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**Monetary policy spillovers across the Pacific when
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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 United States and Japanese monetary policy shocks on their own asset markets, and the spillovers into each other's markets. However, because short-term nominal interest rates have been effectively zero in Japan since January 1998 and the United States from late 2008, 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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Non-technical summary

We investigate the effects of United States and Japanese monetary policy actions on their own financial markets, and the spillovers into each other's markets. In general, understanding such transmissions is important for central banks because financial markets influence economic activity and inflation, which are a primary focus of the central banks' mandate.

Of particular interest in the prevailing global environment is how those transmissions might have changed once the conventional operation of monetary policy using policy interest rates became constrained at near-zero levels, and unconventional monetary policy actions (e.g. expanding the money supply) were used to provide additional monetary stimulus. Japan contains one such period from 1998 to 2006 and, following the Global Financial Crisis in 2008, both Japan and United States operated monetary policy by unconventional means.

We use US and Japanese shadow short rates as the monetary policy indicator for our analysis. Shadow short rates are estimated from the yield curve data (i.e. interest rates across different maturities) for each country. They are similar to short-maturity interest rates in conventional environments, but in unconventional environments shadow short rates freely evolve to negative values to reflect a stance of policy that is more accommodative than a near-zero policy rate setting alone. Shadow short rates therefore provide a convenient and consistent monetary policy indicator over conventional and unconventional monetary policy periods (which short-maturity interest rates would not provide when constrained at near-zero levels in unconventional periods). We test the effect of shadow short rates on interest rates, exchange rates, and equity prices, with a sample period from 1998 to 2015.

Our results show that US and Japanese monetary policy actions affect their own markets and also have spillover effects on the other country, with both effects typically being statistically significant. However, the effects vary depending on the origin country, with US monetary policy shocks generally having larger effects on Japanese financial markets than the other way around.

Our results also show that monetary policy actions typically had larger own-country and spillover effects on financial markets in the unconventional period following the Global Financial Crisis. In particular, unconventional monetary policy had larger effects on foreign exchange markets: we found a limited impact on exchange rates prior to the Global Financial Crisis, but a statistically significant impact afterwards.

The results suggest two general conclusions. First, central banks should be aware that the financial market transmission of monetary policy actions via unconventional methods may differ materially from conventional methods. Second, central banks should be mindful of the spillover potential from monetary policy in foreign economies, which can be more material on the exchange rate during unconventional environments.

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 to market interest rates and asset prices. However, that conventional transmission becomes potentially more complex and different 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 employ their balance sheets with programmes 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 2006, which we call QE0 following Ito (2014),⁴ the Bank of Japan's second QE from 2008, and the Federal Reserve's QE from 2008. Another broad class of unconventional monetary policy is forward guidance on policy rates. Examples are the Bank of

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.

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.

Japan's commitments to maintain near-zero policy rates to meet inflation objectives during the first and second QE, and the Federal Reserve's long-horizon policy rate indications.

Regarding the investigation of monetary policy transmission, several challenges arise when unconventional methods are employed 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 quantitative 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 heteroskedasticity (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 monetary 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 Federal Reserve in the United States 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. Moreover, during this period the Federal Reserve 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.

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 shadow short rate 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 shadow short rate for our empirical analysis in section 5, and we present details underlying its derivation in section 3.

We begin our narrative with the United States as the world's largest economy and because some key events in the United States look to have influenced Japanese asset markets in a significant manner. Note that our analysis could be extended to include more economies, but we have chosen a two-economy focus for clarity and for maximum relevance to Asian economies.

Before proceeding, there are two important points to bear in mind regarding the narrative and illustrations 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, while 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 monetary policy announcements if the announcement 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 US monetary policy using two key policy variables and, as we discuss further below, 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 Federal Reserve 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. However, 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 Federal Reserve's balance sheet; Federal Reserve (FR) liabilities as a percentage of gross domestic product (GDP). From slightly before and since the near-zero policy rate setting in December 2008, the Federal Reserve employed 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 (QE). Note that the Federal Reserve typically announces its intentions for QE programs, and markets react to the announcements rather than the subsequent realized balance sheet expansions.⁵ Hence, we have indicated major QE events with arrows. We use the

⁵This 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 programmes not enacted (e.g. the European Central Bank's Outright Monetary Transactions programme, which had a large announcement effect on sovereign bond yields without any subsequent transactions); and (2) normal market liquidity management and / or

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 Federal Reserve during the unconventional monetary policy period is long-horizon forward guidance on likely policy rate settings.⁶ While 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.

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 Federal Reserve’s policy goals.

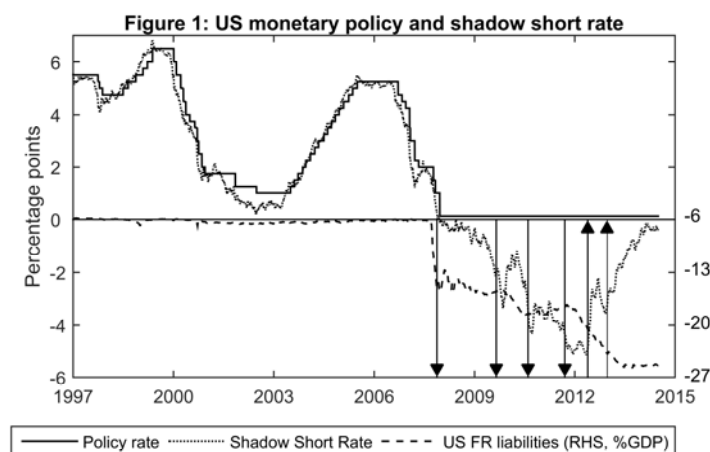


Figure 1 shows six examples of key unconventional monetary policy announcements in the United States:

1. 25 November 2008 (easing): The Federal Open Market Committee (FOMC)⁷ announced the first large-scale asset purchase program, QE1, which amounted to purchases of \$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.

special liquidity programmes 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.

⁷ The FOMC is a committee within the United States Federal Reserve System that sets monetary policy by specifying the short-term objective of the central bank’s open market operations.

2. 27 August 2010 (easing): FOMC Chair Bernanke foreshadowed QE2 at a speech in Jackson Hole. QE2 was subsequently introduced on 3 November 2010 and amounted to purchases of \$0.6 trillion of US 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 \$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 \$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 \$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 \$85 billion purchases per month by adding \$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 at a 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.

Figure 1 also plots estimates of the shadow short rate (SSR). We employ this variable in our 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

⁸ Krippner (2013) originally suggested this use of the SSR, as cited by Bullard (2012, 2013). Wu and Xia (2015) use a shadow short rate as a quantitative measure of monetary policy in a factor-augmented vector autoregression (FAVAR) for the United States with monthly macroeconomic data.

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 programmes and / or forward guidance are employed 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 above, 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 above. 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, like in the conventional monetary policy environment, SSR levels and changes in the unconventional environment continue to reflect the market's anticipations of future policy events. In that regard, all of the easing events discussed above were preceded by SSR movements that were subsequently validated by the Federal Reserve.

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 US 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 percentage of GDP, and several indicator arrows for key unconventional monetary policy announcements. As

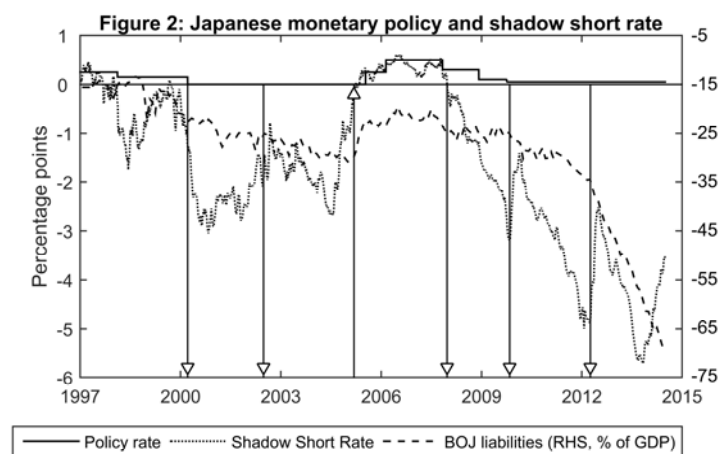
for the United States, the SSR for Japan provides an overall summary of conventional and unconventional monetary policy.

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 global financial crisis (GFC) 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 to 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. However, following the onset of the GFC 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 Federal Reserve 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 two percent target introduced in the second episode). Conversely, US forward guidance was initially based on long forecast horizons, and then on labor market conditions.



⁹ Neely (2013) provides a detailed discussion for both central banks.

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. 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.¹⁰ 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.

¹⁰ This period of quantitative easing is discussed in Ito and Mishkin (2006).

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 to 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 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 two 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 two percent inflation target for the Bank of Japan rather than the current one 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 below 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 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. While 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 US and Japanese SSRs and events together, suggests that the counterintuitive increases in the Japanese SSR mentioned above were influenced by increases in the US SSR. In particular, in October 2010 and May 2013 respectively, the US SSR rose due to optimism on the US 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.

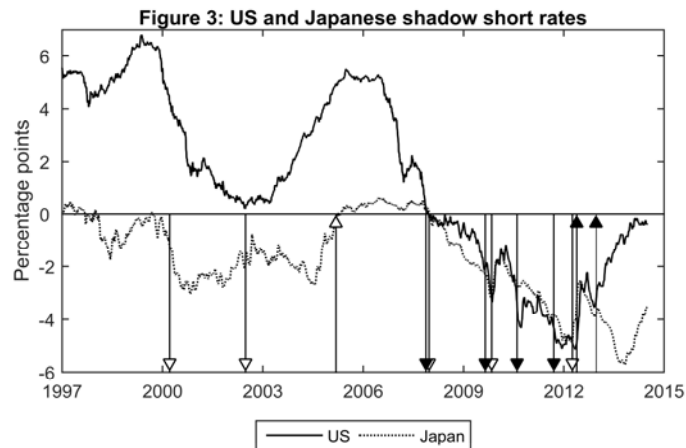
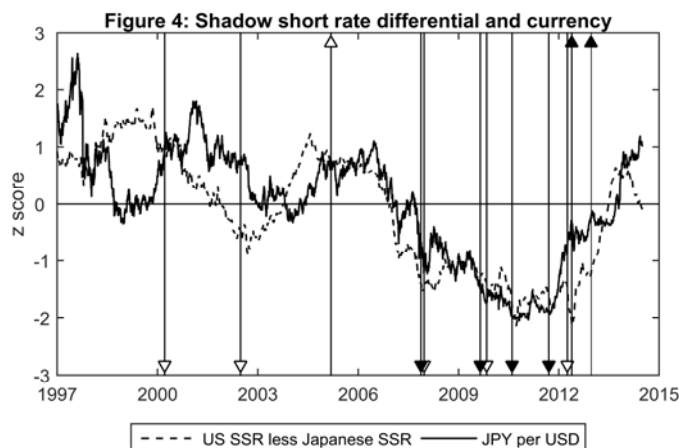


Figure 4 provides an additional check on the US and Japanese shadow short rates by plotting their differential against the US dollar per Japanese yen exchange rate. The exchange rate is an important channel of monetary policy in open economies like the United States and Japan, and one would expect the exchange rate to reflect the relative stance of monetary policy. Figure 4 indeed shows a

correspondence between higher (lower) differences of the US SSR and the Japanese SSR, and strength (weakness) in the US 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

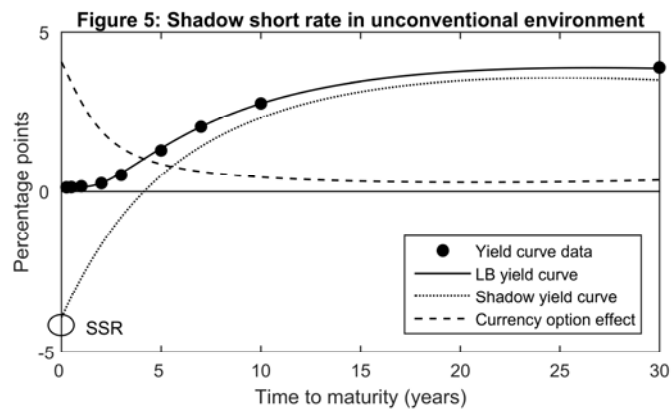
In this section, we outline the estimation of the shadow short rates for the United States and Japan. They are derived using Krippner's (2015) shadow / lower bound (LB) yield curve modeling framework, which is in turn developed as a close approximation to the shadow / LB framework of Black (1995). We 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 shadow short rates that we use in the subsequent empirical analysis.

Shadow / LB models are based on the principle that an actual short-term interest rate \underline{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 shadow short rate is negative. In summary, $\underline{r}_t = r_t + \max[-r_t, 0]$. Therefore $\underline{r}_t = r_t$ if $r_t \geq 0$ or $\underline{r}_t = r_t - r_t = 0$ 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.

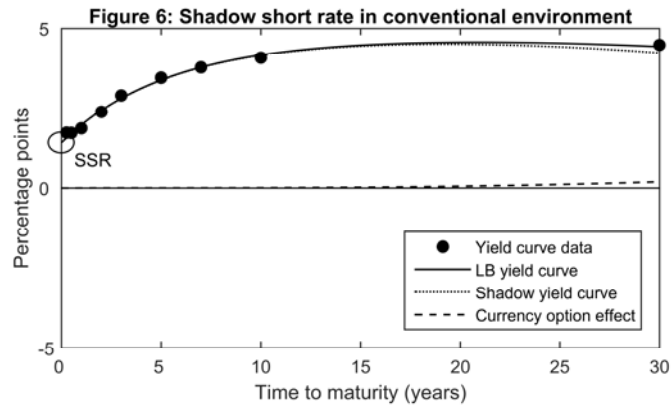
Figure 5 illustrates the concept of the shadow yield curve and the option effect with an example of yield curve data that is materially constrained by the lower bound on nominal interest rates. The shadow yield curve contains negative interest rates for some maturities, and the option effect is very material due to the proximity of the yield curve data to the lower bound. The shadow short rate 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 is not materially constrained by the lower bound. In this case the physical currency option effect is negligible,¹¹ 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, the shadow short rate 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 then, the shadow LB model uses a single consistent framework across conventional and unconventional monetary policy regimes and the estimated shadow short rate provides a single comparable measure of monetary policy across those two regimes.

¹¹ The noticeable option effect for very long times to maturity reflects the potential for interest rates to evolve near to zero over very long horizons.



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) figure 7.8 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, Krippner (2015) figure 7.8 clearly shows that SSRs from three-factor models are very 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.¹² 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 are 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, i.e. 4 January 2008 for the US 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, with ownership concentrated among domestic institutions that often hold bonds to maturity. However, this does not present an issue for our yield curve modelling, 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 on these aspects.

¹² Krippner (2015) figure 7.8 is also reproduced and discussed in the documentation for the website http://www.rbnz.govt.nz/research_and_publications/research_programme/additional_research/5655249.html. The website also contains SSR estimates, which are updated monthly, and the associated MatLab programmes.

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.

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 $t = 1, \dots, T$, a_t is a shock common to all returns and $d_{i,t}$ represents idiosyncratic shocks to $y_{i,t}$.¹³ Equation (2) pertains to all nonmonetary policy days T^{NMP} . On US monetary policy days, T^{UMP} , an additional latent factor applies, which is a monetary policy factor, um_t . A second monetary policy factor operates on Japanese monetary policy days, T^{JMP} , which is jm_t . Adding the two policy factors, um_t and jm_t , to equation (2) yields

$$y_{i,t} = \gamma_i a_t + \delta_i d_{i,t} + \alpha_i um_t \quad (3)$$

where $t \in T^{UMP}$ and

$$y_{i,t} = \gamma_i a_t + \delta_i d_{i,t} + \beta_i jm_t \quad (4)$$

where $t \in T^{JMP}$ and $T = T^{NMP} + T^{UMP} + T^{JMP}$.

All factors, a_t , um_t , jm_t and $d_{i,t}$ for $i = 1, \dots, N$, where N is the number of assets, are assumed to be independent with zero mean and unit variance. The parameters γ_i , δ_i , α_i and β_i are the factor loadings where the α_i 's and β_i 's give the responses to monetary policy shocks in the United States and Japan. 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 to all other days but there is homoskedasticity within the two sets of days.

¹³ Principal component analysis on the data supports the inclusion of just one common factor. For all empirical specifications, the first principal 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

$$\begin{aligned} Y_t &= \Lambda H_t \text{ for } t \in T^{NMP} \\ Y_t &= \Lambda H_t + \Phi m_t \text{ for } t \in T^{UMP} \\ Y_t &= \Lambda H_t + \Psi j_t \text{ for } t \in T^{JMP} \end{aligned} \quad (5)$$

where Y_t is a $(N \times 1)$ vector of $y_{i,t}$, H_t is $((N + 1) \times 1)$ 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 Λ , Φ and Ψ contain the factor loadings and Λ is $(N \times (N + 1))$ and Φ and Ψ are $(N \times 1)$.

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

$$\begin{aligned} \Omega^{NMP} &= \Lambda \Lambda' \\ \Omega^{UMP} &= \Lambda \Lambda' + \Phi \Phi' \\ \Omega^{JMP} &= \Lambda \Lambda' + \Psi \Psi' \end{aligned} \quad (6)$$

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

$$\Omega^{MP} = \begin{bmatrix} \gamma_1^2 + \delta_1^2 + \alpha_1^2 + \beta_1^2 & & & \\ \gamma_1 \gamma_2 + \alpha_1 \alpha_2 + \beta_1 \beta_2 & \gamma_2^2 + \delta_2^2 + \alpha_2^2 + \beta_2^2 & & \\ \vdots & & \ddots & \\ \dots & & & \dots \end{bmatrix} \quad (7)$$

where $\alpha_i \neq 0$ and $\beta_i = 0$ for $t \in T^{UMP}$ and $\beta_i \neq 0$ and $\alpha_i = 0$ for $t \in T^{JMP}$. Ω^{NMP} is analogous with $\alpha_i = \beta_i = 0$ for all i . The model is estimated using generalized method of moments (GMM) 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.¹⁴

The monetary policy spillovers are represented by the monetary policy factor loading in the foreign market.

¹⁴ 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 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 very 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 Board of Governors of the Federal Reserve 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 Federal Reserve Board's websites. 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. Our identification of 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 US dollar (USD), the British pound per Japanese yen (JPY), and the JPY per USD exchange rates (all sourced from Bloomberg); and (2) the US 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 (FRED) on the Federal Reserve Bank of St. Louis website). 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 USD exchange rate will be 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 US shadow short rates, the 10-year interest rates, equity prices, and three exchange rates, the British pound per US dollar, the Japanese yen per US dollar and the British pound per Japanese yen. All variables are included in demeaned first-differences on nonmonetary policy days and on US monetary policy days. But we include two-day changes on Japanese monetary policy days because monetary policy announcements are often made after Japanese markets closed.¹⁵

We report the results for two estimation periods.¹⁶ The first period is 6 January 1998 to 8 March 2006, during which the Bank of Japan introduced quantitative easing and the Federal Reserve 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 Federal Reserve 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 US monetary policy shock and the Japanese monetary policy shock for the Japanese and US shadow short rates, the 10-year rates,¹⁷ 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 the exchange rates. We have standardized US 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 US monetary policy surprises have statistically significant domestic impacts, i.e. on the US SSR, 10-year interest rates, and equity prices, but insignificant impacts on US exchange rates.

The coefficient for the US 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

¹⁵ 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.

¹⁶ Results for the full period, 6 January 1998 to 30 June 2015, are available on request.

¹⁷ Intuitively, the idiosyncratic factor can be thought of as the regression residual. We found that the US 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.

monetary policy tightening is as one would anticipate. However, the 10-year rate 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 Federal Open Market Committee 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 US bond market and / or a decrease in the risk premium for US bonds. The technology stock cycle early in the sample period and the deflation scare around 2003 were two other unique events during the sample period.

Table 1: Estimation results (6 January 1998 to 8 March 2006)

| | Common | Idiosyncratic | US monetary policy | Japanese monetary policy |
|---------------------------------------|----------------------|----------------------|--------------------------|--------------------------------|
| US shadow short rate | 0.624 ** (0.126) | -3.276 ** (0.126) | 2.667 ** (0.240) | 3.447 ** (0.138) |
| US 10-year treasury rate | 5.790 ** (0.066) | 0.000 | -0.950 ** (0.378) | 5.777 ** (0.102) |
| US equity prices | 0.213 ** (0.112) | -1.280 ** (0.230) | -0.503 * (0.328) | 0.039 (0.150) |
| GBP per USD exchange rate | 0.005 (0.111) | -0.567 (0.509) | 0.032 (0.334) | 0.119 (0.150) |
| JPY per USD exchange rate | 0.185 ** (0.111) | 0.887 ** (0.326) | -0.023 (0.334) | -0.055 (0.150) |
| Japanese shadow short rate | -0.676 ** (0.112) | -3.606 ** (0.089) | 0.322 (0.332) | 1.929 ** (0.144) |
| Japanese 10-year government bond rate | -0.148 * (0.110) | 4.232 ** (0.077) | 0.735 ** (0.322) | 2.543 ** (0.138) |
| Japanese equity prices | -0.040 (0.112) | 1.533 ** (0.192) | 0.515 * (0.328) | 0.463 ** (0.150) |
| GBP per JPY exchange rate | -0.101 (0.111) | 0.902 ** (0.321) | 0.022 (0.334) | 0.250 ** (0.150) |

Level of significance: ** 5 percent, * 10 percent

Regarding spillovers of US monetary policy surprises, table 1 shows that Japanese 10-year rates rise on US 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. However, the rise in equity prices seems counterintuitive. One explanation for equities reacting positively to a Bank of Japan of 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 US monetary policy shocks,

Japanese equities may react positively to signals of stronger growth in the United States associated with US policy tightenings.

Regarding spillovers of Japanese monetary policy surprises, the US 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 US monetary policy surprises. These results are consistent with Japanese monetary policy events containing a higher surprise component than US events, which is in turn consistent with a greater degree of transparency and signaling of US 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 US monetary policy tightening shocks had a positive impact with a larger magnitude on US 10-year rates compared to the first sample period. In particular, the response of the 10-year treasury rate changes from the 0.95 basis point decline previously to an 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 the first sample period, including a significant response for the Japanese SSR.

The impact of US monetary policy tightening shocks on US equities is similar to the first sample period, but a bit smaller (i.e. -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 US asset markets are larger for both interest rates and equities than in the first sample period, becoming significant for equities. The US 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 US equity market).

Table 2: Estimation results (9 March 2006 to 30 June 2015)

| | Common | Idiosyncratic | US monetary policy | Japanese monetary policy |
|---------------------------------------|----------------------|----------------------|--------------------------|--------------------------------|
| US shadow short rate | 0.611 ** (0.222) | 3.786 ** (0.087) | 1.629 ** (0.142) | 4.146 ** (0.113) |
| US 10-year treasury rate | 3.090 ** (0.517) | 5.010 | 8.466 ** (0.083) | 8.346 ** (0.083) |
| US equity prices | 0.804 ** (0.251) | -1.339 ** (0.259) | -0.365 ** (0.149) | 0.912 ** (0.134) |
| GBP per USD exchange rate | -0.144 (0.233) | -0.734 ** (0.395) | -0.155 (0.144) | -0.289 ** (0.133) |
| JPY per USD exchange rate | 0.402 ** (0.235) | -0.694 * (0.429) | 0.588 ** (0.144) | 0.360 ** (0.134) |
| Japanese shadow short rate | 0.220 (0.232) | 2.808 ** (0.104) | 0.694 ** (0.143) | 0.514 ** (0.133) |
| Japanese 10-year government bond rate | 1.393 ** (0.295) | 2.201 ** (0.210) | 1.214 ** (0.149) | 1.325 ** (0.136) |
| Japanese equity prices | 0.798 ** (0.248) | -2.063 ** (0.164) | -0.008 (0.149) | 1.011 ** (0.134) |
| GBP per JPY exchange rate | -0.483 ** (0.238) | 0.949 ** (0.323) | -0.017 (0.146) | -0.444 ** (0.134) |

Level of significance: ** 5 percent, * 10 percent

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 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 US nor Japanese monetary policy shocks had a significant impact on the JPY per USD exchange rate.

With unconventional monetary policy in both countries, both US and Japanese monetary policy shocks have a statistically significant impact on the JPY per USD exchange rate. Following an unexpected US 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 US monetary policy relative to Japanese monetary policy.

The effect on currencies from an unexpected tightening by the Bank of Japan is more subtle. US 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 an underlying common factor of faster economic growth mentioned earlier, given it would raise inflation expectations.

6 Concluding remarks

Understanding the effect 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 Federal Reserve's unconventional monetary policy.

The results showed that Japanese and US 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, i.e. the United States or Japan. Moreover, the impact of monetary policy surprises on asset markets increased, except for equity prices in response to US 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 other further 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 growth, employment, and inflation could be investigated. On the latter, our results showed how conventional and unconventional monetary policy may be standardized to 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.

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