Foreign Exchange Intervention When Interest Rates Are Zero: Does the Portfolio Balance Channel Matter After All?

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Rasmus Fatum*

School of Business

University of Alberta

Abstract: This paper provides an empirical investigation of transmission channels of central bank foreign exchange intervention. The main part of our investigation focuses on daily interventions in the JPY/USD market during the 1999 to 2004 Japanese zero-interest rate period. Our research strategy is to formulate empirically testable hypotheses that follow from necessary conditions associated with the intervention transmission channels. These hypotheses compare the exchange rate effects of detected versus undetected interventions. We test these hypotheses in a GARCH time-series framework. Our results suggest that intervention when interest rates are zero works through the portfolio-balance channel alone and that the associated economic effects are very substantial. These findings challenge the notion that intervention is effective primarily via the signaling channel and portfolio-balance effects are unimportant.

Key words: Zero Interest Rates; Foreign Exchange Market Intervention; Channels of Transmission.

JEL Classifications: E52, F31, G14.

* 4-30H Business Building, University of Alberta, Edmonton AB, T6G 2R6 Canada. Telephone: 1-780-492-3951, fax: 1-780-492-3325, email: rasmus.fatum@business.ualberta.ca

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1. Introduction

This paper provides an empirical investigation of transmission channels of central bank foreign exchange intervention. The focus is on transmission channels of sterilized intervention when interest rates are at the lower bound and traditional monetary policy options are constrained.[1] Interventions in the JPY/USD market during the 1999 to 2004 Japanese zero-interest rate period facilitate our investigation. To assess whether intervention works differently across different economic conditions, we also examine transmission channels of JPY/USD interventions over the 1991 to 1998 period when interest rates were above zero.

The Japanese experience of domestic currency sales with interest rates at the lower bound can provide important lessons regarding the effectiveness and the transmission channels of intervention for countries that are currently pursuing, or considering pursuing, policies of active exchange rate management in a macroeconomic environment where traditional monetary policy options are constrained.[2] Previous studies have established that interventions in the JPY/USD exchange rate market during the zero-interest period were, on average, effective in influencing daily exchange rate movements (Fatum and Hutchison 2010, Ito 2005, and Iwata and Wu forthcoming).[3] No previous study, however, provides a comprehensive assessment of the four transmission channels of sterilized intervention (the signaling channel, the portfolio balance channel, the noise-trading channel, and the coordination channel, all of which are summarized in

[1] In a zero-interest rate environment where domestic bonds and domestic money are perfect substitutes, all interventions are, for all practical purposes, sterilized (Christiano 2000).

[2] After more than six years of no intervention in the JPY/USD market, Japan has in the past year intervened on at least three separate occasions to stem the rise of the JPY (on 15 September 2010, 18 March 2011, and 3 August 2011; the first two of these interventions are described in Fawley and Juvenal 2010, and Neely 2011, respectively). Other developed countries such as Israel and Switzerland have recently resumed very active intervention policies aimed at depressing the value of their respective currencies. All these recent interventions occur in a macroeconomic environment of constrained monetary policy options and low or zero interest rates, an environment comparable to that of the Japanese zero-interest rate period under study.

[3] Humpage (2003), Neely (2005), and Sarno and Taylor (2001) provide surveys of the intervention literature.

the next section of the paper) through which effective intervention during the Japanese zero-interest rate period might work.[4]

Our contribution is to propose a new research strategy that considers all four transmission channels in one and the same empirical time-series modeling framework. Our starting point is to develop empirically testable hypotheses that follow from the necessary conditions associated with the intervention transmission channels. These hypotheses compare the exchange rate effects of detected versus undetected interventions. To test these hypotheses we follow the already established methodology for identification of detected and undetected interventions (Beine and Bernal 2007, Beine and Lecourt 2004, Kim and Le 2010, and Marsh 2011).[5]

A necessary condition for the functioning of the signaling and the coordination channel is that intervention is detected by the market. Consequently, if at least one of these two channels is at work, detected intervention will exert a stronger influence on the exchange rate than undetected intervention. If not, the effects of intervention cannot be explained by the signaling or the coordination channel.[6] This is the first testable hypothesis. By contrast, portfolio-balance effects are not contingent on whether or not interventions are detected by the market, but on imperfect substitutability between foreign and domestic assets.[7] Therefore, when interventions

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[4] Existing studies of intervention transmission channels analyze either a particular transmission channel or a sub-set of the four transmission channels identified by the intervention literature. Dominguez and Frankel (1993a), Evans and Lyons (2001) and Kumhoff (2010) consider portfolio-balance effects; Fatum and Hutchison (1999), Ghosh (1992), and Lewis (1995) investigate the signaling channel; Dominguez and Frankel (1993b) and Iwata and Wu (forthcoming) compare signaling and portfolio-balance effects; Fatum, Reitz and Ruelke (2009) and Reitz and Taylor (2008) test the coordination channel hypothesis; Hung (1997) assesses the noise-trading channel.

[5] This literature identifies a detected intervention as one that occurs on a day when there is a rumor of intervention on the newswire. Detected intervention is sometimes referred to as "public intervention", while undetected intervention is sometimes referred to as "secret intervention".

[6] Note that we cannot a-priori dismiss the signaling channel even if interventions occur when interest rates are zero. While the intervention sales of domestic currency cannot credibly signal a future interest rate decrease when interest are already at the lower bound, interventions can potentially signal information regarding the duration of the zero-interest rate period or regarding further quantitative easing. See Oda and Ueda (2007) for a study of the market perception of Bank of Japan's willingness to continue its zero-interest rate policy.

[7] Evans and Lyons (2003) provide empirical evidence of imperfect substitutability between foreign and domestic assets.

are effective through the portfolio-balance channel, detected and undetected intervention will exert the same influence on the exchange rate. If detected and undetected interventions affect the exchange rate differently, it follows that portfolio-balance effects alone cannot account for the effects of intervention. This is the second testable hypothesis. In order for the noise-trading channel to function, intervention must be undetected, and undetected intervention must be associated with an increase in exchange rate volatility. Consequently, if intervention is effective through the noise-trading channel, undetected intervention is associated with a stronger influence on the exchange rate than detected intervention, and undetected intervention increases exchange rate volatility. If not, the effects of intervention cannot be explained by the noise-trading channel. This is the third testable hypothesis. Rejection of a null hypothesis in favor of an alternative hypothesis will allow us to rule out that a particular channel is at work (or rule out that a particular channel is the only channel at work).

An advantage of our research strategy is that all four transmission channels are considered at once using publicly available data and an identification strategy for distinguishing between detected and undetected interventions that has already been established by the intervention literature (Bernal and Beine 2007 and others). A limitation of our approach is that it does not provide direct evidence in favor of a given channel that is not ruled out (since acceptance of a given hypothesis is a necessary but not sufficient condition for the functioning of a given transmission channel).[8]

To test the transmission channel hypotheses, the analysis employs a GARCH time-series framework that distinguishes between the effects of detected and undetected intervention, and explicitly includes undetected intervention in the volatility expression. We find that during the

[8] Another limitation is that the first hypothesis does not allow for a distinction between signaling channel and coordination channel effects.

zero-interest rate period, the effects of detected and undetected interventions are indistinguishable, and undetected intervention does not increase same-day exchange rate volatility. Consequently, the first and the third transmission channel hypothesis are rejected while we cannot reject the second hypothesis, i.e. we reject that intervention during the zero-interest rate period works through the signaling, the coordination, or the noise-trading channel, while we cannot reject that intervention works through the portfolio-balance channel. In other words, our results thus suggest that the effects of the Japanese interventions during the zero-interest rate period are consistent only with the workings of the portfolio balance channel. Our results also show that while the estimated portfolio-balance effects of intervention are in and of themselves fairly small, their economic importance when taking into account the large Japanese intervention volumes is very substantial. These findings challenge the notion that intervention is effective primarily through the signaling channel and portfolio-balance effects are unimportant.

The analysis of the 1991-1998 comparison period of above zero Japanese interest rates reveals additional insights. Contrary to the zero-interest rate period results, our findings show that effective interventions are associated with a significantly stronger exchange rate influence when interventions are detected. Therefore, we can no longer reject that effective intervention works through signaling or coordination channels. Instead, for this period we reject that effective intervention works through the portfolio-balance alone and we, again, reject that effective intervention works through the noise-trading channel. These results imply that the economic environment influences through which transmission channel effective intervention works and, moreover, that the relative effectiveness of intervention varies with the transmission channel through which it works.

The rest of the paper is organized as follows. Section 2 provides a summary of the four transmission channels. Section 3 details the data. Section 4 presents the empirical model. Section 5 discusses the empirical results. Section 6 presents the robustness checks. Section 7 concludes.

2. Transmission Channels

As noted earlier, the intervention literature has identified the signaling channel, the portfolio balance channel, the noise-trading channel, and the coordination channel as possible transmission channels through which sterilized intervention might work.

The idea of the signaling channel hypothesis is that by carrying out intervention the central bank informs the market, or sends a signal, about its future monetary policy intentions. Assuming that financial markets are forward-looking and monetary policy is a foreign exchange rate determinant, information about future monetary policy can then influence current exchange rates. In order for intervention to send a signal, and thus for the functioning of the signaling channel, intervention must be detected by the market. As a result, if intervention works through signaling, the effects of detected interventions are stronger than those of undetected interventions.

The portfolio balance channel relies on foreign and domestic assets (bonds) being imperfect substitutes in which case the intervention induced change in the relative supplies of these assets is accompanied by a corresponding change in relative asset returns in order for investors to be willing to hold both foreign and domestic assets. The portfolio balance channel then suggests that the change in relative asset returns, in the absence of changes in relative nominal interest rates, is generated by an adjustment of the current exchange rate. Since the portfolio-balance channel does not require market detection in order for interventions to be effective, the portfolio-balance effects of detected and undetected interventions are indistinguishable.

The coordination channel pertains to a situation of substantial exchange rate misalignment and coordination failure to the extent that individual market participants are hesitant to risk betting on a reversal of the exchange rate towards its equilibrium. In such a situation the coordination channel proposes that detected or publicly announced intervention can take on a coordinating role that organizes fundamentalist traders to enter the market at the same time, thereby causing the exchange rate to adjust. In order for intervention to send a coordinating signal, and thus for the functioning of the coordination channel, intervention must be detected by the market. As a result, if intervention works through the coordination channel, the effects of detected interventions are stronger than those of undetected interventions.

According to the noise-trading channel monetary authorities intervening against fundamentals to reverse the direction of an exchange rate moving with strong momentum must intervene secretly to achieve an increase in short-term exchange rate volatility in order to manipulate non-fundamentalist traders (i.e. noise-traders, or chartists) to second-guess the strength and duration of the (from the perspective of the monetary authorities) undesirable exchange rate trend. Consequently, if intervention works through the noise-trading channel, the effects of undetected interventions are stronger than those of detected interventions, and undetected interventions increase exchange rate volatility.

For in-depth expositions of the transmission channels see Dominguez and Frankel (1993b) and Edison (1993) regarding the signaling and the portfolio-balance channel, Sarno and Taylor (2001) regarding the coordination channel, and Hung (1997) regarding the noise-trading channel. See Neely (2011) and Sarno and Taylor (2001) for discussions of the relative importance of the transmission channels.

3. Data

The Japanese zero-interest rate intervention period began in January 1999 when money market rates effectively hit the lower bound (see Figure 1) and the Japanese monetary authorities, i.e. the Bank of Japan acting as the agent for the Japanese Ministry of Finance, entered an intervention regime that lasted a little more than five years.[9] During this regime Japan sold a total of almost USD 0.5 trillion worth of JPY against purchases of USD, roughly equivalent to 10% of Japan's yearly GDP. All the interventions in the JPY/USD market during the zero-interest rate period were unilateral Japanese sales of JPY. [10]

The official Japanese intervention data consist of daily volumes of intervention operations in the JPY/USD foreign exchange market.[11] Table 1 shows intervention data summary statistics for the zero-interest rate period and its sub-samples. The table shows that Japan intervened in the JPY/USD exchange rate market on a total of 159 days between January 1999 and March 2004. The average daily intervention amount relative to average daily market turnover is 1.3% across the entire zero-interest rate period.

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[9] As Figure 1 shows, the Japanese money market rates were temporarily raised in 2000 and remained above zero through the early part of 2001. No intervention in the JPY/USD market, however, occurred during this period.

[10] Ito (2005) describes the Japanese institutional framework for intervention. Watanabe and Yabu (2007) report that since the end of 2001 only about 60% of Japanese interventions are immediately sterilized. Consistent with the aforementioned assertion of Christiano (2000), Iwata and Wu (forthcoming) find that Japanese interventions when interest rates are close to zero are, for all practical purposes, sterilized.

[11] Ito (2005) argues that a new intervention policy regime began on 14 January 2003 when Mr. Mizoguchi replaced Mr. Kuroda as Vice Minister for International Affairs at the Japanese Ministry of Finance. Fatum and Hutchison (2010) find that a noticeable increase in intervention frequency towards the end of 2003 constitutes another intervention regime change. They use formal breakpoint tests to confirm both the January 2003 and the December 2003 breakpoints. We carry out the analysis of the zero-interest rate intervention period on the full sample as well as separately across the sub-samples.

The Factiva search engine and a comprehensive combination of various English language search words (e.g. Bank of Japan, intervention etc.) are used to find the days with a rumor of intervention. The second row of Table 2 shows that a total of 269 days across the zero-interest rate period are associated with a rumor of intervention. Row three of Table 2 reports that 92 of the rumor days are also intervention days, i.e. 92 of the 159 interventions are detected. Row four shows that, accordingly, the remaining 67 of the 159 interventions are undetected.[12]

Factiva is also used to find newswire reports of official statements in support of intervention and/or a weaker JPY (denoted "positive statements"), and newswire reports of official statements suggesting that further intervention in the JPY/USD rate is not recommended or unlikely (denoted "negative statements"). Rows six and seven of Table 2, respectively, report a total of 108 positive and 17 negative statements for this period.[13]

The analysis follows Ito (2003) and others in using New York close quotes of the daily JPY/USD spot market exchange rate. The exchange rate data are obtained from Global Financial Data (GFD).

A comprehensive list of macro news control variables capture the surprise component of Japanese news regarding CPI, GDP, Industrial Production, Trade Balance, Unemployment and the surprise component of US news regarding CPI, GDP, Industrial Production, Trade Balance, (Non-Farm Payroll) Employment, and Monetary Policy. For each of these macro news control variables, the surprise measure is the difference between official announcements and results of surveys of expectations of these announcements conducted by Bloomberg during the days

[12] A total of 177 days are associated with false rumors of intervention (row five of Table 2). For comparison, Chang (2006) reports a total of 181 false rumors of Japanese intervention over the January 2000 to March 2003 time period using JiJi News (local Japanese newswire) and Wall Street Journal reports of rumors and speculation.

[13] Factiva is also gleaned for firm reports of intervention. For the 1999 to 2004 period a total of 31 reports of intervention are found (row eight of Table 2). For comparison, Chang (2006) finds 27 reports of intervention over the January 2000 to March 2003 period.

preceding the announcements. The official value of a news variable is announced once a month, or at a lower frequency. The news control variables capture the associated surprise element on announcement dates, thus these variables are non-zero only on announcement dates and only when the announcement differs from market expectations.

Summary statistics for the JPY/USD exchange rate and the macro news surprises pertaining to the zero-interest rate period are displayed in Table 3.

Table 4 provides summary statistics regarding intervention and rumors of intervention for the April 1991 to December 1998 comparison period. Exchange rate and macro news statistics for the comparison period are available from the author upon request.[14]

4. Empirical Analysis

The empirical analysis follows Baillie and Bollerslev (1989) in estimating a regression equation with residuals modeled as a GARCH process. The empirical relationship of the baseline analysis is given by the GARCH(p,q) specification:

$$(1) \qquad \Delta s_t = a + b_1 \Delta s_{t-1} + b_2 INT_t + b_3 INT_t^{DETECTED} + b_4 INT_t^{JAN03} + b_5 INT_t^{DEC03} + CZ_t + \varepsilon_t$$

$$(2) \qquad \varepsilon_t \sim N(0, h_t)$$

$$(3) \qquad h_t = \alpha_0 + \sum_{j=1}^{q} \alpha_j \varepsilon^2{}_{t-j} + \sum_{j=1}^{p} \beta_j h_{t-j} + \gamma INT_t^{UNDETECTED}$$

[14] The full 1991 to 2004 sample encompasses a total of 344 daily interventions of which 138, or 40%, were undetected (67 during 1999 to 2004, and 71 during 1991 to 1998, as reported in tables 2 and 4, respectively). It is reassuring that this ratio is very consistent with those reported by Beine and Bernal (2007) and Kim and Le (2010). The former (latter) study reports that approximately 39% (36%) of all 1991 to 2004 interventions went undetected.

where a is a constant; Δs_t is the first-difference in the log of the spot JPY/USD exchange rate; INT_t is official intervention (millions of USD); $INT_t^{DETECTED}$ is an interaction variable ("slope shifter") containing detected intervention (millions of USD); INT_t^{JAN03} is an interaction variable containing interventions (millions of USD) carried out between 14 January 2003 and 25 December 2003; INT_t^{DEC03} is an interaction variable containing interventions (millions of USD) carried out between 26 December 2003 and 31 March 2004; C is the coefficient vector associated with the control variables contained in Z_t. The control variable matrix Z_t contains the surprise component of Japanese news regarding CPI (JPCPI), GDP (JPGDP), Industrial Production (JPIP), Trade Balance (JPTB), Unemployment (JPUNEMP), and the surprise component of US news regarding CPI (USCPI), GDP (USGDP), Industrial Production (USIP), Trade Balance (USTB), Employment (USNFPR), and Monetary Policy (USFOMC).[15]

Equation (2) states that the error term is normally distributed with zero mean and time-dependant (conditional) variance h_t. Equation (3) shows that the variance depends on the squared error of the past q periods (the ARCH terms), the conditional variance of the past p periods, and undetected intervention $INT_t^{UNDETECTED}$ (millions of USD).

The estimation strategy follows Fatum and Hutchison (1999) and others. First, simultaneous estimations of equations (1) through (3) are carried out across the full sample. Next, insignificant variables are dropped one variable at a time, starting with the most insignificant variable, and the full sample model re-estimated until only significant variables remain. This procedure is repeated separately across sub-samples. For each of the estimations, the most parsimonious GARCH specification possible, that still allows for acceptance of the null

[15] For completeness, we also estimate a specification with additional slope shifter variables included to explicitly allow for the possibility that effects of detected intervention in the conditional mean model and undetected intervention in the volatility model vary across sub-samples. As it turns out, the results are qualitatively identical to those reported in the next section.

hypothesis of no ARCH in the standardized residuals, is selected. As it turns out, GARCH(1,1) models give the better fit in all cases.

5. Results

Table 5 shows the results of the GARCH(1,1) baseline estimations across the full zero-interest rate period. The first column displays the results pertaining to the model with all variables included. The intervention variable INT_t is highly significant (at 99%) and of the correct (positive) sign, confirming that intervention sales of JPY during the zero-interest rate period are, on average, effective and systematically associated with a JPY depreciation. The $INT_t^{DETECTED}$ slope shifter variable is, however, highly insignificant. Insignificance of $INT_t^{DETECTED}$ rejects the signaling and coordination channel hypothesis that detected intervention exerts a stronger influence on the exchange rate than undetected intervention. We cannot reject the portfolio-balance channel hypothesis that the effects of detected and undetected interventions are indistinguishable. We reject the noise-trading channel hypothesis that undetected intervention exerts a stronger influence on the exchange rate than detected intervention. The $INT_t^{UNDETECTED}$ indicator variable in the volatility model is highly insignificant, thereby further rejecting the noise-trading transmission channel hypothesis.

Both sub-sample slope shifter variables, INT_t^{JAN03} and INT_t^{DEC03}, are significant, at 95% and 99%, respectively. Both are negative, implying that the average effect of intervention is smaller from early 2003 and onwards (consistent with Fatum and Hutchison 2010 and Ito 2005). Some significant effects of Japanese macro surprises are detected, while none of the US macro surprise variables is significant.

The second column of Table 5 shows the estimation results with only significant variables included. The coefficient estimates of the significant explanatory variables are practically the same (pair-wise) across the two models and the previously described results are thus repeated.

The conditional variance equation estimates confirm the presence of ARCH effects in the exchange rate time series. The ARCH-F and Q^2 tests indicate that both full sample models are free of any ARCH effects left in the standardized residuals. Moreover, the standard F-test cannot reject the models.

The results of the baseline estimations on sub-samples with only significant variables included are displayed in Table 6.[16] Consistent with the full sample findings, $INT_t^{DETECTED}$ is insignificant in the conditional mean model and $INT_t^{UNDETECTED}$ does not increase the conditional exchange rate volatility, thereby repeating the intervention transmission channel conclusions.

The portfolio-balance effects during the zero-interest rate period are captured by the INT_t coefficient estimate given that no other transmission channel is found to be functioning during this period. The estimates shown in Table 6 range from 1.2E-06 for the first part of the zero-interest rate period to 0.15E-06 (i.e. 0.649E-06 minus 0.496E-06) for the last three months of the zero-interest rate period, corresponding to an exchange rate effect of a USD 100 million intervention operation ranging from a JPY depreciation of 0.012% to a JPY depreciation of 0.0015%, as reported in the second row of Table 7.[17] The third row of Table 7 shows that the exchange rate effect of average daily intervention ranges from a 0.6% depreciation of the JPY during the first 4 years of the zero-interest rate regime when the average daily intervention

[16] The time-period associated with the INT_t^{DEC03} slope shifter variable is too short to facilitate a meaningful separate estimation. Instead, INT_t^{DEC03} is included in the 14 January 2003 to 31 March 2004 sub-sample estimation.
[17] It is reassuring that despite relying on a different estimation technique, these effects are virtually identical to those reported in Ito (2005).

volume was particularly large to a 0.04% depreciation during the last three months of the zero-interest rate intervention period.[18] These calculations suggest that even though the coefficient estimates associated with portfolio-balance effects of intervention are in and of themselves very small, the economic importance implied by the estimates when taking into account the large intervention volumes is very substantial.

To summarize the findings of the baseline estimations, the results corroborate those of other studies in showing that interventions can be effective in influencing the exchange rate level when interest rates are at the lower bound. More importantly, the conditional mean effects of detected and undetected interventions are statistically identical, and undetected intervention is not associated with an increase in exchange rate volatility. Consequently, our results suggest that the Japanese zero-interest rate interventions under study, by elimination of other possible transmission channels, work through the portfolio-balance channel alone. This is a remarkable finding because it counters the generally accepted notion that intervention is effective primarily through the signaling channel and portfolio-balance effects are too small to be important. Our results, instead, suggest that when interest rates are zero and, therefore, intervention sales of domestic currency cannot credibly signal a future interest rate decrease, any signaling effects stemming from the potential ability of intervention to provide information regarding the duration of the zero-interest rate period, or regarding further quantitative easing, are too small to be statistically significant.

[18] The cumulative exchange rate effects of all interventions carried out during the zero-interest rate period are reported in the fifth row of Table 7. The numbers suggest that interventions during the first 4 years of this period depreciated the JPY by 18% and interventions during the last 5 quarters of the period depreciated the JPY by 13%. Again, these exchange rate effects are virtually identical to those reported in Ito (2005). As always, such calculations assume that the effects of intervention on the exchange rate are linear, that the contemporaneous effects are permanent, and no delayed effects occur.

5.1. The 1991 to 1998 Comparison Period

To assess whether intervention works differently when intervention can credibly signal a future interest rate change, we now examine the transmission channels of JPY/USD interventions over the 1991 to 1998 period when interest rates were above zero.[19] During this period the Japanese monetary authorities carried out USD intervention sales as well as USD intervention purchases. With interest rates above zero both intervention sales and intervention purchases can credibly signal a consistent future interest rate change. We estimate the following conditional mean model:

$$(4) \qquad \Delta s_t = a + b_1 \Delta s_{t-1} + b_2 INT_t + b_3 INT_t^{DETECTED} + CZ_t + \varepsilon_t$$

across the full 1991 to 1998 sample and across two sub-samples.[20] Table 8 reports the results of simultaneous estimations of equations (2) through (4). Column 1 shows that intervention was, on average, effective across the full 1991 to 1998 period. Columns 2 and 3 show the sub-sample results. The intervention variable INT_t is insignificant and of the wrong sign in the first sub-sample (consistent with Ito 2003), as is the variable capturing detected intervention, $INT_t^{DETECTED}$. The insignificance of these variables renders an investigation of transmission channels irrelevant for this period. The second sub-sample results are markedly different in that both INT_t and $INT_t^{DETECTED}$ are highly significant and of the correct sign. Significance of the

[19] During this period, the US Federal Reserve intervened in coordination with the Japanese authorities on 22 occasions. Inclusion of the US interventions to the estimated models does not in any way change the results.

[20] Ito (2003) argues that Japanese interventions were not effective until June 1995 when Mr. Sakakibara took office as Vice Minister for International Affairs at the Japanese Ministry of Finance and implemented an intervention policy regime of larger but less frequent interventions. An Andrews (1993) test for unknown breakpoint identifies a structural break at the beginning of April 1996, i.e. roughly 9 months after Mr. Sakakibara took office. Our results are not contingent on whether we use June 1995 or April 1996 as the sub-sample demarcation point.

former variable conforms to the assertion of Ito (2003) that intervention in the JPY/USD market did not become effective until the mid-90s. More importantly, significance of the latter variable implies that the transmission channel hypothesis regarding signaling and coordination channel effects cannot be rejected (the first hypothesis) for this period. Instead, we reject that intervention during this period works through the portfolio-balance channel alone (the second hypothesis) and we reject that the noise-trading channel is at work (the third hypothesis).

Comparing these findings to the zero-interest rate period results suggests that while intervention is effective across both periods, only when intervention can credibly signal a consistent future interest rate change does intervention work through channels other than the portfolio-balance channel. Particularly interesting is the finding that the significant coefficient estimate of the slope-shifter variable $INT_t^{DETECTED}$ during the latter part of the comparison period indicates that when interventions are detected, the relative influence of intervention increase dramatically (i.e. the effect of intervention increases more than ten-fold).

As noted earlier, our methodological approach does not enable us to provide direct evidence in favor of a particular transmission channel and, furthermore, it does not allow us to formally distinguish between signaling and coordination effects. Nevertheless, we know that the functioning of the signaling channel is at least partially affected by whether or not interest rates are zero (since only when interest rates are above zero can a sale of domestic currency credibly signal a future interest rate decrease). By contrast, there is no reason to expect the functioning of the coordination channel to be contingent on whether or not interest rates are zero. The fact that we find detected interventions to be more influential than undetected interventions only when interest rates are above zero, therefore, makes it seem plausible that the significant effects of detected interventions during the latter part of the comparison period are transmitted through the signaling channel rather than through the coordination channel.

6. Robustness

In order to check the robustness of the results we carry out the analysis using a different estimation technique, attempt to address the inherent issue of endogeneity, test for delayed effects, employ a different conditional mean specification, and control for statements and false rumors of intervention.[21]

First, all estimations are carried out using OLS estimations with robust heteroskedasticity- and serial-correlation consistent (HAC) standard errors. All the previously described GARCH estimation results remain completely unchanged across both the 1999 to 2004 zero-interest rate period and the 1991 to 1998 comparison sample. Consequently, the assessment of the transmission channel hypotheses once again rejects all but the presence of portfolio-balance effects for the zero-interest rate period, while the signaling and coordination channel hypothesis cannot be rejected for the 1991 to 1998 comparison period.[22]

Second, to address the issue of endogeneity we follow Humpage (1999) and others in first estimating Japanese intervention reaction functions to capture the expected component of the intervention variable and, subsequently, use the residuals from the reaction function estimations as measures of unexpected interventions (i.e. the expected component of intervention is subtracted from the actual intervention on days when interventions occur).[23] Following Ito

[21] Estimation results pertaining to the robustness checks are available upon request.

[22] The OLS-HAC estimations do not allow for explicit volatility modeling and, therefore, these estimations do not test whether undetected intervention reduces exchange rate volatility (the second part of the third hypothesis).

[23] Although standard in the more recent intervention literature, this procedure is not unproblematic due to, particularly, the estimated regressor concern that arises from using the residuals of the reaction function estimation for re-estimating the conditional mean model. It should also be noted that while the reaction function estimates are free of simultaneity bias due to the exclusion of contemporaneous exchange rate changes as explanatory variables,

(2003) and Ito and Yabu (2007), the explanatory variables included in the intervention reaction functions are Δs_{t-1} (the first lag of first-difference in the log of the spot JPY/USD exchange rate), $TARGET_t$ (the first-difference of the log of the JPY/USD deviation from an exchange rate target of 125 JPY/USD), $MADAY_t$ (the 21-day moving average of the log of the JPY/USD exchange rate), and $MAYEAR_t$ (the one-year moving average of the log of the JPY/USD exchange rate).[24] The reaction function estimations are carried out separately across the 1 April 1991 to 2 April 1996, the 3 April 1996 to 31 December 1998, the 1 January 1999 to 13 January 2003, and the 14 January 2003 to 25 December 2003 period, respectively.[25]

The results of the re-estimation of the models described in Equations (1) through (3) and Equations (2) through (4), respectively, using estimated unexpected intervention in place of actual intervention are qualitatively identical to those pertaining to the baseline analysis that do not attempt to control for endogeneity. Not surprisingly, the size of the coefficient estimates of the conditional mean effect of intervention generally increases, suggesting that controlling for endogeneity reduces downward simultaneity bias in the estimated effect of intervention.[26]

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the cost of avoiding endogeneity is that there is no account for the possibility of within-day exchange rate movements influencing the intervention decision. It is, therefore, quite possible that the estimated reaction function parameters suffer from omitted variable bias.

[24] The variable $TARGET_t$ is included (and significant) in the reaction function estimations displayed in Ito (2003), but not included in Ito and Yabu (2007). Inclusion of this variable, however, is possibly problematic due to a high degree of collinearity with the JPY/USD exchange rate. As it turns out, $TARGET_t$ is insignificant in all the estimations and, therefore, subsequently excluded from the analysis.

[25] While the 26 December 2003 and 31 March 2004 period constitutes a separate intervention regime, this period is too short for a meaningful separate reaction function estimation and thus excluded from the reaction function estimations and the associated re-estimation of the baseline model.

[26] The intervention reaction function models are extended to also include Japanese macro surprises that could influence the decision to intervene. This is done because studies have documented that macro surprises influence day-to-day exchange rate changes and, as argued in Fatum and Hutchison (2010), these surprises can thus be interpreted as proxies for contemporaneous exchange rate movements. As it turns out, (positive) GDP surprises and (positive) CPI surprises help explain intervention, and inclusion of these significant macro surprise variables improve the fit of the reaction function models slightly. Re-estimation of the baseline GARCH models using unexpected intervention derived from the news augmented reaction function models, however, does not change the results.

Third, to account for the possibility of delayed exchange rate effects, Equation (1) of the baseline model is augmented to include five lags of all explanatory intervention variables. None of the lags is significant. The complete absence of delayed effects implies that the previously estimated contemporaneous exchange rate effect of intervention describes the exchange rate response to intervention well.[27]

Fourth, instead of using slope shifter intervention variables to test the transmission channel hypotheses we employ a more traditional approach that simply includes in the conditional mean model two separate explanatory variables containing detected and undetected interventions, respectively (i.e. the previously defined variables $INT^{DETECTED}$ and $INT^{UNDETECTED}$). The GARCH models are re-estimated, and for the zero-interest rate period both variables are highly significant and of the correct (positive) sign. A standard Wald coefficient test cannot reject equality of the two coefficient estimates. While both variables are also significant and of the correct sign during the latter part of the comparison period, the magnitude of the coefficient estimate associated with detected intervention is larger than the coefficient estimate of undetected intervention. A Wald test strongly rejects equality of these two coefficient estimates. These results thus support the same conclusions regarding effectiveness and transmission channels as the baseline analysis.

Fifth, to control for possible effects of false rumors and statements of intervention we augment the conditional mean model to include INT_t^{FALSE} (the indicator variable that takes on the value one only when a rumor of intervention is reported but no actual intervention takes place), $POSSTAT_t$ (the indicator variable that takes on the value one only on a day when there is an official statement in support of intervention and/or a weaker JPY), and $NEGSTAT_t$ (the

[27] For completeness, the lag model was also estimated with lags of undetected intervention included in the volatility expression. None of these lags was significant.

indicator variable that takes on the value one only on a day when there is an official statement suggesting that further intervention in the JPY/USD rate is not recommended or unlikely). All three indicator variables are insignificant during the zero-interest rate period, while $POSSTAT_t$ is (marginally) significant across the latter part of the 1991 to 1998 comparison period. Whether or not any or all three indicator variables are included, the effectiveness and transmission channel results remain unchanged.

7. Conclusion

This paper provides an empirical investigation of transmission channels of central bank foreign exchange intervention. The main part of our investigation focuses on daily interventions in the JPY/USD market during the 1999 to 2004 Japanese zero-interest rate period. Our starting point is to develop empirically testable hypotheses that follow from the necessary conditions associated with the intervention transmission channels. These hypotheses compare the exchange rate effects of detected versus undetected interventions. To test these hypotheses we employ a GARCH modeling framework and follow the already established methodology for identification of detected and undetected interventions.

Our estimation results suggest that detected intervention is no more influential than undetected intervention when interest rates are at the lower bound and, furthermore, undetected intervention is not associated with an increase in exchange rate volatility. These findings allow us to rule out that intervention when interest rates are zero is effective through the signaling or the coordination channel (as effectiveness through either of these channels would imply a significantly stronger effect of detected intervention), and they allow us to rule out that intervention in this macroeconomic environment is effective through the noise-trading channel (as effectiveness through this channel would imply a significantly stronger effect of undetected intervention as well as an increase in exchange rate volatility). By contrast, these findings do not allow us to reject the hypothesis that intervention works through the portfolio-balance channel. Consequently, our results imply that interventions in the JPY/USD market during the Japanese zero-interest rates period were effective through no other channel than the portfolio-balance channel. Our results also show that although the estimated portfolio-balance effects of intervention are in and of themselves fairly small, their economic importance when taking into account the large Japanese intervention volumes is very substantial.

Using the 1991 to 1998 period of daily interventions in the JPY/USD market as a comparison period we show that detected interventions can be much more influential than undetected intervention when interest rates are above zero and intervention in either direction can credibly signal a consistent future interest rate change. This finding implies that effective intervention in this economic environment did not work through the portfolio-balance channel alone and, therefore, that the transmission channels through which intervention works vary with the surrounding macroeconomic environment.

The findings of our study support the following policy lessons for intervention when interest rates are zero. Intervention sales of domestic currency in a zero-interest rate environment can significantly depress the value of the domestic currency via the portfolio-balance transmission channel. However, very large intervention volumes are required in order to achieve economically substantial exchange rate effects when interest rates are zero and the portfolio-balance channel is the only transmission channel through which intervention works.

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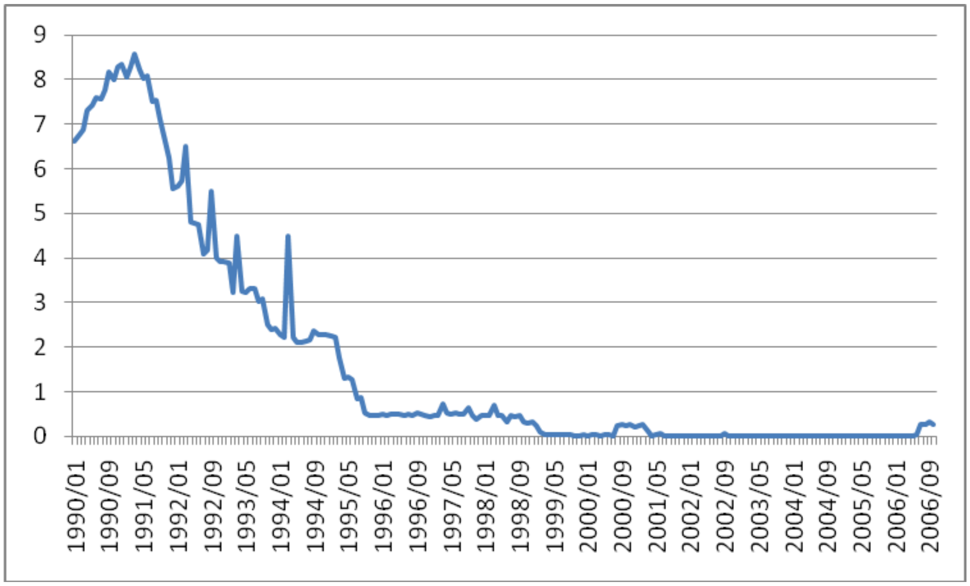
Figure 1: **Japanese Money Market Rate 1990 to 2006**



NOTES:

(a) End of month uncollateralized overnight call rate.
(b) Source: Bank of Japan.

Table 1	**Official Japanese Intervention 1999 to 2004**			
	1 January 1999 to 31 March 2004	1 January 1999 to 13 January 2003	14 January 2003 to 25 December 2003	26 December 2003 to 31 March 2004
Intervention Days	159	30	78	51
Cumulated Amount	464,251	149,428	171,886	142,937
Average Daily Amount	2,920	4,981	2,204	2,803
Standard Deviation	2,974	3,117	2,397	3,178
Average Daily Intervention Amount Relative to Average Daily Market Turnover	1.30%	2.15%	0.75%	1.07%

NOTES:

(a) Daily Bank of Japan intervention data obtained from the Japanese Ministry of Finance data bank.
(b) All Japanese interventions during the 1999 to 2004 period are sales of JPY against purchases of USD. All amounts are in millions of USD. Average Daily Amount and Standard Deviation refer to intervention days only.
(c) The April 2001 BIS statistics are used for calculating the average daily intervention amount relative to average daily market turnover for the 1 January 1993 to 13 January 2003 period while the April 2004 BIS statistics are used for the calculations pertaining to the two most recent sub-periods. A weighted average calculation is used for the full period. Average daily turnover in the JPY/USD market was USD 231 billion in April 2001 and USD 296 billion in April 2004. Source: BIS Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity in 2001 and 2004, http://www.bis.org/publ/rpfxf02t.htm and http://www.bis.org/publ/rpfx05t.htm, Statistical Annex Tables E.2.

Table 2	**Summary Statistics: Days with Intervention, Rumors, Statements and Reports**			
	1 January 1999 to 31 March 2004	1 January 1999 to 13 January 2003	14 January 2003 to 25 December 2003	26 December 2003 to 31 March 2004
Intervention (INT)	159	30	78	51
Rumors of intervention (RUMOR)	269	136	98	35
Intervention on days with a rumor of intervention ($INT^{DETECTED}$)	92	11	54	27
Intervention on days with no rumor of intervention ($INT^{UNDETECTED}$)	67	19	24	24
Rumor of intervention on days with no intervention (INT^{FALSE})	177	125	44	8
Positive statements (POSSTAT)	108	70	28	10
Negative statements (NEGSTAT)	17	17	0	0
Reports of Intervention (REP)	31	27	3	1

NOTES:

(a) INT is official intervention; RUMOR is a rumor of intervention; $INT^{DETECTED}$ is intervention on days with a rumor of intervention; $INT^{UNDETECTED}$ is intervention on days with no rumor of intervention; INT^{FALSE} is a rumor of intervention when no intervention occurs; POSSTAT is an official statement in support of intervention and/or a weaker JPY; NEGSTAT is an official statement suggesting that further intervention in the JPY/USD rate is not recommended or unlikely; REP is a firm report of intervention.

TABLE 3	**Summary Statistics: The JPY/USD Exchange Rate and the Macro News Surprises**				
	Mean	**Std. Dev.**	**Maximum**	**Minimum**	**Non-Zero Observations**
JPY/USD	116.3350	7.81857	134.73	101.56	1364
JP CPI	0.00394	0.001456	0.003	-0.002	33
JP GDP	0.001148	0.005362	0.018	-0.009	27
JP Industrial Production	-0.00232	0.007961	0.015	-0.017	44
JP Trade Balance	-6.6374	171.3451	367.10	-363.40	46
JP Unemployment Rate	-0.0004	0.00161	0.002	-0.004	30
US CPI	-0.00004	0.001536	0.003	-0.003	26
US GDP	0.00175	0.006151	0.0120	-0.0110	12
US Industrial Production	-0.00006	0.002936	0.0070	-0.0050	54
US Trade Balance	-0.4917	2.3448	3.1000	-5.5000	24
US Non-Farm Payroll Employment	-38.9032	101.6827	178.0000	-318.000	62
US FOMC	-0.00083	0.002887	0.0025	-0.0025	3

NOTES:

(a) All data series run from January 1, 1999 to March 31, 2004. All data are five days a week (Monday to Friday).
(b) Data Sources: The Exchange Rate Series is from Global Financial Data (New York close quotes). The Macro News Surprises are from Bloomberg (difference between actual announcement and median survey value).

Table 4	**Summary Statistics 1991 to 1998: Intervention and Rumors**	
	Days	Total Amount (millions of USD)
Intervention (INT)	185	150,953
US Intervention (INT^{US})	22	8,377
Intervention on days with a rumor of intervention ($INT^{DETECTED}$)	114	84,749
Intervention on days with no rumor of intervention ($INT^{UNDETECTED}$)	71	66,204

NOTES:

(a) INT is official Japanese intervention; INT^{US} is official US intervention; $INT^{DETECTED}$ is intervention on days with a rumor of intervention; $INT^{UNDETECTED}$ is intervention on days with no rumor of intervention.

TABLE 5	**The JPY/USD Exchange Rate and Intervention: Baseline Estimations on Full Sample**	
GARCH Models Daily Data: 1 January 1999 to 31 March 2004 (Full Sample)		
	1 January 1999 to 31 March 2004: All Variables	1 January 1999 to 31 March 2004: Significant Variables Only
Constant	-0.235 (0.194)	-0.300 (0.174)
Δs(-1)	-0.022 (0.029)	-
INT	1.240*** (0.333)	1.211*** (0.186)
$INT^{DETECTED}$	-0.079 (0.356)	-
INT^{JAN03}	-0.676** (0.311)	-0.705** (0.296)
INT^{DEC03}	-1.060*** (0.286)	-1.092*** (0.273)
JPCPI	-0.149 (0.594)	-
JPGDP	-0.179 (0.186)	-
JPIP	0.079 (0.123)	-
JPTB	-0.014** (0.006)	-0.012** (0.006)
JPUNEMP	-1.0543* (0.545)	-0.920* (0.526)
USCPI	0.558 (0.921)	-
USGDP	0.466 (0.734)	-
USIP	0.053 (0.277)	-
USTB	-0.001 (0.001)	-
USNFPR	0.001 (0.011)	-
USFOMC	0.220 (2.793)	-
Variance Equation		
Constant	0.759*** (0.249)	0.697*** (0.221)
ARCH(-1)	0.0199*** (0.006)	0.019*** (0.006)
GARCH(-1)	0.959*** (0.010)	0.962*** (0.009)
$INT^{UNDETECTED}$	0.001 (0.003)	-
Observations	1364	1364
R-squared	0.043	0.039
S.E. of regression	0.006	0.006
Durbin-Watson	1.981	2.020
ARCH-F (Q^2)	0.53[0.47]	0.89[0.35]
Q^2 (2)	0.58[0.75]	0.92[0.63]
F-Stat	2.74***[0.00]	6.96***[0.00]

NOTES:

(a) * Denotes significance at 90%, ** Denotes significance at 95%, *** Denotes significance at 99%.
(b) Standard Errors (S.E.) in ( ) below the point estimates; p values in [ ]; lags in ( ) in Variable Names.
(c) GARCH estimations are defined in Equations (1) (2) and (3) in the text.
(d) The dependent variable (Δs) is the first difference of the log of the daily JPY/USD spot exchange rate.
(e) The independent variables: INT is the daily intervention volume; $INT^{DETECTED}$ is detected intervention volume; $INT^{UNDETECTED}$ is undetected intervention volume ; INT^{JAN03} is the daily intervention volume during the 14 January 2003 to 25 December 2003 period;

INT^{DEC03} is the daily intervention volume during the 26 December 2003 to 31 March 2004 period.

(f) Control Variables are measuring macro news surprises (difference between actual announcement and survey expectations extracted from Bloomberg) regarding Japanese CPI (JPCPI), GDP (JPGDP), Industrial Production (JPIP), Trade Balance (JPTB), and Unemployment (JPUNEMP), and US CPI (USCPI), GDP (USGDP), Industrial Production (USIP), Trade Balance (USTB), Non-Farm Payroll Employment (USNFPR), and Interest Rate Changes (USFOMC).

(g) The conditional mean constant, JPTB, and USNFPR are multiplied by 10^3; and INT, $INT^{DETECTED}$, $INT^{UNDETECTED}$, INT^{JAN03}, INT^{DEC03}, and the constant associated with the variance equation, are multiplied by 10^6 for readability.

TABLE 6	**The JPY/USD Exchange Rate and Intervention: Baseline Estimations on Sub-Samples**	
GARCH Models Daily Data: 1 January 1999 to 31 March 2004		
	1 January 1999 to 13 January 2003: Significant Intervention Variables	14 January 2003 to 31 March 2004: Significant Intervention Variables
Constant	-0.111 (0.208)	-0.873*** (0.319)
INT	1.210*** (0.194)	0.649*** (0.203)
INT^{DEC03}	-	-0.496** (0.250)
Variance Equation		
Constant	1.112*** (0.400)	2.100 (1.442)
ARCH(-1)	0.014** (0.007)	0.054* (0.029)
GARCH(-1)	0.959*** (0.013)	0.864*** (0.074)
Observations	1048	316
R-squared	0.038	0.053
S.E. of regression	0.007	0.005
Durbin-Watson	2.019	1.976
ARCH-F (Q^2)	0.15[0.70]	0.04[0.84]
Q^2 (2)	0.63[0.73]	3.80[0.15]
F-Stat	7.05***[0.00]	2.91[0.01]

NOTES:

(a) * Denotes significance at 90%, ** Denotes significance at 95%, *** Denotes significance at 99%.
(b) Standard Errors (S.E.) in ( ) below the point estimates; p values in [ ]; lags in ( ) in Variable Names.
(c) GARCH estimations are defined in Equations (1) (2) and (3) in the text.
(d) The dependent variable (Δs) is the first difference of the log of the daily JPY/USD spot exchange rate.
(e) The independent variables: INT is the daily intervention volume; INT^{DEC03} is the daily intervention volume during the 26 December 2003 to 31 March 2004 period;
(f) Significant control variables measuring macro news surprises are included but not shown for ease of exposition.
(g) The conditional mean constant is multiplied by 10^3; and INT, INT^{DEC03}, and the constant associated with the variance equation, are multiplied by 10^6 for readability.

Table 7	Economic Effects of Intervention		
	1 January 1999 to 13 January 2003	14 January 2003 to 25 December 2003	26 December 2003 to 31 March 2004
Coefficient Estimate	0.00000121	0.00000065	0.00000015
Exchange Rate Effect of a USD 100 Million Intervention	0.0121%	0.0065%	0.0015%
Exchange Rate Effect of a JPY 1 Trillion Intervention	1.03%	0.56%	0.14%
Exchange Rate Effect of average daily Intervention	0.60%	0.14%	0.04%
Exchange Rate Effect of Total Within-Period Intervention	18.08%	11.17%	2.14%

NOTES:

(a) The coefficient estimates are from Table 6 and correspond to intervention in the amount of USD 1 million. The coefficient estimate for the 26 December 2003 to 31 March 2004 period is the sum of the coefficient estimates associated with INT and INT^{DEC03} (second column of Table 6).
(b) The exchange rate effect of a JPY 1 trillion intervention is calculated using JPY/USD exchange rate averages. The average JPY/USD exchange rates across the three sub-periods are 117.04, 115.86, and 107.22, respectively.
(c) The average daily intervention amounts (in billions of USD) across the three sub-periods are 4.9, 2.2 and 2.8, respectively (reported in columns 2 through 4 of Table 1).
(c) The exchange rate effect of the total amount of intervention is the total within-period intervention in millions of USD times the associated exchange rate effect of USD 1 million intervention.

TABLE 8	**The JPY/USD Exchange Rate and Intervention: The 1991 to 1998 Comparison Period**		
GARCH Models Daily Data: 1 April 1991 to 31 December 1998			
	1 April 1991 to 31 December 1998	1 April 1991 to 3 April 1996	4 April 1996 to 31 December 1998
Constant	-0.120 (0.141)	-0.150 (0.163)	0.002 (0.002)
Δs(-1)	0.046* (0.027)	-0.003 (0.032)	0.066 (0.048)
INT	1.160*** (0.013)	-1.840 (1.932)	1.180*** (0.031)
$INT^{DETECTED}$	-1.431* (0.742)	1.061 (2.151)	12.324*** (0.239)
Variance Equation			
Constant	1.140*** (0.177)	2.514** (1.080)	3.641*** (0.590)
ARCH(-1)	0.155*** (0.040)	0.060** (0.029)	0.153*** (0.057)
GARCH(-1)	0.603*** (0.058)	0.869*** (0.048)	0.600*** (0.066)
$INT^{UNDETECTED}$	0.002 (0.011)	0.013 (0.019)	0.005 (0.048)
Observations	1982	1281	701
R-squared	0.003	0.002	0.040
S.E. of regression	0.007	0.007	0.008
Durbin-Watson	2.00	1.97	2.02
ARCH-F (Q^2)	0.46 [0.50]	0.37[0.55]	0.06[0.81]
Q^2 (2)	0.51[0.78]	0.38[.83]	1.08[0.58]
F-Stat	0.83[0.57]	0.63[0.60]	4.84***[0.00]
Andrews Test			
INT only	OBS 1281 = 3 April 1996 [247.13]	-	-
INT and $INT^{DETECTED}$	OBS 1281 = 3 April 1996 [242.03]	-	-

NOTES:

(a) The Andrews test is based on 15% trimming; the maximum Wald F-statistics are shown in [ ].
(b) For all other notes see notes to Table 5.