2017) found evidence that this is the case in the US on average over a long sample of data. On the other hand, Rossi and Sekhposyan (2016, 2018) investigate how the Fed's superior information content has evolved over time and show that, in the last decade, the Central bank lost its informational advantage; hence, the latter suggests that the informational channel is not too important in our empirical analysis.[3]

Let $s_{i,t}$ denote the (log of the) nominal bilateral exchange rate of country i vis-a'-vis the US dollar (USD) at time t, that is the units of that country's currency for one US

[3]If one worries about the information channel, in principle one could clean the instrument of monetary policy using Greenbook forecasts data following the approach in Miranda-Agrippino and Ricco (2018). However, their approach is not directly applicable in our context since our frequency is daily and we would need Greenbook forecasts of the entire term structure of interest rates.

dollar. Thus, an increase in $s_{i,t}$ denotes an appreciation of the US dollar relative to the foreign country. At each point in time, we estimate the response of the rate of growth of the exchange rate ($\Delta s_{i,t} \equiv s_{i,t} - s_{i,t-1}$) to the monetary policy shock ($\varepsilon_t^{mp}(\tau)$) using Inoue and Rossi's (2017) Functional VAR approach as follows:

$$\frac{\partial \Delta s_{i,t+h}}{\partial \varepsilon_t^{mp}(\tau)} = \sum_{\tau=1}^{M} c_\tau^{(h)} \Delta \mathcal{Y}_{\tau,t}^{*} \tag{1}$$

$$= \sum_{\tau=1}^{M} \Delta_{\tau,t} \tag{2}$$

where $\Delta \mathcal{Y}_{\tau,t}^{*} = \Delta \mathcal{Y}_{\tau,t} \cdot d_t$ is the change in the yield curve on a day of a monetary policy announcement (indicated by the dummy variable d_t); and $c_\tau^{(h)} = E\left(\frac{\partial \Delta s_{i,t+h}}{\partial \Delta \mathcal{Y}_{\tau,t}}\right)$ are the (impulse) response coefficients to a shock in the yield curve at maturity τ after h periods, and are estimated from the following VAR:

$$A(L) X_t = \mu + u_t, \tag{3}$$

where $X_t = (\Delta s_{i,t}, \Delta \mathcal{Y}_{3,t}, \Delta \mathcal{Y}_{12,t}, \Delta \mathcal{Y}_{96,t}, \Delta \mathcal{Y}_{216,t}, \Delta \mathcal{Y}_{336,t})'$,[4] $h = 1, 2, ..., 15$ is the horizon of the response and the lag length is two.[5] The Appendix provides detailed information on the VAR estimation.[6]

To allow for changes in the transmission mechanism in different monetary policy periods, we estimate eq. (3) in two sub-samples: the conventional monetary policy period (1995:1-2008:10) and the unconventional period (2008:11-2016:6). Note that the start of the second sub-sample is marked by the start of the first large scale asset purchasing program (LSAP-I), dated November 25, 2008.

In what follows, we separately analyze the effects of conventional and unconventional monetary policy. The next section focuses on monetary policy in conventional times, while the following section focuses on unconventional times.

4 Measuring the Effects of Monetary Policy on Exchange Rates in Conventional Times

In this section we study the effects of monetary policy shocks on exchange rates in the conventional monetary policy period. By conventional monetary policy we mean situations where the monetary authority's instrument is typically the short-term interest rate. In our

[4] An alternative approach is to use the entire yield curve fitted using a parametric model following Nelson and Siegel (1987) and Diebold and Li (2006) – see Inoue and Rossi (2017) for the alternative parametric approach.

[5] That is, in practice, for in the estimation we use the term structure at the following maturities: three months, and 1, 8, 18 and 28 years.

[6] The VAR is estimated using Bayesian methods to control for parameter proliferation – see the Appendix for more details.

data, the conventional period lasts from the beginning of our sample until the end of October 2008 (included).

Our results are depicted in Figure 1. Each of the figures 1A-1D corresponds to a different exchange rate: the US dollar vis-a'-vis the UK pound (depicted in Figure 1A), the Euro (Figure 1B), the Canadian dollar (Figure 1C) and the Yen (Figure 1D). In each figure, we separately consider contractionary and expansionary monetary policy moves as well as their impact at the short- and medium-end of the term structure, depicted in four panels: Panels I and III focus on contractionary monetary policy, while Panels II and IV focus on expansionary monetary policy.

INSERT FIGURE 1 HERE

In particular, Panel I focuses on fully contractionary monetary policy shocks; that is, shocks that are contractionary at both very short- and medium-term maturities (the very short-term maturity is 3 months and the medium-term maturity is 8 years), and where the effect at the medium-end of the term structure is even more contractionary than that on short-term rates (that is, $\Delta\mathcal{Y}^*_{t,3} > 0$ and $\Delta\mathcal{Y}^*_{t,96} - \Delta\mathcal{Y}^*_{t,3} > 0$). The graph on the right in Panel I depicts the monetary policy shock as a function of the maturity (in years). Thus, the events depicted in Panel I correspond to monetary policy announcements where the term structure increased at all maturities; in fact, the difference between the interest rates after and before the announcement ($\varepsilon^{mp}_t(\tau)$) is positive at all maturities. Since the shock is contractionary, agents revised their expectations of current and future interest rates upwards, and even more so for future interest rates.

Panel II, instead, considers fully expansionary shocks, that is shocks that decrease both the short- and the medium-end of the term structure, and are such that the effects are perceived to be even more expansionary in the medium-run than in the short-run. We also separately consider cases in which monetary policy is more contractionary at short than at long maturities (Panel III), and cases in which monetary policy is less expansionary at long than at short maturities (Panel IV). That is, Panel III focuses on cases in which agents expect interest rates to increase in the short-run but not to increase as much (or even decrease) in the long-run. On the contrary, Panel IV considers cases in which the reaction at the short end of the yield curve is expansionary while medium-term yields do not decrease as much as short-term ones (or may even increase).

Each panel has two graphs: as we mentioned, the graph on the right-hand side depicts the monetary policy shocks; on the left hand side, instead, we depict the exchange rate response to each of the shocks depicted on the right hand side. Note that each monetary policy shock is potentially different in both magnitude and shape across maturities, as it can potentially move the yield curve in a different way. Thus, we depict several exchange rate responses, one for each of the monetary policy shocks. Note that the responses are in the same units as the exchange rate (in growth rates).

Our results show that, *on average, for all the bilateral exchange rates that we consider, a monetary policy tightening (easing) during the conventional monetary policy period generally leads to an appreciation (depreciation) of the US dollar*, consistently with the results in

Clarida and Gali (1994), Eichenbaum and Evans (1996) and Faust and Rogers (2003). This result can be appreciated by looking at the two graphs in the top panels in Figures 1A-1D that distinguish between shocks that are fully contractionary and fully expansionary (Panels I and II). For all countries except Canada, a US monetary policy tightening typically results in an appreciation of the US dollar. Similarly, a US monetary easing typically results in a depreciation, as shown in Panel II, where the magnitude again depends on the specific shape of the variation in the yield curve.

However, note that *the effects of monetary policy depend on how it affects agents' expectations and their perception of risk in the short- versus the medium- and long-run. The exchange rate response, in fact, depends on how the yield curve shifts as a result of monetary policy moves.* In the conventional identification approach, shocks of different magnitude result in parallel shifts in the responses, as they only depend on the effect of monetary policy on interest rates at the short-term maturity; in our approach, shocks of different shape may result in exchange rate responses with more complex shapes.

For example, notice how, in the UK pound-US dollar exchange rate, responses with very similar short-run magnitude end up having very different effects on exchange rates. For example, in Panel II in Figure 1A, consider the two shocks associated with the highest change in interest rates: the first peaks around 0.04 and the second peaks around 0.06. Both shocks are characterized by the same change in the 3-month maturity rate as well as around the 10 year interest rate, but a very different change in medium-term rates. The shock that leads to an increase in medium-term interest rates ends up causing an appreciation of the dollar, while the opposite is true for the shock that leads to a decrease in medium-term rates. This example clearly illustrates the differences between the approach to identification that we use in this paper and the conventional identification: in the conventional Cholesky identification approach, these two shocks would be indistinguishable since they are characterized by the same change in the 3-month interest rate, and would thus end up having the same effect on exchange rates. However, it is clear that they do not have the same effect in our approach. Furthermore, this example clarifies how our approach is different from a VAR where researchers focus on a few interest rates on selected maturities: by selecting only the 3-month and the 10-year maturities, the researcher would be unable to distinguish the two shocks, as they are the same at these maturities – thus leading to incorrect empirical conclusions, as the shocks are very different at other maturities.

Our results point to several differences in the international transmission mechanism of US monetary policy shocks. In fact, note how different the responses of the exchange rate are to the same US monetary policy shock: for example, the effects of a US monetary policy easing are larger in Japan than in any of the other countries.

Panel III in Figures 1A-D focuses on the case where the monetary policy shock is contractionary at short maturities but is perceived not quite as contractionary at medium-term maturities, that is, the 8-year interest rate is expected to be higher than the 3-month one. Such shocks typically lead to a short-run appreciation of the US dollar or, only in the case of Canada, to a short-run depreciation. On the contrary, Panel IV depicts results for the case where the shock is perceived as expansionary in the short-run but not as much in the medium run; in such cases, the exchange rate may either appreciate or depreciate. Again, one can immediately appreciate how different this result would be in the conventional identification approach, which only focuses on changes in short-term rates.

INSERT FIGURE 2 HERE

We now turn to discussing in detail the differences between our results and the traditional approach. Note that the information in the raw yield curve data at the shortest maturities is described by the 3-month maturity rate, $\mathcal{Y}_{3,t}$. Thus, one can replicate the traditional approach typically adopted in the literature (maintaining the high frequency identification) as the special case where the VAR includes only the exchange rate and $\mathcal{Y}_{3,t}$. In that case, the response of the exchange rate to the monetary policy shock:

$$\frac{\partial \Delta s_{i,t+h}}{\partial \varepsilon_t^{trad}} = c_3^{(h)} \left(\Delta \mathcal{Y}_{3,t}^{*} \right), \tag{4}$$

and $c_3^{(h)} = E\left(\frac{\partial \Delta s_{i,t+h}}{\partial \Delta \mathcal{Y}_{3,t}}\right)$. Note that the magnitude of the responses in our framework is different from that in the traditional approach, however. In our approach, the magnitude of the response is the actual change in the rate of growth of the exchange rate due to the monetary policy shock, and it is not normalized in standard deviation units. Hence, our responses cannot be directly compared to those in the literature. Furthermore, most of the previous literature estimates VARs with exchange rates in levels rather than in first differences.

Figure 2 revisits the empirical evidence based on the traditional approach, eq. (4). We distinguish between expansionary and contractionary monetary policy, where the definitions of expansionary and contractionary depend on whether the change in the 3-month rate is positive or negative. Our results confirm that, even in our review of the traditional approach, contractionary (expansionary) shocks lead to currency's appreciation (depreciation).

Notice however how, in the traditional approach, the responses are proportional to each other: in fact, other dimensions of monetary policy besides changes in the 3-month interest rate are completely ignored and the exchange rate responses are the same up to a scaling factor, the magnitude depending on the change in the (scalar value of the) short-term interest rate. In fact, the reason why only one response is reported in the conventional approach is exactly because the responses are proportional to each other and they only differ by the magnitude of the contemporaneous effect.

In particular, notice how the expansionary shock in this case always leads to an exchange rate depreciation, no matter how monetary policy affects expectations in the medium and long-run. In our framework, instead, the reaction of exchange rates is much richer, as it depends on how the term structure changes at different maturities.

5 Measuring the Effects of Monetary Policy on Exchange Rates in Unconventional Times

We now turn to analyzing the differences between conventional and unconventional monetary policy. By unconventional monetary policy we mean situations where the Central bank cannot affect the short-term interest rate (as it is stuck at the zero lower bound), and instead either purchases assets to counteract the tightening in financial markets or decrease uncertainty ("Large Scale Asset Purchases", or LSAP in short) or issues announcements about the future path of interest rates that convey information on the length of the zero lower bound period ("Forward guidance"). The start of the unconventional monetary policy period in the US is marked by the first LSAP, in November 2008, although forward guidance was allegedly implemented as a policy instrument since the early 2000 (Gürkaynak, Sack and Swanson, 2005a). Note that our framework does automatically capture both LSAP and forward guidance directly in the way monetary policy shifts in the entire yield curve.

Figure 3 depicts the exchange rate response to the monetary policy shock. Since in the unconventional period short-term interest rates are stuck at the zero-lower bound and cannot be moved further, we distinguish between contractionary and expansionary policy based solely on changes in medium-term interest rates, depicted in Panels I and II respectively. The medium term is defined to be 8 years.

The graphs on the right in each of Panels I and II in Figure 3 depict the US monetary policy shocks in the unconventional period ($\varepsilon_t^{mp}(\tau)$). As the figures show, the monetary policy shock is zero at the short-end of the yield curve while becoming progressively more different from zero at the long end of the yield curve. This reflects the well-known fact that, in the unconventional period, monetary policy mostly operates by affecting medium- and long-term expectations. Notice, however, how the expected lift-off from the zero lower bound is very different across episodes: in some cases it is more gradual while in others it is more sudden.

INSERT FIGURE 3 HERE

Comparing conventional and unconventional monetary policy, thus, it is clear that movements in exchange rates during unconventional monetary policy periods are mostly associated with perceived effects of monetary policy in the medium- and long-run.

By comparing Panels I and II in Figure 3, we find that, *on average, expansionary policy depreciates the exchange rate while contractionary policy appreciates it.*[7] However, again, not all the shocks are the same, and neither are their effects on exchange rates. For example, note from Panel II how episodes that are expansionary at both maturities of 12 months as well as longer maturities cause a depreciation of the exchange rate, while episodes that are expansionary at the 12 month maturity but contractionary at the long-end of the yield curve result in appreciations. The only exception is Canada, for which expansionary policies may result in both appreciation and depreciations.

By comparing Figures 1 and 2, we draw the following conclusions. *Overall, the effects of unconventional monetary policy are similar to those in the conventional period: expansionary monetary policy shocks in the US typically result in a depreciation of the US dollar.* The magnitudes are also similar.

Our empirical results are thus related to Rogers, Scotti and Wright (2014, 2016) and Glick and Leduc (2015), who similarly have investigated the effects of unconventional monetary

[7] Our unconventional sample ends in 2016, and thus it includes some episodes of contractionary policy.

policy on exchange rates. However, there are several important differences between our paper and theirs.

A first difference is that, in the latter papers, the shock is the exogenous change in the principal component(s) extracted from a cross section of interest rates, while in our work the shock is the entire *shift in the entire term structure* due to an exogenous monetary policy move. It is the analysis of how the whole yield curve shifts over time that allows us to crucially differentiate our results from those existing in the literature.

A second, important difference is that Rogers, Scotti and Wright (2014) and Glick and Leduc (2015) use an event study approach which allows them to estimate the contemporaneous correlation between changes in the term structure due to monetary policy on specific dates and the exchange rate, but is otherwise silent on the dynamic effects; in contrast, our paper estimates the *whole dynamic impulse response.*

Rogers, Scotti and Wright (2014, 2016) also complement their analyses with VARs either using a heteroskedasticity-based identification (as in Rogers, Scotti and Wright, 2014, and Wright, 2012), or external instruments (as in Rogers, Scotti and Wright, 2016) to trace out the effects of monetary policy shocks over time. Our approach instead relies on the *Functional VAR approach* (Inoue and Rossi, 2017), which provides the dynamic response to the shift in the whole term structure viewed as a function of maturity.

Finally, our analysis naturally leads to *time-varying responses* of exchange rates that fundamentally depend on the ways in which monetary policy affects agents' expectations of current and future interest rates as well as the risk and uncertainty in the economy.

6 Which Expectations Matter the Most?

Given that, in our framework, the monetary policy shock has multiple dimensions, it is important to examine which changes in agents' expectations about future interest rates and risk premia cause the exchange rate appreciation/depreciation. We do so by reporting the components of the responses defined in eq. (2). The results are shown in Figures 4 and 5 for the conventional and unconventional periods, respectively. *Overall, we find interesting differences across currencies as well as specific episodes, although the results are broadly similar for conventional and unconventional monetary policy regimes.*

INSERT FIGURE 4 HERE

By comparing the shape of the responses, depicted in the graph in the top left corner for each country, with the various components in the decomposition, depicted in the remaining graphs, we draw the following conclusions. *In the conventional period, the most important components are the short-term rates* (typically one year). The importance of specific maturities depends on the currency: for example, the most important components are the 1 year for the UK and Japan, the one and eight years for the Euro, and the 3 months and the 1 and 28 years for Canada.

INSERT FIGURE 5 HERE

In the unconventional period, the exchange rates fluctuations are also driven by longer term maturities, typically 8 years (but also the 18 or 28 years, depending on the country), in addition to the one year maturity. Interestingly, however, fluctuations at the very long-end of the yield curve are most important in contractionary episodes while slightly shorter maturities are most important in expansionary episodes. Again, the details depend on the specific country.

7 Conclusions

In this paper we investigated the effects of monetary policy shocks on exchange rates. The advantage of the approach is that it identifies monetary policy shocks as shifts in the whole yield curve and allows to analyze how changes in agents' expectations of interest rates and changes in risk premia across all maturities dynamically affect exchange rates.

We find that, on average across episodes, the effects of monetary policy shocks on exchange rates are qualitatively similar in both conventional and unconventional periods; in particular, a US monetary policy easing results in a depreciation of the US dollar exchange rate. However, the exchange rate response differs depending on the effects of monetary policy on people's expectations of the interest rate path and risk premia in the short, medium and long run in specific episodes. Thus, our approach can help in quantifying and further advancing our understanding of the different dimensions of monetary policy first discussed in Gürkaynak, Sack and Swanson (2005a).

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Appendix. Details About the Estimation Procedure

Let s_{t+h}, y_t and I_t denote an exchange rate at time $t+h$, a vector of yields at time t and the information set at time t excluding y_t, respectively. Following Inoue and Rossi (2017), define

$$f_t(y_t) \;=\; E(s_{t+h}|y_t, I_t). \tag{5}$$

To simplify the notation, we drop the subscript t from this point on.

Then the h-step-ahead impulse response of an exchange rate to a yield curve shock ε, where ε is a vector of yield shocks, is defined as

$$\lim_{\alpha\to 0} \frac{f(y+\alpha\varepsilon) - f(y)}{\alpha} \tag{6}$$

provided the limit exists. Let Θ_h denote an $(M+1)\times(M+1)$ matrix of h-step-ahead structural impulse responses and θ_h denote the last row of the matrix. Then the differential can be written as

$$\theta_h \varepsilon. \tag{7}$$

We consider a VAR model of the m time-varying parameters of the yield curve and exchange rate returns with normally distributed disturbance terms:

$$y_t \;=\; B_0 + B_1 y_{t-1} + \cdots + B_p y_{t-p} + u_t, \tag{8}$$

where the last element of y_t is the exchange return, $u_t \overset{iid}{\sim} N(0_{(m+1)\times 1}, \Sigma_{m+1})$ and Σ_{m+1} is an $(m+1)\times(m+1)$ positive definite matrix.[8] The normal-Wishart family with the uninformative prior parameters is used as a prior for the VAR parameters (see Appendix B of Uhlig, 2005, for example).

To identify structural impulse responses, we impose the short-run restriction that the yield curve does not contemporaneously respond to exchange rate shocks. In other words, the impact matrix takes the form of:

$$\begin{bmatrix} X & X & X & 0 \\ X & X & X & 0 \\ X & X & X & 0 \\ X & X & X & X \end{bmatrix}. \tag{9}$$

To impose this restriction, let

$$A \;=\; \begin{bmatrix} A_{11} & 0_{m\times 1} \\ A_{21} & a_{22} \end{bmatrix} \tag{10}$$

denote the Cholesky factor of Σ. That is, A is the lower triangular matrix such that $AA' = \Sigma$, where A_{11} is $(m\times m)$, A_{21} is $(1\times m)$ and a_{22} is (1×1). Let Q denote a draw from the Haar distribution over the space of $(m\times m)$ orthogonal matrices and define

$$\tilde{A} \;=\; \begin{bmatrix} A_{11}Q & 0_{m\times 1} \\ A_{21}Q & a_{22} \end{bmatrix}. \tag{11}$$

[8] When appropriate, we use subscripts in matrices and vector to denote their dimensions. For square matrices, for simplicity, we only include the row dimension in the subscript.

Because

$$\begin{bmatrix} Q & 0_{m\times 1} \\ 0_{1\times m} & 1 \end{bmatrix} \begin{bmatrix} Q & 0_{m\times 1} \\ 0_{1\times m} & 1 \end{bmatrix}' = I_{m+1}, \tag{12}$$

$\tilde{A}$ takes the form of (9) and satisfies $\tilde{A}\tilde{A}' = \Sigma$. Thus h-step-ahead structural impulse responses are given by the h-step-ahead reduced-form impulse responses Θ_h post-multiplied by $\tilde{A}$. Note that these structural impulse responses are not point-identified but set-identified, since we allow for arbitrary correlations among reduced-form shocks to the yields.

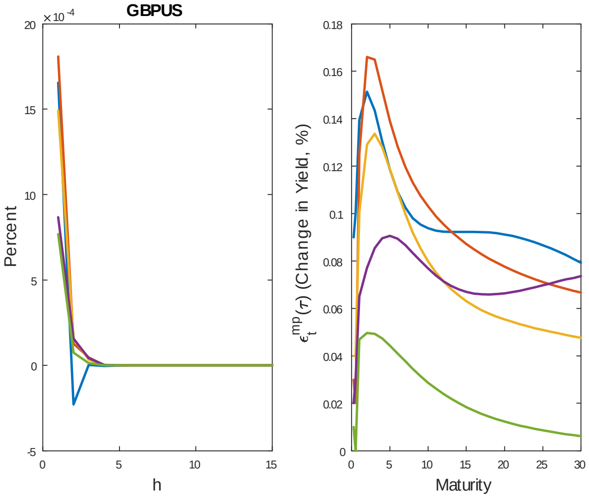
To calculate the h-step-ahead structural impulse response to an $(m \times 1)$ monetary policy shock ε_t, we post-multiply the last row of $\Theta_h\tilde{A}$ by $(A_{11}Q)^{-1}\varepsilon_t$.

Figures

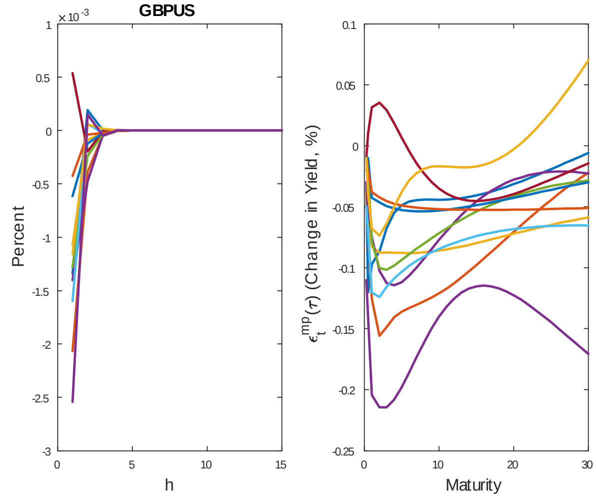
Figure 1. Response to Monetary Policy Shocks: Conventional Period

Panel A. United Kingdom

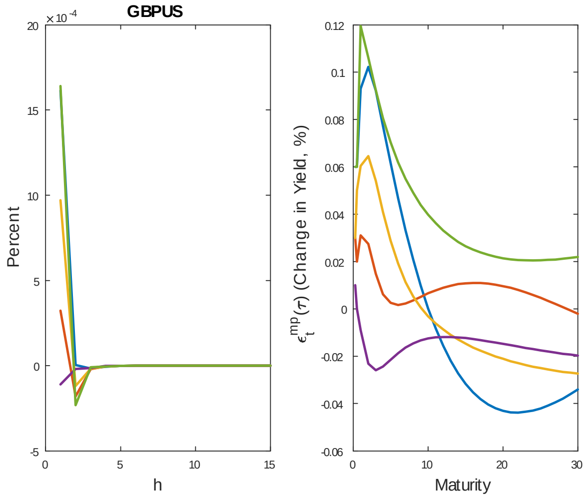
I. Fully Contractionary



II. Fully Expansionary



III. More Contractionary at Short



IV. More Expansionary at Short

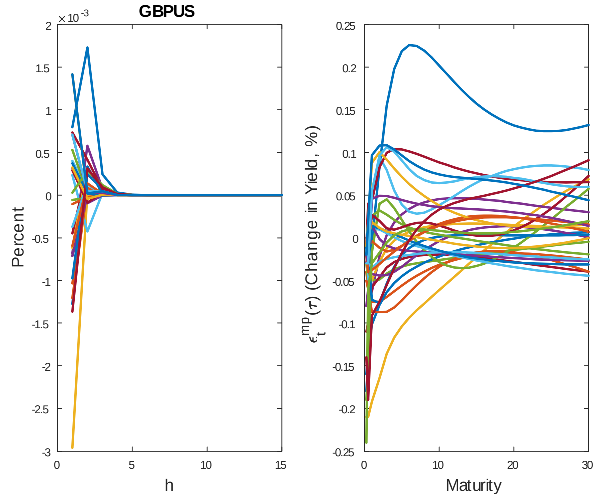


Figure 1 (continued)

Panel B. Euro

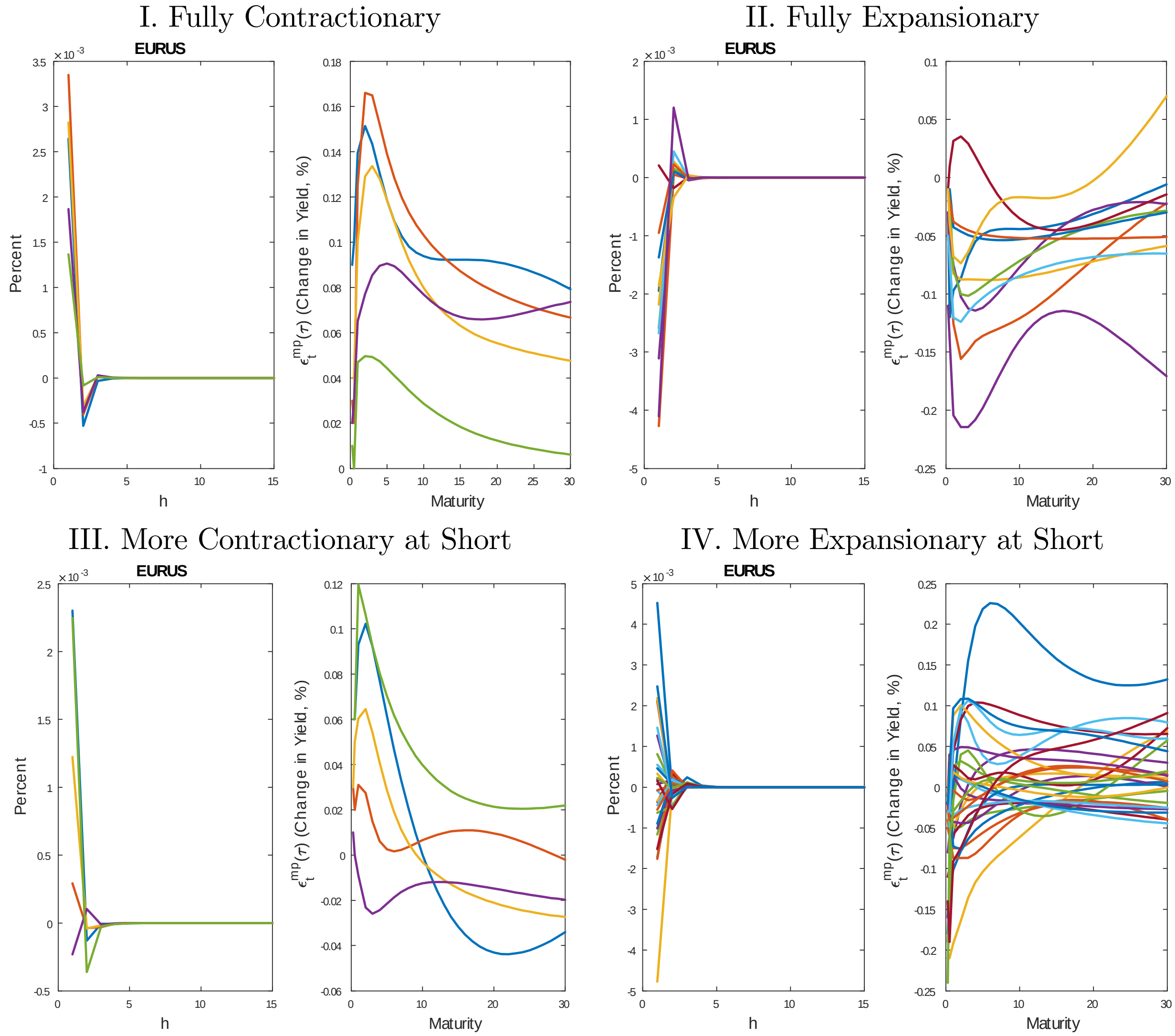


Figure 1 (continued)
Panel C. Canada

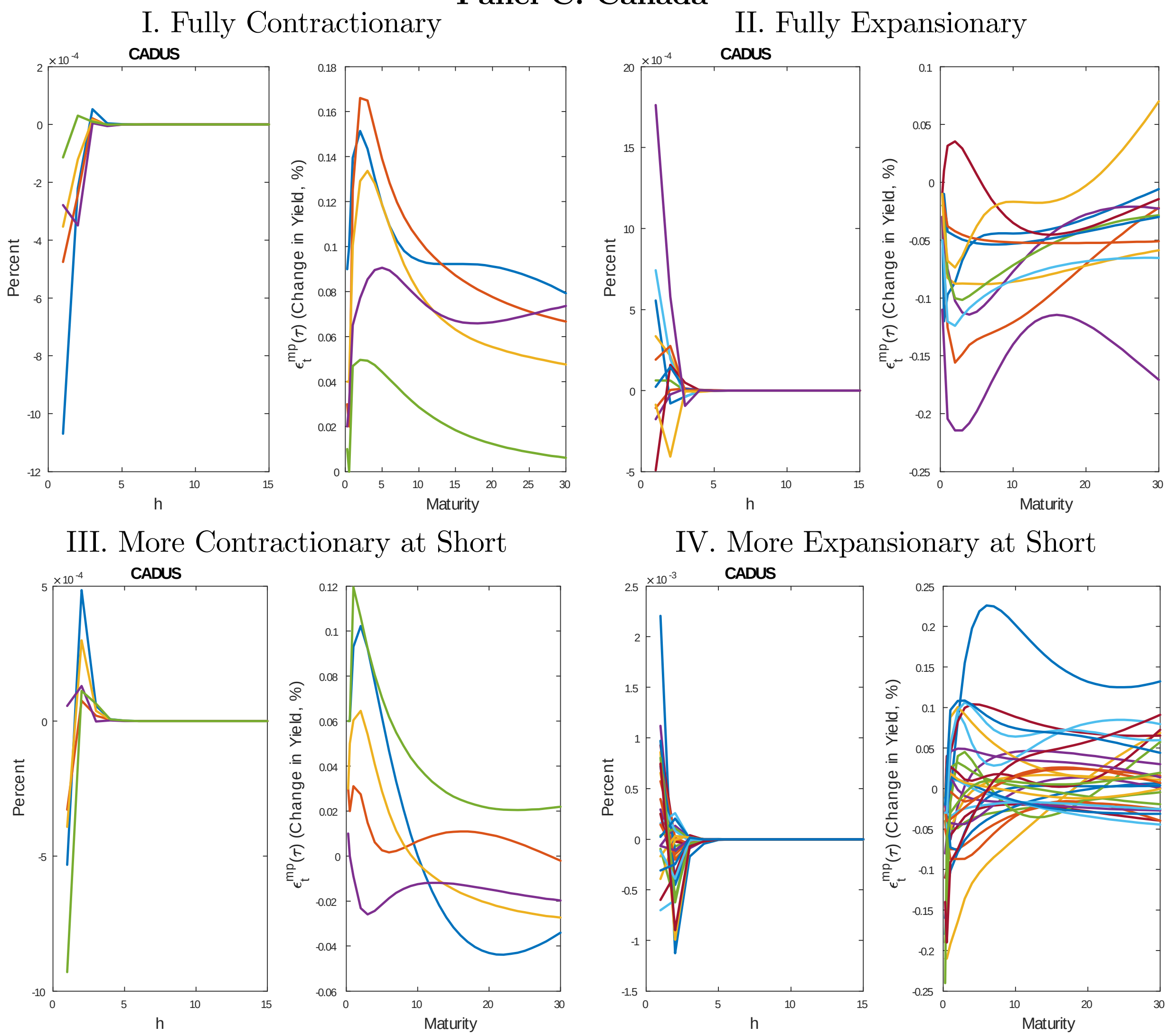
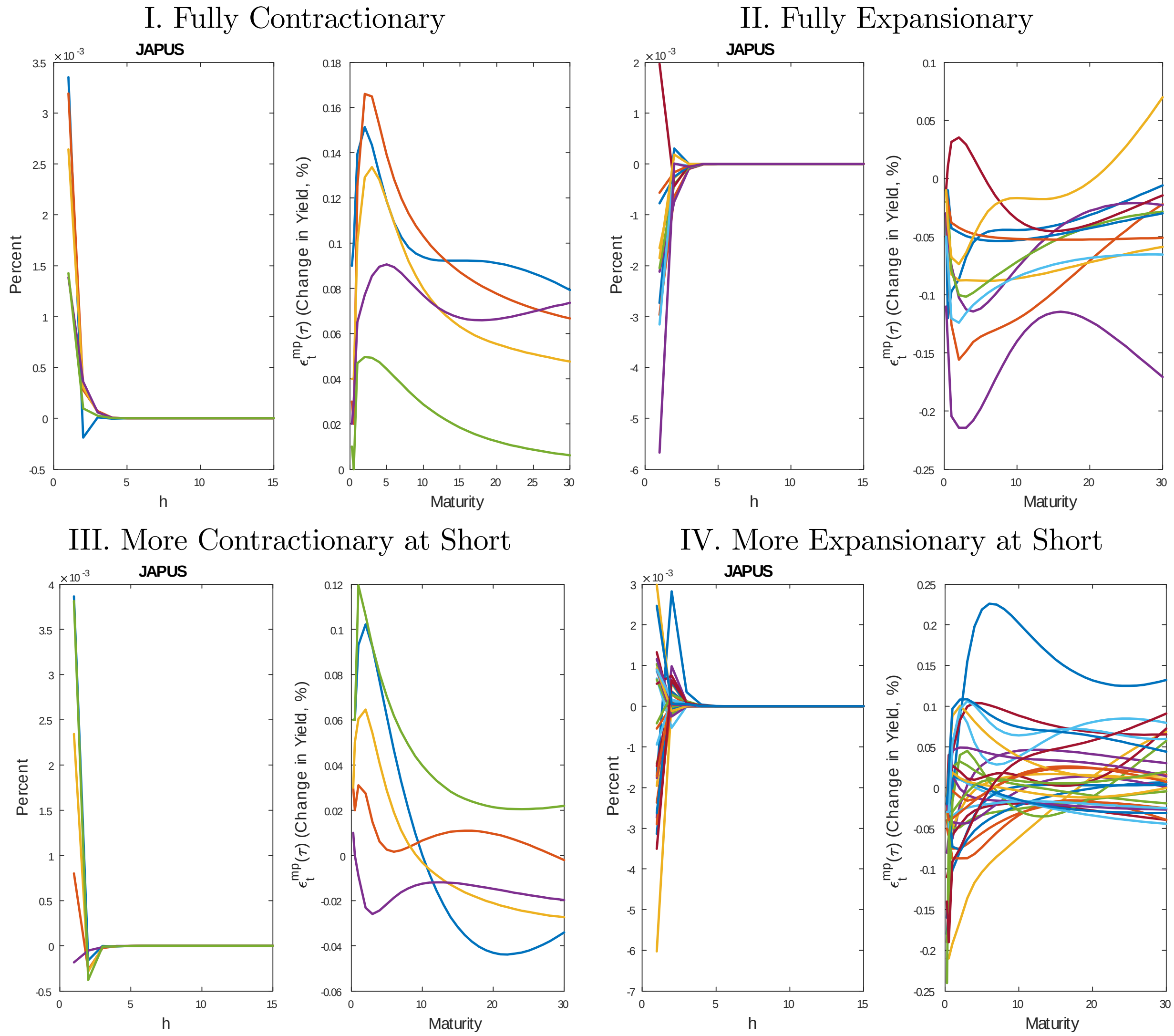


Figure 1 (continued)
Panel D. Japan

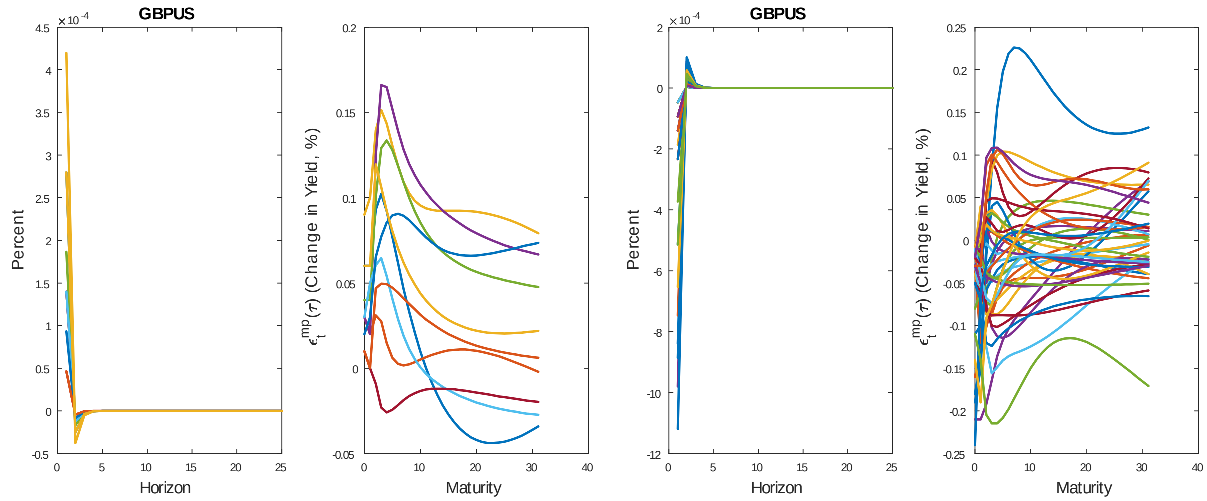


Note to the Figure. "Fully Contractionary" means $\mathcal{Y}_{3,t} > 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} > 0$ and "Fully Expansionary" means $\mathcal{Y}_{3,t} < 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} < 0$. "More Contractionary at Short" means $\mathcal{Y}_{3,t} < 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} > 0$ while "Less Expansionary at Long" means $\mathcal{Y}_{3,t} > 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} < 0$.

Figure 2. Responses to Traditional Monetary Policy Shocks in the Conventional Period

Panel A. United Kingdom

I. Contractionary II. Expansionary



Panel B. Europe

I. Contractionary II. Expansionary

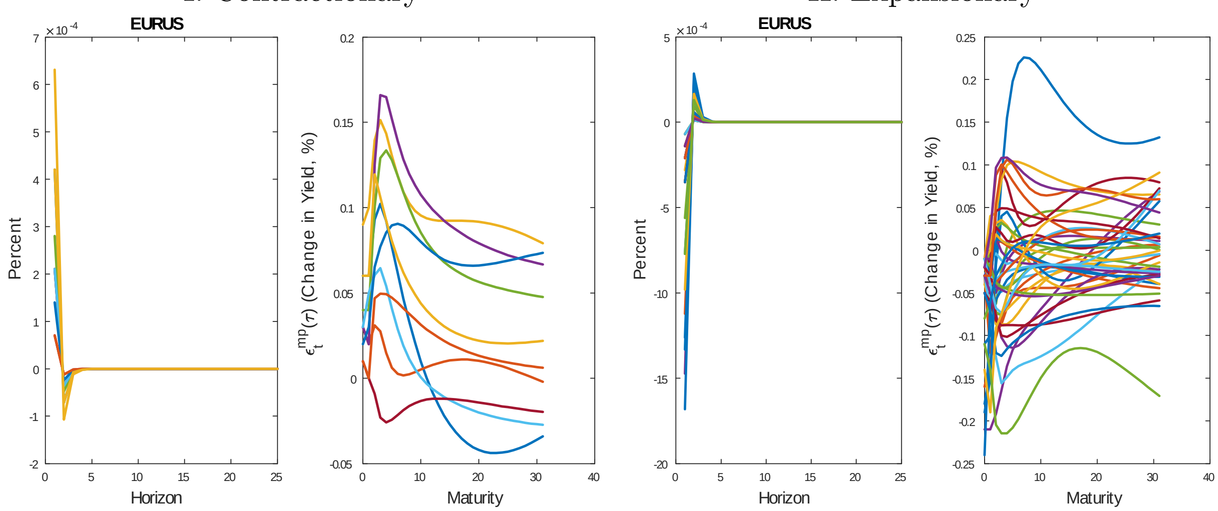
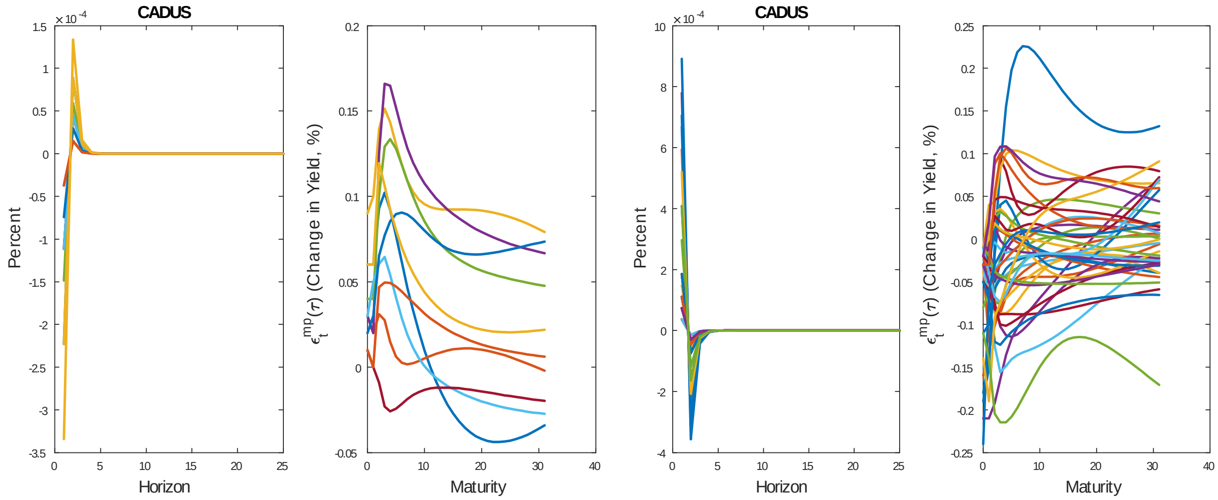


Figure 2 (continued)

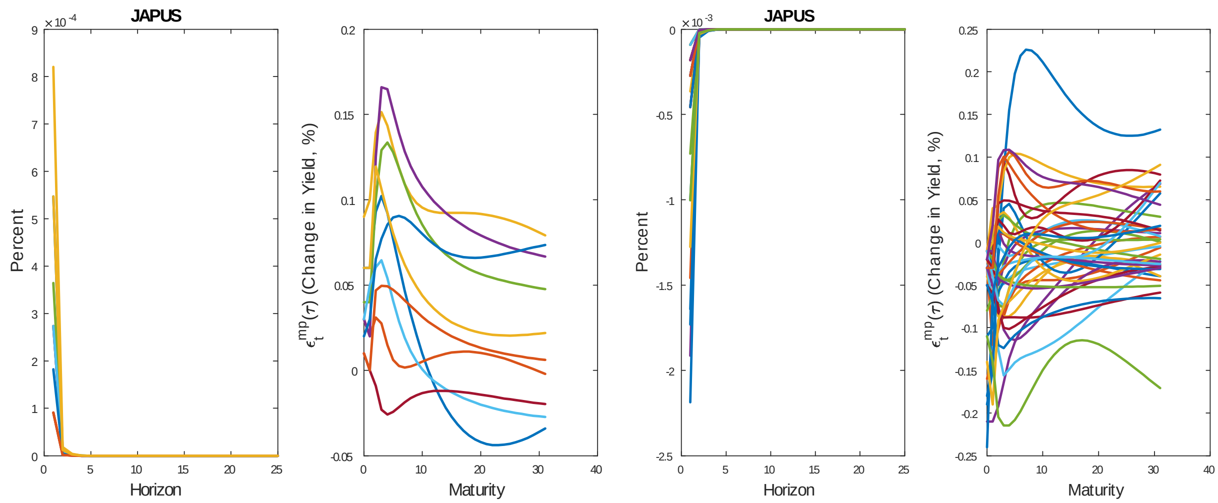
Panel C. Canada

I. Contractionary II. Expansionary



Panel D. Japan

I. Contractionary II. Expansionary

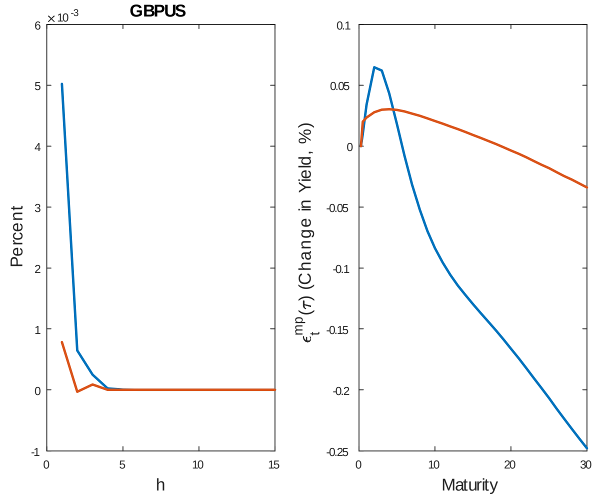


Notes to the figure. Each of the eight figures plots the monetary policy shock (panel on the right) and the corresponding exchange rate's response (panel on the left) for the currencies indicated in the title. The monetary policy shocks are selected to be contractionary (Panel A) and expansionary (Panel B) at the shortest maturity. "Contractionary" means $\mathcal{Y}_{3,t} > 0$ and "Expansionary" means $\mathcal{Y}_{3,t} < 0$.

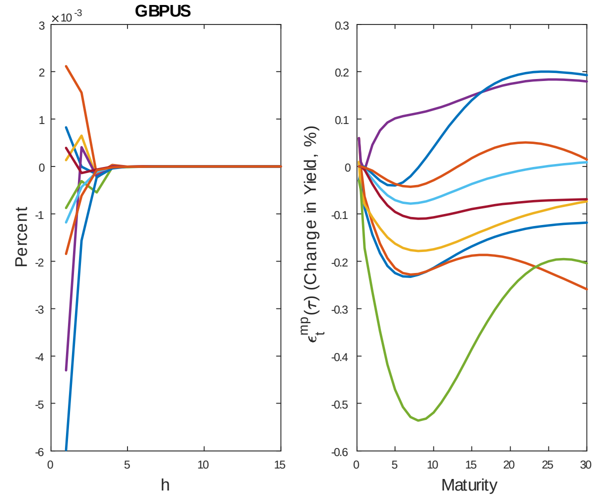
Figure 3. Response to Monetary Policy Shocks: Unconventional Period

Panel A. United Kingdom

I. Contractionary

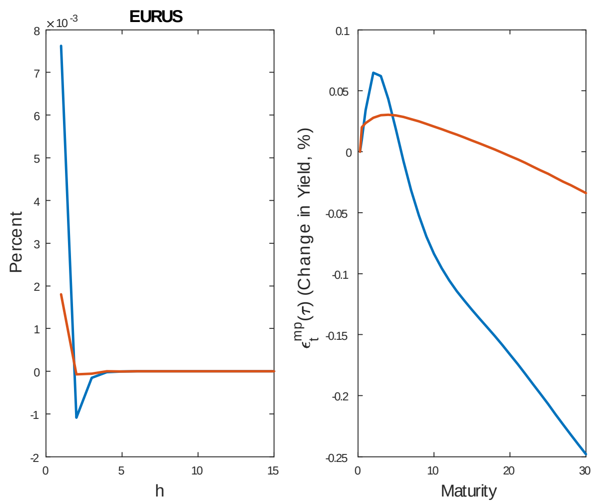


II. Expansionary



Panel B. Europe

I. Contractionary



II. Expansionary

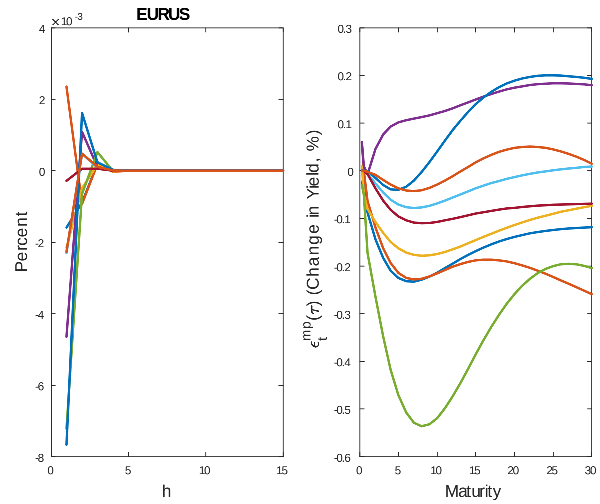
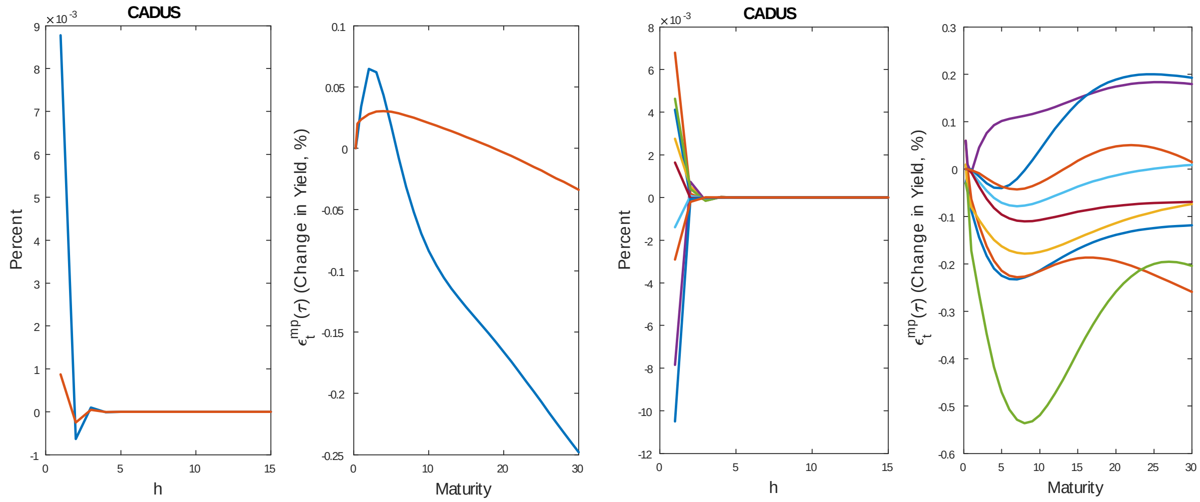


Figure 3 (continued)

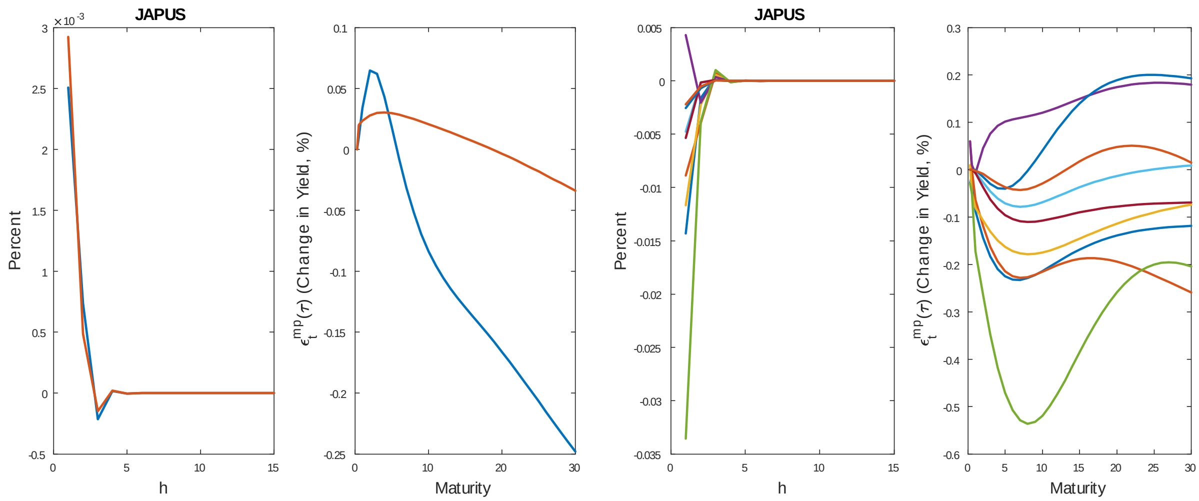
Panel C. Canada

I. Contractionary II. Expansionary



Panel D. Japan

I. Contractionary II. Expansionary

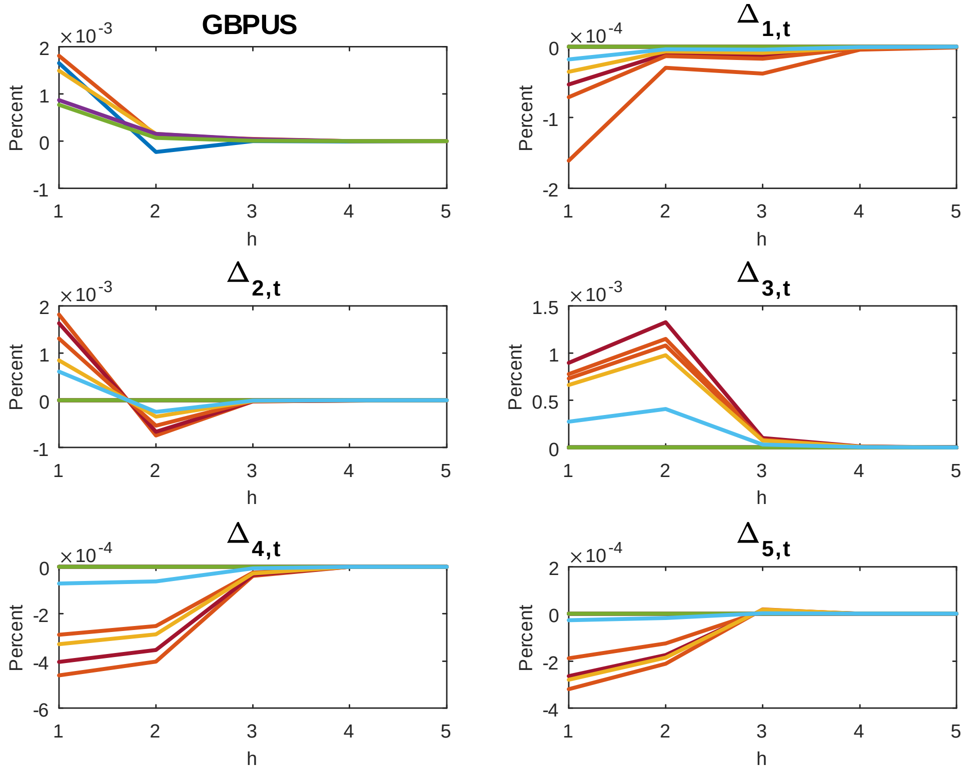


Note to the figure. Each of the four figures plots the monetary policy shock (panel on the right) and the corresponding exchange rate's response (panel on the left) for the currencies indicated in the title. "Contractionary" means $\mathcal{Y}_{12,t} > 0$ and "Expansionary" means $\mathcal{Y}_{12,t} < 0$ for all countries.

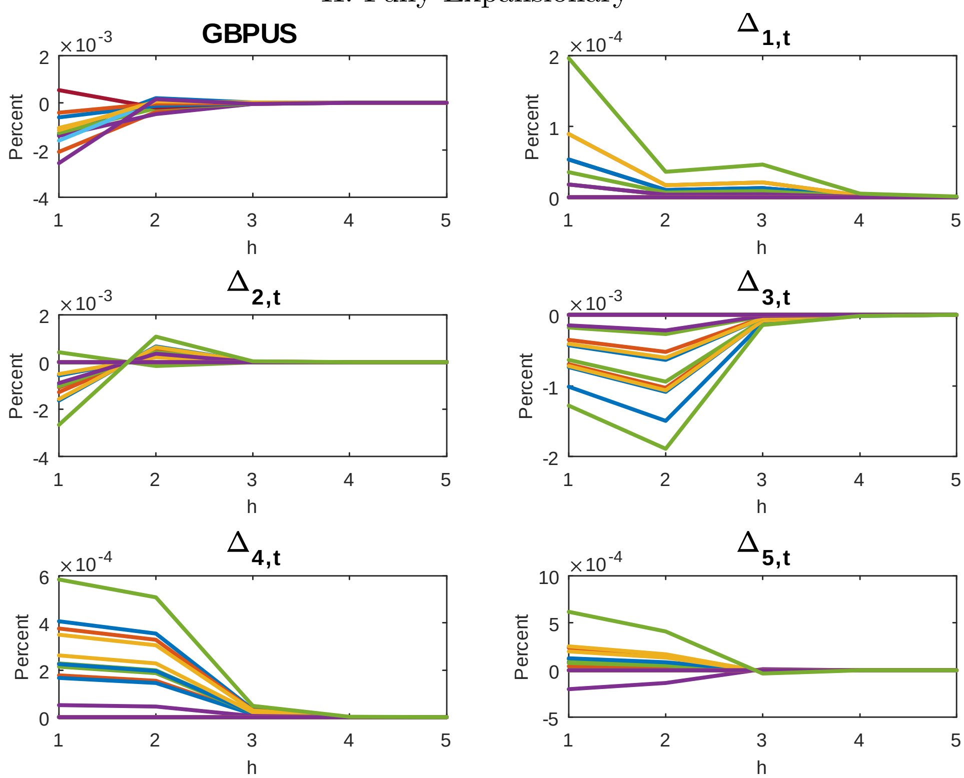
Figure 4. Response Decomposition: Conventional Period, UK

Panel A. United Kingdom

I. Fully Contractionary

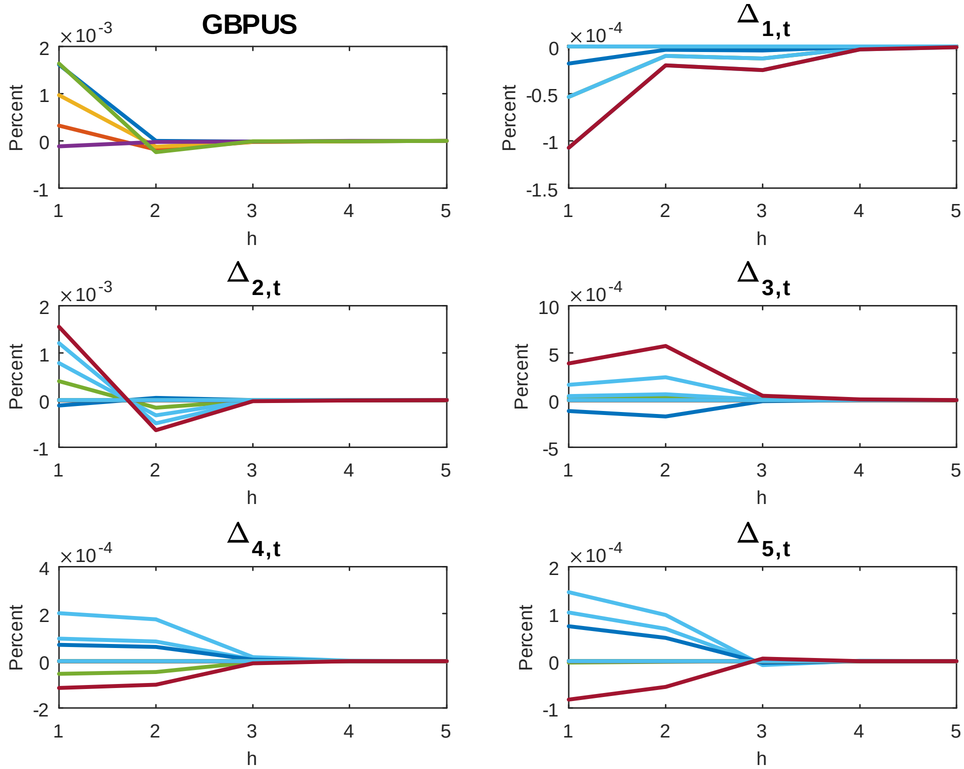


II. Fully Expansionary



Panel A (continued). United Kingdom

III. More Contractionary at Short



IV. More Expansionary at Short

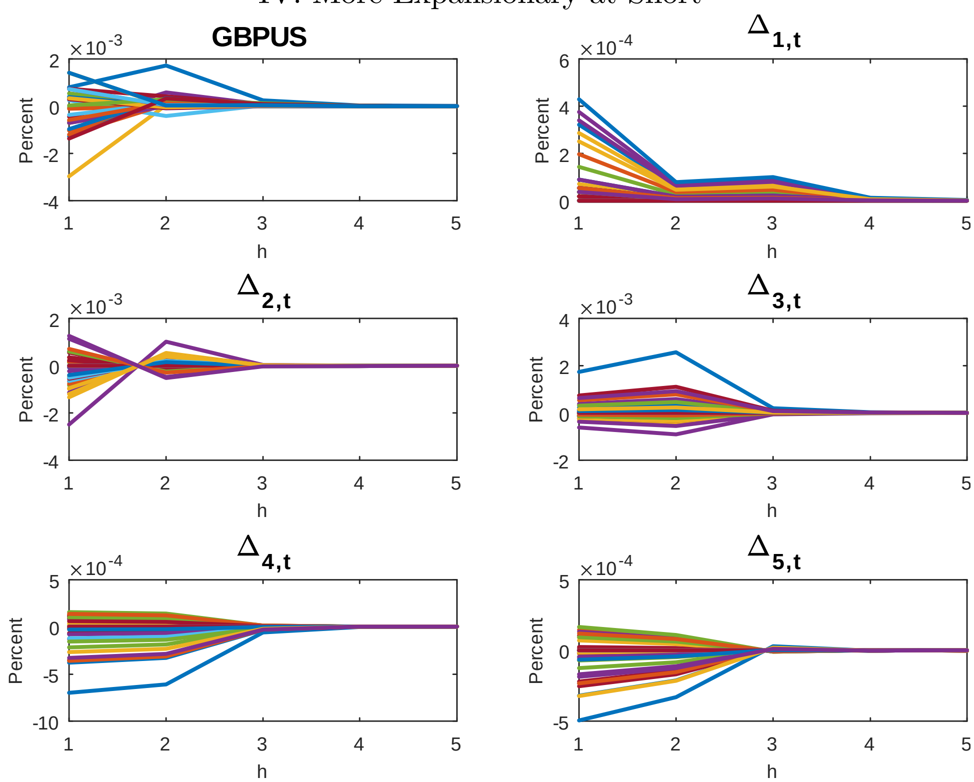
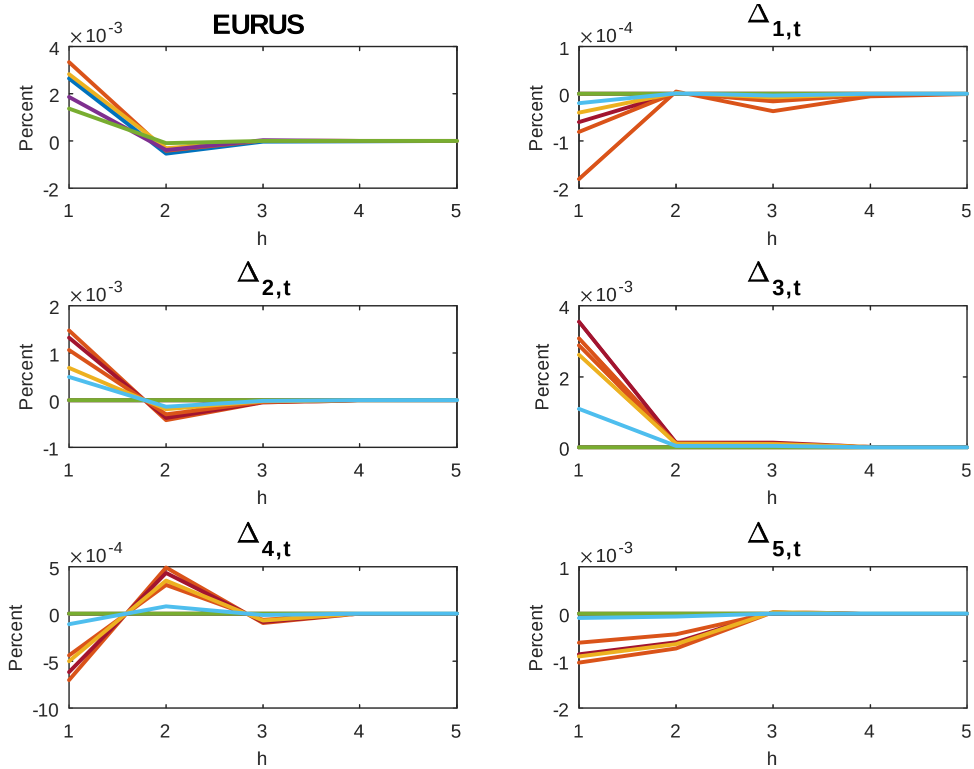
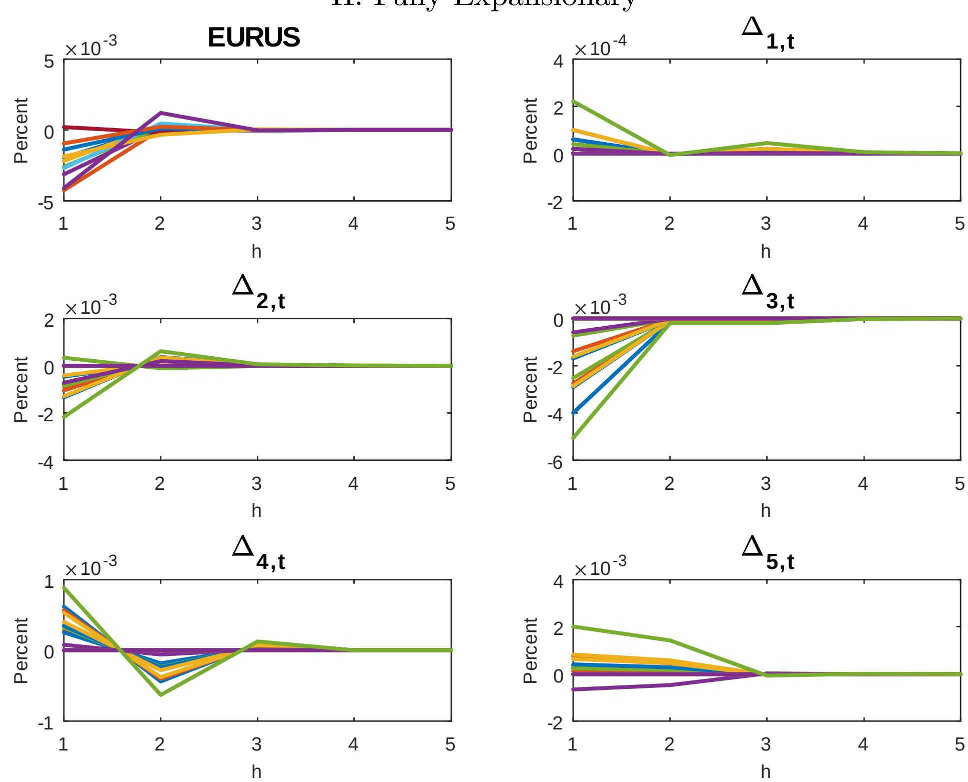


Figure 4 (continued)
Panel B. Euro
I. Fully Contractionary

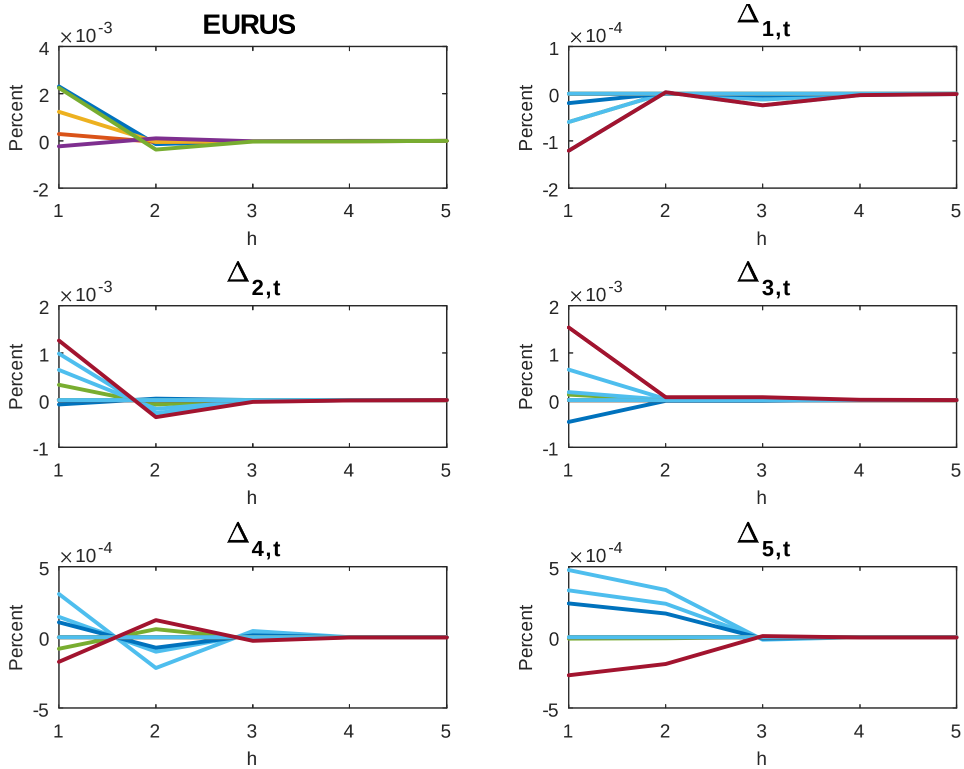


II. Fully Expansionary



Panel B (continued). Euro

III. More Contractionary at Short



IV. More Expansionary at Short

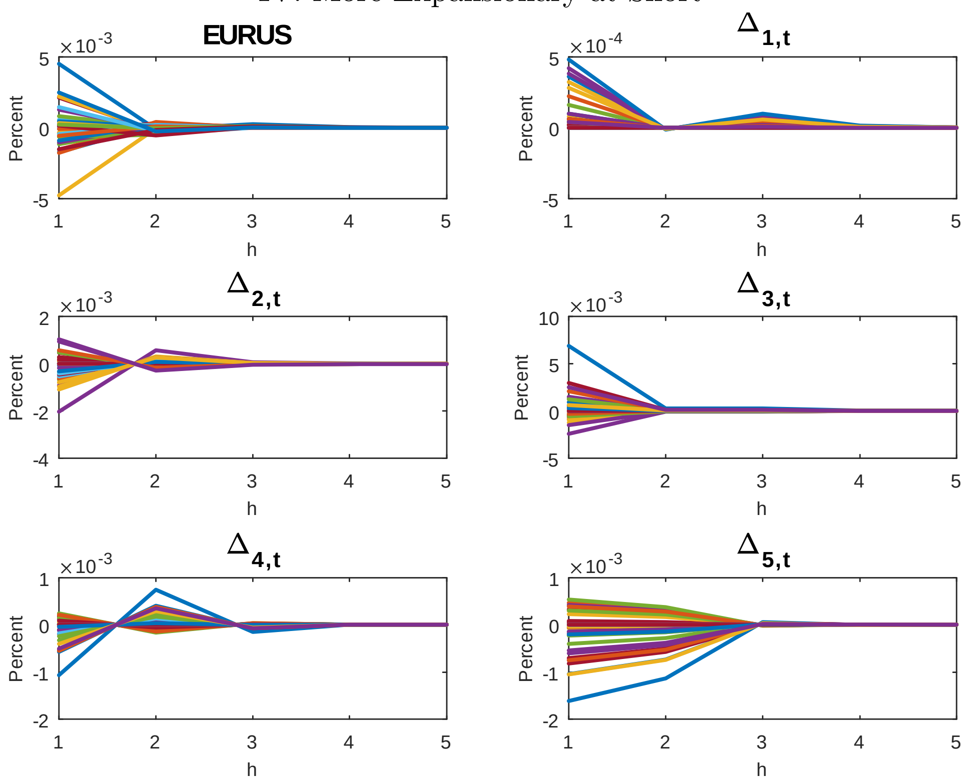
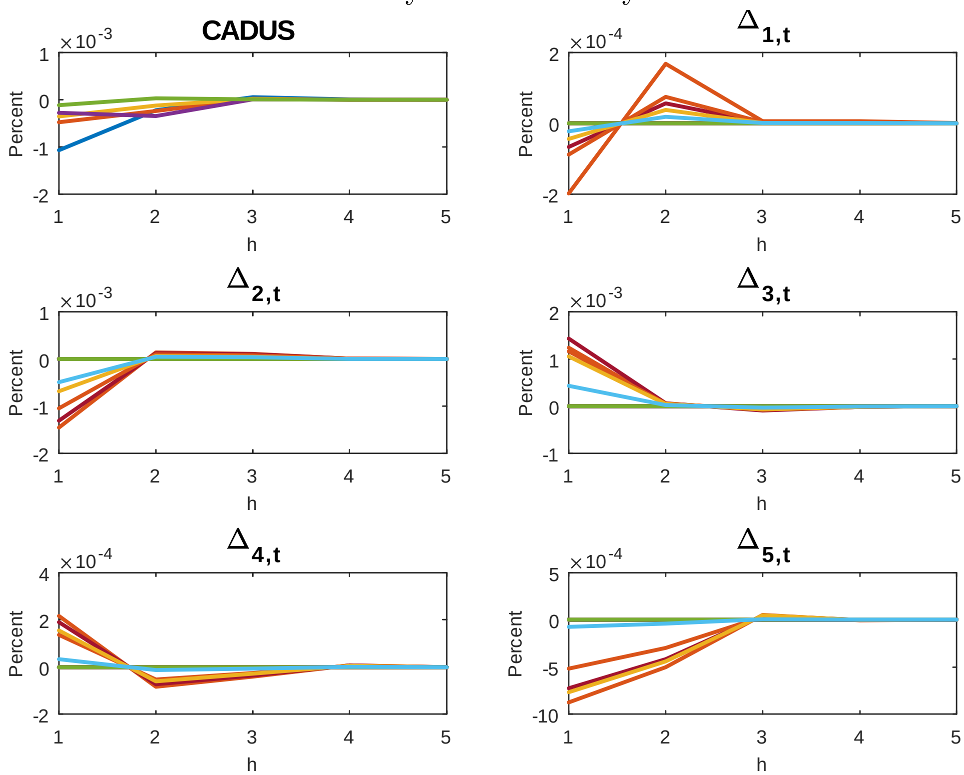
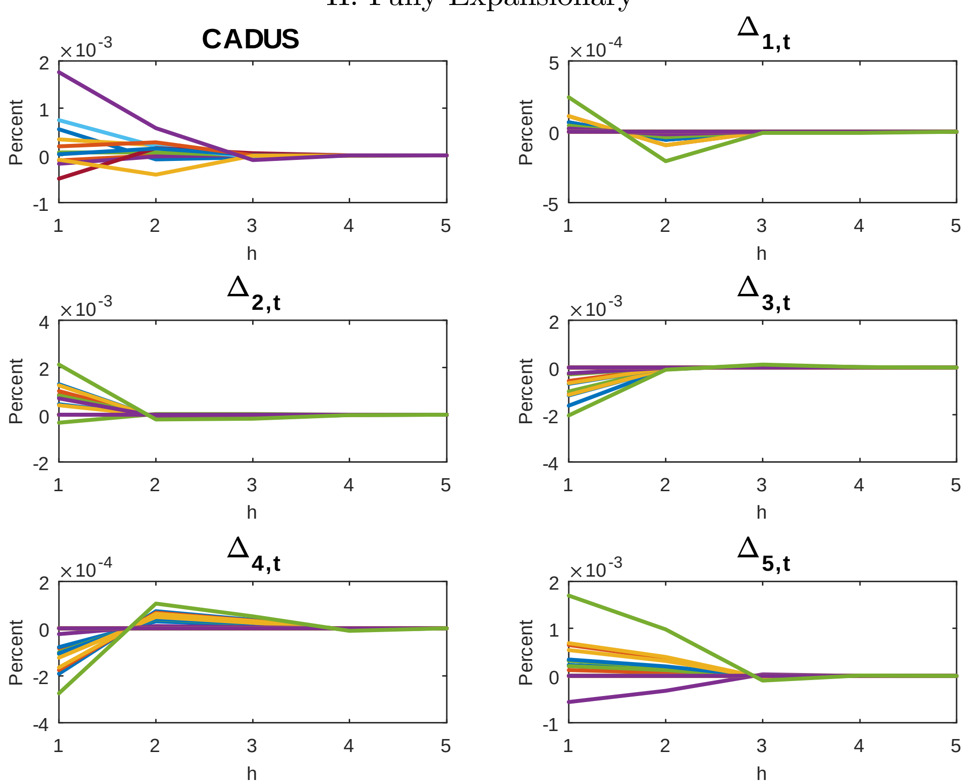


Figure 4 (continued)
Panel C. Canada

I. Fully Contractionary

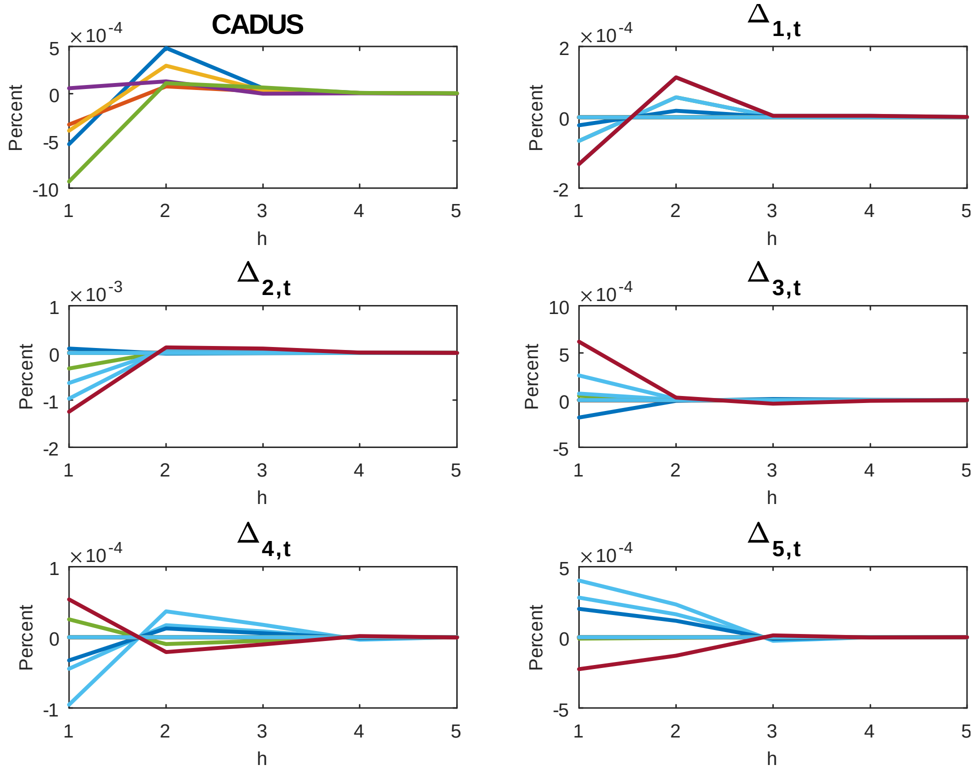


II. Fully Expansionary



Panel C (continued). Canada

III. More Contractionary at Short



IV. More Expansionary at Short

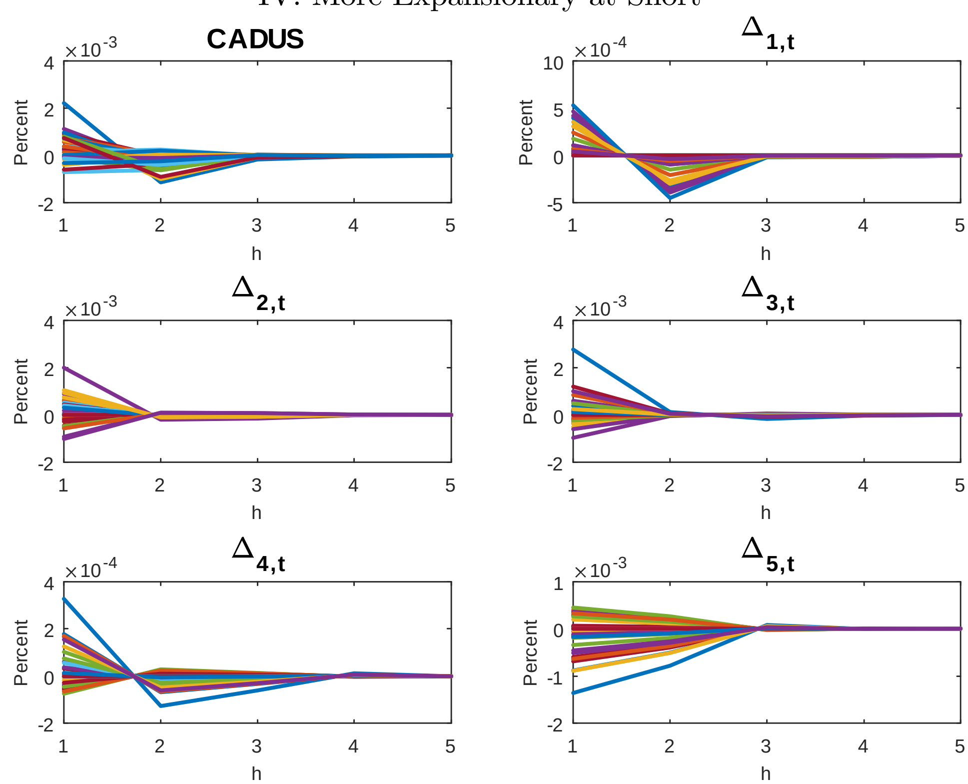
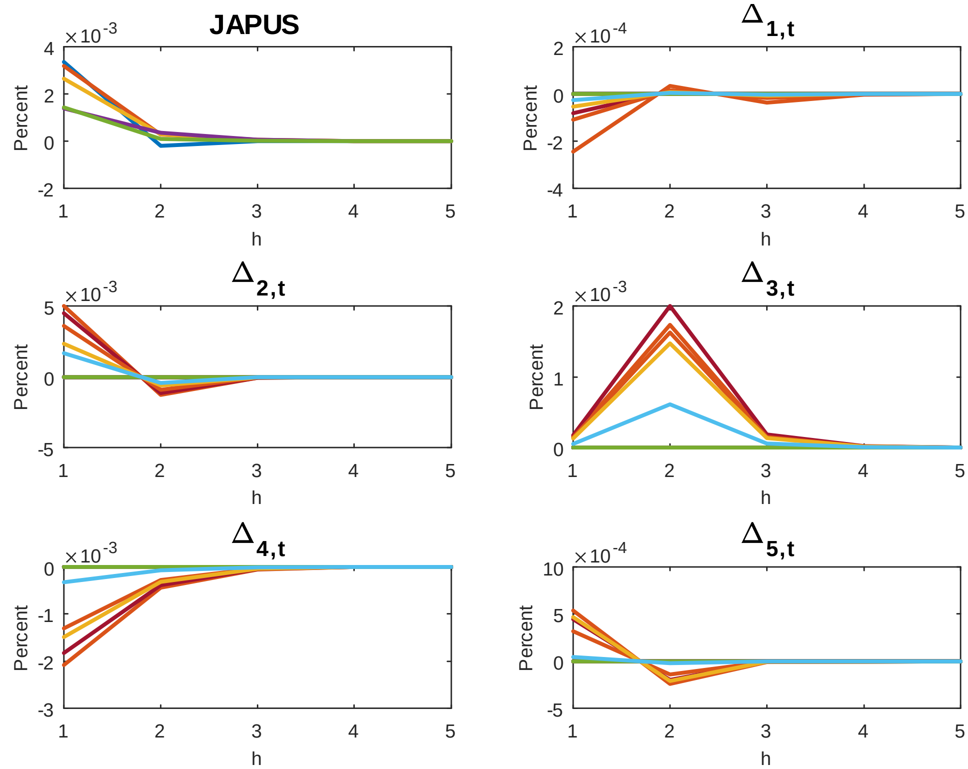


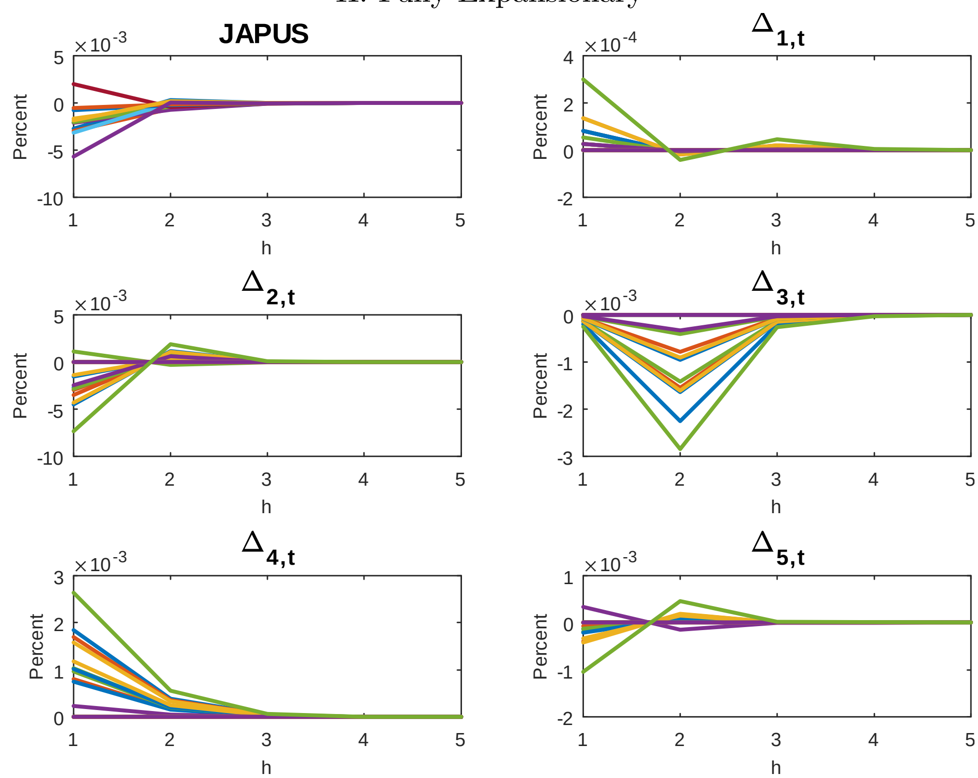
Figure 4 (continued)

Panel D. Japan

I. Fully Contractionary

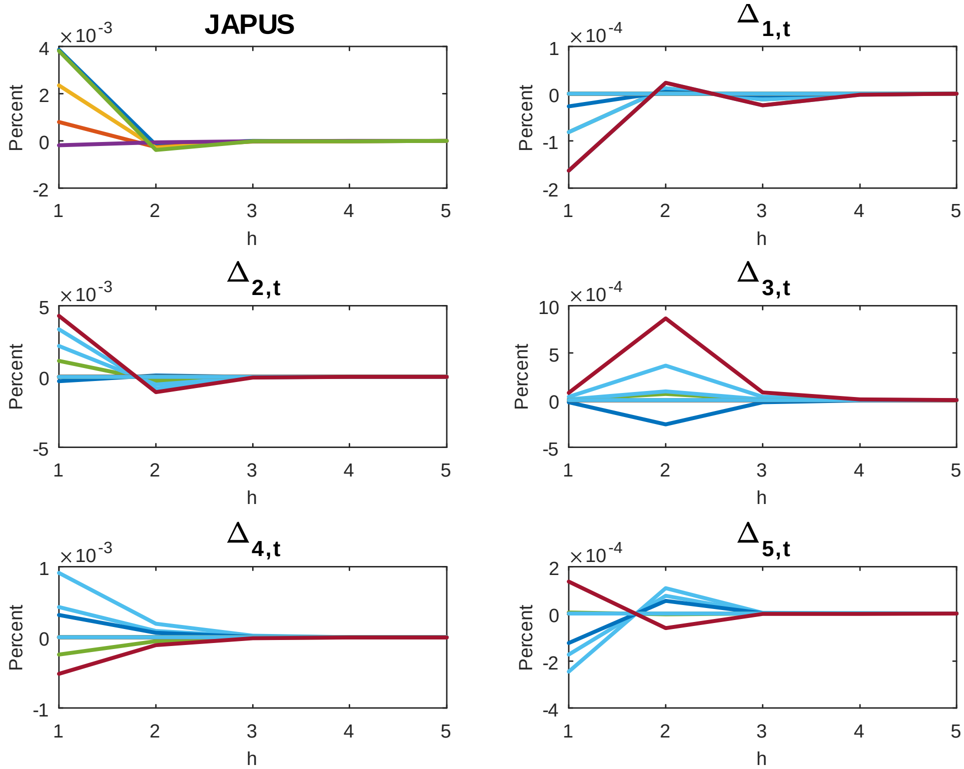


II. Fully Expansionary

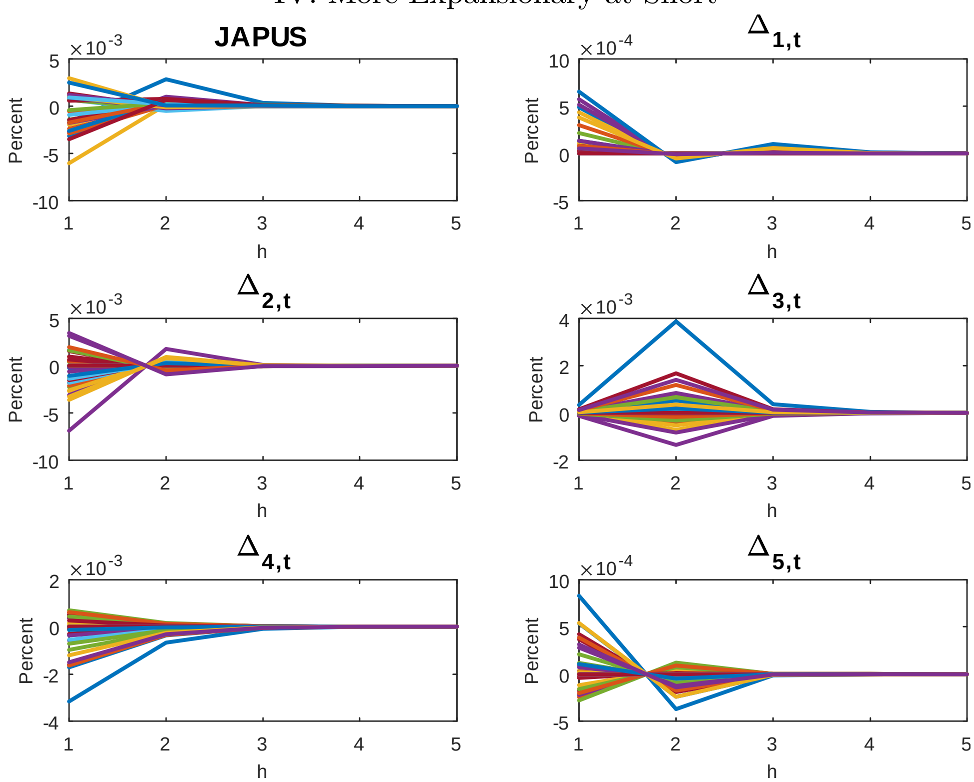


Panel D (continued). Japan

III. More Contractionary at Short



IV. More Expansionary at Short

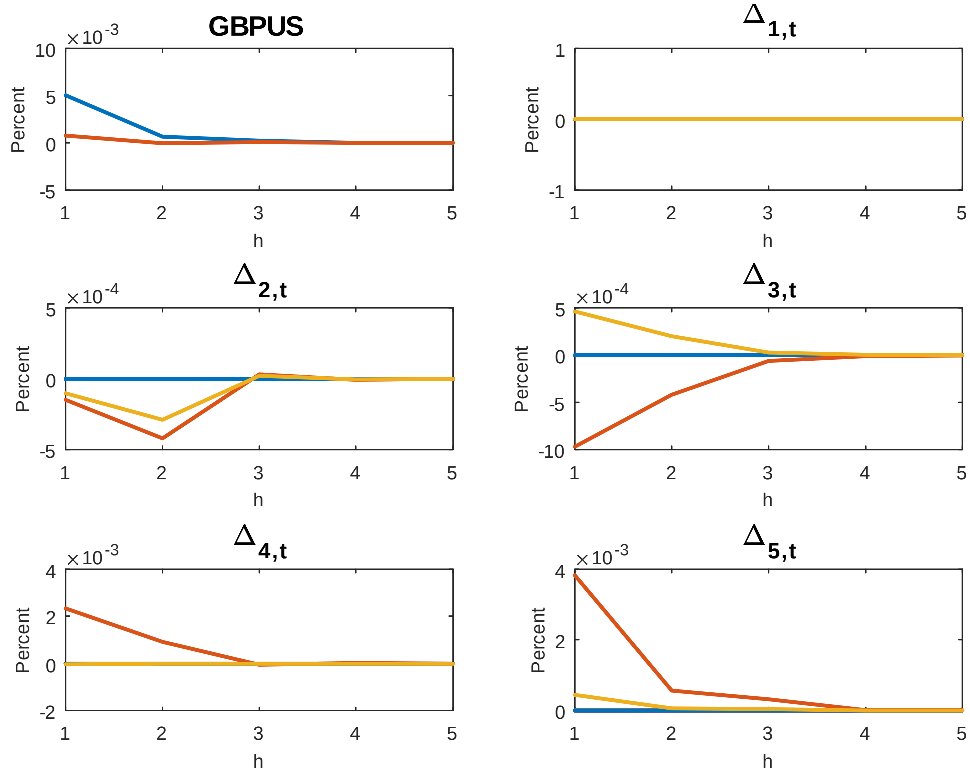


Note to the Figure. "Fully Contractionary" means $\mathcal{Y}_{3,t} > 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} > 0$ and "Fully Expansionary" means $\mathcal{Y}_{3,t} < 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} < 0$. "More Contractionary at Short" means $\mathcal{Y}_{3,t} < 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} > 0$ while "Less Expansionary at Long" means $\mathcal{Y}_{3,t} > 0, \mathcal{Y}_{96,t} - \mathcal{Y}_{3,t} < 0$.

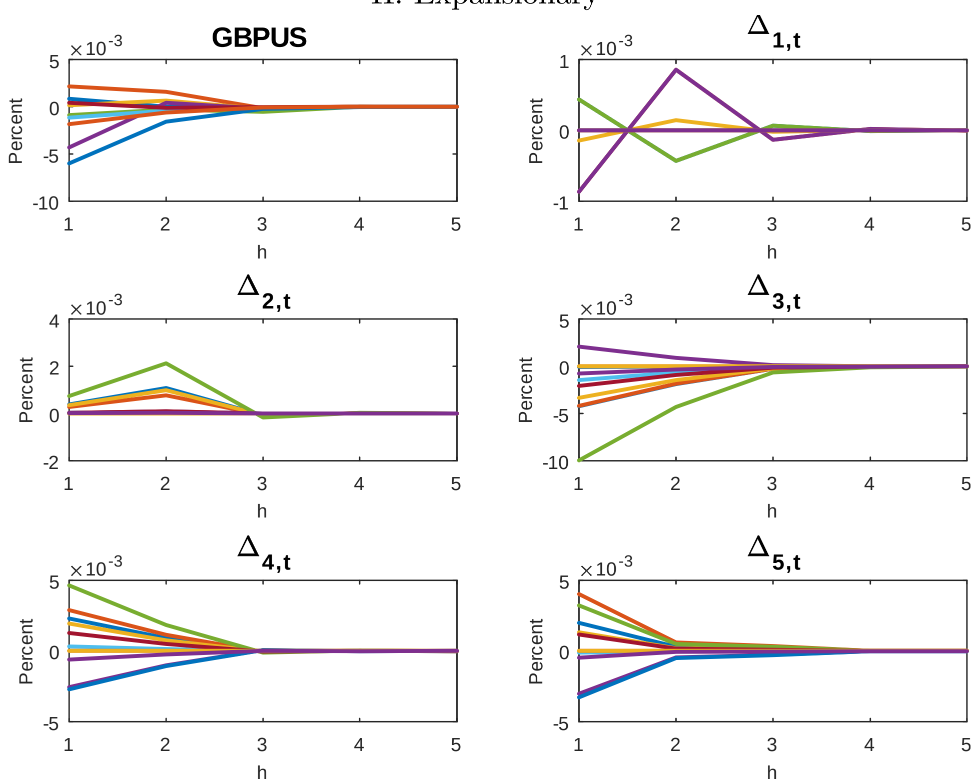
Figure 5. Response Decomposition: Unconventional Period

Panel A. United Kingdom

I. Contractionary

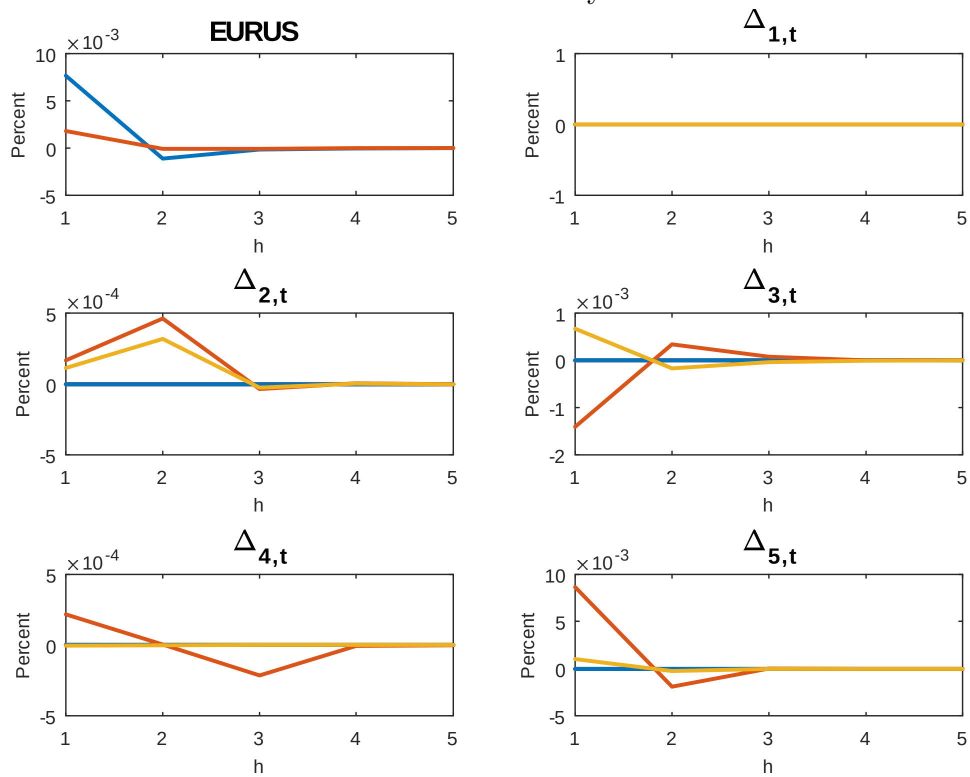


II. Expansionary



Panel B. Europe

I. Contractionary



II. Expansionary

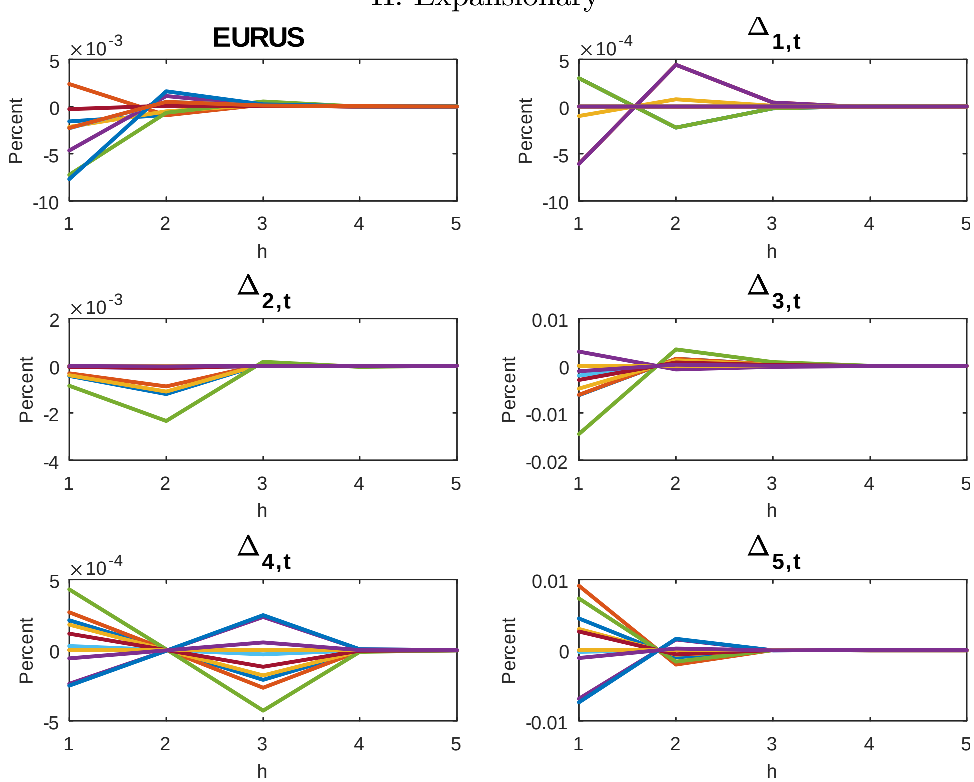
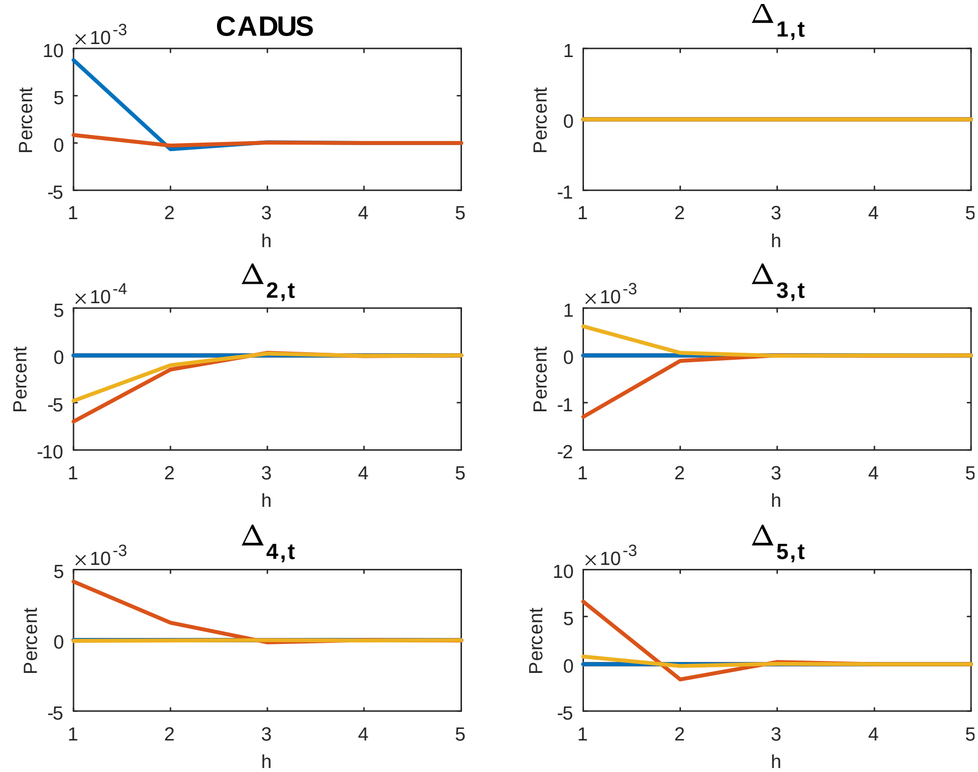


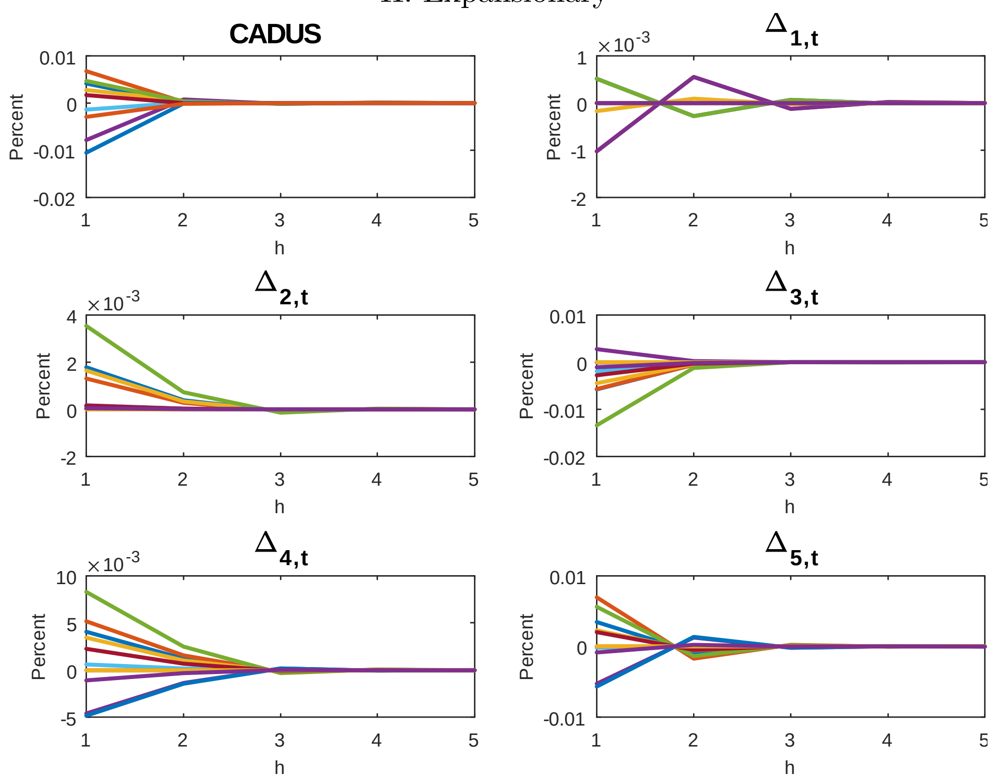
Figure 5 (continued)

Panel C. Canada

I. Contractionary

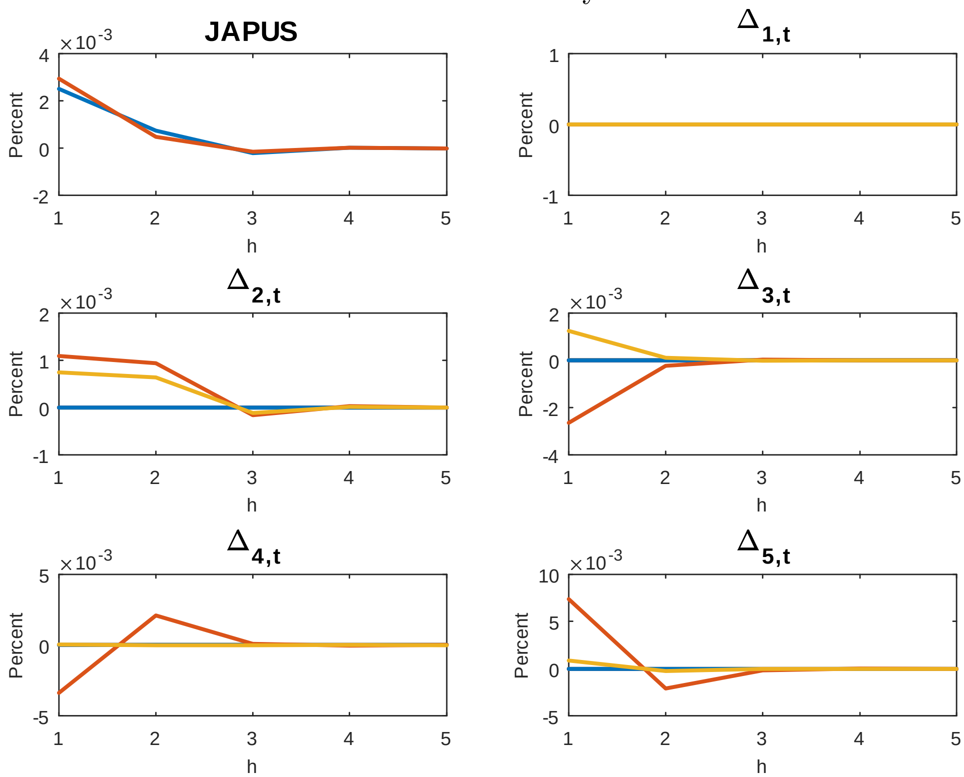


II. Expansionary

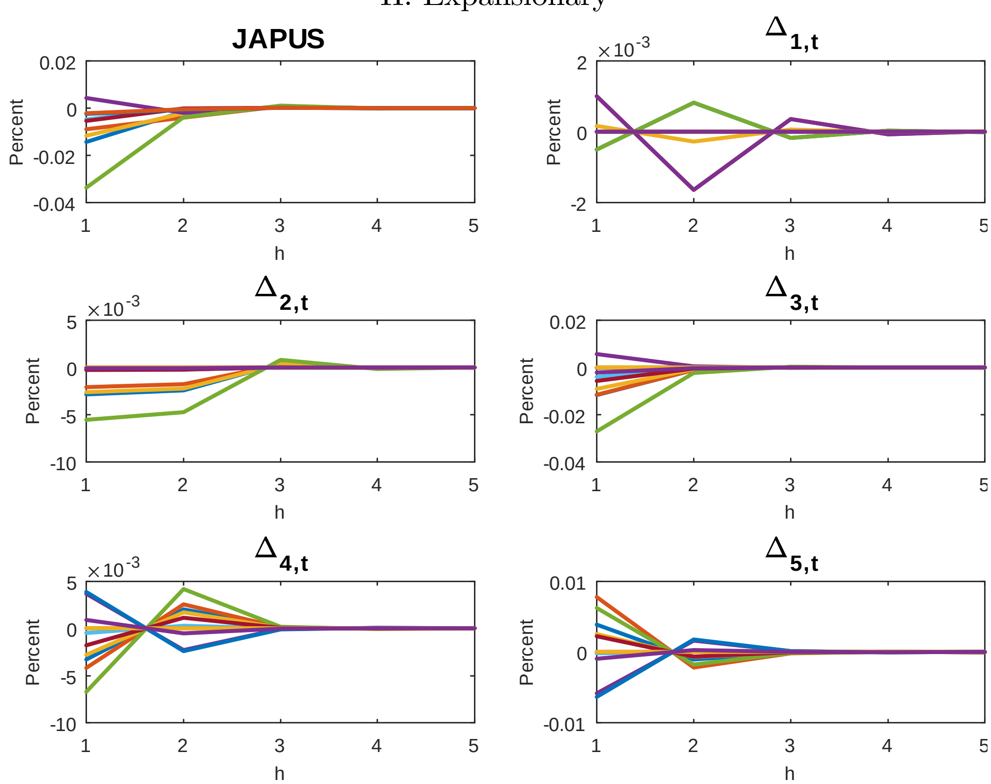


Panel D. Japan

I. Contractionary



II. Expansionary



Note to the figure. Each of the four figures plots the monetary policy shock (panel on the right) and the corresponding exchange rate's response (panel on the left) for the currencies indicated in the title. "Contractionary" means $\mathcal{Y}_{360,t} > 0$ and "Expansionary" means $\mathcal{Y}_{360,t} < 0$ for all countries except Japan, for which "Contractionary" means $\mathcal{Y}_{240,t} > 0$ and "Expansionary" means $\mathcal{Y}_{240,t}$