

Central Banks' Interventions Strategies and the Effects on Realised Moments: A preliminary study from the Bank of Japan*

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Abstract

This study aims at testing the effects of different strategies of intervention used by the Bank of Japan on the exchange rate realised moments. It provides a contribution to the existing literature by using: (i) a new database which captures three different kinds of statements, i.e. the usual confirmation speeches, as well as threats of intervention and oral interventions that we guess were respectively oriented to speculators and the fundamentalists; (ii) intra-daily (30-minute) data. In line with Beine *et al.* (2005) ruling regressions based on AR(FI)MA models were performed. Moreover, their robustness was checked with alternative models (HAR-RV) and bootstrap inference.

The results show that different strategies have different impacts on the exchange rate. Overall, transparent policies (actual interventions confirmed by a speech and oral interventions) were the most effective. These results emphasize the crucial role of the communication policy and the necessity for central banks to properly select their audiences.

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To the readers: We would like to apologize to the reader for the lack of Tables and Figures in this version due to technical problems.

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1 Introduction

With the end of the Bretton Woods system and the shift to a floating exchange rate regime, major industrial countries undertook different policies to correct undesirable currency moves such as misalignment or excessive volatility. In this regard, the question of the effectiveness of these policies became a major issue for both academics and policy makers.

A rapid review of practices highlights the great heterogeneity across central banks and also across time (Beine and Lecourt, 2005). In the last few years, for example, some industrialised countries seem increasingly reluctant act through actual interventions¹. In this regard, the Federal Reserve (Fed henceforth) and, to a lesser extent, the European Central Bank (ECB) have almost disregarded this tool, stepping into the market only four times in the past five years². In parallel, many policy makers have regularly expressed their concern about the mis-pricing of the Euro/Dollar and possible new rounds of interventions, covering the front page of the financial or general press with headlines such as 'Trichet Reaffirms Euro Is Undervalued' (*Dow Jones* February 18, 2002) or 'Duisenberg: Intervention A Weapon In ECB's Arsenal' (*Dow Jones* May 28, 2004). This behaviour, somewhat paradoxically, actually reflects the growing desire of some countries to turn the page on the former Plaza and Louvre type of regulation³, and to gradually adopt new policies based on communication.

Conversely, other authorities maintained a deep pressure on the market with frequent and massive interventions. Over the last decade, the Bank of Japan (BoJ), acting on the behalf of the Japanese Ministry of Finance, remained amongst the most aggressive central banks with 341 days of interventions since 1991⁴. On a more qualitative level, its behaviour was sometimes full of ambiguity and sometimes highly transparent. These contextual nuances in the design of policies provided some room for manoeuvre for Japanese officials to play with traders' perceptions and market mechanisms (Ito, 2002; Gnabo and Lecourt, 2005). Hence, the timing of actions, the amount invested, the coordination with other central banks (CBs), the frequency of actual interventions, their visibility and the communication policy have all served to draw polymorphic policies that we call strategies in this paper.

¹An actual intervention is a sale or a purchase of domestic currency against foreign currency by a central bank designed to influence the exchange rate.

²The Fed only conducted one coordinated intervention with the ECB. On the other hand, the ECB bought Euros unilaterally against others currencies three times.

³Under the Plaza (1985) and the Louvre (1987) accords, industrialized countries agreed to regulate the dollar through unilateral and coordinated actual interventions.

⁴The Ministry of Finance decided to disclose data on official interventions in 2001. The day and the amount per day of interventions are precisely reported. However, there is no official information on interventions conducted before April 1991.

The motivation for selecting one instrument rather than another remains still unclear and frequently puzzling (see for example the Sarno and Taylor (2001))⁵. In the same way, their influence on the exchange rate or market perception is still obscure (King, 2003), despite an abundant empirical literature.

This study attempts to capture the strategic dimension of central banks' practices by providing empirical evidence of their effectiveness. Investigations on the mode of intervention is not within the scope of this paper and is left for further studies (see also Fratzscher (2004); Beine and Bernal, 2005). Data from Japan has been selected for the estimations because of both its strong vitality and the diversity of its regulatory policy⁶. This diversity prevents too much generality being lost, since Japanese officials also relied strongly on communication strategies.

Our objectives are: (i) to portray the central bank's activities properly by disentangling the different strategies, i.e. actual and oral interventions but also mixed policies; and (ii) to see whether or not these activities have influenced the exchange rate moments, i.e. first (level), second (volatility) and third (asymmetry) moments. This constitutes an interesting issue since the empirical literature has somewhat underestimated the strategic dimension of central bank interventions (CBIs) (King, 2003; Fratzscher, 2004), focusing almost exclusively on the effectiveness of actual interventions and only opening the door to a limited range of strategies (covert versus open interventions, or unilateral versus coordinated interventions). Only recently, has communication policy started to be examined seriously⁷.

Unfortunately, the extensive empirical literature fails to reach a strong consensus. For a long time, CBs large bids or sales of currencies were argued to be ineffective or worse, to have undesirable effects (Jurgensen, 1982; Edison, 1993; Sarno and Taylor, 2001; Humpage, 2003). More recently, however, the disclosure of further data along with the introduction of different CBI objectives (King, 2003) have tempered previous conclusions. Both Dominguez (1998) and Beine *et al.* (2004b) provided empirical support for the idea that a clear signal was likely to influence the exchange rate virtuously, i.e. to reduce the volatility and to move the exchange rate level in the desired direction. These results, fully consistent with the signalling channel⁸, also well illustrated the potentially key role of transparency.

⁵These choices are made by officials according to their own beliefs or specific market situations. The process of decision making is, however, outside the remit of our study and is left for further research (see for example Fratzscher (2004)).

⁶The exchange rate policy is governed by the Ministry of Finance. The decision to intervene is under its control. However, the physical purchases and sales are conducted by the Bank of Japan on its behalf. That is why the literature usually associates the exchange rate policy with the BoJ. For the sake of clarity we will also do this.

⁷Unlike exchange rate policy, it is noteworthy that many studies have been devoted to the communication of monetary policy (see amongst others Blinder, 1998; Woodford, 2003; Carpenter, 2004).

⁸According to this model, authorities may try to influence their currency by conveying a signal to the market.

Also relying on the signalling channel others authors have recently turned to the rhetoric of officials (sometimes called 'jawboning'). This type of practice is quite attractive for policy makers, at least at first glance. On the one hand, it can serve as a vehicle to convey private information (signal) to the market in the same way as actual interventions. But on the other hand, the CB does not bear risk of losing money (Jansen and De Haan, 2005).

Fatum and Hutchison (2002) and Jansen and De Haan (2003) explored different aspects of ECB policy around the launch of the Euro (1999 2002). During this period, officials regularly expressed their view on the currency, whether to signal a mismatch between the current value and the fundamentals or to rattle the spectre of further interventions. Unfortunately for European policymakers, both studies conclude that these actions failed either to talk up the Euro (Fatum and Hutchison, 2002)⁹ or to calm the 'disorderly market' in the medium and long term¹⁰. Working with higher frequency data, Jansen and De Haan (2005) were also unable to find a knee-jerk reaction (i.e. short-run effects at 5-minute intervals).

Dealing with the Euro/Dollar and Yen/Dollar exchange rates over much longer periods (1988 2004 and 1991 2004 respectively), Fratzscher (2004) drew a less pessimistic portrait. The EGARCH models with three types of statements (strengthening oral, weakening oral, and ambiguous oral), revealed possible virtuous effects¹¹, robust to various actual interventions and monetary policy conditions. Fratzscher suggests that oral interventions may constitute an autonomous policy tool by coordinating the market expectations. This is the coordination channel.

At least, Beine *et al.* (2004b) departed from previous studies by viewing the communication policy as a complement rather than a substitute of actual interventions. The GARCH(1,1) estimation for the Yen/Dollar and Euro/Dollar from 1992 2004 and 1986 2004, support the conclusion that, by confirming physical sales or purchases clearly and rapidly, the officials improve both the visibility and the quality of the initial signal and strengthen its effectiveness.

The following study is in line with the previous literature but extends it in two ways. First, I rely on a new dataset with a far longer time-series of actual interventions and statements than those used by Fatum and Hutchinson (2002) and Jansen and De Haan (2003). Moreover, unlike Fratzscher (2004), I introduce

⁹The estimation is conducted through a times series AR(1) model.

¹⁰Jansen and De Haan (2003) extended their analysis to the volatility with an EGARCH model. The statements selected were those on the future value of the Euro. The effects were short lived and waned after only one day.

¹¹These results remain conditional for the Yen/Dollar. On the other hand, they are clearly significant for the Euro(DM)/Dollar.

a distinction between (i) statements on future interventions called 'threats' that are probably oriented to speculators and (ii) more qualitative statements reflecting the views of authorities, whereby they provide private information on the exchange rate to fundamentalists. This allows to portray the CB behaviour in a more realistic way, with different classes of statements tailored to specific audiences¹².

Second, earlier studies apply some well-known time-series GARCH-type models. However, this measure of volatility has been proved to be very noisy (Andersen *et al.*, 2002). Therefore, it is highly preferable to rely on realised moments as Beine *et al.* (2005) did. It is also noteworthy that this study is extended to realised third moments, to measure the impact on exchange rate asymmetry. This is a very recent issue, potentially fruitful for market practitioners since the asymmetry in financial assets plays a key role in different trading strategies.

The remainder of this paper is organised as follows. Section 2 presents the role of transparency in the exchange rate intervention policies of CBs. Section 3 discusses the actual strategies and their theoretical effects. Section 4 describes the data in detail while Section 5 reviews the methodology. Section 6 presents the results. Section 7 investigates the robustness of the results with bootstrap methods. Section 8 offers some concluding comments.

2 The Theoretical Background

2.1 Is It Better to Show?

According to a former member of the Federal Reserve, the Fed considers three factors before intervening: whether market conditions merit intervention, whether a policy consideration exists which 'can and should be broadcast to the market' through intervention and, finally, whether market conditions are appropriate¹³. The corresponding process of decision making can obviously be summarised in two steps. First, does the economic and the exchange rate situation require an intervention? This refers to CBs' reaction functions

¹²The basic idea is that different statements may not be directed to the same audience and may not have the same targets. By isolating 'threats' from others statements we hope to capture this dimension. This is an important issue since the aggregate level is actually very noisy and potentially meaningless. Fatum and Hutchinson (2002) and Jansen and De Haan (2003) introduce this distinction but do not explicitly present either its theoretical motivations or its implications. The selection of statements is not refined further (for example by distinguishing dovish from hawkish statements) to avoid the bias of subjectivity. Obviously there is a trade off between the sophistication of the classification and the ability to collect the news and to interpret it properly. Given the form of statements from officials speeches, the difference between the two types of announcement (threats and views on the fundamentals) is sufficiently clear to avoid 'voodoo-type analysis' (Rosa and Verga, 2004).

¹³Interview with Mr Fisher on 30 July 30 1998 (*Down Jones* July 30, 1998). Mr. Fisher worked at the Federal Reserve Bank of New York, where he was responsible for all the Federal Reserve's open market and foreign exchange operations.

(see inter alia Baillie and Osterberg 1997; Almekinders and Eijffinger, 1996; Ito and Yabu, 2004). Second, how can tactics or strategies be designed to fit market conditions or specific targets¹⁴ ?

This last point is actually a key issue, well reflected by the great diversity and heterogeneity in CBs' strategies. Behind the selection of one strategy over another stand the guesses or beliefs of policymakers on the effects of specific approaches. For example, when he became head of the exchange rate division in the Japanese Ministry of Finance in June 1995, Mr Sakakibara clearly expressed his desire to surprise the market as well as his scepticism about the effectiveness of opaque and monotonous approaches. From a theoretical point of view, many mechanisms or channels have been proposed to justify the effects of various approaches, opening the door to a large set of practices.

Most strategies are articulated around the concept of transparency. In the seminal work of Mussa (1981) on the signalling channel, the authorities may try to influence their currency by conveying a signal. This signal may be about future monetary policy, future movements of exchange rates (Humpage, 2000), or more broadly about a misalignment of the current rate with the fundamentals. By disclosing private information, the authorities lead market participants to change their initial beliefs about the exchange rate, present or future, and allow a re-alignment of current rates. In an ideal scenario, a transparent policy here synonymous with intervention, since the CB provides private information to the public may lead to an adjustment of the exchange rate level without increasing volatility, since agents readjust their beliefs immediately.

But of course, such reasoning relies on strong assumptions which are, to some extent, questionable. To better understand this reasoning and also to properly identify strategies it is useful to investigate the concept of transparency more closely. In a narrow sense¹⁵, transparency reflects the amount of information provided by the CB to the public (Geraats, 2002). Winkler (2002), however, judges this definition too restrictive. He argues that the bridge between disclosing information (also called 'openness'), and the effect on financial assets relies on specific hypotheses such as market efficiency, rational expectation and market homogeneity which may be violated. Consequently, he proposes a more ambitious definition which captures the multi-dimensional aspect of transparency (Edey and Stone, 2004), where transparency is viewed as the degree of common understanding between the CB and the public. In this framework, transparency does not only depend on the disclosure of information but on a complex relationship between a sender (the CB) and a recipient (the public). Therefore, the content of the message and both the clarity (i.e. the quality of the signal) and the common understanding (i.e. the common language or the ability of the authorities to tailor

¹⁴This is a recent concern in the empirical literature. Beine and Bernal (2005) identify precise situations where the CB chooses not to reveal its movements, i.e. secret interventions.

¹⁵Winkler (2002) called this the one dimensional definition.

their information to particular audiences (De Haan and Amtenbrink, 2003)) have to be considered in CB policy.

Returning to the signalling channel, a CB may actually consider different factors in designing its policy to ensure a full and correct understanding of the signal. (i) If the market is not fully efficient, for example, some friction may arise when the information arrives ¹⁶. Therefore, the quality of the signal (i.e. its precision and clarity) may influence the success of the policy to a large extent by reducing the volatility enhanced by uncertainty. (ii) Analogously, if agents are not homogeneous, the revision of private beliefs may potentially differ. More precisely, different groups of agents in the market (such as the speculators and the fundamentalists) may interpret the same information in different ways (and then price it differently). In this case, the price adjustment is likely to be slow and to be accompanied by an increase in volatility. Authorities may then tailor their message to specific audiences to be more effective and in a way more transparent. (iii) At least previous reasoning is based on the assumption of full credibility. If this is not in fact the case (Reeves, 1997) (i.e. if the public believes that the CB is pursuing some idiosyncratic goal or does not have the relevant information) the signal will be disregarded by market participants. Therefore, a more costly signal may be selected to strengthen the credibility and to convey the inside information properly.

More recently another channel through which transparent actions may influence the exchange rate has been proposed in the literature. In the coordinating channel, agents do not only pay attention to the level of fundamentals to price financial assets but also to what others agents think. In this framework, market participants form their beliefs from (i) their own private information, (ii) public information, sporadically enlarged by the disclosure of information from the CB, and (iii) the distance between their beliefs and those of other private agents. This last point could be interpreted as a way of confirming their own beliefs (Demertzis and Viegi, 2005). This is also a means of forming private beliefs closer to the final price. In this 'beauty-contest'-based reasoning (Keynes, 1936), the signal issued by the authorities can serve as a double-edged instrument (Morris and Shin, 2002). As before, it provides inside information to the public that helps to reshape their prior beliefs, but it also serves as a focal point for market participants. In this scenario the CB's policy can be effective without being fully credible.

Both theories support the view that a transparent policy is likely to influence the exchange rate. But it seems to be important to bear in mind that full or real transparency consists of more than the simple disclosure of information to overcome market frictions and factors of inefficiency. This dimension has concrete implications whose strategies should be properly identified to test their theoretical effects.

¹⁶In some circumstance market participants may be unable to understand the content of the message accurately.

2.2 Or Better to Hide?

The literature also provides some theoretical examples of drawbacks to transparency. I will separate them into two parts. The first refers to the credibility of CBs through the noise-traders' channel (Hung, 1997) and the microstructure model of Vitale (1999). The second relies on the news theory, whereby a signal is only effective if it is a surprise.

In the noise-traders' channel, Hung (1997) introduces heterogeneity among market participants. On the one hand, fundamentalists trade according to their guesses at economic fundamentals. On the other hand, noise traders follow trading rules not fully consistent with fundamentals. In certain circumstances the exchange rate can be driven by these latter. Providing a signal about the fundamentals would be useless. Therefore, authorities may prefer to establish some strategies, by increasing or decreasing the volatility, of playing with noise-traders' perceptions, disturbing their trading rules and allowing a resumption of the fundamental values. For example if the currency experiences a strong one-way trend, it is difficult to break it through an intervention that 'leans against the wind'. Moreover, failure in such an effort would have adverse effects by eroding the authorities' credibility. Therefore, they might prefer to wait for a short downward trend to sell secretly. In this way, they can increase the volatility in prices and break the former trend.

In his microstructure model, Vitale (1999) does not question the market homogeneity but rather the preferences of CBs. Indeed, previous reasoning on the signalling channel rests on the notion that authorities target the fundamental value of the exchange rate. Relaxing this assumption opens up the possibility of having a 'wrong signal'. This is coherent with empirical evidence from several studies. For example Dominguez and Frankel (1993) and Beine and Bernal (2005) note that external policy objectives such as competitiveness could sometimes have motivated inconsistent targets. The theoretical microstructure model is, here, a batch model *la* Kyle. The market makers receive orders from informed and uninformed traders. But they are unable to discern both. Therefore, they can only extract information on the exchange rate fundamentals from the aggregate flow of orders. In this context, it is in the interest of the CB to conceal its orders so as to 'fool' the market makers. Vitale (1999) concludes that transparent actions are neither credible nor desirable in this case. Contrary to Bhattacharya and Weller's (1997) and Barnett and Ozerturk's (2005) reasoning, this framework leaves no room for sporadic announcements or selective disclosures.

This approach is, in a way, quite close to that developed in the 'cheap talk' framework (Stein, 1989) devoted to communication policy. In this case, the CB is also portrayed as a potential liar. Too precise

announcement is viewed by market participants as a way of manipulating them, opening the door to inconsistent policies. Therefore the market only reacts to vague signals (i.e. statements), and only these are effective.

Overall, these different theories enlarge the set of preferences for both the CB and the market, i.e. they do not exclusively target the fundamental level of the exchange rate. By doing so, they relax to a large extent former assumptions about rationality, and open some space for specific strategies where isolated actions need to be hidden or unclear.

In the news theory, the visibility of isolated actions is not questioned. Ambiguity refers rather to a policy as a whole or, in others words, to a sequence of actions. Indeed, if we admit the semi-strong efficiency hypothesis (Fama, 1970), all pertinent information is already contained by the price. Only unanticipated or surprising news is likely to be considered by the market. An over-transparent policy risks allowing future actions to be accurately inferred. Therefore, redundant interventions or actual interventions preceded by announcements are likely be ineffective. In this line of thinking the authorities should hide their strategy up to the last moment, i.e. the time of intervention.

3 Strategies and Hypotheses

3.1 Japanese Regulatory Policy 1991 2005: Transparency as a Yo-Yo Game

In this Section I will attempt to disentangle the different strategies (see Table 1) by reviewing in detail how Japan articulated its policy between 1991 and 2004. This description is in line with Ito's (2002) analysis, with the notable development that his picture is completed by the introduction of communication policy.

3.1.1 The pre-Sakakibara period, characterised by secret and clustered interventions

After acting in cooperation with others CBs during the 1980s through the Plaza (1985) and Louvre (1987) accords, Japan was strongly active on the exchange rate market during the first part of the 1990s. During the pre-Sakakibara period (1991 June 1995), the BoJ intervened on the both sides of the market 'against the wind' whether to dampen the continuous yen depreciation (1991 1992) or to smooth the upward trend (1993 June 1995). In general operations were clustered in long sequences of several days or weeks in a row. However the amounts invested in each operation remained quite modest, averaging \$ 463 million.

Paradoxically, this high level of engagement was not particularly visible. Officials rarely talked to market participants, whether to confirm actual interventions (confirmation speeches were only issued on 6 %

Preliminary distinctions	
Actual Intervention	an official sale or purchase of foreign assets against domestic assets in the foreign exchange market that intended to influence the exchange rate.
Statement	a statement issued by an official to express whether their view on fundamentals (private information) or on possible actual interventions in the near future.
Sophisticated distinctions	
Actual intervention policies	
Clustered Intervention	an actual intervention preceded by at least one actual intervention the 15 previous days
Isolated intervention	an actual intervention not preceded by another actual intervention during the 15 previous days.
Reported Interventions	an actual intervention clearly perceived by the market the same day (reported by the major news providers).
Secret Interventions	an actual intervention not clearly perceived by the market the same day.
Incoherent intervention	an actual intervention not coherent with the fundamentals (for example, a sale of yen against dollars when the Japanese currency is under-valued)
Oral intervention policies	
Oral intervention	a statement expressing the view of an official on the fundamental value of the exchange rate. Therefore, it provides private information (and so may be regarded as orientated towards the fundamentalists)
Threat	a statement from an official warning about possible actual interventions in the near future, which does not provide information on the fundamentals but raises the possibility of a loss of portfolio value if market participants continue their existing behaviour (and which is thus obviously oriented towards speculators)
Mixed policies	
Confirmation Speeches	an actual intervention confirmed orally by an official the same day.
Preceded intervention	an actual intervention preceded by a statement during the 15 previous days.

Table 1: A Glossary of Central Bank Interventions Strategies

of actual interventions), or to specify their views on the exchange rate(oral interventions occurred on 8.7 % of days and threats on 8.6 %). When intervening, the orders flows were conducted through channels that minimised the likelihood of being perceived. Despite the lack of official data on their reasoning, many newswires described the BoJ as using various 'masked approaches'. On 14 March 1995, for example, Reuters reported that BoJ 'started using a new method of currency intervention by having a limited number of banks discreetly buying dollars through U.S. and European banks in Singapore'. Overall, only 82 percent of interventions were well perceived by the market (Table ??).

Despite this lack of transparency, the repetition of dollar sales removed the surprise component. Traders were getting used to rumours of intervention, either true or false, and were barely surprised by BoJ actions.

3.1.2 The recipes of 'Mr Yen' reintroduce surprise into the market

The arrival of Eisuke Sakakibara (Mr Yen) at the Ministry of Finance in June 1995, clearly changed the approach. From that time the authorities sought to restore some room to manoeuvre by implementing a new philosophy described as 'intervene (ing) when it (the BoJ) can win' (Sakakibara). In other words, they relied more on the timing of operations than on secrecy to surprise the market. In contrast to the previous defensive actions, BoJ created surprise by stepping into the market 'with the wind' in June 1995. During the rest of the year, it intervened only 8 times, in contrast to 35 interventions between January and June 1995. The degree of transparency also gradually improved. Actions became much more visible with some orders passing through one of the major electronic broking systems, namely the MINEX ¹⁷.

The large gap between economic growth in the US and the sluggish performance of the Japanese economy, hurt by the Asian crisis and the deterioration of the banking system, forced Japanese policymakers both to loosen their monetary policy and to underpin their currency ¹⁸. While only 17 operations to prop up the yen were conducted between June 1995 and August 1998, the amount invested increased dramatically, with an average value of \$3.89 billion per operation.

The trend changed in August 1998, reversing three years of continuous depreciation during which the yen lost 80% of its initial value. From that time onwards, the authorities devoted their policy exclusively to countering a premature appreciation in the yen, which could have weakened the budding economic recovery. Purchases of dollar against yen were then pursued up to January 2003 in line with the former philosophy

¹⁷MINEX was launched in March 1991 by Tokyo Forex Co. Ltd and other Japanese firms and is mostly used in Asian trading hours.(*Reuters*,14 September 1995). In this way they let dealers see large dollar bids sitting at places below the market price.

¹⁸The Japanese authorities tried to control the exchange rate's adverse effects on its neighbours to prevent competitive devaluation, especially from China.

(isolated interventions and reported interventions). During the overall period (June 1995–2002), only 49 operations were conducted with a total value of \$ 223 billion, which represented only 22% of the number of interventions and 74% of the amount invested since 1991.

As well as actual interventions, the Bank of Japan took a number of steps to enhance the signalling effect and increase the transparency of its interventions. As stressed previously, the interventions were conducted in a visible manner, so that virtually all operations were well reported between June 1995 and 1997. From 1997 to 2002, Japan clarified its actions further by issuing a confirming speech after almost every one of its interventions. *Ex post* transparency (Enoch, 1998) also improved significantly with the disclosure of intervention data in 2001. More interestingly, Japanese officials talked much more to the market: there were oral interventions on 17% of working days, compared to 9% during the preceding period (Table ??). In this way, they managed to provide private information (to fundamentalists) throughout the period, with only sporadic actual interventions.

The BoJ kept also speculators alert by regularly raising the spectre of further interventions. The number of days on which threats to intervene were issued rose sharply to reach 17.3%. It is, however, noteworthy that these words were rarely followed by actions. In 1998, for example, we counted 74 days with threats but only 4 actual interventions. Consequently, there are few doubts that this type of rhetoric introduced more confusion or noise than information onto the market. One interpretation may be that the authorities attempted to introduce a two-way risk by playing on market fears.

Insert Figure 2 about here

3.1.3 Japan at the cross roads, the temptation of high frequency interventions

The departure of Haruhiko Kuroda at the beginning of 2003, prompted the resumption of frequent and discreet sales of yen. The authorities intervened on 128 days during 2003 and 2004 that is almost twice as often as between June 1995 and 2002. This policy was very efficient in maintaining secrecy, with 81.5% of interventions being secret. This lack of transparency opened the door to market guessing and speculation about BoJ activities. For example, some news agencies reported 'two tactics in particular that help hide intervention, and in one case potentially negate intervention'. (*Reuters* August 29, 2003). The first consisted of intervening in the forward market by buying forward dollar/yen and regularly rolling over the delivery dates. The second, called 'all or nothing', was more sophisticated. It involved large private banks and was

based on 'all or nothing' orders ¹⁹.

It is difficult to identify precisely why Japan resumed its earlier ambiguous tactics. Beine and Bernal (2005) showed that secret interventions were motivated by inconsistent targets. These inconsistent interventions are consistent with Vitale's (1999) micro-structure model. Moreover, conducting visible operations would have drowned out the fire from Japan's Asian neighbours, whose exports were suffering. In the same way, the United States authorities clearly expressed their disagreement with the use of intervention as a tool for economics aims²⁰. At least, monetary policy reasons may also have played a significant role since Japan was continuously struggling with deflationary pressures.

Insert Figure 3 about here

3.2 Tests of the BoJ's strategies

To test most of BoJ strategies we propose six models. Each of them is estimated on the first, second and third exchange rate moments:

- **Model 1, mouth versus amount**

The first model estimates the effects of actual interventions versus statements (i.e. threats and oral interventions). It follows Fratzscher's (2004) thinking. In this way, we can test whether a more costly signal is more effective. It also serves as a benchmark.

- **Model 2, visible versus hidden interventions**

This model tests the impact of transparency. Actual interventions are split into reported versus secret interventions. Statements are similarly split into oral interventions (which are viewed as an element of transparency, with a signal) versus threats.

- **Model 3, confirmation speeches**

This model tests the quality of the signal. Hence, interventions confirmed by a confirmation Speech are differentiated from the others.

¹⁹Hence, the BoJ leaves orders for large banks, mainly, to buy whole amounts (mainly in dollar/yen) at particular levels. As the level is approached the bank with the order uses its own capital and buys dollar/yen in the amount of the BoJ order. If the market comes back to the bank's position, the order is crossed with the standing order from the BoJ. The closer the buying is to the BoJ order, the less at risk, the less the loss'. (*Reuters* August 29, 2003)). Therefore, if the trend is curbed by the first round of commercial bank purchase the BoJ may not have to step into the market. In that sense the tactics may have potentially negated intervention.

²⁰US officials underlined regularly their hostility to exchange rate manipulation. For example 'US Snow: (a former U.S. Treasury) Dollar Value Should Be Set By Competitive Mkts' (*Reuters* May 13, 2003)

- Model 4, mixed policies

This model tests whether actual interventions preceded by a statement are more or less effective than other interventions. Unanticipated interventions, like unanticipated news in general, may take a longer time for agents to absorb and react to. However if the actual intervention is perfectly anticipated, all the information it contains could already be in the exchange rate, in which case the market would disregard it.

- Model 5, clustered interventions

This model tests whether repeated interventions are effective. In practice, an intervention preceded by (at least) one other intervention (of the same nature) during the 15 previous days is considered as a part of a cluster. Other interventions are considered isolated. To be consistent with our theoretical approach we only include interventions which were perceived by the market (i.e. reported interventions).

- Model 6, incoherence

This model tests the effectiveness of the microstructure framework described by Vitale(1999). In this line of thinking, the authorities may try to influence the exchange rate through secret intervention when they follow an inconsistent target. An intervention is considered inconsistent if its sign does not conform to the fundamental value of the currency. To remain consistent, only secret interventions are considered.

4 Data

To perform the empirical analysis, two datasets were used. The first contained intra-daily data on the yen/dollar rate between 1991 and 2004 and the second was a new dataset capturing the BoJ's intervention strategies over the same period.

4.1 Intra-daily Data

The 5-minute scaled prices provided by Olsen and Associates returns were computed as:

$$r_{t,i} = 100 * (\log(P_{t,i}) - \log(P_{t,i-1})) \quad (1)$$

Where $P_{t,i}$ is the price for day t and the 5-minute period i . To avoid liquidity problems and artificial patterns in the series, a number of days on which the liquidity was especially low were removed. Although, the exchange rate market is known to be one of the most liquid, activity is sharply lower during weekends and some holidays. I followed Andersen *et al.* (2000) and removed US holidays. Apart from these days, the

20 days with the longest sequences of zero returns were also isolated. This left 3354 complete trading days between 2 April 1991 and 1 October 2004.

As well as liquidity problems, data may also suffer from microstructure noises. These noises (non-synchronous trading or bid-ask bounce effects) may bias the volatility. The magnitude of the bias depends on the correlation between the intra-daily returns. Therefore, I decided to rely on 30-minute rather than 5-minute frequency data. This is in line with others empirical studies (e.g. Corsi, 2004; Neely, 2004).

4.2 Newswires

One of the main contributions of this study to the existing literature relies on its ability to discriminate between a large set of strategies. This is achieved by a close reading of the newswires. In this way, it was determined whether market participants perceived an intervention or whether statements were issued on such and such a day. This data collection uses the online database Factiva. It allows newswires from Reuters and Dow Jones (which are, with Bloomberg, the most important sources of information for traders) to be collected ²¹. Moreover, Factiva offers users the opportunity to conduct a key-word search on the headline or the whole text. The combination of key words 'BOJ or Bank of Japan or intervention' was used here to discriminate between reported and secret interventions, while the names of successive officials (Ministers of Finance, Prime Ministers, Vice Ministers of Finance for International Affairs, Governors of the BoJ) between 1991 and 2004 were used to identify statements. Table 2 gives some examples of news items and their classification.

Oral intervention	'Yen Rise Excessive, Doesn't Reflect Fundamentals' (Kuroda) (<i>Reuters</i> March 23, 1999).
Threat	'Time for Effective Intervention Approaching' (Sakakibara) (<i>Reuters</i> August 17, 1998).
Confirmation speech	'Minister of Finance's Sakakibara confirms BOJ Forex Intervention' (<i>Reuters</i> June 14, 1999).
Reports of intervention	'BOJ seen buying dlrs at around 104.00 yen in Tokyo' (<i>Reuters</i> August 11, 1993).

Table 2: Sources: Reuters and Dow Jones reports.

²¹According to Oberlechner and Hocking (2003), the wire services are the most important sources of information and this information often consists of market participants' perceptions and interpretations .

5 Model

Up to now, the effects of CBIs have been investigated for a large set of measures including the spot exchange rate, the implicit moments of options data (Galati and Melick, 1999; Morel and Teiletche, 2005), and the heterogeneity of exchange rate forecasts (Beine *et al.*, 2004a), and various models. In this study, intra-daily data were used to estimate the impact on the first, second and third moments. The realised first moment is simply the daily return. Therefore, the focus is on the theoretical properties of the realised volatility and, at a lower level, on the realised skewness.

5.1 Realised Volatility

Officials have often justified their attempts to regulate the currency by the need to 'calm the disorderly market'. That is, to reduce the volatility. Therefore, one of the main issues in the CBI literature has been the empirical verification of the real impact of interventions on volatility (Dominguez, 1998; Beine *et al.*, 2002). The variety of measures of volatility used in the various studies GARCH (Dominguez, 1998), FI-GARCH (Beine *et al.*, 2002), EGARCH (Fratzscher, 2004) reflects progress in the modelling of this financial time-series pattern. Volatility cannot be directly observed, but it has crucial implications for many portfolio management strategies. To fill this gap, researches have proposed numerous sophisticated statistical models to capture the usual characteristics of financial data (such as fat tails, inertia in the volatility, leverage and feedback effects (Bollerslev *et al.*, 2005)).

Until recently, great attention was paid to parametric models. Many of these were in the tradition of Engel's (1982) seminal work, where the volatility expectation was formulated in terms of directly observable variables ²². Although this specification is convenient ²³, it is quite restrictive. As Andersen *et al.* (2000) pointed out, 'the existence of competing econometric volatility models with different properties, e.g., GARCH versus stochastic volatility models, suggests misspecification; after all, at most one of the models could be correct, and surely, none of the models is strictly correct'.

More recently the availability of intra-daily time-series data has revived interest in non-parametric realised-volatility models. Formerly used for weekly data, to construct monthly realised volatilities (French *et al.*, 1987; Schwert, 1989), this approach has been extended to measure daily volatility. Andersen *et al.* (2000) showed that under the assumption of a continuous time-diffusion process for the underlying asset price,

²²Engel's work on ARCH in 1982 has been developed in numerous models intended to provide a more parsimonious form using the GARCH model (Bollerslev, 1986), to capture the leverage effects with EGARCH (Nelson, 1991), and, more recently, to capture the long-memory with FIGARCH.

²³It allows computational estimations or forecasts to be performed easily.

the realised volatility computed from high-frequency data provides an unbiased and consistent estimate of latent notional or integrated volatility. In practice the realised volatility (RV) for day t and period i is computed by sampling intra-daily data at a high frequency and cumulating the square products of the relevant returns over a specific horizon (here a day). Let m be the fixed sampling frequency ($m=48$ for 30-minute intervals over 24 hours). The daily measure of realised volatility is then simply

$$RV_{t,i} = \sum_{j=0}^{47} (r_{t,i-j})^2 \quad (2)$$

5.2 Realised Skewness

Although asymmetry is an important component of financial markets (see, for example, risk reversal in option data), few studies have investigated the properties of the third moment. Papers on option data have investigated some elements, with the computation of the risk-neutral density. However, liquidity problems and strong assumptions about the underlying model make them very noisy (Neely, 2004). Recently Beine *et al.* (2005) performed a set of estimations on realised skewness (see also Dacorogna *et al.*, 2001). Following their approach, the realised skewness (RS) can be defined as

$$RS_{t,i} = \frac{\sum_{j=0}^{47} r_{t,i-j}^3}{(\sigma_{t,i}^2)^{3/2}} \quad (3)$$

6 ARFIMA

As the daily returns, the realised volatility and the realised skewness are observable they can be modelled by the usual ARMA(n, q) type of models. The selection of a simple ARMA(n, q) or a more sophisticated long-memory ARFIMA(n, d, q) model was made according to the specific pattern of each series²⁴. Then, exact maximum likelihood estimation (Sowell, 1992) through Oxmetrics ARFIMA 1.01 Package (see Doornik and Ooms, 1999) was performed for the most suitable model. Following Beine *et al.* (2005), rolling regressions were used to identify precisely the impact of CB actions at different periods of the day. Since 30-minute data was being used, 48 models per day ($i = 0, 1, 2, \dots, 47$) were estimated. A window of two days after each special event is reported to capture persistence. Formally, the general ARFIMA(n, d, q) is written as

$$\Phi(L)(1-L)^d[y_{t,i} - \mu] = \Theta(L)\epsilon_t + \mu_t \quad (4)$$

²⁴The specification is based on preliminaries studies for each series. For space reasons they are not reported here, but are available from the author on request.

where

$$\mu_t = \sum_{j=1}^p \beta. Cont_{t,j} + \sum_{j=1}^n \beta. Strat_{t,j} \quad (5)$$

Where $y_{t,i}$ is the endogenous variable((i) the yen/dollar daily returns, (ii) the realised volatility or (iii) the realised skewness); t is the day and i the period of the day; d is the fractionally integrated parameters; $\Phi(L)$ and $\Theta(L)$ are the autoregressive and moving average terms respectively; and ϵ_t is the error term which is assumed to be normally and identically distributed.

Explanatory variables are separated in two groups:

- The control variables designated $Cont_{t,j}$. In line with the literature, the Monday effect(Hsieh 1989)is captured by a dummy variable which was set to 1 on each Monday. Dummy variables with 1 on the days of interventions from the Bundesbank and the Federal Reserve on the mark/dollar exchange rate were also introduced.
- The different strategies designated $Strat_{t,j}$, where 1 is used for the day of intervention and 0 elsewhere. Regressions where also performed for a window of two days after an intervention. In this case the dummies were shifted by the appropriated number of days.

Insert Table 3 about here

7 Preliminary results

Most researchers have looked at the effect of intervention at a daily level (Dominguez, 1998; Beine *et al.*, 2002). This induces them to select a precise exchange rate quotation. In general studies adopt 21.00 GMT, the close of the US foreign exchange market. This remains, however, subjective, with a potential impact on final results, since short-run effects (Dominguez, 2003; Beine *et al.*, 2005)²⁵ and those with a time delay are likely to be missed. With this in mind, I decided to include daily results at 21.00 GMT in Appendix Tables ?? so as to be able to compare my results with the rest of the literature. However, this constraint is loosened in Appendix Figures ?? which present the ruling regressions coefficients and the 95% confidence intervals (dashed lines) for different quotation times²⁶.

7.1 Benchmark Model 1: Mouth versus Amount

The first model compares the effectiveness of actual interventions and statements. Both can convey a signal. However the former is usually considered more credible since the authorities accept a financial cost. Ac-

²⁵Both these studies identify mainly short-run effects which daily studies are unable to capture properly.

²⁶For space reasons the Appendix figures and tables are not included here, but are available from the author on request.

According to Table ?? neither actual interventions nor statements influence the exchange rate returns. Worse, the realised volatility is significantly higher when the central bank tries to actively regulate its currency (actual intervention or statements). To a certain extent, these results confirm the existing empirical literature. In general, researchers have not identified robust effects of actual intervention on returns. Volatility is, however, argued to increase in most cases. For statements, Jansen and De Haan (2003) found only a slight negative effect of talk (announcing possible interventions) on euro/dollar rates. Fratzscher on the other hand, identified clearly a negative impact on the yen/dollar rate. This result is quite surprising as my research covered a similar period. However, my sample contained many more days with statements. This difference between the samples could be explained by their definitions. The present study captured every statement from an official (on the value of the currency or possible interventions) which was likely to influence the exchange rate. Fratzscher on the other hand, restricted his sample to statements advocating a stronger or weaker domestic currency. The second model (below) differentiates between these two types of statement, and may so be more informative on this point. It is worth noting that these negative results are slightly tempered by those on the realised skewness, which were significant at 5% for actual interventions.

7.2 Benchmark Model 2: Visible versus Hidden Interventions

As a whole, the second model draws a less pessimistic picture. Table ?? clearly shows that reported interventions are highly significant. Indeed, the first and third moments move significantly in the desired direction when the volatility is markedly higher. Secret interventions, on the other hand, are clearly snubbed by the market in the short term. From a theoretical point of view, all of this is fully coherent with both the signalling and the coordinating channels. Indeed, by clearly indicating its presence on the market the CB helps agents decide whether to change their ideas about the exchange rate or target a new focal point. In both situations strong volatility may indicate that market participants are having difficulty absorbing this new information (see Section 2 above).

If we shift to the event window, we can discern a significant sensitivity of the exchange rate skewness to secret interventions in the medium term. Although the yen/dollar returns did not move much, the dollar selling or buying by the Bank of Japan was successful in putting a floor under the yen. This last point could be interpreted as an element of validation for the noise-trader channel where central banks buy or sell secretly to reverse a strong one-way trend. In this framework, the skewness reveals that the asymmetry on the market evolved in the direction desired by the authorities. The delay is also coherent with the framework, since market participants are only likely to gradually change their view on the existing trend.

Results on statements are also fruitful. The most striking is probably that oral interventions (which convey a signal about fundamentals) virtuously influenced the exchange rate returns. This is particularly interesting since nothing significant was noted at an aggregate level. Threats, however, had the opposite effect.

A preliminary conclusion would be that it is essential to maintain a dialogue with the market, but that this should be done under certain conditions, and that words alone cannot systematically stem the tide.

The failures of threats remains quite surprising, and demands further explanation. First, such statements cannot be precisely associated with a theoretical channel. Some would probably argue that there is at least an indirect reference to the fundamentals in statements such as 'MOF Kuroda/Steps -2: Will Take More Steps To Stem Yen Rise' (*Dow Jones*, 14 June 1999). But even if this is admitted, there is no doubt that this message is far less clear or transparent than an oral intervention. More importantly, its main target is obviously somewhere else ²⁷. By warning the market against acting in the near future the authorities paved the way for rumours and speculations about future interventions (Beine *et al.*, 2004a; Dauchy (2001); Gnabo and Lecourt (2005)) .

Another way of interpreting this issue (or, more precisely, extending it) is to consider that the central bank does not tailor all its messages to the same audience. Oral interventions are *a priori* aimed at people concerned with the fundamentals. Threats, on the other hand, explain the risks associated with speculative positions and portfolio losses. For example on 5 April 2001 the financial press reported that 'During Asian trading, trenchant remarks from Finance Minister Kiichi Miyazawa and his deputy Haruhiko Kuroda injected into the market an element of risk that has not been felt by yen traders in two years: a fear of intervention' (*Reuters* April 5, 2001). Another example occurred on 22 June 1994 when an official issued a threat of intervention: 'Japan to take steps on currencies - MOF official' (*Reuters* June 22, 1994). Later that day, the financial press interpreted this as a message tailored to speculators: 'The comment was viewed as a warning to currency speculators that intervention involving massive dollar purchases ... was possible' (*Reuters* June 22, 1994). These failures tend to show that the central bank is unable to talk effectively to this category of agents. This result obviously reflects a lack of credibility, with traders voicing scepticism over whether words would be backed by action ²⁸, and whether any such action would be successful. It also illustrates the drawbacks of transparency when speculators decide to challenge the CB's words or targets (Chiu, 2003). Like Beine *et al.* (2005) and Dominguez (2003) this study revealed only short-lived effects on persistence. Most effects waned after one day. More interestingly, the persistence of oral interventions was greater than that

²⁷Its main goal is obviously to prevent the market from pushing the exchange rate out of the CB's range.

²⁸'Traders still wary of verbal threats from MOF officials but most doubt they would intervene at present levels and it would take a fast move toward 130.00 to draw actual fire'. (*Reuters*, 9 April 2001)

of reported interventions (Figure ??). The results on realised skewness were quite similar to those on returns.

7.3 Model 3: Confirmation Speeches

Model 3 with confirmation speeches reinforces previous remarks (Table ??). Hence by adding comments to actions, the CB sharply increased its impact on returns since other reported interventions were no longer significant. This is in line with the signalling channel model, where the quality of the signal (its clarity) is an important component of success (Figure ??). It can also be viewed as a more credible focal point for the market. These results are in line with the existing literature, since Beine *et al.* (2004b) also found that confirmation speeches had a significant impact on returns. On the other hand, this study revealed a strong increase in volatility after confirmation speeches, where Beine *et al.*'s (2004) conditional GARCH(1,1) model found none. This is quite interesting as it raises the possibility of a trade-off between returns and volatility. The difference between these studies might be due to the measure of volatility, but it could also be attributed to the data collection. This study identified 46 days with confirmation speeches, compared to 30 in Beine *et al.* (2004b) over the same period.

7.4 Model 4: Mixed Policies

Up to now, empirical evidence has emphasised the key role of communication policy. In sum, words can replace acts or strengthen them. Transposing these conclusions to Enoch's (1998) transparency framework allows two conclusions to be drawn. First, words can replace acts by improving real-time transparency since talking to the market is by definition transparent in real time (the market has full information on what the central bank is doing). Second, statements can underpin the actual interventions policy by improving the signal after an intervention. That is *ex post* transparency. Now we investigate whether an improvement in *ex ante* transparency is useful. The basic idea is that, by improving the transparency of future actions or the central bank's expectations, the market should be able to understand the signal more easily, i.e. react faster and absorb it in a better way. Concretely, the effects of reported interventions preceded or not preceded by statements were compared. Table ?? shows that interventions which were not preceded by statements had no significant effects on the returns. Those preceded by a statement were slightly more effective, although this effect was really short lived. Both strategies affected the volatility and the realised skewness to the same extent. As a whole, the results are less clear than those for confirmation speeches. So it is not clear whether central banks should seek to improve their *ex ante* transparency to improve their effectiveness, or should try to surprise the market.

7.5 Model 5: Clustered Interventions

Another way for CBs to maximise their impact is to work on the timing of actions that is, for example, to act only through isolated interventions (as happened under Sakakibara) so as to surprise the market, or to use clustered interventions to show their determination and strengthen their credibility. Table ?? suggest that, for returns, isolated reported interventions are much more effective than clustered interventions. This result is consistent with both the news theory and the signalling channel. Both types of action were followed by higher moments for volatility and skewness.

7.6 Model 6: Incoherence

Some inconsistent targets may lead CBs to move secretly in order to 'fool' the market (Vitale, 1999; Beine and Bernal, 2005). These actions are likely to operate through the order flows as described by the microstructure framework used by Vitale (1999) and Lyons (2001). This theory can be tested by estimating the impact of secret interventions when the target is inconsistent with the fundamentals. Columns 2 and 6 Table ?? suggest that this strategy is rather ineffective. As for secret interventions as a whole, inconsistent secret interventions failed to change the moments in either the short and the medium term (2 days).

7.7 Robustness

Robustness of the results is test for robust standard errors, bootstrap inference and alternative models for the long memory, namely the HAR-RV. Previous feature remain unchanged. More details are provided in the Annex.

Insert Figure 4 about here

Insert Figure 5 about here

Insert Figure 6 about here

Insert Figure 7 about here

Insert Figure 8 about here

8 Conclusion

This study tested the effects of different intervention strategies on the realised moments. It provides a contribution to the existing literature by using a new dataset which captures three different kinds of statements. Moreover, it performs ARFIMA estimation on daily returns, realised volatility and realised skewness. These measures are based on the recent promising econometric literature on realised moments. Unlike former GARCH type models or implicit moments from option data, realised moments are under some assumptions unbiased estimators. Our results show that different strategies have different impacts on the exchange rate. It is important to discriminate between three types of actual intervention (secret, reported, confirmed by speeches) and three types of statements (threats, oral interventions, confirmation speeches). Overall, transparent policies (actual interventions confirmed by a speech and oral interventions) are the most effective. These results emphasise the crucial role of the communication policy and the necessity for CBs to select their audience properly. The impact of the various strategies on skewness are quite similar to those on returns. On the other hand, these policies are accompanied by a strong increase in volatility.

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9 Annex: Robustness and Inference, The Bootstrap

9.1 Introduction to the Bootstrap

The first set of results are based on classical t-tests, as are those in Beine et al. (2005). In this approach the null hypothesis of no effect is rejected if Student's t-statistic is above a specific critical value. This value depends on strong assumptions about the theoretical distribution of the t-statistic for a finite sample. Hence we have assumed that (with more than 3000 observations), the t-statistic followed a normal distribution. For a two-tailed test, the 5% level of significance is associated with a t-value of 1.96.

The idea of the bootstrap method is to provide an alternative way of obtaining the distribution to which test statistics are to be compared (Davidson and MacKinnon, 2004). In practice, it consists of generating a large number of bootstrap samples, for each of which a bootstrap test statistic is computed. This collection of bootstrap statistics then constitutes the empirical distribution, which is a good approximation to the (unknown) true distribution of the test statistic. In a last step, the original test statistic is compared to this distribution. In sum, the bootstrap is a way to relax excessively strong assumptions about the data generating process (DGP) of statistics and thus to improve the statistical inference.

The final objective, here, is to compute new p-values for our two-tailed test. With the bootstrap approach the p-value is defined as

$$p^*(\widehat{tstat}) = R^{-1} \sum_{r=1}^R I(|tstat_r^*| \geq |\widehat{tstat}|) \quad (6)$$

where $I(.)$ is equal to one if the inequality is satisfied and zeros otherwise. R is the total number of bootstrap samples, with the same size that the original sample. $\widehat{tstat}$ is the original statistic and $tstat_r^*$ are the bootstrapped statistic.

Although an increasing number of studies relies on bootstrap methods, their accuracy is quite sensitive to specific patterns in the original data. For example, the re-sample can not be performed in the same way for time series or cross-sectional data. Specific patterns such as autocorrelation or heteroskedasticity should also be carefully considered.

Residuals for different models contain no autocorrelation but highlight some heteroskedasticity. In the following section the properties of different test procedures are briefly investigated. In a second step, these test procedures are applied to previous models to see whether results are robust.

The traditional way to deal with heteroskedasticity in time-series models is to compute a robust estimator of the covariance. This can be done using the White estimator.

$$(X'X)^{-1}X'diag(\epsilon_t^2)X(X'X)^{-1} \quad (7)$$

Where X is the matrix of regressors and ϵ_t is the residual.

Then we rely on bootstrap methods to have a better inference. Goncalves and Kilian (2004) suggested three types of bootstrap method: (i) recursive-design wild bootstrap; (ii) fixed-design wild bootstrap; and (iii) the pairwise bootstrap, to deal with heteroskedastic time-series data. The recursive-design wild bootstrap was implemented here, mainly because of its performance in large sample (Goncalves and Kilian, 2004). It is also less time-consuming to apply than the others (mainly the pairwise bootstrap). It consists of generating a large number of bootstrap sample y^* for the dependent variable and X^* for the regressors. Both types are constructed as

$$y_t^* = X_t^{*'} \cdot \hat{\phi} + \epsilon_t^* \quad (8)$$

with the possibility of including the lags of the dependent variables y_{t-i}^* in the regressors, $\epsilon_t^* = \hat{\epsilon}_t \cdot \eta_t$, with $\hat{\epsilon}_t = y_t - X_t' \hat{\phi}$ and where η_t is an i.i.d. with zero mean and variance one. In practice $\eta_t \rightarrow N(0, 1)$ was used. Previous empirical studies (Goncalves and Kilian, 2004) have shown that results are robust to alternative choices. Under certain conditions the recursive-design wild bootstrap (RDWB) is asymptotically valid for finite-order autoregressive variables with conditionally heteroskedastic errors (see Kreiss, 1997 and Goncalves and Kilian, 2004 for further details). To estimate the new models through simple ordinary least squares (OLS) the original specifications were slightly modified. Hence for the first and the third moments AR (2) models were applied. The ARFIMA model cannot be estimated through OLS so the shift to the HAR-RV proposed by Corsi (2004) to capture the long memory was employed. The basic idea is to view the realised volatility as a simple AR-type model with the feature that it can consider realised volatility over different time horizons. Formally the model can be written as

$$RV_t = c + \alpha Var_t + \beta_{t-1}^d RV_{t-1}^d + \beta_{t-1}^w RV_{t-1}^w + \beta_{t-1}^m RV_{t-1}^m + w_t \quad (9)$$

where c is a constant, Var a set of explicative variables, RV_{t-1}^d the short-run resistance (the volatility corresponding to a time horizon of one day (d), one week (w), and one month (m)). For further details see Corsi (2004).

Insert Table 4 about here