Monetary Policy Spillovers across the Pacific when Interest Rates Are at the Zero Lower Bound

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Abstract
To conduct monetary policy effectively, central banks need to understand the transmission of monetary policy into financial markets. In this paper we investigate the effects of Japanese and U.S. monetary policy shocks on their own asset markets, and the spillovers into each other’s markets. Because short-term nominal interest rates have been effectively zero in Japan since January 1998 and in the United States from late 2008, however; monetary policy shocks cannot be quantified by considering observable changes in short-term market interest rates. Therefore, in our analysis we use a shadow short rate—a quantitative measure of overall conventional and unconventional monetary policy that is estimated from the term structure of interest rates. Our results suggest that the operation of monetary policy at the zero lower bound of interest rates alters the transmission of shocks. In particular, we find a limited response of exchange rates during the first episode of unconventional monetary policy in Japan but a significant impact since 2006.

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1. Introduction

In this paper we investigate the effects of United States and Japanese monetary policy shocks on the asset markets of both economies. Understanding the impact of monetary policy shocks, whether domestically generated or from foreign monetary policy spillovers, is crucial for central banks because changes in interest rates, exchange rates, and asset prices affect the decisions of firms, households, banks, and investors.¹

In principle, examining the transmission of monetary policy to financial markets is relatively straightforward when a policy interest rate is the central bank’s instrument. Although the institutional details may differ from country to country, monetary policy is conventionally conducted by setting the interest rate at which the central bank lends and receives high-powered money with the inter-bank market and by buying and selling short-term debt securities to target short-term nominal interest rates around that setting. Shocks to monetary policy are therefore reflected as observable unanticipated changes to policy interest rates or short-maturity interest rates, which in turn co-vary with changes in market interest rates and asset prices. That conventional transmission becomes potentially more complex and different, however, when policy interest rates are constrained near zero. This constraint was almost continuously in effect for Japan from January 1998, when the Bank of Japan gained legal independence,² and in the United States from late 2008. When nominal interest rates are near zero, conventional monetary policy cannot meaningfully lower interest rates further because the availability of physical currency effectively offers a risk-free investment at a zero rate of interest. A zero return would be more attractive than central bank deposits or buying securities that offer a negative interest rate.³

To provide further monetary stimulus beyond a zero policy rate setting, central banks can and have used a range of unconventional monetary policy actions. One broad class of unconventional monetary policy is for central banks to use their balance sheets with programs such as large-scale asset purchases, targeted asset purchases, and liquidity provisions. Actions involving central banks’ balance sheets are typically abbreviated as quantitative easing (QE), which is the terminology we adopt in this paper. Examples are the first QE introduced by the Bank of Japan in March 2001 and maintained until March

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¹ In turn, those changes ultimately influence the level of economic activity and inflation that central banks seek to deliver within their policy mandates. That investigation is beyond the scope of this paper, but is an obvious important extension for future research.

² The Bank of Japan law was revised in 1997 and became effective on 1 April 1998.

³ A central bank setting its lending rate below zero would also allow an arbitrage for settlement banks, via borrowing to obtain holdings of physical currency. Non-zero lower bounds, either negative or positive, can exist due to the central bank’s logistical arrangements, institutional frictions, and costs associated with holding physical currency. However, the financial incentive to hold physical currency will dominate at some threshold negative interest rate.
2006, which we call QE0 following Ito (2014),
the Bank of Japan’s second QE from 2008,
and the U.S. Federal Reserve System’s (Fed) QE from 2008. Another broad class of uncon-
ventional monetary policy is forward guidance on policy rates. Examples are the Bank of 
Japan’s commitments to maintain near-zero policy rates to meet inflation objectives dur-
ing the first and second QE, and the Fed’s long-horizon policy rate indications.

Regarding the investigation of monetary policy transmission, several challenges arise 
when unconventional methods are used in addition to a near-zero policy interest rate. The 
first is that the levels and changes of policy interest rates or short-maturity interest rates 
no longer provide a complete measure of monetary policy and its shocks. The second 
is that the different forms of QE and forward guidance means that no single observable 
variable provides a summary of the overall stance of monetary policy, like policy rates or 
short-maturity interest rates in the conventional monetary policy environment.

To examine the transmission of monetary policy to financial markets in the recent history 
of Japan and the United States we therefore follow Krippner (2015) to derive a quanti-
tative monetary policy measure from yield curve data—a shadow short rate (SSR)—that 
consistently summarizes the stance of both conventional and unconventional monetary 
policy settings. We investigate the international transmission of monetary policy shocks to 
asset markets by estimating a latent factor model that relies on identification through het-
eroskedasticity (see Rigobon and Sack 2004 and Craine and Martin 2008). The latent factor 
model is applied to interest and exchange rates, including our measures of the shadow 
short rate for Japan and the United States, and equity prices.

We focus on two periods in our analysis to assess how the use of unconventional mone-
tary policy has affected the international transmission of monetary policy shocks to asset 
markets. Our first estimation period is 6 January 1998 to 8 March 2006 and includes the 
first episode of quantitative easing in Japan. During this period the Fed was still operating 
monetary policy with a policy interest rate. The second estimation period, 9 March 2006 
to 30 June 2015, covers the second experience with quantitative easing in Japan. More-
over, during this period the Fed implemented unconventional monetary policy measures 
having exhausted conventional means of monetary policy easing by late 2008.

The plan for the remainder of this paper is as follows. Section 2 describes the operation 
of monetary policy in Japan and the United States. Section 3 describes the methodology 
behind obtaining the shadow short rates. Section 4 discusses the empirical framework 
and data used in the estimation of the latent factor model. Section 5 presents the empirical 
results and the last section offers concluding remarks.

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4 Ito (2014) named this period “QE0” because it predates the quantitative easing by major central 
banks following the onset of the global financial crisis in 2007.
2. A narrative on monetary policy in the United States and Japan

In this section, we provide a narrative on the operation of monetary policy in the United States and Japan over our sample period. The purpose is to introduce some key policy variables and unconventional policy events for both countries, to illustrate that the SSR provides a quantitative summary measure of both conventional and unconventional monetary policy, and to broadly present the monetary policy spillovers that we later investigate in our empirical application. We use the SSR for our empirical analysis in Section 5, and we present details underlying its derivation in Section 3.

We begin with the United States as the world’s largest economy and because some key events in the United States appear to have influenced Japanese asset markets in a significant manner. There are two important points to bear in mind in this section. First, our empirical analysis, which we detail in Section 4.2, accounts for many more events than the ones we discuss in this section. Second, although we indicate easing and tightening events for the purposes of our narrative illustrations, we do not impose such directionality in our estimations. The analysis only relies on movements in the data on monetary policy and nonmonetary policy days, and therefore allows for the possibility that asset markets may move counter to a monetary policy announcement if it is more or less accommodative relative to market expectations prior to scheduled monetary policy announcements.

2.1 United States

Figure 1 summarizes the operation of U.S. monetary policy using two key policy variables and, as we discuss further subsequently, the shadow short rate as an overall summary of conventional and unconventional monetary policy. The first policy variable is the federal funds target rate (FFTR). In the conventional monetary policy environment, when interest rates are not materially constrained by the zero lower bound, the Fed at discrete intervals sets the level of the FFTR to achieve its policy goals. At any point in time, markets gauge the stance of monetary policy from the FFTR setting and any guidance on potential future changes, and the stance of monetary policy transmitted through to asset markets and the economy. Once the FFTR was set in December 2008 to a range of 0 to 0.25 percent, which we illustrate with a mid-point value of 0.125 percent, it could no longer be meaningfully lowered to provide further monetary stimulus.

The second policy variable is a measure of the size of the Fed’s balance sheet; Fed liabilities as a percentage of GDP. From slightly before and since the near-zero policy rate setting in December 2008, the Fed used its balance sheet to provide a range of unconventional monetary policy actions, such as large-scale asset purchases, targeted asset purchases, and liquidity provisions, abbreviated by markets (and in this paper) as quantitative easing. Note that the Fed typically announces its intentions for QE programs, and markets react to the announcements rather than the subsequent realized balance sheet.
Figure 1. U.S. monetary policy and shadow short rate

Source: Board of Governors of the Federal Reserve System and authors’ calculations.
Note: Arrows represent major QE events; down arrow = easing of monetary policy, up arrow = tightening of monetary policy. See text for details.

expansions.\(^5\) We have indicated major QE events with arrows. We use the direction on the arrow to indicate our classification, for illustrative purposes in this section, of whether the event was an easing of monetary policy (a down arrow) or a tightening of monetary policy (an up arrow).

Another tool that has been increasingly used by the Fed during the unconventional monetary policy period is long-horizon forward guidance on likely policy rate settings.\(^6\) Although similar to conventional monetary policy guidance, the long-horizon versions during the unconventional period were typically more explicit and for longer horizons into the future. There is no ready single measure of this policy channel, but the third arrow indicates the first instance of long-horizon forward guidance being used.

\(^5\) This is one reason why realized balance sheet changes alone cannot be used for high-frequency unconventional monetary policy analysis, such as ours. Two more reasons that apply generally for any analysis are: (1) balance sheet changes alone ignore any signaling on future policy rates and/or contingent balance sheet programs not enacted (e.g., the European Central Bank’s Outright Monetary Transactions program, which had a large announcement effect on sovereign bond yields without any subsequent transactions); and (2) normal market liquidity management and/or special liquidity programs will alter the size of the balance sheet without necessarily indicating an intended change to the stance of monetary policy.

\(^6\) Woodford (2012) provides an excellent discussion of the different methods of unconventional monetary policy.
Unconventional monetary policy can therefore be used to set an overall stance of monetary policy that is more accommodative than a zero (or near-zero) policy rate setting alone. In other words, the low policy rate setting combined with unconventional monetary policy actions both influence asset markets and the economy, with the ultimate aim of achieving the Fed’s policy goals.

Figure 1 shows six examples of key unconventional monetary policy announcements in the United States:

1. 25 November 2008 (easing): The Federal Open Market Committee (FOMC) announced the first large-scale asset purchase program, QE1, which amounted to purchases of US$ 1.725 trillion of mainly asset-backed securities up to when it ended in March 2010. On 16 December, the FOMC announced a 0 to 0.25 percent range for the FFTR, effectively beginning the near-zero lower bound environment.

2. 27 August 2010 (easing): FOMC Chair Bernanke foreshadowed QE2 in a speech at Jackson Hole, Wyoming. QE2 was subsequently introduced on 3 November 2010 and amounted to purchases of US$ 0.6 trillion of U.S. treasuries up to when it ended in June 2011.

3. 9 August 2011 (easing): The FOMC released its first explicit extended calendar forward guidance for the FFTR, with a conditional expectation that the FFTR would remain near-zero to mid 2013. On 21 September 2011, the FOMC announced the maturity extension program, “operation twist.” Operation twist was initially a US$ 0.4 billion program to sell shorter-maturity treasury securities and buy longer-term treasury securities. On 20 June 2012 its extension was announced, which ultimately amounted to US$ 0.67 trillion when it ended in late 2012. On 25 January 2012, the FOMC extended the calendar forward guidance to late 2014.

4. 13 September 2012 (easing): The calendar forward guidance was further extended to mid 2015 and QE3 was introduced. QE3 was an open-ended program to purchase US$ 40 billion of asset-backed securities per month. On 12 December 2012, the FOMC changed from calendar forward guidance to guidance based on an unemployment rate of 6.5 percent. At the same meeting, QE3 was increased to US$ 85 billion purchases per month by adding US$ 45 billion of longer-term treasury securities.

5. 22 May 2013 (tightening): Chair Bernanke foreshadowed the potential “tapering,” a reduction in the bond buying program, of QE3 during congressional testimony on the economic outlook.

6. 18 December 2013 (tightening): The FOMC statement announced the first tapering of QE3. Further tapering was announced after each subsequent FOMC meeting, and QE3 finished on 29 October 2014.

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7 The FOMC is a committee within the Fed that sets monetary policy by specifying the short-term objective of the central bank’s open market operations.
Figure 1 also plots estimates of the SSR. We use this variable in the subsequent empirical analysis, and detail its intuition and derivation in the following section. For the purpose of this section, we simply note that the SSR is estimated from yield curve data using Krippner’s (2015) shadow/lower bound yield curve framework, and Figure 1 illustrates that it provides a convenient quantitative measure of monetary policy that can be used over both conventional and unconventional monetary policy periods.\(^8\)

Specifically, positive values of the SSR evolve closely with the FFTR series during the conventional monetary policy period. The match is not identical, and neither is it expected to be, because the SSR is influenced by the FFTR setting and expectations inherent in the yield curve from which the SSR is estimated. In particular, even during periods where the FFTR remains unchanged, the yield curve and the estimated SSR may evolve to reflect changing market expectations about future FFTR settings. In turn, those changing expectations could be in response to central bank guidance given to the market regarding monetary policy and risks, and/or in response to nonmonetary policy events of relevance to monetary policy and risks, such as macroeconomic data releases.

In the unconventional monetary policy period, the SSR evolves to negative levels, which are well below the near-zero FFTR setting. A negative level of the SSR indicates that unconventional monetary policy actions are providing additional accommodation beyond the near-zero FFTR. In particular, balance sheet programs and/or forward guidance are used to influence lower interest rates along the yield curve, and a negative SSR summarizes the degree to which those rates are lower than would be expected with just a near-zero FFTR alone. As such, the negative SSRs standardize the near-zero FFTR plus the different methods of unconventional monetary policy into a single metric. Being derived from the same model, the series of negative and positive SSRs are also consistent with each other and, as mentioned earlier, the positive SSRs are interpretable as a close proxy for the FFTR during the conventional monetary policy period.

With reference to Figure 1, the SSR evolves as one might expect in response to the indicated unconventional monetary policy events described herein. That is, the SSR first declined to negative levels following the near-zero FFTR setting (with QE1 already announced). The SSR declined following the QE2 foreshadowing, the first announcement of long-horizon forward guidance, and the announcement of QE3. The SSR increased following the foreshadowing of QE3 tapering, the onset of QE3 tapering, and subsequently rose gradually as tapering progressed. The SSR settled at mildly negative levels after QE3 concluded on 29 October 2014. Note that, as in the conventional monetary policy environment, SSR levels and changes in the unconventional environment continue to reflect

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\(^8\) Krippner (2013) originally suggested this use of the SSR, as cited by Bullard (2012; 2013). Wu and Xia (2016) use a shadow short rate as a quantitative measure of monetary policy in a factor-augmented vector autoregression for the United States with monthly macroeconomic data.
Monetary Policy Spillovers across the Pacific when Interest Rates Are at the Zero Lower Bound

2.1 U.S.

Figure 2 summarizes the operation of Japanese monetary policy using the policy interest rate (the uncollateralized overnight call rate), the Bank of Japan’s balance sheet (i.e., liabilities as a percent of GDP), and several indicator arrows for key unconventional monetary policy events. In that regard, all of the easing events discussed here were preceded by SSR movements that were subsequently validated by the Fed.

Apart from the movements on individual events, the SSR also summarizes the overall easing and tightening cycle. The SSR declined fairly steadily to its lowest level after the accumulation of unconventional monetary policy actions put in place from QE1 to QE3. It then rose fairly steadily to its current level as the tapering of QE3 was signaled and then enacted. There are several notable exceptions to the broad trends, but these were consistent with events at the time. For example, the rise in the SSR following the QE2 foreshadowing and the first forward guidance announcement coincided with optimism on the U.S. economy at those times. The fall in the SSR following the foreshadowed tapering of QE3 resulted from FOMC efforts to somewhat counter the large and sharp market over-reaction to the original announcement.

2.2 Japan

Figure 2 summarizes the operation of Japanese monetary policy using the policy interest rate (the uncollateralized overnight call rate), the Bank of Japan’s balance sheet (i.e., liabilities as a percent of GDP), and several indicator arrows for key unconventional monetary policy events.
policy announcements. As for the United States, the SSR for Japan provides an overall summary of conventional and unconventional monetary policy.

Figure 2 shows some obvious points of difference relative to the United States. First, the Bank of Japan was the first central bank to introduce unconventional monetary policy, which Ito (2015) termed QE0. QE0 was operational from March 2001 to March 2006. Following the 2008–09 global financial crisis, Japan implemented further quantitative easing starting in December 2008 but a comprehensive unconventional monetary policy easing program was only adopted in November 2010 following the introduction of QE2 in the United States.

Also different from the United States, the Bank of Japan’s conventional policy rate settings have only been mildly positive, between March 2006 and December 2008. After exiting QE0 the uncollateralized overnight call rate increased to 0.25 percent on 14 July 2006 and to 0.5 percent on 21 February 2007. Following the onset of the global financial crisis, however, the Bank of Japan lowered the rate again on 31 October 2008 to 0.3 percent and to 0.1 percent on 19 December 2008.

The Bank of Japan also differed from the United States in how it implemented its unconventional policy in terms of quantitative easing and forward guidance. Regarding QE, in addition to purchasing government securities, the Bank of Japan also purchased a wide range of private assets. Conversely, the Fed purchased mainly mortgage-backed securities and long-maturity treasury securities.9

Regarding forward guidance, both of the Japanese unconventional monetary policy episodes emphasized a commitment to maintain zero nominal interest rates until conditions on consumer price inflation were met (zero or increasing year-on-year inflation in the first episode, and a 2 percent target introduced in the second episode). Conversely, U.S. forward guidance was initially based on long forecast horizons, and then on labor market conditions.

The indicator arrows in Figure 2 illustrate six key unconventional monetary policy announcements by the Bank of Japan along with our classification, for illustrative purposes in this section, of whether the event was an easing of monetary policy (a down arrow) or a tightening of monetary policy (an up arrow). The six monetary policy events are:

1. 19 March 2001 (easing): The Bank of Japan began the first episode of unconventional monetary policy when it changed its main operating target from the uncollateralized overnight call rate to the outstanding balance of current accounts (i.e., bank reserves).

9 Fawley and Neely (2013) provide a detailed discussion for both central banks.
It announced that the target for the outstanding balance of current accounts would be increased from ¥ 4 trillion to ¥ 5 trillion, which was expected to lower the overnight call rate from 0.15 percent to zero. Moreover, it stated that it would increase, if necessary, the outright purchase of long-term government bonds from the prevailing ¥ 400 billion per month. The Bank of Japan subsequently raised the outstanding balance of current accounts target progressively, to a maximum of ¥ 30–35 trillion on 20 January 2004 and purchased increasing amounts of public and private debt. For example, the announced purchases of long-term Japanese government bonds peaked at ¥ 1.2 trillion per month on 30 October 2002.

2. 25 June 2003 (easing): Following the monetary policy meeting, the Bank of Japan announced that it left monetary policy unchanged but it established the principal terms and conditions for the outright purchases of asset-backed securities, which had been decided at the monetary policy meeting on 10–11 June 2003, including synthetic-type securities and asset-backed commercial paper.

3. 9 March 2006 (tightening): The Bank of Japan effectively terminated the program of quantitative easing when it reinstated the uncollateralized overnight call rate as its main policy instrument at a target of zero percent. Moreover, the Bank of Japan announced that the outstanding balance of current accounts would “be reduced towards a level in line with required reserves . . . over a period of a few months,” while outright purchases of long-term Japanese government bonds continued at the current amounts and frequency.

4. 19 December 2008 (easing): Apart from lowering the policy rate to 0.1 percent, the Bank of Japan expanded its outright purchases of Japanese government bonds to ¥ 1.4 trillion per month and issued the principal terms and conditions of special funds supplying operations to facilitate corporate financing due to commence on 8 January 2009. It had already announced, on 2 December 2008, unlimited lending to banks, collateralized by corporate debt, at an interest rate equivalent to the target of the uncollateralized overnight call rate. Shortly after, it announced reverse auction purchases in commercial paper of up to ¥ 3 trillion on 22 January 2009 and ¥ 1 trillion on 19 February 2009. Furthermore, its outright purchase of Japanese government bonds rose to ¥ 1.4 trillion per month on 18 March 2009.

5. 5 November 2010 (easing): The Bank of Japan implemented a comprehensive unconventional monetary policy-easing program comprising three main measures. The first measure was to lower the target of the uncollateralized overnight call rate from 0.1 percent to 0–0.1 percent. Second, the Bank of Japan clarified the conditions for exiting the zero interest rate policy and third, it established an asset purchasing program under which it planned to purchase a wide range of assets, including short- and long-term government bonds, securities, commercial paper, corporate bonds, exchange-traded

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10 This period of quantitative easing is discussed in Ito and Mishkin (2006).
funds, and Japanese real estate investment trusts. The objective of the purchases was to encourage “the decline in risk premiums to further enhance monetary easing.” The initial size of the asset-purchasing program was set at ¥ 35 trillion, and it subsequently increased to ¥ 156 trillion on 22 January 2013. Moreover, the Bank of Japan provided additional funds for loans to private financial institutions on 13 March 2012 and reintroduced unlimited liquidity provision on 30 October 2012.

6. 4 April 2013 (easing): The Bank of Japan announced that it would achieve a 2 percent price stability target “at the earliest possible time, with a time horizon of about two years.” Moreover, it entered a new phase of “quantitative and qualitative monetary easing,” by which it would double the monetary base and the amounts outstanding of Japanese government bonds and exchange-traded funds in two years and more than double the average remaining maturity of Japanese government bond purchases. On 26 April 2013 the Bank of Japan announced that it would conduct money market operations to increase the monetary base at an annual pace of ¥ 60–70 trillion. To a large extent, these events were anticipated, because Shinzo Abe was elected Prime Minister on 16 December 2012, and his election campaign was based on monetary policy accommodation to counteract deflationary conditions and a 2 percent inflation target for the Bank of Japan rather than the current 1 percent target. On 22 January 2013 the Bank of Japan had already introduced a price stability target and an “open-ended asset purchasing method,” which meant that it purchases assets under the asset purchase program without setting a termination date. The most recent announcement under this program was on 31 October 2014, which accelerated the annual pace of increase of the monetary base to about ¥ 80 trillion.

The Japanese SSR in Figure 2 provides a useful summary measure for changes to Japanese monetary policy over both conventional and unconventional periods. As discussed in Section 2.1, the SSR standardizes different methods of unconventional policy into a single comparable metric. This is important and convenient, because it standardizes what would otherwise be quite distinct differences between the monetary policy operations in the two economies, and potentially between the two Japanese unconventional monetary policy periods. At first glance there are two notable counterintuitive SSR movements in the second Japanese unconventional monetary policy period, but we explain these further later in the context of events at the time. In particular, the November 2010 and April 2013 SSR increases are examples of the monetary policy spillovers that we formally investigate in Section 4.

The levels of the SSR summarize the overall easing and tightening cycles in Japan. Hence, the SSR declined to very negative levels following the announcement of the first episode

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of unconventional monetary policy in March 2001, trended lower after the asset purchase program commenced in June 2003, and rose sharply when the first unconventional episode ended in March 2006 (with some apparent anticipation beforehand). The SSR decline to negative levels in 1998 was due to bond yields falling sharply in many major economies in response to the Asian/Russian/Long-Term Capital Management crisis. Although not an explicit unconventional easing announcement by the Bank of Japan, lower bond yields (and a fall in the price of the currency) nevertheless provided monetary stimulus beyond the low policy setting at that time.

Similarly, the SSR declined to negative levels following the announcement of the second episode of unconventional monetary policy in December 2008, and trended lower with subsequent related announcements. Somewhat counterintuitively, the SSR rose quite sharply following the comprehensive unconventional monetary policy easing program in November 2010, and the quantitative and qualitative monetary easing of April 2013.

Figure 3, which plots the United States and Japanese SSRs and events together, suggests that the counterintuitive increases in the Japanese SSR mentioned earlier were influenced by increases in the U.S. SSR. In particular, in October 2010 and May 2013, respectively, the U.S. SSR rose because of optimism on the U.S. economy and the foreshadowing of QE3 tapering. In addition, the decline in the Japanese SSR prior to the November 2010 and April 2013 events indicates that markets largely anticipated the events, and
there may have been some relative disappointment after the Bank of Japan made the actual announcements.

Figure 4 provides an additional check on the U.S. and Japanese shadow short rates by plotting their differential against the U.S. dollar per Japanese yen exchange rate. The exchange rate is an important channel of monetary policy in open economies like the United States and Japan, and one would expect the exchange rate to reflect the relative stance of monetary policy. Figure 4 indeed shows a correspondence between higher (lower) differences of the U.S. SSR and the Japanese SSR, and strength (weakness) in the U.S. dollar versus the yen. Moreover, Figure 4 shows that the co-movement between the SSR differential and the exchange rate has increased since the end of QE0 in Japan in March 2006.

3. Estimation of the shadow short rates

In this section, we outline the estimation of the shadow short rates for the United States and Japan. They are derived using Krippner’s (2015) shadow/lower bound (LB) yield curve modeling framework, which is in turn developed as a close approximation to the shadow/LB framework of Black (1995). We refer readers to Krippner (2015) for the complete details of the framework and its estimation. For the purposes of this paper, we provide the essential overview and intuition that readers require to interpret the SSRs that we use in the subsequent empirical analysis.
Shadow/LB models are based on the principle that an actual short-term interest rate $r_t$ at time $t$ may be viewed as the sum of two components: (i) a shadow short rate $r_t$ that can take positive or negative values; and (ii) an expression $\max[-r_t, 0]$ that accounts for investors’ option to hold physical currency to avoid a negative return if the SSR is negative:

$$r_t = r_t + \max[-r_t, 0].$$

(1)

Therefore $r_t = r_t$ if $r_t \geq 0$ or $r_t = r_t - r_t = 0$ if $r_t < 0$, which hence establishes the zero lower bound for the short-term interest rate. As mentioned in footnote 3, the lower bound may not necessarily be strictly zero in practice, and hence we estimate the lower bound as an extra parameter for our derivation of the SSR.

Given the shadow rate/currency option decomposition of the short-term interest rate, the whole observed actual yield curve (i.e., interest rates as a function of time to maturity at time $t$, all subject to the zero lower bound) may be analogously viewed as the sum of two components: (i) a shadow yield curve as a function of maturity that would exist if physical currency was not available; and (ii) an option effect that the availability of physical currency provides to investors to avoid any realizations of negative shadow short rates that could potentially occur at any time up to each given maturity. Krippner (2015) represents the shadow yield curve with a generic continuous-time Gaussian affine term structure model (GATSM) and calculates the associated option effect to create the generic continuous-time shadow/LB-GATSM framework, which we abbreviate to the shadow/LB framework.

Figure 5 illustrates the concept of the shadow yield curve and the option effect with an example of yield curve data that is materially constrained by the lower bound on nominal interest rates. The shadow yield curve contains negative interest rates for some maturities, and the option effect is material because of the proximity of the yield curve data to the lower bound. The SSR is the shortest maturity rate on the shadow yield curve. Hence, the SSR is conceptually analogous to a policy rate, which is the shortest maturity rate on the yield curve in a conventional monetary policy environment.

To illustrate the consistency of the SSR between conventional and unconventional monetary policy periods, Figure 6 shows an example of yield curve data that are not materially constrained by the lower bound. In this case the physical currency option effect is negligible,14 because the yield curve data are far from the lower bound, and the shadow yield curve is therefore almost identical to the lower bound yield curve. Correspondingly,

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14 The noticeable option effect for long times to maturity reflects the potential for interest rates to evolve near to zero over long horizons.
the SSR and the policy rate are almost identical, which is the case for the conventional monetary policy period of Figure 1 for the United States.

In summary, the shadow/LB model uses a single consistent framework across conventional and unconventional monetary policy regimes and the estimated SSR provides a single comparable measure of monetary policy across those two regimes.
The shadow short rates that we use in our estimation of the latent factor model are obtained from a two-factor arbitrage-free Nelson and Siegel (1987) shadow yield curve within the shadow/LB framework. Krippner (2015) shows that the SSR estimates from this two-factor model are relatively robust, with similar magnitudes and the same profile, and move consistently with known monetary policy events. Conversely, he shows that SSRs from three-factor models are extremely sensitive to the precise model specification, producing very different magnitudes and profiles for only minor changes in the lower bound specification, and they often move counterintuitively to known monetary policy events. Bauer and Rudebusch (2014) also show that three-factor SSR results are specification sensitive, and the three-factor SSR from the Christensen and Rudebusch (2015) application to Japanese data is inconsistent with known monetary policy events.

We estimate the shadow/LB model from daily yield curve data for the United States and Japan, specifically zero-coupon government bond rates and overnight indexed swaps rates (from when the latter are available, namely, 4 January 2008 for the United States and 6 August 2009 for Japan) sourced from Bloomberg, with maturities of 0.25, 0.5, 1, 2, 3, 5, 7, 10, and 30 years. The sample period is from 31 January 1995 to 30 June 2015 (the last data point at the time of estimation). The result is an estimated set of parameters and daily state variables from which we calculate the SSR for each day. These are the SSR series plotted in Figures 1, 2, and 3.

Note that we are aware that the Japanese government bond market differs from the United States bond market, with ownership concentrated among domestic institutions that often hold bonds to maturity. This does not present an issue for our yield curve modeling, in terms of potentially distorted data, because new bond maturities are issued to match demand and supply, and foreign banks in Japan are active on the secondary market; see Yoshino and Vollmer (2014) for discussion of these aspects.

4. Empirical framework and data

In the remainder of this paper we quantify the spillovers of monetary policy shocks in Japan and the United States to interest rates, exchange rates, and equity prices. In this section we present the empirical framework and discuss the data used in the estimations.

15 See Figure 7.8 in Krippner (2015), which is reproduced and discussed in the documentation for the Web site http://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy/comparison-of-international-monetary-policy-measures. The Web site also contains SSR estimates, which are updated monthly, and the associated MatLab programs.
4.1 Latent factor model

We apply a latent factor model to quantify the impact of monetary policy shocks on asset returns in Japan and the United States. In particular, we rely on identification through heteroskedasticity where the additional volatility on monetary policy days is attributed to the policy shocks (see Rigobon and Sack 2004).

Asset returns are expressed as a linear function of common (systemic) and idiosyncratic (diversifiable) unobservable factors

\[ y_{i,t} = \gamma_i a_t + \delta_i d_{i,t}, \quad (2) \]

where \( y_{i,t} \) is the demeaned first difference of the yield or the price of an asset \( i \) at time \( t \) for \( t = 1, \ldots, T \), \( a_t \) is a shock common to all returns and \( d_{i,t} \) represents idiosyncratic shocks to \( y_{i,t} \).\(^{16}\) Equation (2) pertains to all nonmonetary policy days \( T_{NMP} \). On U.S. monetary policy days, \( T_{UMP} \), an additional latent factor applies, which is a monetary policy factor, \( u_{m_t} \). A second monetary policy factor operates on Japanese monetary policy days, \( T_{JMP} \), which is \( j_{m_t} \). Adding the two policy factors, \( u_{m_t} \) and \( j_{m_t} \), to equation (2) yields

\[ y_{i,t} = \gamma_i a_t + \delta_i d_{i,t} + \alpha_i u_{m_t}, \quad (3) \]

where \( t \in T_{JMP} \) and

\[ y_{i,t} = \gamma_i a_t + \delta_i d_{i,t} + \beta_i j_{m_t}, \quad (4) \]

where \( t \in T_{JMP} \) and \( T = T_{NMP} + T_{UMP} + T_{JMP} \).

All factors, \( a_t \), \( u_{m_t} \), \( j_{m_t} \), and \( d_{i,t} \), for \( i = 1, \ldots, N \), where \( N \) is the number of assets, are assumed to be independent with zero mean and unit variance. The parameters \( \gamma_i \), \( \delta_i \), \( \alpha_i \), and \( \beta_i \) are the factor loadings where the \( \alpha_i \)'s and \( \beta_i \)'s give the responses to monetary policy shocks in the United States and Japan. The monetary policy spillovers are represented by the monetary policy factor loading in the foreign market. The common shock, \( a_t \), to all assets may be, but does not necessarily represent, macroeconomic shocks. The model imposes two restrictions. There is heteroskedasticity on monetary policy days compared with all other days but there is homoskedasticity within the two sets of days.

\(^{16}\) Principle component analysis on the data supports the inclusion of just one common factor. For all empirical specifications, the first principle component explains about 80 percent or more of the sample variance. The first normalized eigenvalue is 0.81 and above. Detailed results are available from the authors.
Re-writing equations (2) to (4) in matrix form gives

\[ Y_t = \Lambda H_t \text{ for } t \in T^{NMP} \]
\[ Y_t = \Lambda H_t + \Phi u_t \text{ for } t \in T^{UMP} \]
\[ Y_t = \Lambda H_t + \Psi j_t \text{ for } t \in T^{JMP}, \]

where \( Y_t \) is a \((N \times 1)\) vector of \( y_{i,t} \), \( H_t \) is a \(((N + 1) \times 1)\) vector of shocks, where the common shock, \( a \), is in the first row and the idiosyncratic shocks are in the remaining \( N \) rows. The matrices \( \Lambda, \Phi, \) and \( \Psi \) contain the factor loadings and \( \Lambda \) is \((N \times (N + 1))\) and \( \Phi \) and \( \Psi \) are \((N \times 1)\).

Using the independence assumption and the first and second moment assumptions for the latent factors yields

\[ \Omega^{NMP} = \Lambda \Lambda' \]
\[ \Omega^{UMP} = \Lambda \Lambda' + \Phi \Phi' \]
\[ \Omega^{JMP} = \Lambda \Lambda' + \Psi \Psi', \]

where \( \Omega^k \) with \( k = NMP, UMP \) and \( JMP \) is the variance covariance matrix of \( Y_t \). \( \Omega^{UMP} \) and \( \Omega^{JMP} \) apply on the exogenously identified monetary policy days and \( \Omega^{NMP} \) on all other days. Writing out the first elements of equation (6) gives

\[ \Omega^{MP} = \begin{bmatrix} 
\gamma_1^2 + \delta_1^2 + \alpha_1^2 + \beta_1^2 \\
\gamma_1 \gamma_2 + \alpha_1 \alpha_2 + \beta_1 \beta_2 & \gamma_2^2 + \delta_2^2 + \alpha_2^2 + \beta_2^2 \\
\vdots & \ddots & \ddots \\
\ddots & \ddots & \ddots 
\end{bmatrix}, \]

where \( \alpha_i \neq 0 \) and \( \beta_i = 0 \) for \( t \in T^{UMP} \) and \( \beta_i \neq 0 \) and \( \alpha_i = 0 \) for \( t \in T^{JMP} \). \( \Omega^{NMP} \) is analogous with \( \alpha_i = \beta_i = 0 \) for all \( i \). The model is estimated using generalized method of moments techniques where the model’s theoretical second moments in equation (6) are matched to the empirical moments of the data. In the case of an overidentified model, which occurs when \( N \geq 6 \), the Hansen (1982) method for combining the generated moment conditions with the number of parameter estimates is implemented; see Claus and Dungey (2012) for details.\(^\text{17}\)

\(^\text{17}\) For the empirical results we report in Tables 1 and 2 we have used the identity weighting matrix. Altonji and Segal (1996) show that equal weights are generally optimal in small samples, which is relevant to our analysis given that the number of policy days is relatively small (even though the total sample size is large). We have also obtained results using the inverse of the variance covariance matrix, and they are similar to those we report in this paper.
4.2 Data
The estimation period is 6 January 1998 to 30 June 2015. The beginning of the estimation period is determined by the availability of monetary policy days for Japan. The Bank of Japan and the Fed have been making explicit monetary policy announcements since January 1998 and January 1994, respectively, allowing the exogenous identification of monetary policy days. We obtained monetary policy days from the Bank of Japan and the Fed Board’s Web sites. For Japan we included all monetary policy meetings. We also identified 10 April 2013 as a monetary policy announcement date because on that day Governor Kuroda signaled that monetary easing may last for more than two years.

For the United States we included FOMC meetings and conference calls if these were followed by a statement or speech by the Fed Chair, as well as days of the Chair’s semi-annual monetary policy report to Congress. We also identified 25 November 2008, 1 December 2008, and 22 May 2013 as monetary policy announcement days. 25 November 2008 marks the beginning of QE1. The 25 November 2008 press release was followed by a speech on 1 December 2008 by Chair Bernanke, in which he stated that “the Fed could purchase longer-term Treasury or agency securities on the open market in substantial quantities.” On 22 May 2013 Chair Bernanke signaled the tapering of QE3 in his testimony before Congress. In addition, during the period of unconventional monetary policy we included as announcement days speeches by the Chair at the Annual Economic Symposium in Jackson Hole, Wyoming. Our identification of unconventional monetary policy days for the United States is in line with Rogers, Scotti, and Wright (2014). We excluded the 14 joint monetary policy days from the empirical application for the simple fact that there are insufficient observations to estimate the regime of joint monetary policy changes.

Aside from the SSR series detailed in Section 3, the additional data we use are: (1) the Japanese 10-year government bond rate, the British pound (GBP) per U.S. dollar (USD), the British pound per Japanese yen (JPY), and the JPY per USD exchange rates (all sourced from Bloomberg); and (2) the U.S. 10-year treasury rate, the Standard & Poor’s (S&P) 500, and the Nikkei stock price indexes (all sourced from the Federal Reserve Economic Database on the Federal Reserve Bank of St. Louis Web site). The interest rates and index values are recorded at the domestic market closes, and the exchange rates are all at the Tokyo close. We have aligned the data appropriately to allow for the date difference between the United States and Japanese trading periods (e.g., United States surprises on day \( t \) can only affect Japanese data on trading day \( t+1 \)).

Note that we include the exchange rates with the British pound to independently assess the effects of policy surprises on the USD and JPY exchange rates, because the JPY per

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USD exchange rate is jointly influenced by both sets of surprises. Including these cross rates does not require the additional identification and/or correction for United Kingdom monetary policy event days, because the latter are not systematically aligned with United States and Japanese monetary policy event days.

5. **Empirical results**

This section reports the estimation results of applying the latent factor model to Japanese and U.S. shadow short rates, the 10-year interest rates, equity prices, and three exchange rates, the British pound per U.S. dollar, the Japanese yen per U.S. dollar and the British pound per Japanese yen. All variables are included in demeaned first-differences on non-monetary policy days and on U.S. monetary policy days. But we include two-day changes on Japanese monetary policy days because monetary policy announcements are often made after Japanese markets close.\(^{19}\)

We report the results for two estimation periods.\(^{20}\) The first period is 6 January 1998 to 8 March 2006, during which the Bank of Japan introduced quantitative easing and the Fed was operating monetary policy conventionally. The second period is 9 March 2006 to 30 June 2015. During this period the Bank of Japan implemented further quantitative easing and the Fed started operating unconventional monetary policy following the onset of the global financial crisis and the decline in its policy rate to near-zero in late 2008. Testing these two periods also allows us to assess any differences between the two unconventional periods for Japan.

5.1 **First episode of zero short-term nominal interest rates and quantitative easing in Japan: 6 January 1999 to 9 March 2006**

Table 1 reports the estimation results for the first episode of zero nominal short-term interest rates and quantitative easing in Japan. It shows the parameter estimates (and standard errors in parentheses) of the common shocks, the idiosyncratic shocks, the U.S. monetary policy shock and the Japanese monetary policy shock for the Japanese and U.S. shadow short rates, the 10-year rates,\(^{21}\) equity prices, and the three exchange rates. The parameter estimates, which give the responses to a one standard deviation shock, are reported in basis points for the interest rates and in percentage points for equity prices and

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\(^{19}\) Re-classifying monetary policy event days was not feasible because the time of release is not published for all monetary policy announcements. Moreover, bond and equity markets close at different times in Japan and some announcements were made when one market was open while the other was closed.

\(^{20}\) Results for the full period, 6 January 1998 to 30 June 2015, are available on request.

\(^{21}\) Intuitively, the idiosyncratic factor can be thought of as the regression residual. We found that the U.S. 10-year rate can almost fully be explained by the common and the two monetary policy factors leading us to impose a zero on the loading of its idiosyncratic factor.
Table 1. Estimation results (6 January 1998 to 8 March 2006)

<table>
<thead>
<tr>
<th></th>
<th>Common Idiosyncratic</th>
<th>U.S. monetary policy</th>
<th>Japanese monetary policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. shadow short rate</td>
<td>0.624**</td>
<td>−3.276**</td>
<td>2.667**</td>
</tr>
<tr>
<td></td>
<td>(0.126)</td>
<td>(0.126)</td>
<td>(0.240)</td>
</tr>
<tr>
<td>U.S. 10-year treasury rate</td>
<td>5.790**</td>
<td>0.000</td>
<td>−0.950**</td>
</tr>
<tr>
<td></td>
<td>(0.066)</td>
<td>(0.378)</td>
<td>(0.102)</td>
</tr>
<tr>
<td>U.S. equity prices</td>
<td>0.213**</td>
<td>−1.280**</td>
<td>−0.503*</td>
</tr>
<tr>
<td></td>
<td>(0.112)</td>
<td>(0.230)</td>
<td>(0.328)</td>
</tr>
<tr>
<td>GBP per USD exchange rate</td>
<td>0.005</td>
<td>−0.567</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td>(0.509)</td>
<td>(0.334)</td>
</tr>
<tr>
<td>JPY per USD exchange rate</td>
<td>0.185**</td>
<td>0.887**</td>
<td>−0.023</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td>(0.326)</td>
<td>(0.334)</td>
</tr>
<tr>
<td>Japanese shadow short rate</td>
<td>−0.676**</td>
<td>−3.606**</td>
<td>0.322</td>
</tr>
<tr>
<td></td>
<td>(0.112)</td>
<td>(0.089)</td>
<td>(0.332)</td>
</tr>
<tr>
<td>Japanese 10-year government bond rate</td>
<td>−0.348*</td>
<td>4.232**</td>
<td>0.735**</td>
</tr>
<tr>
<td></td>
<td>(0.110)</td>
<td>(0.077)</td>
<td>(0.322)</td>
</tr>
<tr>
<td>Japanese equity prices</td>
<td>−0.040</td>
<td>1.533**</td>
<td>0.515*</td>
</tr>
<tr>
<td></td>
<td>(0.112)</td>
<td>(0.192)</td>
<td>(0.328)</td>
</tr>
<tr>
<td>GBP per JPY exchange rate</td>
<td>−0.101</td>
<td>0.902**</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td>(0.321)</td>
<td>(0.334)</td>
</tr>
</tbody>
</table>

Source: Authors’ calculations.

Note: **Statistically significant at the 5 percent level; *statistically significant at the 10 percent level.

The exchange rates. We have standardized U.S. and Japanese monetary policy shocks to be unexpected tightenings (i.e., to have positive changes on the respective SSRs). Unexpected easing shocks would have the opposite effect to the tightening shocks we discuss subsequently in the text.

The results in Table 1 first show that U.S. monetary policy surprises have statistically significant domestic impacts (i.e., on the U.S. SSR, 10-year interest rates, and equity prices) but insignificant impacts on U.S. exchange rates.

The coefficient for the U.S. SSR has the opposite sign to equity prices, showing that an unexpected tightening in monetary policy lowers equity prices. This response of equity markets to a domestic monetary policy tightening is as one would anticipate. The 10-year rate, however, falls mildly on an unexpected tightening, which seems counterintuitive. This result likely reflects unique events during the sample period. One was the so-called term structure puzzle during the gradual but persistent series of 0.25 percent FFTR increases during 2004 and 2005. From June 2004 to September 2005, the FOMC adopted the consistent line that “the Committee believes that policy accommodation can be removed at a pace that is likely to be measured.”

During that tightening cycle, 10-year interest rates remained fairly steady or even fell, and that unexpected result was well discussed at the time. Subsequent explanations were global savings directed to the U.S. bond market and/or a decrease in the risk premium for U.S. bonds. Two other unique events...
during the sample period were the technology stock cycle early in the sample period and the deflation scare around 2003.

Regarding spillovers of U.S. monetary policy surprises, Table 1 shows that Japanese 10-year rates rise on U.S. policy tightenings. Japanese equity prices also rise, which seems counterintuitive, but which we discuss shortly in the context of the domestic Japanese results.

The responses of Japanese asset markets to Japanese monetary policy surprises are all statistically significant, along with the JPY per GBP exchange rate. The signs are mostly as one would anticipate. Specifically, an unexpected tightening in monetary policy raises 10-year rates and appreciates the JPY per GBP exchange rate. The rise in equity prices, however, seems counterintuitive. One explanation for equities reacting positively to a Bank of Japan tightening is that the latter is coincident with faster economic growth than previously anticipated by markets, and faster economic growth is positive for the Japanese equity market. Similarly, regarding the U.S. monetary policy shocks, Japanese equities may react positively to signals of stronger growth in the United States associated with U.S. policy tightenings.

Regarding spillovers of Japanese monetary policy surprises, the U.S. SSR and 10-year rates rise significantly on Japanese policy tightenings.

In general, the magnitudes of responses to Japanese monetary policy surprises are typically larger than for U.S. monetary policy surprises. These results are consistent with Japanese monetary policy events containing a higher surprise component than U.S. events, which is in turn consistent with a greater degree of transparency and signaling of U.S. monetary policy. The latter allows markets to anticipate monetary policy changes and incorporate them appropriately into asset markets before monetary policy event days.

5.2 Second episode of quantitative easing in Japan: 9 March 2006 to 30 June 2015

Table 2 reports the results for the second episode of quantitative easing in Japan. During most of this period short-term nominal interest rates in Japan and the United States were at or near the zero lower bound and the central banks operated monetary policy using unconventional methods.

The results show that U.S. monetary policy tightening shocks had a large positive impact on U.S. 10-year rates compared with the first sample period. In particular, the response of the 10-year treasury rate changes from a 0.95 basis point decline previously to a 8.47 basis point increase. This result supports earlier findings (e.g., Krishnamurthy and Vissing-Jorgensen 2011 and Gagnon, Raskin, Remache, and Sack 2011) that quantitative easing lowered longer-maturity interest rates in the United States, and is also consistent with
forward guidance being intended to lower longer-maturity interest rates. Spillovers to Japanese interest rates are also larger than in the first sample period, including a significant response for the Japanese SSR.

The impact of U.S. monetary policy tightening shocks on U.S. equities is similar to the first sample period, but somewhat smaller (−0.37 versus −0.50 percentage points). That result accords with earlier findings of an attenuated response of equity prices (e.g., Rosa 2012 and Kiley 2014) when the zero lower bound on interest rates is binding in the United States. The spillover response into Japanese equity prices also declines from the first sample period, becoming insignificant in the second sample period.

Regarding Japanese monetary policy surprises on Japanese asset markets, Japanese 10-year rates respond less than in the first sample period but equity prices respond more strongly. Again, Japanese equity prices increase on policy tightening shocks, suggesting an underlying common factor of a stronger economy driving both tighter policy and equity prices.

The Japanese spillover effects to the U.S. asset markets are larger for both interest rates and equities than in the first sample period, becoming significant for equities. The U.S. equity response is positive to a Japanese tightening shock, again suggesting a common factor between the Japanese economy, Japanese monetary policy, and equity market performance (in this case the U.S. equity market).

The implementation of a comprehensive program of unconventional monetary policy in Japan and a binding zero lower bound in the United States appear to have greatly

<table>
<thead>
<tr>
<th>Common</th>
<th>Idiosyncratic</th>
<th>U.S. monetary policy</th>
<th>Japanese monetary policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. shadow short rate</td>
<td>0.611**</td>
<td>3.786**</td>
<td>1.629**</td>
</tr>
<tr>
<td>(0.222)</td>
<td>(0.087)</td>
<td>(0.142)</td>
<td>(0.113)</td>
</tr>
<tr>
<td>U.S. 10-year treasury rate</td>
<td>3.090**</td>
<td>5.010</td>
<td>8.466**</td>
</tr>
<tr>
<td>(0.517)</td>
<td>(0.083)</td>
<td>(0.083)</td>
<td></td>
</tr>
<tr>
<td>U.S. equity prices</td>
<td>0.804**</td>
<td>−1.339**</td>
<td>−0.365**</td>
</tr>
<tr>
<td>(0.251)</td>
<td>(0.259)</td>
<td>(0.149)</td>
<td>(0.134)</td>
</tr>
<tr>
<td>GBP per USD exchange rate</td>
<td>−0.144</td>
<td>−0.734**</td>
<td>−0.155</td>
</tr>
<tr>
<td>(0.233)</td>
<td>(0.395)</td>
<td>(0.144)</td>
<td>(0.133)</td>
</tr>
<tr>
<td>JPY per USD exchange rate</td>
<td>0.402**</td>
<td>−0.694*</td>
<td>0.588**</td>
</tr>
<tr>
<td>(0.235)</td>
<td>(0.429)</td>
<td>(0.144)</td>
<td>(0.134)</td>
</tr>
<tr>
<td>Japanese shadow short rate</td>
<td>0.220</td>
<td>2.808**</td>
<td>0.694**</td>
</tr>
<tr>
<td>(0.232)</td>
<td>(0.104)</td>
<td>(0.143)</td>
<td>(0.133)</td>
</tr>
<tr>
<td>Japanese 10-year government bond rate</td>
<td>1.393**</td>
<td>2.201**</td>
<td>1.214**</td>
</tr>
<tr>
<td>(0.295)</td>
<td>(0.210)</td>
<td>(0.149)</td>
<td>(0.136)</td>
</tr>
<tr>
<td>Japanese equity prices</td>
<td>0.798**</td>
<td>−2.063**</td>
<td>−0.008</td>
</tr>
<tr>
<td>(0.248)</td>
<td>(0.164)</td>
<td>(0.149)</td>
<td>(0.134)</td>
</tr>
<tr>
<td>GBP per JPY exchange rate</td>
<td>−0.483**</td>
<td>0.949**</td>
<td>−0.017</td>
</tr>
<tr>
<td>(0.238)</td>
<td>(0.323)</td>
<td>(0.146)</td>
<td>(0.134)</td>
</tr>
</tbody>
</table>

Source: Authors’ calculations.

Note: **Statistically significant at the 5 percent level; *statistically significant at the 10 percent level.
changed the transmission of monetary policy shocks to foreign exchange markets. During the first episode of quantitative easing in Japan only Japanese monetary policy shocks had a statistically significant impact on the GBP per JPY exchange rate, and neither the United States nor Japanese monetary policy shocks had a significant impact on the JPY per USD exchange rate.

With unconventional monetary policy in both countries, the United States and Japanese monetary policy shocks have a statistically significant impact on the JPY per USD exchange rate. Following an unexpected U.S. tightening and higher interest rates in the United States and Japan, the USD appreciates against the JPY. This result confirms the broader levels illustration in Figure 4, which shows a closer correlation in the second half of the sample period of the JPY per USD exchange rate versus U.S. monetary policy relative to Japanese monetary policy.

The effect on currencies from an unexpected tightening by the Bank of Japan is more subtle. U.S. interest rates increase by more than Japanese rates, leading to an appreciation of the USD against the JPY. Similarly, the GBP appreciates against the JPY, and the USD appreciates against the GBP, although we do not know the response of United Kingdom interest rates in this case given our two-economy investigation. The depreciation of the JPY in response to a tightening shock would again be consistent with an underlying common factor of faster economic growth mentioned earlier, given it raises inflation expectations.

6. Concluding remarks

Understanding the effects of monetary policy shocks on asset markets is key for central banks, because they affect the decisions of economic agents and ultimately the level of economic activity and inflation that central banks seek to target. In this paper we investigated the domestic effects and spillovers from monetary policy shocks in the United States and Japan over the period January 1998 to June 2015. During this time, short-term nominal interest rates have effectively been zero in Japan and in the United States since late 2008. When monetary policy operates at the zero lower bound and is delivered by unconventional methods, the effects of monetary policy shocks can no longer be quantified by considering observable changes in short-term market interest rates. In our analysis, we therefore used a shadow short rate measure that quantitatively summarizes the stance of monetary policy consistently over conventional and unconventional monetary policy environments.

A narrative on monetary policy in the United States and Japan showed that the estimated shadow short rates evolved consistently with conventionally operated policy rate settings and key unconventional monetary policy events.
In the empirical application, we investigated whether the international transmission of monetary policy shocks to interest and exchange rates and equity prices has changed between the first period of unconventional monetary policy in Japan (6 January 1998 to 8 March 2006), while short-term nominal interest rates in the United States were still comfortably above the zero lower bound, and recent history (9 March 2006 to 30 June 2015), which includes the second episode of quantitative easing in Japan and the Fed’s unconventional monetary policy. The results showed that Japanese and U.S. monetary policy shocks have statistically significant spillover effects to asset markets in both countries but the magnitude and direction of change vary depending on the origin country of the shock, namely, the United States or Japan. Moreover, the impact of monetary policy surprises on asset markets increased, except for equity prices in response to U.S. monetary policy shocks, during the second episode of quantitative easing in Japan and the introduction of unconventional monetary policy in the United States. In particular, a binding zero lower bound on interest rates in Japan and the United States appears to have affected the transmission of monetary policy shocks to foreign exchange markets. We found a limited response of exchange rates during the first episode of quantitative easing in Japan but a significant impact since 2006.

Our results indicate that the use of unconventional monetary policy measures altered the transmission of monetary policy shocks. The implication of this finding is that if different monetary policy tools affect asset markets differently, stabilization of economic activity and inflation will require central banks to adjust their policy responses accordingly. The investigation of how central banks should adjust their responses is left for future research.

There are further possible extensions to our analysis, and we note three of them here. First, asset prices are an important channel for monetary policy to affect the real economy and other asset classes, such as corporate bond yields and real estate investment trust prices, should be included in the analysis. Second, increasing globalization suggests incorporating more economies into the analysis, such as the euro area and the United Kingdom. Third, the transmission of monetary policy shocks into macroeconomic variables, such as output, employment, and inflation could be investigated. On the latter, our results showed how conventional and unconventional monetary policy may be standardized into a single metric, and that should provide a useful means for analyzing the operation of monetary policy to achieve the macroeconomic targets desired by central banks.

References


