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US MONETARY POLICY ANNOUNCEMENTS AND THE TERM STRUCTURE OF INTEREST RATE DIFFERENTIALS: EVIDENCE FROM HONG KONG AND SINGAPORE

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US Monetary Policy Announcements and the Term Structure of Interest Rate Differentials: Evidence from Hong Kong and Singapore

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Abstract

This paper investigates the effect of US monetary policy announcements on the term structure of US interest rate differentials with Hong Kong and Singapore. US monetary policy surprises on domestic and international interest rates are measured by using data from short-term interest rate futures markets in all three countries around the FOMC meetings dates. Our results, based on careful treatment of interest rate endogeneity and time-varying risk premia in the futures markets, document that US monetary policy announcements significantly affect the behavior of the term structure of interest rates in the US and in both Asian countries. The implications of these results in light of the expectations hypothesis of the term structure of interest rates (EHTS) are also discussed.

JEL Classification: E43, E44, E52, F31, G13.
Keywords: Monetary policy, interest rate futures, term structure of interest rates

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1. Introduction

In recent years a great deal of attention has been paid to understanding the relationship between monetary policy and market interest rates. A common finding of this literature is that unanticipated changes in the US Federal Reserve target rate cause US bond yields to move substantially (see, *inter alia*, Cook and Hahn, 1989; Kuttner, 2001; Cochrane and Piazzesi, 2002; Piazzesi, 2004 and Rigobon and Sack, 2004 and the reference therein). Most of the contributions in this literature have focused exclusively on the US market.[1] Surprisingly, little attention has been paid to understanding the relationship between US monetary policy actions and international market interest rates. In internationally integrated financial markets, interest rates co-move to a larger extent and Federal Open Market Committee (FOMC) announcements [2] are likely to influence the dynamics of market interest rates not only in the US but also in other countries. The magnitude of this response is also amplified by the fact that many economies are linked to the US economy by different exchange rate arrangements (Phylaktis, 1999; Phylaktis and Ravazzolo, 2002).

This paper contributes to the literature in several respects. First, by using market-based proxies for expectations obtained from short-term interest rate futures, we investigate the response of the term structure of interest rates to FOMC announcements for three different countries: the US, Hong Kong SAR (Hong Kong henceforth) and Singapore. Second, we extend previous works to explore the role of the FOMC announcements on the dynamics of the term structure of US interest rate differentials rather than focusing exclusively on the response of market interest rates in each country in isolation. Third we discuss the implications of US monetary policy shocks for the dynamics of US interest rate differentials in light of the predictions of the expectations hypothesis of the term structure of interest rates (EHTS).

The choice of Hong Kong and Singapore is twofold: they represent an interesting case study of two small open economies with developed financial markets which have experienced two different exchange rate arrangements in the last twenty years. Further, in both Hong Kong and Singapore, short-term interest rate futures contracts with characteristics similar to the Eurodollar futures contract, routinely employed in this literature, are traded on their exchanges.

Our results with regard to the questions addressed in the paper, based on careful treatment of interest rate endogeneity and risk premia in the futures markets, are as follows. We find that FOMC announcements affect the expectations about the future path of short-term interest rates which, in turn, substantially influence the behavior of the term structure of interest rates in the US and, more interestingly, in both Asian countries.

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1 Notable exceptions are represented by the papers by Clare and Courtenay (2001), Gurkaynak, Sack and Swanson (2003), Melvin, Sager and Taylor (2004) and Fuertes and Thomas (2004) who investigate the reaction of UK asset prices to UK macro announcements.

2 The term ‘announcements’ is used to denote official communications provided at the end FOMC meetings. These may involve potential changes (or no changes) in the monetary policy target rate. We label ‘surprises’ monetary policy moves which are not anticipated by the market. In this paper we use monetary policy announcements in a broad sense, since we employ in our empirical investigation *all* FOMC announcements over the sample period, whose content may or may not have been anticipated by the market.

This paper is related to earlier research by Ehrmann and Fratzscher (2002, 2004), who investigate the economic and monetary interdependence between the US and the euro area by looking at the effects of monetary policy announcements and macroeconomic news on the dynamics of daily interest rates. Our paper differs from these contributions in several important respects. First our empirical analysis focuses on the interaction between interest rates at different maturities up to ten years. Second we investigate the implications of the announcements for the term structure of interest rate differentials rather than looking at individual interest rate markets in isolation. Third, in our framework we take into account the role of diverse exchange rate arrangements. Fourth, our measure of monetary policy shocks is based upon interest rate futures prices comparable in terms of underlying assets.

Another related paper is Fair (2003) who empirically identifies events that led to large and rapid price changes in stock, bond and exchange rate futures markets. Our study differs from this paper in that we focus exclusively on interest rate markets in order to estimate the effect of FOMC announcements on US and international market interest rates. Further, in our empirical investigation we consider two emerging economies linked to the US markets by different exchange rates arrangements.

The rest of the paper is organized as follows: Section 2 provides a brief summary of the existing literature and describes the empirical framework adopted in throughout the paper emphasizing the role of interest rate endogeneity as well as risk premia in the futures market. Section 3 describes the data employed in the empirical investigation and discuss potential data issues. Section 4 reports the description of the empirical results. Sections 5 and 6 explore and discusses the implications of the empirical results reported in Section 4 in light of the predictions of the EHTS. A final section concludes.

2. Previous Studies and the Empirical Framework

The effect of monetary policy announcements on market interest rates has been largely investigated in the literature. Arguably Cook and Hahn (1989) are among the first to explore the one-day response of bond rates to changes in the target Fed fund rate. Over the sample period ranging between 1974 and 1979, comprising 75 dates on which the Fed changed the funds rate target, their results indicate that the interest rate's response to target rate increases was positive and significant at all maturities, but smaller at the long end of the yield curve. In the spirit of Cook and Hahn's analysis Radecki and Reinhart (1994), Roley and Sellon (1995, 1998), and Thornton (1998) find that the market interest rate's reaction to monetary policy changes is still positive and statistically significant; however, the relationship is much weaker then previously reported. These papers have modified the work by Cook and Hahn in various directions; however, in all these contributions the procedure adopted was to estimate OLS regressions of the changes in the k-period bond yields on the changes in the Fed funds target rate around the FOMC meetings dates:[3]

$$\Delta r_{t,k} = \beta_{0k} + \beta_{1k}\Delta\widetilde{r}_t + e_t \tag{1}$$

[3] Another way adopted in the literature to estimate the market's reaction to monetary policy shocks is based upon Vector Autoregression (VAR) models (see, *inter alia*, Mehra, 1996; Thorbecke, 1997; Evans and Marshall, 1998 and the references therein). However, others are skeptical as to the reliability of these measures (Rudebusch, 1998; Brunner, 2000).

where $\Delta r_{t,k}$ and $\Delta\widetilde{r}_t$ are changes in the k-period bond yields and the Fed funds target rate respectively. Estimates of the parameters β_{1k} , for any bond maturity k, measure the impact of changes in the target rate on the term structure of interest rates. Kuttner (2001) pointed out that the weaker reaction of market interest rates to policy rate changes in the 1990s was mainly due to the fact that target rate changes have been more widely anticipated in recent years. In forward-looking markets bond yields should react differently to anticipated and *unanticipated* monetary actions. In particular long-term interest rates should mostly (if not only) react to unanticipated changes in monetary policy actions. Researchers have addressed this problem by proxying unanticipated monetary policy actions with measures of expectations obtained from asset prices, mainly from short-term interest rate futures (see *inter alia* Kuttner, 2001; Faust, Swanson and Wright, 2001; Bomfim, 2002; Poole, Rasche and Thornton, 2002; Cochrane and Piazzesi, 2002; Rigobon and Sack, 2004 and the references therein). This choice can be rationalized by assuming that short-term interest futures rates contain information about expectations of the future path of short-term interest rates plus a risk premium:

$$f_t^{(n)} = E_t\left(r_{t+n,1}\right) + \Phi_{t,k}^{(n)} \quad (2)$$

where $f_t^{(n)}$ is the implied rate [4] of a future contract with maturity n, $E_t\left(r_{t+n,1}\right)$ is the expectation, formed at time t, about the value that a 1-period bond rate will have in n period times and $\Phi_{t,k}^{(n)}$ represents a risk premium.[5] If the risk premium is constant or changes little from period to period[6] we can write that:

$$f_t^{(n)} - f_{t-1}^{(n)} = \Delta f_t^{(n)} \simeq E_t\left(r_{t+n,1}\right) - E_{t-1}\left(r_{t+n,1}\right) \quad (3)$$

Equation (3) tells us that changes in the short-term interest futures rates represent a correct proxy for changes in expectations as to where the short-term (i.e. 1-period) interest rate will be at the expiration of the futures contract, $t+n$. Following this recent strand of literature (see, *inter alia*, Kuttner, 2001 and Rigobon and Sack, 2004 and the references therein), we modify Cook and Hahn's approach in order to include unanticipated monetary policy changes as follows:

$$\Delta r_{t,k} = \beta_{0k} + \beta_{1k}\Delta f_t^{(1)} + \epsilon_t \quad (4)$$

where $f_t^{(1)}$ is the rate on the nearest short-term interest rate futures contract to expire. In this framework β_{1k} measures the impact of US monetary policy shocks on the term structure of interest rates around FOMC meeting dates.

4 Implied futures rates are calculated as 100 – futures prices at time t (measured in percentage points).

5 As pointed out in Kuttner (2001) $\Phi_{t,k}^{(n)}$ may also represent day-of-the-month effect in the futures market. However, under the risk-neutral market efficiency hypothesis (RNMEH) this term should be equal to zero or the realization of a stationary process (see, *inter alia*, Clarida, Sarno, Taylor and Valente, 2003 and the references therein).

6 It is documented that realized futures excess returns are statistically different from zero (Sack, 2002; Piazzesi and Swanson, 2004). In this case changes in short-term interest futures rates are not an unbiased proxy for changes in expectations. This issue is discussed more in detail in Section 2.1 and Section 4.

2.1 Interest rate endogeneity and risk premia in the interest rate futures markets

The empirical framework summarized in equation (4) does not account for the fact that interest rates at different maturities and futures prices are simultaneously determined in financial markets. Further, a number of other variables, which are not explicitly modelled in our framework, are likely to have an impact on the determination of interest rates and futures prices. As shown by Rigobon and Sack (2004), these two issues result in an endogeneity bias and omitted variable problems which complicates the identification of the responsiveness of market interest rates to unanticipated monetary policy actions. The authors address these problems by developing a new estimator based upon the heteroskedasticity of the unanticipated monetary policy shocks. In our empirical analysis, we use this estimator to quantify the importance of those biases in the identification of the effect of FOMC announcements on US and international market interest rates. [7]

Another important assumption embedded in equation (4) relates to the measurement of unanticipated monetary policy shocks by means of short-term interest rate futures prices. Daily changes in the futures prices are unbiased predictors of changes in expectations about the futures path of short-term interest rates only if risk premia are constant of change little from period to period. Recently, Sack (2002) and Piazzesi and Swanson (2004) reported that realized excess returns in the federal funds futures market and Eurodollar futures market are nonnegligible. There are indeed large and time-varying risk premia in the US interest rate futures markets and the magnitude of the excess returns is directly related to the maturity of the futures contracts. Disregarding the existence of risk premia in the futures market or allowing for constant risk premia would result in a biased measure of unanticipated monetary policy shocks:

$$\Delta f_t^{(n)} \simeq E_t\left(r_{t+n,1}\right) - E_{t-1}\left(r_{t+n,1}\right) + \Delta\Phi_{t,k}^{(n)} \tag{5}$$

where $\Delta\Phi_{t,k}^{(n)}$ is the daily change in the futures risk premium. To correct for the extra term $\Delta\Phi_{t,k}^{(n)}$ in equation (8), Piazzesi and Swanson (2004) have suggested adjusting futures rates as follows:

$$\widetilde{f}_t^{(n)} = f_t^{(n)} - \left(\delta_0^{(n)} - \delta_1^{(n)} X_t\right) \simeq E_t\left(r_{t+n,1}\right) - \left(\delta_0^{(n)} - \delta_1^{(n)} X_t\right) \tag{6}$$

where X_t is a vector of variables known to financial markets at time t which is able to predict expected excess returns in the futures markets. This risk-adjusted futures rate can be used to construct an unbiased measure of monetary policy shocks which does not suer from a systematic bias due to risk premia in the futures markets:

$$\Delta\widetilde{f}_t^{(n)} \simeq E_t\left(r_{t+n,1}\right) - E_{t-1}\left(r_{t+n,1}\right) \tag{7}$$

We turn now to the description of our data set.

[7] Technical details on the Rigobon and Sack's (2004) heteroskedasticity-based estimator are reported in Appendix A below.

3. Data

Our data set comprises daily interest rates and futures rates time series for the US, Hong Kong and Singapore. The interest rates employed in the empirical investigation are Treasury yields with 3-month, 1-, 5- and 10-year maturity for the US and Singapore, and 3-month Exchange Fund Bills yields and 1-, 5-, 10-year Exchange Funds Notes yields for Hong Kong. The series are obtained from the Federal Reserve H.15 statistical release for the US interest rate data, the Monetary Authority of Singapore (MAS) and the Hong Kong Monetary Authority (HKMA) for the Singapore and the Hong Kong interest rate data respectively. As for the market-based measure of expectations we used three futures contracts on comparable underlying interest rates. In particular we used closing prices for the 3-month Eurodollar futures, the 3-month Hong Kong Interbank Oered Rate (HIBOR) futures and the 3-month Singapore Dollar Interest Rate futures respectively. We have chosen futures contracts with and underlying 3-month interest rate because this will reduce the influence of the timing of monetary policy shocks, picking up the level of the interest rate expected over the upcoming three months (Rigobon and Sack, 2004; Elligsen, Söderström and Massenz, 2004).

3.1 Interest rates issues

The 3-month Eurodollar futures have traded on the Chicago Mercantile Exchange (CME) since 1981 and the settlement price is based upon the spot 3-month Eurodollar deposit rate (LIBOR) prevailing on the date of expiration. Eurodollar futures contracts are listed in the March quarterly cycle (i.e. March, June, September and December) and they have maturities that extend out to 2 years (8 quarters) ahead.

The 3-month HIBOR futures contract was introduced on the Hong Kong Exchange (HKEx) on September 27th, 1997.[8] This contract settles on the spot 3-month HIBOR rate prevailing on the date of expiration, generally the third Wednesday of the contract month. Similarly to the 3-month Eurodollar futures contracts, the 3-month HIBOR futures contracts are listed in the March quarterly cycle with maturities that extend out to 2 years ahead.

The 3-month Singapore Dollar Interest Rate futures contract was first traded on the Singapore Exchange (SGX) on September 10th, 1999. Its settlement price is based upon the 3-month interbank rate quoted by the Association of Banks in Singapore (ABS) on the second business day preceding the third Wednesday of the contract month. The 3-month Singapore Dollar Interest Rate futures contracts follow the same listing practice reported for the 3-month Eurodollar futures and the 3-month HIBOR futures. The data relative to individual futures contracts are obtained from *Datastream*. From individual contracts we constructed a measure of changes in market expectations about the future path of short-term interest rates by using the rate on the nearest futures contract to expire (Kuttner, 2001; Rigobon and Sack, 2004).

[8] This date refers to the introduction of electronic trading for this futures contract (see HKEx Derivative Market, 2001). Before September 1997, the 3-month HIBOR futures contract was traded in a open outcry system with a much smaller volume of transactions.

The sample period for the empirical analysis covers the period between February 1994 and July 2004 for the US, September 1997 and July 2004 for Hong Kong and September 1999 and July 2004 for Singapore. While the sample periods selected for Hong Kong and Singapore are limited because of data availability, the starting point of the sample period for the US is chosen because it was only in February 1994 that the Fed began the practice of announcing federal funds target changes immediately upon making them. Further, also in 1994 the FOMC began the practice of changing the federal funds rate target primarily at regularly scheduled FOMC meetings.

This sample period includes 87, 61 and 42 FOMC meetings dates for the US, Hong Kong and Singapore respectively.

Before turning to the description of the empirical results it is worth discussing the implications of different trading times of the interest rate markets for the estimation of equation (4). In all three countries under investigation, Treasury yields are generally recorded at different times than interest futures closing prices. For example, the rates reported in the Federal Reserve H.15 statistical release are recorded at 5:00 p.m. New York time while the 3-month Eurodollar futures closing price is generally recorded at 2:00 p.m. Chicago time. Similarly the Treasury yields are at 11:00 a.m. for Hong Kong and 4:30 p.m. for Singapore, Hong Kong/Singapore time. Indeed, these two spot markets lead the US interest rate spot market by 19 and 14:30 p.m. hours respectively. The futures market closing price is for both Hong Kong and Singapore recorded at 5:00 p.m. Hong Kong/Singapore, time preceding the Eurodollar futures closing price by 9 hours. FOMC announcements are generally disclosed at 2:15 p.m., Washington/New York time. At that time, the US interest rate futures market is closed while the US spot interest rate market is still trading. The Asian market, however, has already recorded the relevant prices since FOMC announcements occur when the time in Hong Kong and Singapore is 4:15 a.m..[9]

This trading time difference in different time zones may aect the estimation of equation (4) because of dating errors. In order to take into account this issue we define and use throughout the paper, consistently with Cochrane and Piazzesi (2002), the interest rate changes corresponding to the shock $\Delta r_{t,k}, \Delta f_t^{(1)}$, as the movement in spot and futures interest rates from two days before to one day after FOMC announcements.

4. Empirical results

In this section we report our main empirical results from estimating the response of US, Hong Kong and Singapore market interest rates to US monetary policy shocks. We then consider the impact of interest rate endogeneity and risk premia in the futures market on the estimated responses of the term structure on interest rates.

[9] These calculations ignore Daylight Savings Time (DST). Taking into account DST would affect the difference between the US time and the Hong Kong/Singapore time by -1 hour.

Some preliminary statistics on the interest rates time series are reported in Table 1. The figures reported are interest rates daily changes (expressed in basis points) on FOMC meetings dates and non-FOMC meetings dates.[10] During the sample periods interest rates decreased on average in all countries, without any remarkable difference between FOMC and non-FOMC meeting dates. The analysis of interest rate standard deviations and covariances suggest that around FOMC meeting dates there were significant shifts in the variability of interest rates changes and an increased covariation among interest rates and futures rates changes. This pattern is evident for the US and Hong Kong while for Singapore there are no evident differences in the variability and covariation between interest rates across FOMC and non-FOMC meeting dates.

Estimates of equation (4) are reported in Table 2 Panel A. As expected, the coefficients β_{1k} are all positive and statistically significant; however their magnitude is different across countries and bond maturities. In particular, for the US the results are qualitatively and quantitatively consistent with previous empirical works (see, *inter alia*, Kuttner, 2001; Piazzesi, 2004; Rigobon and Sack, 2004). The response is large at shorter maturities (i.e. up to one year) and it progressively declines as the maturity increases. The impact of 1 percentage point shock results in 98 basis points changes in the 1-year bond yield and about a half in the 10-year bond yield. The reaction of the term structure of interest rates in Hong Kong follows the same pattern; however it is smaller in magnitude when compared to the reaction of the term structure of interest rates in the US. The impact is again strong at short maturities, with about 60 basis points at the 1-year maturity; and it declines to 11 basis points at the 10-year maturity. The response of the term structure of interest rates in Singapore is different in that it exhibits a flat pattern at about 38 basis points regardless of the bond maturity.

As pointed out in Rigobon and Sack (2004), these results may be biased upward, in particular at longer maturities, because of the effect of interest rate endogeneity and omitted variable problems. Table 2 Panel B reports the estimates of equation (4) where Rigobon and Sack's (2004) heteroskedasticity-based estimator has been employed. The coefficients β_{1k} are still all positive and statistically significant across countries and maturities. However, their magnitude is smaller compared to the one obtained when interest rate endogeneity and omitted variable problems are not taken into account. In particular the correction is generally stronger for longer maturities with a magnitude which varies across countries. While the US interest rates experience the largest correction followed by Hong Kong, Singapore interest rate responses are not significantly different from the ones reported in Table 2 Panel A. These results are not surprising given that Rigobon and Sack's (2004) estimator can successfully correct for endogeneity and omitted variable problems only if the shifts in the variance-covariance matrix (5) are large enough to allow for the parameters to be identified. Indeed, the preliminary evidence presented in Table 1 suggests that this is not the case for Singapore, where there is little evidence of shifts in the variance-covariance matrix between FOMC and non-FOMC dates.

In order to understand the importance of risk premia in the futures market we calculated realized excess returns as follows:

$$rx_{t+n}^{(n)} = f_t^{(n)} - r_{t+n,1} \tag{8}$$

[10] As in Rigobon and Sack (2004) non-FOMC meeting dates are defined as the day before each FOMC meeting date.

where $r_{t+n,1}$ is the ex-post value of the short-term interest rate at time $t+n$. The results calculated for holding periods up to eight quarters ahead and for all countries, are reported in Table 3. Realized excess returns in the futures market (annualized to facilitate comparisons across holding periods) are all positive on average and statistically significant across countries and futures contracts maturities. Further, the magnitude of the realized excess returns is generally non decreasing with the horizon of the futures contracts, n. In fact, for short-maturity futures contracts, $n = 1$ (i.e. three month), the average excess return across countries amounts to 3 basis points per month, increasing to 13 basis points per month for futures contracts with maturity $n = 8$. To correct our measures of monetary policy shocks for any potential bias due to risk premia in the futures markets we estimated the following regression

$$rx_{t+n}^{(n)} = \delta_0^{(n)} + \delta_1^{(n)} X_t + \varepsilon_t \tag{9}$$

where X_t is a $q \times 1$ vector of variables known to financial markets at time t which is able to predict excess returns in the futures markets and $\delta_1^{(n)}$ is a $1 \times q$ vector of parameters. For this exercise, consistent with Piazzesi and Swanson (2004) we used a vector of interest rate term spreads with consecutive maturities (i.e. $r_{t,1y} - r_{t,3m}, r_{t,5y} - r_{t,1y}, r_{t,10y} - r_{t,5y}$ where $r_{t,3m}, r_{t,1y}, r_{t,5y}, r_{t,10y}$ denote bond yields with maturity 3-month, 1-year, 5-year and 10-year respectively). Some key results of this estimation are reported in Table 3. For all countries and across different futures contracts maturities we find that interest rate term spreads predict future excess returns. The test for the null hypothesis $\delta_1^{(n)} = 0$ is always strongly rejected at conventional statistical levels. Further, the adjusted coefficients of determination obtained out of the individual estimations are very satisfactory ranging, on average, between 0.14 for Hong Kong and 0.30 for the US and Singapore.

We then calculated a risk-adjusted futures rate as $\widetilde{f}_t^{(n)} = f_t^{(n)} - \left(\delta_0^{(n)} - \delta_1^{(n)} X_t\right)$. The results of the estimation of equation (4) carried out by using the risk-adjusted futures rate are reported in Table 4. The OLS estimates of β_{1k} are all positive and statistically significant and the adjustment for risk does not significantly affect the magnitude of the parameters.[11] This result may be interpreted in light of the fact that the magnitude of risk premia in the futures markets is, consistent with the existing empirical literature, very small at very short maturities of the futures contracts. Since in our estimations we have always proxied monetary policy shocks by using the nearest futures contract to expire, this result suggests that, in this context, the adjustment for risk is small and it does not remarkably affect the parameter estimates.

5. US Monetary Policy Announcements and the EHTS

The results reported in the previous Section 4 show that the impact of FOMC announcements on the term structure of interest rates in the US, Hong Kong and Singapore is statistically significant even by correcting for interest rate endogeneity and omitted variable problems and risk premia in the futures markets. A logical related issue is whether or not the response of market interest rates at different maturities is consistent with the EHTS. In this respect Kuttner (2001) demonstrates that if the EHTS holds, the one-day change in a k-period bond can be written as:

$$r_{t,d-1} - r_{t-1,d} = \frac{1}{d-1}\left[r_{t,1} - E_{t-1}\left(r_{t,1}\right)\right] + \Psi_t \tag{10}$$

[11] We have also carried out a similar exercise by using Rigobon and Sack's (2004) estimator. The results, not reported to conserve space, are not qualitatively and quantitatively different from the ones reported in Table 4.

where d is the number of days to maturity of the k-period bond [12] and Ψ_t is a term containing information about the revision in the expectations of the next day's interest rate and the difference between the expected k-period bond rate (minus 1 day) and the 1-period rate at time $t-1$.[13] The key implication of equation (10) is that if the EHTS holds, the direct effect of a surprise change in the short-term interest rate $r_{t,1} - E_{t-1}(r_{t,1})$ on the daily change in the k-period bond yield $r_{t,d-1} - r_{t-1,d}$ is inversely related to the number of days to maturity of the k-period bond, d. Therefore, the longer the maturity of the k-period bond, the smaller the effect on its daily rate change.[14]

The estimated impact of US monetary policy announcements on the term structure of market interest rates in all three countries under investigation, with and without the effect of interest rate endogeneity, is plotted in Figure 1.[15] For the US and Hong Kong the behavior of the estimated responses is generally consistent with the predictions of the EHTS as outlined in equation (10). In fact the response of interest rates is larger at short maturities and it progressively declines as the maturity increases. By contrast, for Singapore the reaction is relatively flat implying that the effect of FOMC announcements on market interest rates in Singapore may not be consistent with the EHTS.

The magnitude of market interest rate responses is different across countries. In particular it is larger in the US and Hong Kong and smaller in Singapore, suggesting that the exchange rate regime in operation may have played a significant role. In fact, over the sample period investigated, the Hong Kong dollar was tied to the US dollar by means of a currency board, while over the same sample period the Singaporean dollar has experienced a managed float. Another interest stylized fact emerges from the response of long-term interest rates to FOMC announcements. In fact while the response of market interest rates at short-maturities varies across countries, at longer maturities (i.e. 10 years) the response of market interest rates is indeed very similar, close to 50 basis points regardless of the exchange rate regime in place.

The behavior of long-term interest rates after a monetary policy shock is not uniquely identified in the literature. In fact, it is still controversial whether the term structure of interest rates should shift or rotate after a policy change. Some researchers suggest that short-term interest rate increases should drive up long-term interest rates, but with a smaller magnitude (see, *inter alia*, Cook and Hahn, 1989; Skinner and Zettlemeyer, 1995; Mehra, 1996; Kuttner, 2001). Others argue that short-term interest rate increases should reduce long-term interest rates because of the impact of short-term interest rate on inflation (Romer and Romer, 2000). Elligsen and Söderström (2001) propose a framework where the impact of short-term interest rate changes on long-term interest rates depends on whether changes are due to central banks, reactions to new and possibly private information about the economy or to changes in their policy preferences. The authors show that in the first case (i.e. reaction to new information) long-

12 In other words, d = number of months to maturity d = number of days in each month.

13 For further technical details, see Kuttner (2001) p. 540.

14 As pointed out in Kuttner (2001), changes in the 1-period bond rate aect longer-term interest rates only to the extent that they lead to revisions in expectations of future short-term interest rates. Further, this effect is larger the more persistent are the changes. See also on this point Cook and Hahn (1989).

15 The estimated impact reported in Figure 1 is computed over the sample period September 1999 - July 2004, where data are available for all countries. The intermediate maturities are calculated by using the method described in Nelson and Siegel (1987).

term interest rate changes should be positively correlated with short-term interest rate changes, while in the second case (i.e. changes in policy preferences) the response of long-term interest rates may be uncorrelated or negatively correlated with short-term interest rates changes.

Our previous empirical results show that for the US and Hong Kong the term structure of interest rates reacts to FOMC announcements by shifting and rotating such that long-term interest rates move less than short-term interest rates (i.e. the yield curve flattens). By contrast, for Singapore, our results suggest that the term structure of interest rates react to FOMC announcements by shifting upwards or downwards according to the sign of the policy rate changes. Therefore it is worthwhile investigating further the response of market interest rates to FOMC announcements by using the framework introduced by Elligsen and Söderström (2001) where FOMC announcements are classified in two groups: one where the Fed reacts to new information about the state of the US economy and another where the Fed reacts because of changes in its policy preferences.[16] With this new classification, equation (4) becomes:

$$\Delta r_{t,k} = \beta_{0k} + \left(\beta_{1k}^{NI} d_t^{NI} + \beta_{1k}^{NI} d_t^{P}\right) \Delta f_t^{(1)} + \epsilon_t \tag{11}$$

where d_t^{NI} and d_t^{P} are dummy variables which are equal to one when FOMC announcements are classified as reactions to new information and changes in policy preferences respectively, and zero otherwise. Similarly β_{1k}^{NI} and β_{1k}^{P} measure the response of market interest rates to FOMC announcements due to Fed reactions to new information and changes in policy preferences respectively.

The results from estimating equation (11) are reported in Table 5. Two clear patterns can be identified: first, consistently with Elligsen and Söderström (2001), reactions of market interest rates to FOMC announcements classified to be due to Fed reactions to new informations are all positive and statistically significant for all countries and across bond maturities with a magnitude decreasing as the maturity increases. By contrast, the reaction of market interest rates to FOMC announcements classified to be due to changes in policy preferences are statistically significant only for the US and only for short-term maturities (up to one year).[17]

Figure 2 shows the estimated responses of market interest rates to classified and unclassified FOMC announcements, where the classification is limited to reactions to new information about the US economy. For the US and Hong Kong, market interest rates react less to classified FOMC announcements than to unclassified FOMC announcements. Further, it is worth noting that when the classification is used, the reaction of market interest rates in Singapore is not flat but follows the pattern exhibited by the US and Hong Kong interest rate markets, implying that the response of market interest rates in Singapore follows the predictions of the EHTS only when it occurs to Fed reactions to new information about the state of the US economy.

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[16] More specifically, Elligsen and Söderström (2001) define FOMC announcements as endogenous if they reflect that fact that the Fed have obtained new information about the state of the economy, and exogenous if they reflect changes in policy preferences. In a recent paper Elligsen, Söderström and Massenz (2004), by using the information provided by the “Credit Markets” column of the *Wall Street Journal*, report the classification of the FOMC announcements since 1988.

[17] Also in this case we have carried out a similar exercise by using the Rigobon and Sack’s (2004) estimator. The results were not qualitatively and quantitatively different from the ones reported in Table 5.

These findings can be rationalized by claiming that agents in internationally integrated financial markets are aware of the dichotomy between changes in the Fed policy preferences and the state of the US economy. However, they appear to be more (if not exclusively) reactive to news regarding the state of the US economy, having this first order effect on the global economic growth and the behavior of international financial markets.

6. US Monetary Policy Announcements and the Dynamics of US Interest Rate Differentials

The focus of this empirical analysis thus far has been to analyze the response of the US, Hong Kong and Singapore market interest rates to US monetary policy announcements. This response has been investigated for each country in isolation. It is interesting to enlarge the scope of this analysis by looking at the impact of FOMC announcements on the term structure of US interest rate differentials with Hong Kong and Singapore.

In order to address this issue we use Kuttner's (2001) result previously discussed to show that the one-day change in a k-period US interest rate differential with country i can be written as:

$$\left(r_{t,d-1}^{US}-r_{t,d-1}^{i}\right)-\left(r_{t-1,d}^{US}-r_{t-1,d}^{i}\right)=\frac{1}{d-1}\left\{\left[r_{t,1}^{US}-E_{t-1}^{US}\left(r_{t,1}^{US}\right)\right]-\left[r_{t,1}^{i}-E_{t-1}^{i}\left(r_{t,1}^{i}\right)\right]\right\}+\Theta_{t}^{US,i} \quad (12)$$

where $\Theta_t^{US,i}=\Psi_t^{US}-\Psi_t^{i}$. Hence, if the EHTS holds, the direct effect of a common surprise change in the short-term interest rates on the daily change in the k-period interest rate differential is also inversely related to the number of days to maturity of the k-period bonds.

Figure 3 shows the impact of the US term structure of interest differentials to FOMC announcements calculated as the difference between the response of market interest rates in the US and the corresponding market interest rate reaction in Hong Kong or Singapore. Our results indicate that for both Asian countries, the impact of FOMC announcements is positive across bond maturities (i.e. interest rates in the US react more than the foreign ones) and the response is stronger at short maturities, gradually declining towards zero as the bond maturity increases. When all FOMC announcements in the sample are employed, the magnitude of the response of the US short-term interest differential with Singapore is nearly twice as large as the impact of the same FOMC announcements on the short-term interest rate differential with Hong Kong. However, when FOMC announcements are classified in order to take into account Fed reactions to new information about the state of the US economy are used, the response of both interest rate differentials appears to be very similar. It is also interesting to note that at very short maturities, the impact of US monetary policy announcements to both interest rate differentials is about 25 basis points, a value that is very close to the average change of the Fed funds target rate over the sample period.

7. Conclusions

In this paper we have examined the impact of US monetary policy announcements on the term structure of interest rates for three countries: the US, Hong Kong and Singapore. In particular we have proxied US monetary policy surprises by using short-term interest rate futures prices. We have also extended our analysis to the effects of US monetary policy announcements on the behavior of the US term structure of interest rate differentials with Hong Kong and Singapore. By using data spanning the period between 1994 to 2004, our results suggest that, consistent with much previous empirical literature, US monetary policy announcements affect changes in expectations about the future path of short-term interest rates which, in turn, substantially influence the term structure of interest rates in the US and in both Asian countries. The responses of market interest rates are consistent with predictions of the EHTS for the US and Hong Kong, while the response of market interest rates in Singapore is consistent with the EHTS only after FOMC announcements are classified to extrapolate Fed reactions to new information about the state of the US economy *à la* Elligsen and Söderström (2001).

This study ought to be seen as a preliminary attempt towards the understanding of how market expectations in different countries are affected by common shocks and how monetary policy shocks in relevant economies (i.e. the US or the euro area) affect the dynamics of interest rates in other financially integrated markets. There are a number of ways in which this study could be extended. First, one obvious concern is that our results may be sample specific. Our choice of interest rates and sample period is mainly driven by data availability and reflect our intention to focus on small open economies where financial market are important and fully developed. Testing the robustness of our findings using other interest rate market data and/or sample periods is a logical extension. Second, the empirical framework employed is essentially a static framework, in that we only consider the impact of US monetary policy announcements at FOMC meeting dates. It would be interesting to extend this analysis to a dynamic framework where the effect of the shocks is not only limited to FOMC meeting dates but fully explores the impact of US monetary policy announcements on market interest rates after they occur (see, *inter alia*, Frankel, Schmukler and Servén, 2004) . Third, although the empirical results tell us that the term structure of interest rates in different countries reacts differently to FOMC announcements, our framework does not explain *why* these differences occur. Explaining these findings would require an extension of the existing framework where money market trading activity and interbank liquidity are explicitly incorporated. These issues remain on the agenda for future research.

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Table 1. Preliminary Statistics

	FOMC dates			non-FOMC dates		
k	$\overline{\Delta R}$	$\sigma_{\Delta R}$	$\text{cov}(\Delta R_i, \Delta R_{fut})$	$\overline{\Delta R}$	$\sigma_{\Delta R}$	$\text{cov}(\Delta R_i, \Delta R_{fut})$
			US			
futures	-0.693	4.681	—	-0.497	3.011	—
3-month	-1.080	6.188	18.123	0.782	3.805	5.909
1-year	-0.414	5.571	21.922	0.080	4.787	12.402
5-year	-0.110	6.790	19.970	-0.782	5.479	12.221
10-year	-0.105	6.333	15.201	-0.732	5.032	10.581
			Hong Kong			
futures	-4.106	18.305	—	-4.931	13.790	—
3-month	-3.600	17.988	219.396	-3.879	14.319	75.750
1-year	-2.983	15.393	218.389	-3.466	12.901	93.929
5-year	-0.890	8.464	50.387	-1.278	8.496	35.414
10-year	-0.739	8.217	36.558	-0.934	8.111	32.289
			Singapore			
futures	-0.829	4.686	—	-0.476	2.796	—
3-month	-0.467	4.521	8.280	-0.594	4.093	6.444
1-year	-0.808	3.908	7.057	-0.219	3.032	11.581
5-year	-0.353	5.067	9.090	-1.288	5.941	10.905
10-year	-0.228	5.711	8.509	-1.064	5.491	8.161

Notes: The table reports descriptive statistics on daily changes in the futures rates and in the term structure of interest rates. The source, sample period and characteristics of the securities employed are explained in the data section of the paper. $\overline{\Delta R}, \sigma_{\Delta R}$ and cov $(\Delta R_i, \Delta R_{fut})$ denote averages, standard deviations and covariances with the futures rates changes of the term structure of interest rates over the sample period. Figures reported are expressed in basis points.

Table 2. 1-day response of interest rates to US monetary policy announcements

Panel A. Without correction for endogeneity and omitted variables

k	β_{0k}		β_{1k}		$\overline{R^2}$	SE	DW
			US				
3-month	-0.627	(0.32)	1.051	(0.06)	0.50	5.03	2.27
1-year	0.062	(0.20)	0.989	(0.04)	0.68	3.29	2.25
5-year	0.324	(0.36)	0.757	(0.07)	0.29	5.71	1.86
10-year	0.164	(0.36)	0.519	(0.07)	0.16	5.77	1.82
			Hong Kong				
3-month	-1.247	(0.86)	0.602	(0.03)	0.55	13.36	1.91
1-year	-0.651	(0.64)	0.597	(0.02)	0.69	9.94	1.97
5-year	-0.390	(0.51)	0.153	(0.02)	0.19	7.95	1.95
10-year	-0.404	(0.51)	0.113	(0.02)	0.11	7.92	1.91
			Singapore				
3-month	-0.152	(0.32)	0.379	(0.06)	0.15	4.16	1.83
1-year	-0.540	(0.29)	0.323	(0.05)	0.15	3.61	1.79
5-year	-0.007	(0.36)	0.416	(0.07)	0.14	4.69	1.76
10-year	0.095	(0.42)	0.389	(0.08)	0.10	5.42	1.86

Panel B. With correction for endogeneity and omitted variables

k	β_{0k}		β_{1k}		$\overline{R^2}$	SE	DW
			US				
3-month	-0.225	(0.27)	1.120	(0.06)	0.48	4.81	2.24
1-year	0.018	(0.18)	0.890	(0.04)	0.66	3.31	2.15
5-year	-0.059	(0.32)	0.595	(0.08)	0.28	5.63	1.89
10-year	-0.162	(0.32)	0.360	(0.08)	0.15	5.66	1.85
			Hong Kong				
3-month	-1.020	(0.77)	0.636	(0.03)	0.50	13.33	1.81
1-year	-0.546	(0.59)	0.614	(0.02)	0.64	10.09	2.15
5-year	-0.474	(0.47)	0.142	(0.02)	0.16	8.14	2.04
10-year	-0.467	(0.46)	0.099	(0.02)	0.09	8.02	1.97
			Singapore				
3-month	-0.074	(0.30)	0.374	(0.09)	0.14	4.30	1.83
1-year	-0.395	(0.25)	0.318	(0.07)	0.14	3.61	1.82
5-year	-0.141	(0.32)	0.394	(0.09)	0.15	4.50	1.81
10-year	-0.014	(0.36)	0.396	(0.10)	0.10	5.09	1.92

Notes: The table reports the estimate of equation (4) in the text. Figures reported in Panel A are OLS estimates while figures reported in Panel B are estimates obtained by using Rigobon and Sack's (2004) heteroskedasticity based estimator. $\overline{R^2}$ denotes the adjusted coefficient of determination, SE is the standard error of the estimated regression and DW is the Durbin-Watson statistics. Values in parentheses are asymptotic standard errors. Interest rate changes used in the estimation are expressed in basis points.

Table 3. Annualized average interest rate futures excess returns

n	1	2	3	4	5	6	7	8
				US				
average	23.81	49.83	83.11	120.90	128.57	131.86	131.60	129.21
	(2.65)	(4.82)	(7.22)	(9.67)	(9.53)	(9.29)	(8.90)	(8.35)
p-value	0	0	0	0	0	0	0	0
$\overline{R^2}$	0.26	0.33	0.34	0.34	0.30	0.32	0.32	0.32
				Hong Kong				
average	40.31	95.68	157.67	217.27	220.80	224.03	224.70	223.23
	(3.99)	(4.96)	(5.85)	(7.40)	(7.12)	(6.61)	(5.89)	(5.06)
p-value	0	0	0	0	0	0	0	0
$\overline{R^2}$	0.11	0.17	0.19	0.18	0.13	0.10	0.11	0.19
				Singapore				
average	38.34	65.09	95.60	128.28	132.75	133.17	131.25	127.12
	(2.87)	(3.36)	(3.75)	(4.64)	(4.35)	(3.99)	(3.83)	(4.03)
p-value	0	0	0	0	0	0	0	0
$\overline{R^2}$	0.12	0.17	0.26	0.29	0.39	0.48	0.46	0.41

Notes: The table reports statistics of realized excess returns in the interest rate futures markets measured over the sample period indicated in the data section of the paper. Average denotes estimates of annualized average futures excess returns calculated as the intercept $\delta_0^{(n)}$ of the auxiliary regression $rx_{t+n}^{(n)} = \delta_0^{(n)} +$ error, where $rx_{t+n}^{(n)}$ is the realized excess return to the buyer of futures contract with maturity n . $\overline{R}^2$ and p-value denotes adjusted coefficients of determination and the p-values of the null hypothesis that all coefficients in the auxiliary predictive regression $rx_{t+n}^{(n)} = \delta_0^{(n)} + \delta_1^{(n)} X_t +$ *error* are equal to zero. X_t are interest rate term spreads calculated as in Piazzesi and Swanson (2004). Values in parentheses are heteroskedasticity and autocorrelation consistent standard errors (Newey and West, 1987). 0 denotes p-values lower than 10^{-5}.

Table 4. Correction for risk premia in the futures markets

k	β_{0k}		β_{1k}		$\overline{R^2}$	SE	DW
			US				
3-month	-0.559	(0.32)	1.047	(0.06)	0.50	5.03	2.27
1-year	0.126	(0.21)	0.987	(0.04)	0.68	3.29	2.25
5-year	0.373	(0.36)	0.755	(0.07)	0.29	5.71	1.86
10-year	0.198	(0.36)	0.517	(0.07)	0.16	5.77	1.82
			Hong Kong				
3-month	-1.151	(0.86)	0.601	(0.03)	0.55	13.35	1.92
1-year	-0.558	(0.64)	0.597	(0.02)	0.68	9.94	1.98
5-year	-0.365	(0.51)	0.153	(0.02)	0.18	7.94	1.95
10-year	-0.386	(0.51)	0.113	(0.02)	0.11	7.92	1.91
			Singapore				
3-month	-0.111	(0.32)	0.379	(0.06)	0.15	4.16	1.83
1-year	-0.505	(0.28)	0.323	(0.05)	0.15	3.61	1.79
5-year	0.036	(0.37)	0.416	(0.07)	0.14	4.69	1.76
10-year	0.137	(0.42)	0.389	(0.08)	0.10	5.42	1.86

Notes: This table reports estimates of equation (4) in the text where interest futures rates have been corrected for risk premia in the futures markets as in Piazzesi and Swanson (2004). See notes to Table 2.

Table 5. 1-day response of interest rates to classified policy announcements

k	β_{0k}		β_{1k}^{NI}		β_{1k}^{P}		$\overline{R^2}$	SE	DW
				US					
3-month	-1.019	(0.68)	1.182	(0.09)	0.779	(0.24)	0.62	6.29	2.13
1-year	-0.298	(0.45)	0.979	(0.06)	0.670	(0.16)	0.72	4.18	2.22
5-year	-0.421	(0.71)	0.615	(0.10)	0.351	(0.25)	0.29	6.57	1.93
10-year	-0.697	(0.72)	0.388	(0.10)	0.094	(0.26)	0.13	6.68	1.90
				Hong Kong					
3-month	-1.211	(1.13)	0.703	(0.05)	0.451	(0.28)	0.55	7.10	2.01
1-year	-0.882	(0.97)	0.649	(0.06)	0.392	(0.31)	0.57	6.26	2.13
5-year	0.210	(0.94)	0.397	(0.08)	0.211	(0.85)	0.28	6.96	2.15
10-year	-0.154	(1.05)	0.324	(0.10)	0.209	(0.71)	0.18	7.50	2.21
				Singapore					
3-month	0.216	(0.86)	0.721	(0.12)	0.042	(0.25)	0.38	4.57	1.84
1-year	-0.362	(0.84)	0.606	(0.14)	-0.014	(0.21)	0.33	4.30	1.92
5-year	-0.308	(0.55)	0.320	(0.14)	0.229	(0.29)	0.25	3.12	1.91
10-year	0.019	(1.46)	0.303	(0.12)	0.165	(0.90)	0.13	5.01	1.95

Notes: The table reports the estimate of equation (11) in the text. The classification of US Monetary policy announcements in reaction to new information (NI) and changes in policy preferences (P) over the sample period is carried out according to Ellingsen, Söderström and Massenz (2004). The coefficients β_1^{NI} and β_1^{P} measure the responses of the k-maturity interest rates to announcements classified as due to new information about the state of the US economy changes in the Fed policy preferences respectively. See notes to Table 2.

Figure 1. Interest Rate Reaction

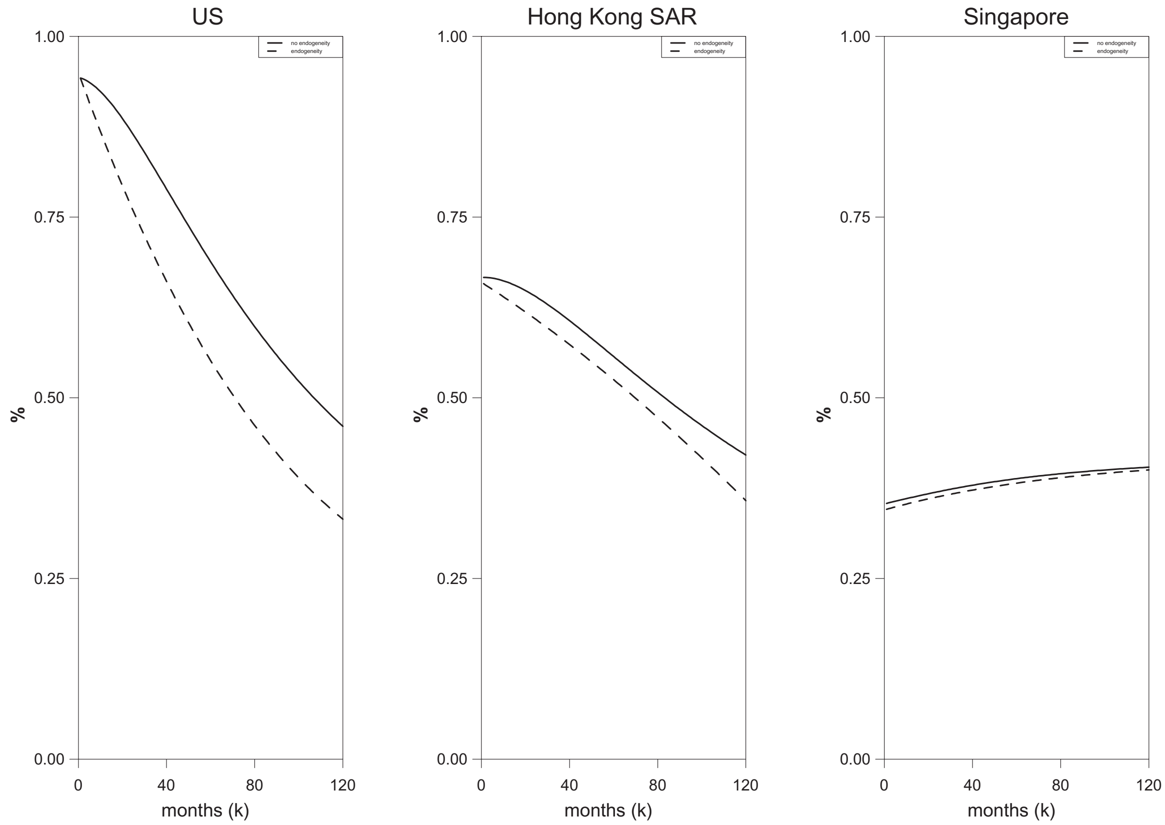


Figure 2. Reaction to Classified FOMC Announcements

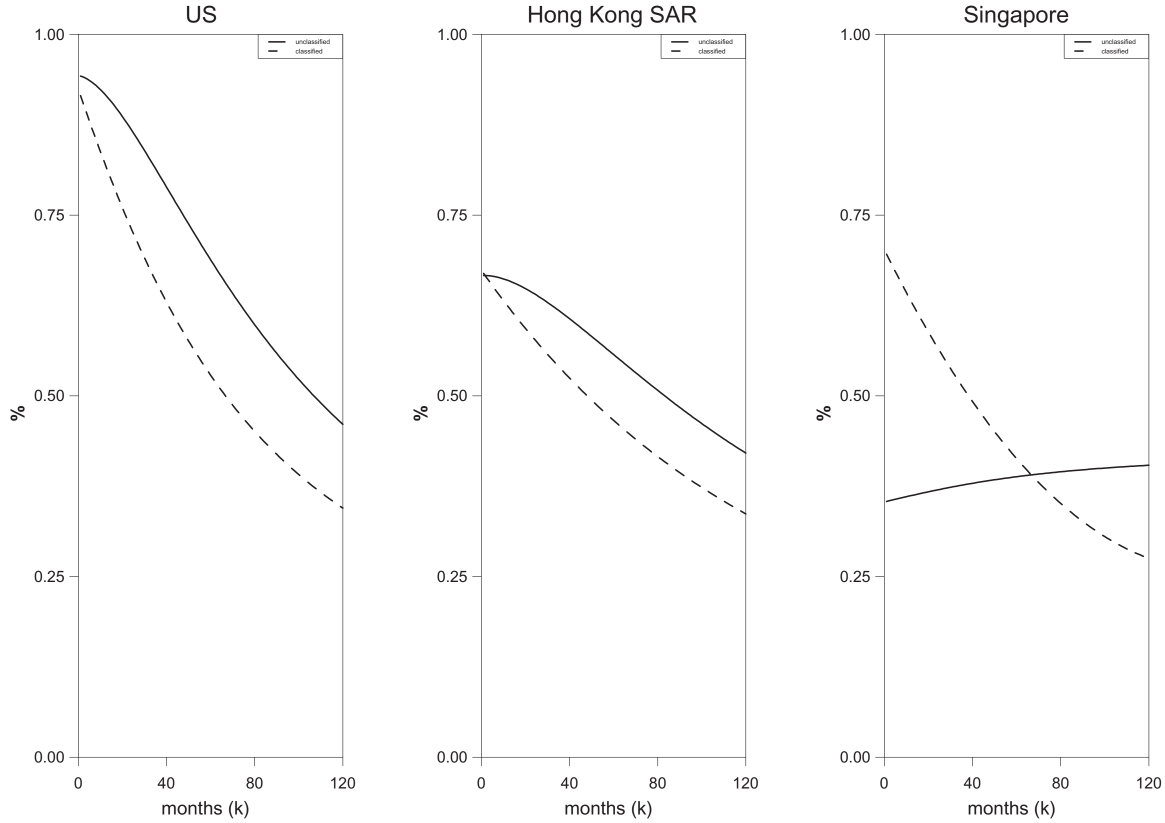
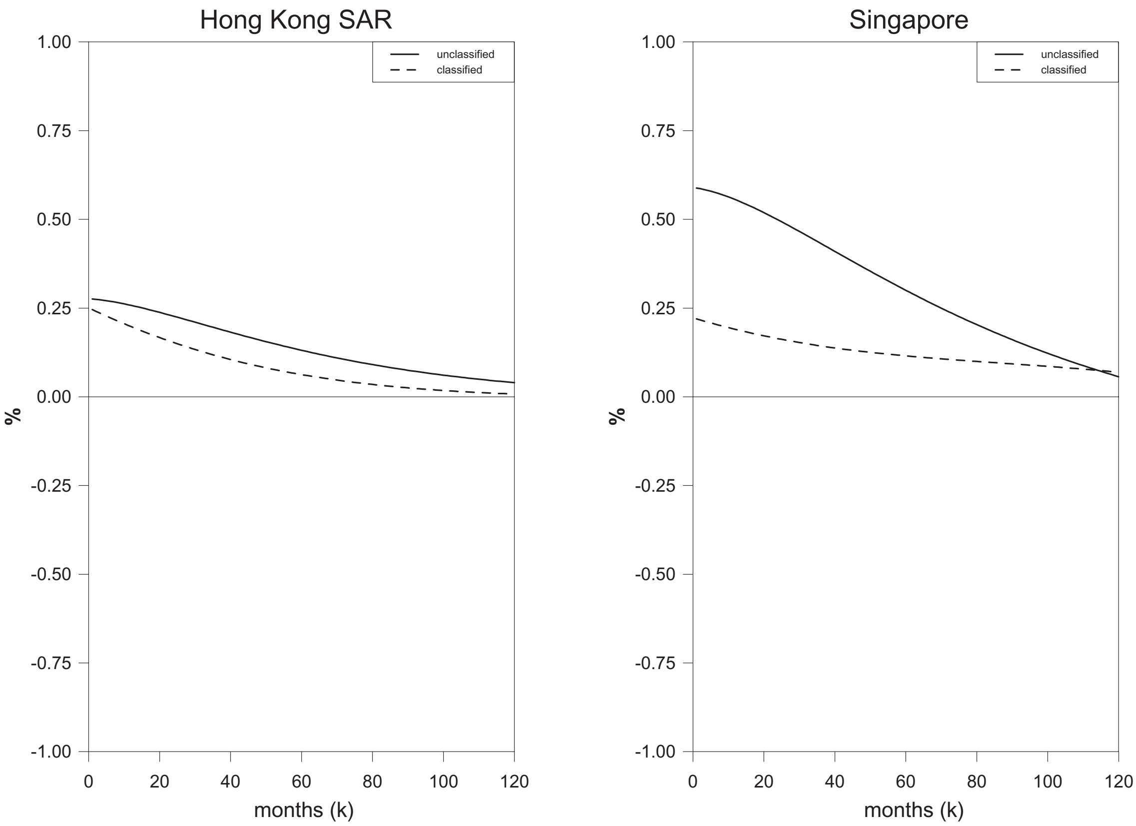


Figure 3. The Response of Interest Rate Differentials



Appendix A: The Correction for Interest Rate Endogeneity and Omitted Variable Problems

The empirical framework summarized in equation (4) can be seen as part of a more general system of equations where both monetary policy shocks and interest rates are explicitly modelled:

$$\Delta f_t^{(1)} = \zeta_0 + \zeta_1 \Delta r_{t,k} + \zeta_2 z_t + \eta_t \tag{A1}$$

$$\Delta r_{t,k} = \beta_{0k} + \beta_{1k} \Delta f_t^{(1)} + z_t + \epsilon_t \tag{A2}$$

where z_t is an unobservable variable comprised in the monetary policy reaction function. As is well known equations (A1) cannot be estimated consistently using OLS due to the presence of simultaneous equations and omitted variables. Rigobon and Sack (2004, p. 1556) show that the OLS estimate of β_{1k} is biased because the shock term ϵ_t is correlated with the regressor $\Delta f_t^{(1)}$ as a result of the response of the monetary policy rate to market interest rates as determined by parameter ζ_1. Further, if some relevant variables are not incorporated, then this would also generate some bias depending on the value of ζ_2.

Rigobon and Sack (2004) address these problems by developing a new estimator based upon the heteroskedasticity of the unanticipated monetary policy shocks. In particular under the assumption that the variance of these shocks is higher during FOMC meeting dates than on other days, the authors show that the estimator for the parameter β_{1k} in equation (A2) can be derived as follows: define $\Delta x_t = \left[\Delta f_t^{(1)} \Delta r_{t,k}\right]'$ as a $T \times 2$ vector of variables comprising unanticipated monetary policy shocks and the k-period bond yield changes. Also define d_t^{FOMC} ($d_t^{NFOMC} = 1 - d_t^{FOMC}$) as a dummy variable which is equal to 1 when t is (is not) an FOMC meeting date. The sample estimate of shift in the covariance matrix of residuals $\Delta\widehat{\Omega}$ is equal to

$$\Delta\widehat{\Omega} = \widehat{\Omega}^{FOMC} - \widehat{\Omega}^{NFOMC} \tag{A3}$$

where $\widehat{\Omega}^{FOMC} = \frac{1}{T_{FOMC}} \sum_{t=1}^{T} d_t^{FOMC} \Delta x_t \Delta x_t'$ and $\widehat{\Omega}^{NFOMC} = \frac{1}{T_{NFOMC}} \sum_{t=1}^{T} d_t^{NFOMC} \Delta x_t \Delta x_t'$. The responsiveness of market rates to shocks in expectations due to unanticipated monetary policy actions, β_{1k}, can be estimated as:

$$\begin{aligned} \widehat{\beta}_{1k}^{\Delta r} &= \frac{\Delta\widehat{\Omega}_{12}}{\Delta\widehat{\Omega}_{11}} \\ \widehat{\beta}_{1k}^{\Delta f} &= \frac{\Delta\widehat{\Omega}_{22}}{\Delta\widehat{\Omega}_{12}} \end{aligned} \tag{A4}$$

where $\Delta\widehat{\Omega}_{ij}$ represents the (i, j) entry in the matrix $\Delta\widehat{\Omega}_{ij}$ and $\widehat{\beta}_{1k}^{\Delta r} = \widehat{\beta}_{1k}^{\Delta f}$ are asymptotically equivalent if all the assumptions regarding the heteroskedasticity of the monetary policy shocks and parameter stability were to hold perfectly. Further, Rigobon and Sack (2004) also show that the estimators (A4) can be practically implemented by using an instrumental variable (IV) estimation technique applied to the following equation:

$$\Delta r^{IV} = \beta_{0k} + \beta_{1k}\Delta f^{IV} + \xi_t \tag{A5}$$

where $\Delta r^{IV} = \left[\Delta r_{t,k}^{FOMC\prime} \Delta r_{t,k}^{NFOMC\prime}\right]$, $\Delta f^{IV} = \left[\Delta f_t^{(1),FOMC\prime} \Delta f_t^{(1),NFOMC\prime}\right]$ are vectors of variables with dimension $(T_{FOMC} + T_{NFOMC}) \times 1$. The relative $(T_{FOMC} + T_{NFOMC}) \times 1$ vectors of instruments are given by $\omega_{\Delta f} = \left[\Delta f_t^{(1),FOMC\prime} - \Delta f_t^{(1),NFOMC\prime}\right]'$ and $\omega_{\Delta r} = \left[\Delta r_{t,k}^{FOMC\prime} - \Delta r_{t,k}^{NFOMC\prime}\right]'$.