Does Intervention Alter Private Behavior?

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Abstract

A new line of theory posits that intervention in currency markets works indirectly, either by (1) coordinating private trades in the same direction or (2) damping the price impact of private trades. Using daily data on trades from three institution types—hedge funds, mutual funds, and non-financial corporations—we find strong evidence for the coordination channel. Over the period of aggressive Japanese intervention in 2003-04, the trades of corporates and hedge funds shifted significantly in the intervention direction. Evidence for the second, the damping channel, is present in periods when exchange rate stabilization was successful.

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I. Introduction

Textbook currency intervention by central banks, whether sterilized or unsterilized, operates through a direct channel, in the sense that observable intervention has an immediate and direct effect on prices. An alternative school of thought, cited often by policymakers, is that intervention works indirectly by inducing changes in private sector behavior. For example, intervention is more effective under this view if it can induce trades of fundamentalists (Taylor 2005, Reitz and Taylor 2006), or of noise traders (e.g., Hung 1997), in the same direction. Another indirect channel is that intervention, when credible, damps volatility by damping private trades' price impact (Vitale, 1999; Killeen et al. 2006). These indirect channels shift the analytical focus from macroeconomics to the microeconomics of how prices are actually determined.

This paper addresses how intervention alters private behavior, if at all. This is of interest both for the conceptual debate above and as a guide to new policy tools. Though the idea of indirect channels is old, direct (as opposed to reduced-form) testing for their presence was not done previously since it requires micro data on institutions like hedge funds and mutual funds, coupled with sufficient intervention data. Analysis of this type is now feasible. We use daily data on trades from three institution types—hedge funds, mutual funds, and non-financial corporations. We overlap these data with detailed intervention data from the Bank of Japan (BOJ). Our primary focus is the punctuated period of aggressive BOJ intervention in the yen/dollar market in 2003 and early 2004. (BOJ intervention has not been active from April 2004 to the present.) We find strong evidence for the coordination channel: Over the period of aggressive Japanese intervention in 2003-04, the trades of corporates and hedge

funds shifted significantly in the intervention direction compared to the previous period. Evidence for the second channel, damping, is more mixed in that it operated only in periods when stabilization was successful.

We refer to the first of the two indirect channels as the coordination channel. Taylor (2005) and Hung (1997) provide theoretical perspective respectively for the coordination of fundamentalists and of noise traders. In the Taylor (2005) model it is not optimal for a fundamentalist trader to trade aggressively on her own. Intervention serves as a coordinating signal that induces fundamentalists to trade jointly, and this shift in private behavior accounts for intervention's success. The Hung (1997) model is in the same spirit, except that in her model intervention induces a shift in behavior of noise, or non-fundamentalist, traders. Specifically, intervention induces private trades in the direction of the intervention via positive feedback trading (perhaps due to technical analysis). In her model, positive feedback trades make otherwise temporary portfolio balance effects more persistent.

We refer to the second of the two indirect channels as the damping channel. The damping channel is based on the degree to which private trades affect price (Vitale, 1999). Intervention represents a signal about the exchange rate target of the bank. Such intervention is most effective the stronger the commitment to the target or the most secret the intervention. At the limit, when such intervention is most effective, the informativeness of order flow vanishes, and market liquidity rises sharply, i.e. private trades have no price impact, even if the central bank is not itself trading. More formally, the elasticity of private demand becomes infinite and return volatility shrinks to zero, making the holding of foreign exchange effectively riskless. In contrast, when intervention is perfectly ineffective, then the price impact of private trades is as usual, namely, positive and significant.[1] Between these extremes, intervention can be viewed as more effective when it damps the price impact of a

[1] Empirically, the price impact of private trades has been variously estimated in the range of three to ten basis points per $100 million, see, e.g., Evans and Lyons (2002), Lyons (2001), and Rime, Sarno, and Sojli (2006).

given-sized private trade. For the damping channel, we use the term *weak effectiveness* to describe the case where private trades have no price impact on intervention days, but do have impact on other days. Strong effectiveness is when private trades have no price impact on any day, including days without intervention.

The literature on central bank intervention in currency markets is vast. The branch that focuses on macroeconomics, in particular sterilized and unsterilized intervention, is surveyed by Dominguez and Frankel (1993) and Sarno and Taylor (2001). Before 2000, the macro branch tended toward a consensus that intervention is generally ineffective in moving exchange rate levels, and tends only to increase volatility (Baillie, Humpage and Osterberg 2000). The early 2000s brought a new phase of macro-based intervention research with the release of historical intervention data by the BOJ. The consensus was shaken when Ito (2002) showed, with daily data, that BOJ intervention through the 1995-2001 period was successful in affecting the exchange rate level (see also Fatum and Hutchison 2002, Ramaswamy and Samiei 2000, Nagayasu 2004, and Watanabe et al. 2006).

There is now a second, distinct branch of intervention analysis grounded largely in microstructure finance (e.g., Dominguez 2003, D'Souza 2001, Pasquariello 2007, Evans and Lyons 2002, Carpenter and Wang 2003, Scalia 2004, Fatum and King 2005, Vitale 2005, and Chari 2006). This micro-based work suggests, among other things, that scrutinizing the trading process is essential for understanding how currency markets aggregate information, particularly at times of intervention. A downside of work in this branch is that detailed trade data are usually available only over short samples (e.g., the forty-five days of trading and thirteen days of intervention addressed by Carpenter and Wang, 2003). This paper is the first in this branch to examine the empirical relevance of the two indirect channels and we do so with dataset spanning many years. Reitz and Taylor (2006) also address the fundamentalist-

type coordination channel empirically, but their evidence is indirect, since they estimate their model using exchange rate data, not data on private trades.

The remainder of the paper is structured as follows. Section II presents our data and some stylized facts about Japanese intervention from 1995 to 2004. Section III introduces the theoretical framework for the coordination and damping channels. Section IV presents results specific to the coordination and damping channels. Conclusions are in section V.

II. Data and Stylized Facts

Our tests exploit a unique database. It covers the period July 1995 to March 2004 and includes all yen-dollar trades—with a sign corresponding to the direction of trade—between Citibank and all its end-user customers. (Citibank was among the top three worldwide and managed roughly 10 percent of end-user trades on the large foreign exchange markets.) The data include both spot and forward trades, but are netted of any trade in FX swaps, because swaps do not constitute net order flow in FX. Even though inter-bank transactions (as used by Evans and Lyons, 2002) account for about half of total volume in major currency markets, they are largely derivative of the underlying shifts in end-users flows. Data on end-user trades present the major advantage of being in direct relationship with the underlying sources of demand in the economy, and are not generally available to researchers, hence the special opportunity here. Three types of end-users corresponding to the categories commonly applied by practitioners are included: non-financial corporations, unleveraged financial institutions (institutional investors like mutual funds, life insurance companies and pension funds), and leveraged financial institutions (hedge funds and banks' proprietary trading desks). The three segments span the full set of underlying demand types. With such a disaggregation, it is possible to study to what extent order flows from certain types of market participants have greater impact on price—dollar for dollar—than others. The data are available on a daily

basis, corresponding to the aggregation of all the end-user orders (executed trades only) received by this bank worldwide (see Fan and Lyons 2003 for a descriptive analysis of these data up to 1999). The data span almost nine years, which is much longer than the sample over which data are usually available for inter-bank order flows. Per Table 1, on average over the sample both corporates and mutuals sold dollars for yen, while hedge funds bought dollars (except during the most recent period). Naturally, these averages mask considerable variability.

[Insert Table 1 here]

Daily Bank of Japan intervention data come from the Japanese Ministry of Finance, and Federal Reserve intervention from the Federal Reserve Board. To mitigate possible endogeneity of order flow as well as to study the effects of Fed intervention, the yen-dollar exchange rate that we use is that for the end of the New York trading day. We present, in Figure 1, BOJ intervention converted into dollars.

[Insert Figure 1 here]

The intervention regime prior to the 2003-2004 regime began in mid 1995 with the arrival of Mr. Sakakibara at the Ministry of Finance (Ito 2002). From August 1995 through December 2002, the BOJ intervened on 54 days, trading an average daily amount of $4.8 billion (Table 1). A substantial change occurred in mid January 2003 with the arrival of Mr. Mizogushi at the Ministry of Finance (Ito, 2005; Chaboud and Humpage 2005), as well as with the request by the Ministry to the Bank of Japan to cease the active conduct of foreign exchange operations and place standing orders with a few dealing banks confidentially, entering the market *intuitu personae*. Over this much shorter period until March 2004, intervention occurred on 140 days with an average daily amount of $2.3 billion. This was decomposed into $239 billion over 85 days after the G7 finance ministers' meeting[2] on 20th

[2] In its communiqué, the G7 affirmed "that exchange rates should reflect economic fundamentals" and emphasized "that more flexibility in exchange rates is desirable for major countries".

September 2003 (average $2.8 billion per day) as against $75 billion over 55 days before that date ($1.4 billion per day). From early 2003 through March 2004, the BOJ followed a strategy in line with leading prescriptions for kick-starting the Japanese economy at a time of near-zero interest rates (Bernanke 2000; McCallum 2000; Svensson 2000). It poured yen into the foreign exchange markets, roughly $300 billion, in trying to stabilize the yen/dollar rate. In spite of the presence of positive macroeconomic news for the Japanese economy, which might have led to an appreciation of the yen vis-à-vis the dollar, over the second quarter of 2003 the yen was kept inside a narrow trading band relative to the U.S. dollar. Accordingly for the first eight months of 2003 (figure 2) "there has been unprecedented stability in the yen-dollar: its rate remained between 115 and 122 yen to the dollar…the narrowest trading band these currencies have exhibited since the breakdown of the Bretton Woods system" (Spiegel, 2003, p.3). After the Dubai Summit, in late September 2003, the BOJ stopped intervening and the yen appreciated; but subsequently, with the resumption of intensive intervention, appreciation was slowed. The fall in the dollar during three weeks from late September to early October 2003 suggests omitting these three weeks when splitting the period of heavy intervention around the Dubai Summit. Overall, the volatility of the yen-dollar rate was reduced by a third after December 2002.

[Insert Figure 2 here]

The extent to which intervention was sterilized is a major issue. Officially all Japanese interventions are fully sterilized by the issuance of bills.[3] However, the interest rate floor of zero reached by interbank yen rates in February 1999 implies that in interest rate terms, sterilization would make no difference. In March 2001, as part of the strategy aimed at kick-

[3] Intervention by the BOJ is automatically sterilized. As argued by Ito (2002, p.5): "Financial bills (short-term government bills, with maturity of three months) are issued to the market to obtain yen cash that is used to purchase the foreign currency denominated assets in the intervention. Since domestic bills are issued to obtain the yen before the dollar is purchased through intervention by the yen, the intervention can be regarded as automatically sterilized."

starting the Japanese economy, the BOJ changed its policy approach and switched to quantitative easing by saturating banks with reserves. Existing evidence indicates that during the period of the "Great Intervention" (Taylor, 2006) of 2003-2004, at least 40 percent of yen-selling interventions were not immediately offset by the monetary operations of the BOJ and remained in the market for some time, while previously nearly 100 percent were offset. (Specifically, over the most recent period, financing bills issued to sterilize intervention were immediately purchased by the BOJ after their issuance; see Watanabe and Yabu, 2007.) The extent of quantitative easing can be measured by changes in excess reserves held by banks with the BOJ. The average rise in excess reserves on days of intervention, which was close to 8 billion yen from 1999-2002, jumped to more than 100 billion yen over the Great Intervention period (Table 1, last column).

III. Theoretical rationales for the coordination and damping channels

Rationales for the indirect channels are examined first from the point of view of the styles of private behavior, both fundamentalist and chartist, and second with respect to the ability of central bank intervention to dampen the price impact of private trades.

Coordination channel

We refer to the first of the two indirect channels as the coordination channel. Two variants have been put forward involving respectively the coordination of fundamentalists and of noise traders. Taylor (2005) and Hung (1997) provide theoretical perspective respectively on the former and the latter.

In the Taylor (2005) model, a fundamentalist trader does not find it optimal to trade aggressively on her own. Intervention serves as a coordinating signal that induces fundamentalists to trade jointly, and it is this shift in private behavior that accounts for

intervention's success. Intervention by the central bank acts as a coordinating device, signalling to fundamentalists that it is time to act jointly so as to suppress the misalignement.

The asymmetric information model of Kyle (1985) is a useful framework to portray such behavior by fundamentalists. The centralised batch structure of this model, although not truly representative of the over-the-counter nature of the foreign exchange market, is well suited since it conveys well the absence of transparency which characterises such a market: the market maker cannot observe the trading motivations of her clients, and therefore cannot distinguish between informed and uninformed traders (Vitale, 1999). The order flows of supposedly informed fundamentalists would depend on their confidence in fundamentals. Such confidence is a function of past intervention by central banks in the foreign exchange market because the central bank is assumed to possess superior information about the fundamental value. A central bank, buying a currency which fundamentalists perceive as undervalued, reveals incremental private information that the bank has. Observing past intervention (I_{t-j}) in support of such a currency, fundamentalists' confidence in mean-reversion to fundamentals rises and they follow in the footsteps of the central bank, buying the currency. The order flows by informed traders (D^I) can thus be modelled as:

$$(1) \qquad D_t^I = \sum_{j=0}^{n} a_j I_{t-j} + b(i_t^* - i_t)$$

The sign of the interest rate differential term $(i^*_t - i_t)$ is ambiguous. The positive coefficient implied by Uncovered Interest rate Parity (UIP) may be balanced by a negative coefficient stemming from bets by traders against UIP (Reitz and Taylor, 2006).

The noise-trader coordination model of Hung (1997) is in the same spirit, except that in her model intervention induces a shift in behavior of non-fundamentalist traders. Specifically, intervention induces private trades in the direction of the intervention via positive feedback trading (perhaps due to technical analysis, though the motivation is unmodeled). In her model, positive feedback trades make otherwise temporary portfolio

balance effects more persistent. A transitory price effect from intervention leads chartists to perceive that a trend is broken. Chartists' subsequent trades are bets that the reversal initiated by the intervention will stick.

The chartists, or technical traders, follow strategies that naively depend on past returns (Barberis, Schleifer and Vishny, 1998), relying on trend-extrapolating methods. Within the framework outlined above, order flows by such agents (D^U) can be modelled as a positive function of recent lagged exchange rate returns (Δe_{t-k}), plus the interest rate differential (whose coefficient has an ambiguous sign as before):

$$(2) \qquad D_t^U = \sum_{k=0}^{n} c_k M * \Delta e_{t-k} + d(i_t^* - i_t)$$

Suppose that intervention (represented here by a multiplicative dummy, M) succeeds in influencing returns, inducing a trend reversal, the noise-trader coordination channel would be vindicated whenever evidence of momentum strategies is documented. Of course, this is a necessary, but not sufficient condition for vindicating such a channel. However, if momentum strategies are absent, then the noise-trader coordination channel is ruled out.

There is an additional dimension to the coordination channel that relates to effects on order flow persistence. Persistence is a well-recognised feature of international portfolio flows (documented for instance by Froot and Donohue, 2004). The occurrence of central bank intervention may be responsible for increased persistence, i.e. a rise in autocorrelation coefficients of order flow (d_k in equation 3). This may involve the coordination of fundamentalists who, due to various costs and frictions, choose not to react simultaneously. Alternatively, this may involve coordination of noise traders. In a fundamentalist setting, for example, when agents receive private information in a sequential way, rational herding can occur intertemporally (Hirschleifer et al. 1994). To the extent that intervention could succeed in influencing trades of some funds, other fund managers would observe and follow their

trades, leading to a reduction in risk relative to benchmarks (Chow, 1995). Intervention would then have triggered sustained initiation of trades in the same direction.

(3) $$D_t = \sum_{k=0}^{n} c_k \Delta e_{t-k} + d(i_t^* - i_t) + \sum_{k=0}^{n} d_k * M * D_k$$

Damping channel

We refer to the second of the two indirect channels as the damping channel. The damping channel is based on the degree to which private order flows into the market affect price. The damping channel can arise from the signalling role of central bank intervention, from the credibility of the exchange rate level, or from a band announced by the central bank.

To model the damping channel, Vitale (1999) also uses a one-period Kyle microstructure framework. The central bank is the informed insider, replacing the private informed trader of the Kyle model. As is the case for the Kyle insider, the central bank can influence the exchange rate only by altering the dealer's expectations about the fundamental value, with realization V, which is unaffected by intervention, because of sterilization. Through its intervention, the central bank targets the current exchange rate level E so as to minimize the gap with the target E*. However, the bank also wants to minimise the cost of its intervention (buying the currency at E larger than V amounts to a loss), carried out through a market order I. Accordingly the loss function of the central bank is such that:

(3) $$L = I(E - V) + g(E - E^*)^2$$

where g, the degree of commitment to the predetermined target, is common knowledge.

The essence of the model is contained in this loss function, particularly in the fact that the target E* and the fundamental V are not in general equal. In such circumstances the announcement of the target would not be credible, it is thus best to keep it secret. However, these are also circumstances where sterilized intervention is most useful, because it will

convey information to traders. Since sterilized intervention is expensive, the central bank can buy credibility and alter exchange rates by purchasing foreign exchange.

Intervention thus represents a signal about the exchange rate target of the bank. Such intervention is more effective the stronger the commitment to the target and the more secret the intervention. At the limit, when such intervention is most effective, the informativeness of order flow vanishes, and market liquidity rises sharply. That is, in the returns equation (4), the price impact of order flow (f_1) drops to zero.

(4) $$\Delta e_t = f_0 + f_1 D_t + f_2 I_t$$

Killeen, Lyons and Moore (2006), describe a perfectly effective intervention regime as one in which private participants are happy to continue trading at a given price – e.g., a credibly fixed exchange rate. In this regime, private trades have no price impact, even if the central bank is not itself trading.[4] More formally, the elasticity of private demand becomes infinite and return volatility shrinks to zero, making the holding of foreign exchange effectively riskless. In contrast, when intervention is perfectly ineffective, then the price impact of private trades is significant. Between these extremes, intervention can be viewed as more effective when it damps the price impact of a given-sized private trade.

IV. Empirical evidence supporting the indirect Channels

When assessing the coordination channel, the objective is to determine if traders follow in the footsteps of the BOJ when it intervenes, and if so, whether traders adopt strategies that naively depend on past returns, or whether the direction of their trades shows more persistence. An order flow regression for each customer type is thus estimated to account for the three different aspects of the coordination channel. Subsequently we assess the relevance of the damping channel by estimating return equations.

[4] The evidence of Killeen et al. (2006) addresses the announcement of euro conversion rates in early May 1998. The prediction from their theoretical model is borne out: between the pre and post announcement periods, the effect of private order flow on the exchange rate changed from one of clear impact to one of no impact.

Coordination Channel

The fundamentalist-based coordination channel finds some support over the aggressive intervention period of 2003-2004. We test this by estimating the effects of current and past intervention on the dollar purchases of each end-user type (Table 2). Before the start of the Great intervention, intervention by the BOJ always led to trades by customers over the subsequent four days in the *opposite* direction. Over the period of aggressive BOJ intervention in 2003-2004, some shift occurred in the behavior of hedge funds, and to a lesser extent of corporates (row two in each panel of Table 2). As controls in this regression, we have included an autoregressive term, a chartist term (the gap between the one-year and one-month moving averages of the yen-dollar rate), and the London interbank interest rate differential (dollar minus yen). We also controlled for the lagged conditional variance of yen-dollar returns obtained with a GARCH (1,1) model, but we dropped this variable which was insignificant.

[Insert Table 2 here]

By construction, as noted above, intervention is fully sterilized through the issue of bonds. However, expansionary monetary policy decided independently by the BOJ may contribute to the effects of intervention on private behavior. Given the zero interest rate policy after February 1999, including past values of the interest rate differential cannot account for such monetary policy influences. Excess reserves with the BOJ, on the other hand, provide a good proxy for the new monetary policy introduced in 2001.

When we account for quantitative easing, the fundamentalist coordination channel gets more convincing support. Indeed while the overall effects of intervention are mostly negative for corporates and mutuals, past intervention can have positive effects on these end-users order flow on days when excess bank reserves increase. This is the case for corporates or mutuals over the whole Great Intervention period, as well as for hege funds

before the latter (Table 2, third row). When adding the two effects, a significant coordination channel appears in the Great Intervention period for both corporates and hedge funds, but for opposite reasons, due to quantitative easing for the former and intervention for the latter customer type. For hedge funds, in addition, this channel was already present before 2003.

When conditioned on the occurrence of central bank intervention, the feedback effects from past exchange rate changes on order flows provide support for the chartist version of the coordination channel (Table 3). When the dollar appreciates against the yen, perhaps partly as a result of BOJ intervention, corporates and mutual funds subsequently respond by buying the dollar. There is evidence of momentum trading three days after the market moves for corporates in both subsamples, and for unleveraged institutions over the second subsample. Negative feedback trading was present for corporates over the first subsample. Though the noise-trading coordination effect was present in the second half of the nineties for corporates, it strengthened in the period of heavy intervention, by a factor of four, and it only arose in the Great Intervention period for mutual funds.

[Insert Table 3 here]

The 2003-2004 period is unique for the momentum effects triggered by BOJ intervention in the case of both corporates' and mutual funds' trades. In absence of such intervention, momentum effects are not present. For hedge funds' trades, momentum effects occur only when the BOJ is not in the market. This is not new to the 2003-2004 period, but simply sharper. In the noise-trading coordination channel, the presence of quantitative easing does not make any difference (results not reported).

The occurrence of intervention generates additional persistence in customer order flow. We provide supporting evidence based on interacting the presence of intervention with the degree of order flow autoregressivity. For both corporates and mutual funds, over the

1995-2002 period the autocorrelation of order flow is positive and (almost always) of similar magnitude irrespective of the presence of the BOJ in the market (Table 4). However for hedge funds persistence is much higher when the BOJ intervenes. During the Great Intervention period of 2003-2004, this feature is sharpened and generalised. Indeed, an opposite pattern tends to emerge between days (and weeks) with and without BOJ intervention. Indeed, when there is no BOJ intervention, order flow is negatively autocorrelated, while such autocorrelation becomes positive when the BOJ intervenes. Such a pattern is present for both mutual funds and corporates over the full January 2003-March 2004 period, as well as for the two subperiods separated by the Dubai summit. For hedge funds a variation on this contrast is present with persistence always larger on days of BOJ intervention than on days without such intervention (except for the January 2003-March 2004 subperiod).

[Insert Table 4 here]

The role of quantitative easing in explaining flow persistence is clearest when we condition the autoregressive coefficients on the occurrence of both intervention and the change in bank excess reserves (Table 5). In almost all subperiods, for all customer types, persistence is higher when intervention is accompanied by a positive change in bank reserves than when accompanied by a negative change. It is only in the most recent sub-sample that this effect is not present for corporates and mutuals. The first row of each panel of Table 5 provides additional evidence on the low degree of persistence or end-user order flow when we do not control for intervention or expansionary monetary policy. Overall these results imply that the persistence of customer order flow is tied to BOJ intervention, and amplified when the latter is accompanied by quantitative easing.

[Insert Table 5 here]

Damping Channel

As noted, we use the term weak effectiveness to describe the case where the price impact of private trades disappears on intervention days. Strong effectiveness describes the case where private trades have no price impact on any day.

[Insert Table 6 here]

To limit the impact of endogeneity, we work on open-to-close returns in New York (though close-to-close results are qualitatively similar). Over the 1995-2002 period the direct effect, or price impact, of BOJ intervention is one-third to one-sixth the price impact of private trades (Table 6). This may be due to an overestimation of the latter impact due to missing variables. (Our customer data account for about ten percent of all end-user trades, and are likely to be positively correlated with the end-user trades received at other banks.) The price impact coefficients drop to insignificance for both corporates and unleveraged institutions over the first nine months of 2003, corresponding to the stabilization of the yen-dollar within a corridor. After the Dubai summit, insignificance remains for corporates' trades. The direct price impact of BOJ intervention was **slightly smaller** in the first nine months of 2003 as over the 1995-2002 period, and decreased further after the Dubai summit. Further light is shed on the price impact of public trades when account is taken of quantitative easing. Up to September 2003, quantitative easing does not explain the price impact of public trades. Indeed, such price impact is much larger on days when excess reserves fall than when they rise (Table 7). However the evidence is reversed after the Dubai summit, since the presence of a rise in excess bank reserves amplifies by fifty percent the price impact of BOJ intervention.

[Insert Table 7 here]

Evidence of the damping channel is confirmed when we consider the extent to which price impact coefficients are dependent on intervention occurring on the same day. A sharp contrast is apparent (Table 8) between the two sub-periods, 1995-2002 and 2003-2004. Consistent with the damping channel, in the 1995-2002 period trades by all end-users had price impact only on days with no BOJ intervention (noted NOBOJ). This corresponds to our definition of weak effectiveness of intervention. Things changed in the first three quarters of 2003 when trades by both corporates and mutual funds had no price impact irrespective of the presence of the BOJ in the market. This supports the hypothesis of strong effectiveness for these two customer types. In addition weak effectiveness is supported for hedge funds given that their trades only had a significant price impact on days without BOJ intervention. It is noticeable that the latter exhibits a four-fold rise in the price-impact of their trades compared to the first sub-period, despite intervention being more aggressive in the second subperiod. However, leveraged institutions did not go counter to BOJ policy since overall they bought the dollar (Figure 3). After the Dubai summit in September 2003, the significance of the price impact of corporates and hedge funds is only present when the BOJ was intervening. This runs counter to the damping channel and is difficult to interpret using extant theory. Besides, over that last part of the sample, BOJ intervention appears ineffective in damping the price impact of mutuals whatever the sign of excess reserve movements.

[Insert Table 8 here]

[Insert Figure 3 here]

V. Conclusions

Using daily data on trades from three institution types, we find evidence that intervention works through the coordination channel. Over the period of aggressive Japanese intervention in 2003-04, the trades of corporates and unleveraged financial institutions shifted significantly in the intervention direction. The full picture involves all three variations of the

coordination channel: fundamentalist, noise-trading and persistence. For the fundamentalist variant, the shift toward coordination was dependent on accompanying quantitative easing, except for leveraged institutions. Coordination under the noise-trading variant was not dependent on quantitative easing. For hedge funds, the main shift was in their trades' persistence, and even then only when intervention was accompanied by quantitative easing. Evidence for the second damping channel implies weak effectiveness of intervention up to late 2002, and mostly strong effectiveness for the first nine months of 2003 when the yen-dollar was maintained within a corridor.

Though we have referred to intervention that operates through the coordination channel as effective, we need to be clear about our use of the term. Ours is a different definition than that used in traditional intervention literature, which focuses directly on prices. This distinction is important for understanding why our results regarding effectiveness can depart from those in recent price-based studies (e.g., Chaboud and Humpage 2005).

Though the literature on intervention is vast, this paper is the first to use actual transactions data to test whether the two indirect channels actually operate. In textbook treatments, they do not: textbook intervention operates through a direct channel only, in the sense that observable intervention has an immediate and direct effect on prices. Policymakers, on the other hand, have long argued that intervention can work indirectly by inducing changes in private behavior. There is evidence for their view.

Appendix:

Source of data

Daily order flow for corporates, leveraged and unleveraged financial institutions come form Citibank. The daily yen-dollar exchange rate opening and closing rate in New York, as well as the Libor yen and dollar interest rates come from Global Financial Data. The daily intervention data come from the Japanese Ministry of Finance. The daily excess bank reserves data come from the Bank of Japan. All these data cover the sample 28 July 1995 through 18 March 2004, except the excess reserves series which starts on 12 February 1999.

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References

Baillie, R., O. Humpage and W. Osterberg, 2000, Intervention from an information perspective, *Journal of International Financial Markets, Institutions and Money*, 10, 407-21.

Barberis, N., A. Schleifer, and R. Vishny, 1998, A model of investor sentiment, *Journal of Financial Economics*, 49, 307-343.

Bernanke, B., 2000, Japanese monetary policy : A case of self-induced paralysis, in *Japan's financial crisis and its parallels to U.S. experience*, edited by R. Mikitabi and A.S. Posen, Washington D.C., Institute of International Economics, 149-166.

Carpenter, A. and Wang, J. 2003, Sources of private information in FX trading, Working paper, School of Banking and Finance, University of New South Wales, Sydney. January.

Chaboud, A., and O. Humpage, 2005, An assessment of the impact of Japanese foreign exchange intervention: 1991-2004, Board of Governors of the Federal Reserve System, International Finance Discussion Paper 824, January.

Chari, A., 2006, Heterogeneous market making in foreign exchange markets: Evidence from individual bank responses to central bank interventions, *Journal of Money, Credit, and Banking*, forthcoming.

Chow, G. (1995) Portfolio selection based on return, risk, and relative performance. *Financial Analyst Journal*, 54-60.

Dominguez, K., 2003, The market microstructure of central bank intervention, *Journal of International Economics*, 59, 25-45.

D'Souza, C., 2001, A market-microstructure analysis of FX intervention in Canada, Working paper, Financial markets division, Bank of Canada, Ottawa, March.

Evans, M., and R. Lyons, 2002, Portfolio balance, price impact, and secret intervention, NBER Working Paper 8356.

Evans, M., and R. Lyons, 2002b, Time-varying liquidity in foreign exchange, *Journal of Monetary Economics*, 49, 1025-1051.

Evans, M., and R. Lyons, 2005, Are different-currency assets imperfect substitutes? in *Exchange Rate Economics: Where do we Stand?* Edited by P. DeGrauwe, Cambridge: MIT Press.

Evans, M., and R. Lyons, 2006, Understanding order flow, *International Journal of Finance and Economics*, 11,3-23.

Fan, M., and R. Lyons, 2003, Customer trades and extreme events in foreign exchange, in *Central Banking, Monetary Theory and Practice: Essays in Honor of Charles Goodhart*, edited by P. Mizen, Cheltenham: Edward Elgar, Volume 2: 160-179.

Fatum, R. and M. Hutchison, 2002, Is foreign exchange intervention an alternative to monetary policy? Evidence from Japan. University of Copenhagen, Department of Economics, working paper 02-11.

Fatum, R., and M. King, 2005, Rules Versus Discretion in Foreign Exchange Intervention: Evidence from Official Bank of Canada High-Frequency Data, University of Copenhagen, Department of Economics, working paper 05-06.

Froot, K. and Donohue (2004) Decomposing the persistence of international equity flows, *Finance Research letters*, 154-170.

Girardin, E., and N. Horsewood, 2002, New transmission mechanisms and instruments of monetary policy at near zero interest rates: The case of Japan in the 1990s. In *Essays in honour of Maxwell J. Fry*, edited by D. Dickinson and A. Mullineux, Edward Elgar.

Hirschleifer, D., A. Subrahmanyam, and S. Titman, 1994, Security analysis and trading patterns when some investors receive information before others, *Journal of Finance*, 49, 1665-1698.

Hung, J., 1997, Intervention strategies and exchange rate volatility: A noise trading perspective, *Journal of International Money and Finance*, 16, 779-93.

Ito, T., 2002, Is foreign exchange intervention effective? The Japanese experience in the 1990s. NBER working paper, n°8914, April.

Ito, T., 2005, The yen and the Japanese economy: 2004, in *Dollar adjustment: How far? Against what?* Edited by F. Bergsten and J. Williamson, Institute of International Economics, Washington D.C. pp. 171-196.

Killeen, W., R. Lyons, and M. Moore, 2006, Fixed versus flexible: Lessons from EMS order flow, *Journal of International Money and Finance*, 25, 551-579.

Kyle, A., 1985, Continuous auctions and insider trading, *Econometrica*, 53, 1315-1335.

Lyons, R., 2001, *The microstructure approach to exchange rates*, MIT Press, Cambridge, MA.

McCallum, B., 2000, Theoretical analysis regarding a zero lower bound on nominal interest rates. N.B.E.R. working paper n° 7677. April.

Nagayasu, J., 2004, The effectiveness of Japanese foreign exchange interventions during 1991-2001, *Economics Letters*, 84, 377-81.

Pasquariello, P., 2007, Informative trading or just costly noise? An analysis of central bank interventions, *Journal of Financial Markets*, 10, 107-143.

Payne, R., 2003, Informed trade in spot foreign exchange markets: An empirical analysis, *Journal of International Economics*, 61, 307-329.

Ramaswamy, R. and H. Samiei, 2000, The yen-dollar rate: Have interventions mattered? IMF working paper, n°00/95, June.

Reitz, S. and M. Taylor, 2006, The coordination channel of foreign exchange intervention: A non-linear microstructural analysis, Deutsche Bundesbank discussion paper, n°08/2006.

Rime, D., L. Sarno, and E. Sojli, 2006, Exchange rate dynamics and order flow: A step beyond, typescript, Warwick University.

Sager, M., and M. Taylor, 2006, Under the microscope: The structure of the foreign exchange market, *International Journal of Finance and Economics*, 11, 81-95.

Sarno, L. and M. Taylor, 2001, Official intervention in the foreign exchange market: Is it effective and if so how does it work? *Journal of Economic Literature*, 39, 839-68.

Scalia, A., 2004, Is foreign exchange intervention effective? Some micro-analytical evidence from Central Europe, typescript, Bank of Italy, August.

Spiegel, M., 2003, Japanese foreign exchange intervention, *Federal Reserve Bank of San Francisco Newsletter*, 2003-36.

Svensson, L., 2000, The zero bound in an open economy: A foolproof way of escaping from a liquidity trap. *N.B.E.R. Working paper* 7957, October.

Taylor, J.B., 2006, Lessons from the recovery from the 'lost decade' in Japan: The case of the Great Intervention and money injection. ESRI international conference, Cabinet Office, Government of Japan, September 14.

Taylor, M., 2005, Official foreign exchange intervention as a coordinating signal to the dollar-yen market, *Pacific Economic Review*, 10, 73-82.

Vitale, P., 1999, Sterilized central bank intervention, *Journal of International Economics*, 49, 245-67.

Watanabe, T. and K. Harada, 2004, Effects of the Bank of Japan's intervention on yen-dollar exchange rate volatility, *Journal of the Japanese and International Economies*.

Watanabe, T. and T. Yabu, 2007, The great intervention and massive money injection: The Japanese experience 2003-2004. Working paper, Institute of Economic research, Hitotsubashi university, June.

Figure 1: Bank of Japan intervention: 2003-04.

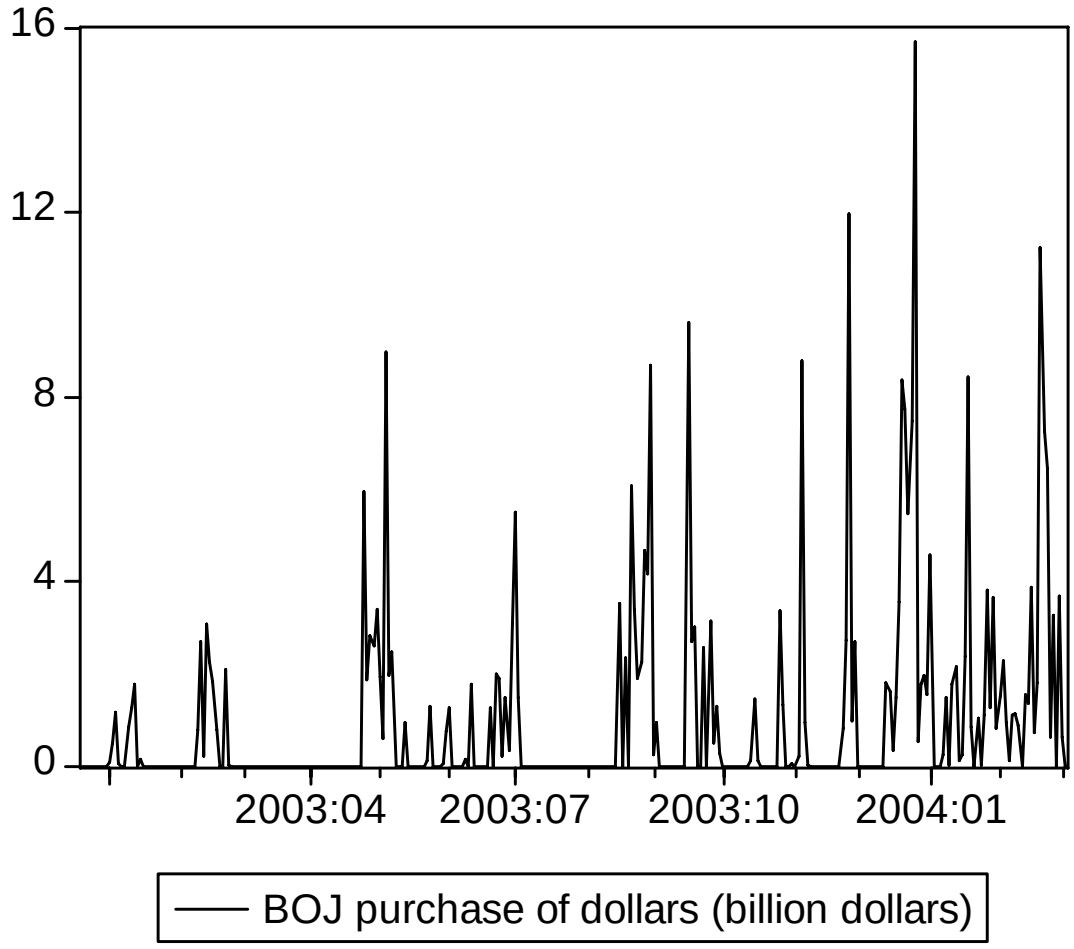

Figure 2: Yen-dollar rate 2003-04.

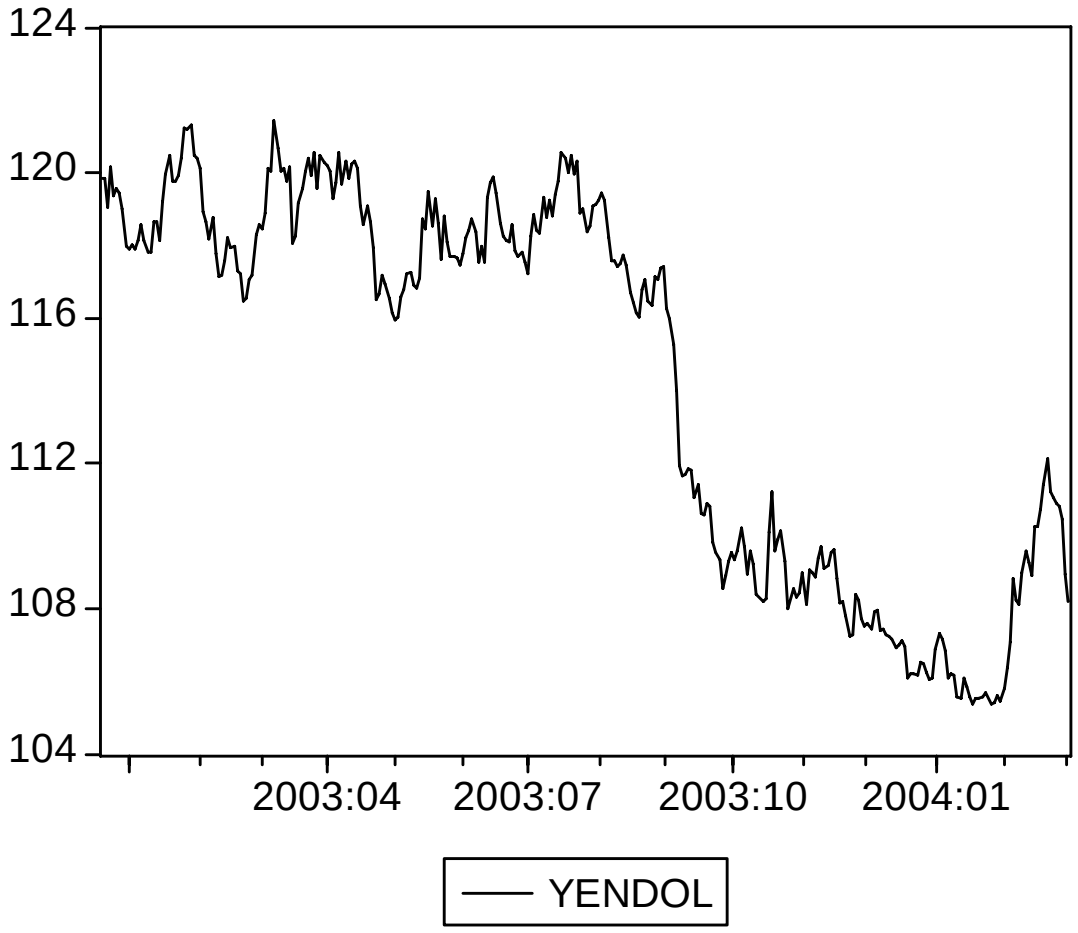

Figure 3: Cumulated dollar purchases by hedge funds: First eight months of 2003

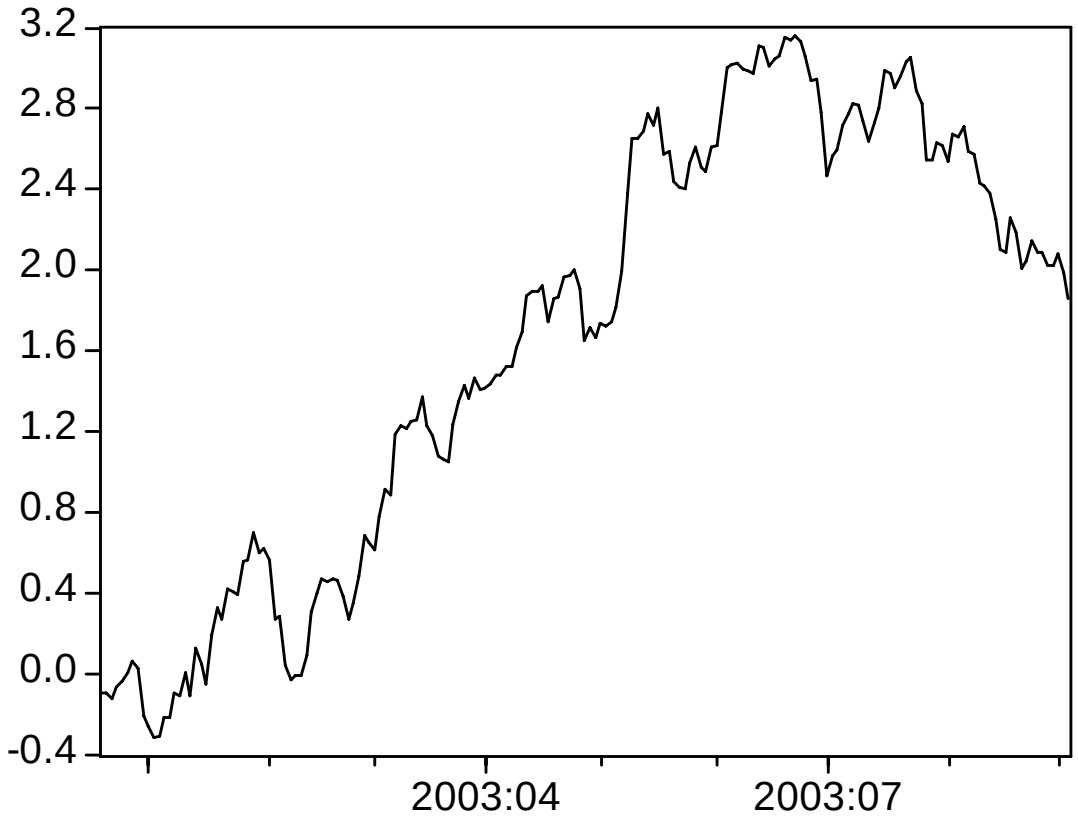

Table 1: Descriptive statistics on private trades, intervention, and returns

Period[c]	**Corporates**[b]	**Mutual Funds**[b]	**Hedge Funds**[b]	**BOJ**[ab]	**Yen/$ returns**	**Change in excess reserves on int. days**[abd]
Mean						
7/1995-3/2004	-0.022	-0.057	0.009	3.01	0.009	0.32
7/1995-1/2003	-0.011	-0.056	0.015	4.8	0.015	0.07
1/2003-3/2004	-0.009	-0.006	-0.003	2.36	-0.03	0.92
Variance						
7/1995-3/2004	0.078	0.152	0.141	-	0.72	
7/1995-1/2003	0.078	0.155	0.144	-	0.75	
1/2003-3/2004	0.077	0.134	0.124	-	0.526	

a) includes intervention days only.
b) billion U.S. dollars, except returns (percent).
c) 7/95 is July 28, 1995; 1/03 is January 13, 2003; 3/04 is March 18, 2004.
d) For the last column, the whole sample and the first subsample start on Feb. 12, 1999.

Table 2: Do end-users shift their trades in the direction of intervention?

	2/1999-1/2003	1/2003-3/2004	01/2003-09/2003	10/2003-3/2004
Corporates [(a)]				(b)
c_0	-0.0087 [0.00]**	0.0341 [0.00]**	-0.038 [0.00]**	-0.417 [0.00]**
c_1 to c_5	-0.0198 [0.02]*	-0.0035 [0.00]**	-0.0094 [0.00]**	0.0026 [0.00]**
c_6 to c_{10}	-0.0073 [0.00]**	0.0054 [0.00]**	0.017 [0.00]**	-0.0054 [0.06]
c_{11} to c_{14}	0.201 [0.00]**	-0.0156 [0.00]**	0.0443 [0.00]**	-0.142 [0.09]
c_{15} to c_{18}	-0.702 [0.00]**	-0.010 [0.00]**	-0.047 [0.00]**	0.0045 [0.09]
c_{19} to c_{22}	0.003 [0.00]**	-0.040 [0.00]**	0.018 [0.84]	0.390 [0.00]**
Q(5)	0.75 [0.98]	1.99 [0.85]	1.30 [0.93]	2.25 [0.81]
Q^2(5)	0.36 [0.99]	3.68 [0.59]	2.40 [0.79]	2.74 [0.74]
Mutual funds	(b)			
c_0	-0.0176 [0.00]**	0.126 [0.00]**	0.114 [0.00]**	1.46 [0.00]**
c_1 to c_5	-0.0204 [0.08]	-0.0131 [0.00]**	-0.0055 [0.00]**	-0.0374 [0.00]**
c_6 to c_{10}	0.0255 [0.00]**	0.0125 [0.00]**	-0.0053 [0.00]**	0.0136 [0.00]**
c_{11} to c_{14}	0.0563 [0.00]**	-0.0365 [0.00]**	-0.337 [0.00]**	-0.216 [0.00]**
c_{15} to c_{18}	0.0586 [0.16]	0.0847 [0.00]**	0.0380 [0.00]**	0.162 [0.00]**
c_{19} to c_{22}	0.0028 [0.00]**	-0.109 [0.10]	-0.101 [0.04]*	-1.328 [0.00]**
Q(5)	3.64 [0.60]	0.77 [0.97]	0.35 [0.99]	1.09 [0.95]
Q^2(5)	2.03 [0.84]	0.20 [0.99]	0.99 [0.96]	0.21 [0.99]
Hedge funds	(c)			
c_0	0.0002 [0.00]**	0.248 [0.00]**	-0.145 [0.00]**	-1.223 [0.00]**
c_1 to c_5	-0.0173 [0.00]**	0.0217 [0.00]**	0.0451 [0.00]**	0.0335 [0.00]**
c_6 to c_{10}	0.0294 [0.00]**	-0.00385 [0.00]**	-0.0563 [0.00]**	-0.0481 [0.01]*
c_{11} to c_{14}	0.0945 [0.12]	-0.0681 [0.00]**	-0.0118 [0.00]**	-0.219 [0.07]
c_{15} to c_{18}	0.0269 [0.10]	0.0286 [0.00]**	0.0885 [0.00]**	-0.0123 [0.01]*
c_{19} to c_{22}	0.0018 [0.07]	0.217 [0.00]**	0.126 [0.00]**	1.09 [0.00]**
Q(5)	1.14 [0.95]	0.94 [0.96]	2.59 [0.76]	0.51 [0.97]
Q^2(5)	0.92 [0.96]	3.31 [0.65]	6.22 [0.28]	2.61 [0.76]

$$D_{it} = c_0 + c_1 BOJ_t + c_2 BOJ_{t-1} + c_3 BOJ_{t-2} + c_4 BOJ_{t-3} + c_5 BOJ_{t-3} + c_6 BOJDXR_t + c_7 BOJDXR_{t-1} + c_8 BOJDXR_{t-2} + c_9 BOJDXR_{t-3} + c_{10} BOJDXR_{t-4} + c_{11} D_{it-1} + c_{12} D_{it-2} + c_{13} D_{it-3} + c_{14} D_{it-4} + c_{15} \Delta e_{t-1} + c_{16} \Delta e_{t-2} + c_{17} \Delta e_{t-3} + c_{18} \Delta e_{t-4} + c_{19} (i^{us}-i^{j})_{t-1} + c_{20} (i^{us}-i^{j})_{t-2} + c_{21} (i^{us}-i^{j})_{t-3} + c_{22} (i^{us}-i^{j})_{t-4} + \varepsilon_t$$

where D_i = dollar purchases by Corporates, Mutual Funds, Hedge Funds; Δe = New York yen-dollar close-to-close returns; BOJ= Bank of Japan intervention, billion dollars. $(i^{us}-i^{j})$ = London interbank interest rate differential on the dollar minus the yen. BOJDXR= Bank of Japan intervention, billion dollars, on days when excess bank reserves increase.
* denotes significant at the 5% level; ** at the 1% level. Q and Q^2 are the Ljung Box statistics on residuals and squared residuals**.** (a) Sum of coefficients and [p-value] using HACSE of F tests for exclusion. (b) EGARCH (1,1) model for column; (c) GARCH(1,1) for column.

Table 3: The noise-trading coordination channel

	c_0	$\Sigma_j c_{1j}$	$\Sigma_j c_{2j}$	$\Sigma_j c_{3j}$	$\Sigma_j c_{4j}$	Q and Q2 [P-values]
Corporates[a]						
8/1995-1/2003	-0.010 [0.09]*	0.115 [0.06]*	0.0022 [0.01]**	-0.0057 [0.12]	0.003 [0.25]	[0.37] [0.29]
1/2003-3/2004	0.030 [0.55]	-0.032 [0.06]*	0.091 [0.01]**	-0.06 [0.00]**	-0.037 [0.71]	[0.64] [0.98]
Mutual Funds[a]						
8/1995-1/2003	-0.014 [0.13]	0.117 [0.22]	0.0275 [0.72]	0.0274 [0.04]**	0.000 [0.14]	[0.99] [0.29]
1/2003-3/2004	0.090 [0.32]	-0.073 [0.31]	0.161 [0.04]**	0.0482 [0.50]	-0.084 [0.86]	[0.99] [0.99]
Hedge Funds[a]						
8/1995-1/2003	-0.003 [0.71]	0.113 [0.06]*	0.0479 [0.56]	0.0297 [0.00]**	0.003 [0.19]	[0.65] [0.84]
1/2003-3/2004	-0.217 [0.01]**	0.0261 [0.60]	-0.045 [0.35]	0.065 [0.06]*	0.187 [0.07]*	[0.98] [0.78]

[p-value, using HACSE]

$$D_{kt} = c_0 + \Sigma j\, c_{1j}\, D_{kt-j} + \Sigma j\, c_{2j}\, DBOJ{*}\Delta e_{t-j} + \Sigma j\, c_{3j}\, DNOBOJ{*}\Delta e_{t-j} + \Sigma j\, c_{4j}\, (i^{us}-i^{j})_{t-j} + \mu_t$$

where k = (1,...,3), j = (0,..., 4); D_k = dollar purchases by Corporates, Mutual Funds, Hedge Funds; Δe_t = New York close-to-close yen-dollar returns; DBOJ = Dummy equals 1 on days of BOJ intervention, DNOBOJ = Dummy equals 1 on days without BOJ intervention, $(i^{us}-i^{j})$ = London interbank interest rate differential on the dollar minus the yen.

a) Sum of coefficients and [p-value] of Likelihood ratio tests for exclusion. * denotes significant at the 5% level; ** at the 1% level.
b) GARCH(1,1) estimation for mutual and hedge funds in the first subsample.
* denotes significance at the 10% level; ** at the 5% level.

Table 4: The persistence coordination channel

Panel A	**Corporates**		
	(1)	(2)	(3)
	BOJ	NOBOJ	NOBOJ5
8/1995-1/2003	0.11 [0.14]	0.114 [0.00]**	0.108 [0.00]**
1/2003-3/2004	0.144 [0.00]**	-0.140 [0.00]**	-0.023 [0.00]**
1/2003-9/2003	0.498 [0.00]**	-0.0621 [0.00]**	0.112 [0.00]**
10/2003_3//2004	0.0291 [0.01]*	-0.734 [0.00]**	-0.76 [0.00]**

Sum of c_1 to c_4, [p-value, using HACSE]

Panel B	**Mutual Funds**		
	(1)	(2)	(3)
	BOJ	NOBOJ	NOBOJ5
8/1995-1/2003	0.131 [0.00]**	0.146 [0.00]**	0.121 [0.00]**
1/2003-3/2004	0.13 [0.00]**	-0.081 [0.00]**	-0.212 [0.04]*
1/2003-9/2003	0.313 [0.00]**	-0.507 [0.00]**	-0.859 [0.00]**
10/2003_3//2004	0.0947 [0.00]**	-0.055 [0.00]**	-0.693 [0.18]

Sum of c_1 to c_4, [p-value, using HACSE]

Panel C	**Hedge Funds**		
	(1)	(2)	(3)
	BOJ	NOBOJ	NOBOJ5
8/1995-1/2003	0.266 [0.00]**	0.084 [0.00]**	0.077 [0.00]**
1/2003-3/2004	0.02 [0.14]	0.019 [0.49]	0.0704 [0.00]**
1/2003-9/2003	0.307 [0.00]**	0.117 [0.00]**	0.077 [0.00]**
10/2003_3//2004	-0.081 [0.47]	-0.576 [0.00]**	-0.634 [0.00]**

Sum of c_1 to c_4, [p-value, using HACSE]

(1) Model with BOJ intervention dummy

$$D_{it} = c_0 + c_1 DBOJ*D_{it-1} + c_2 DBOJ*D_{it-2} + c_3 DBOJ*D_{it-3} + c_4 DBOJ*D_{it-4} + c_5 (i^{us}-i^{j})_{t-1} + c_6 (i^{us}-i^{j})_{t-2} + c_7 (i^{us}-i^{j})_{t-3} + c_8 (i^{us}-i^{j})_{t-4} + \varepsilon_t$$

where D_i = dollar purchases by Corporates, Mutual Funds, Hedge Funds; DBOJ= Dummy equals one on days with BOJ intervention. $(i^{us}-i^{j})$ = London interbank interest rate differential on the dollar minus the yen.

(2) Model with dummy for no BOJ intervention

$$D_{it} = c_0 + c_1 DNOBOJ*D_{it-1} + c_2 DNOBOJ*D_{it-2} + c_3 DNOBOJ*D_{it-3} + c_4 DNOBOJ*D_{it-4} + c_5 (i^{us}-i^{j})_{t-1} + c_6 (i^{us}-i^{j})_{t-2} + c_7 (i^{us}-i^{j})_{t-3} + c_8 (i^{us}-i^{j})_{t-4} + \varepsilon_t$$

where DNOBOJ = Dummy equals one on days without BOJ intervention.

(3) Model with dummy for no current and previous BOJ intervention

$$D_{it} = c_0 + c_1 DNOBOJ5*D_{it-1} + c_2 DNOBOJ5*D_{it-2} + c_3 DNOBOJ5*D_{it-3} + c_4 DNOBOJ5*D_{it-4} + c_5 (i^{us}-i^{j})_{t-1} + c_6 (i^{us}-i^{j})_{t-2} + c_7 (i^{us}-i^{j})_{t-3} + c_8 (i^{us}-i^{j})_{t-4} + \varepsilon_t$$

where DNOBOJ5 = Dummy equals one on days without BOJ intervention and no BOJ intervention the 5 previous days.

Table 5: Quantitative easing and persistence of order flow.

	2/1999-1/2003	1/2003-3/2004	1/2003-9/2003	10/2003-3/2004
Corporates				
(3)	0.164 [0.00]**	-0.029 [0.00]**	0.074 [0.00]**	-0.32 [0.03]*
(1)	0.631 [0.00]**	0.144 [0.00]**	0.498 [0.00]**	0.0291 [0.00]**
(4)	0.776 [0.00]**	0.189 [0.39]	0.518 [0.00]**	0.0072 [0.37]
Mutual				
(3)	0.0364 [0.00]**	0.0553 [0.00]**	-0.261 [0.00]**	0.076 [0.03]*
(1)	1.25 [0.00]**	0.13 [0.00]**	0.313 [0.00]**	0.0947 [0.00]**
(4)	1.748 [0.00]**	0.151 [0.00]**	0.35 [0.00]**	0.087 [0.00]**
Hedge				
(3)	0.106 [0.00]**	0.0194 [0.06]*	0.15 [0.00]**	-0.188 [0.24]
(1)	0.711 [0.00]**	0.02 [0.14]	0.307 [0.00]**	-0.081 [0.47]
(4)	1.039 [0.00]**	0.103 [0.00]**	0.548 [0.00]**	-0.0499 [0.01]*

Sum of c1 to c4, [p-value, using HACSE]

(1) Model with BOJ intervention dummy

Same as in Table 4

(3) Autoregressive Model without intervention dummy

$$D_{it} = c_0 + c_1 D_{it-1} + c_2 D_{it-2} + c_3 D_{it-3} + c_4 D_{it-4} + c_5 (i^{us}-i^{j})_{t-1} + c_6 (i^{us}-i^{j})_{t-2} + c_7 (i^{us}-i^{j})_{t-3} + c_8 (i^{us}-i^{j})_{t-4} + \varepsilon_t$$

(4) Model with dummy for BOJ intervention and positive change in bank excess reserves with BOJ

$$D_{it} = c_0 + c_1 DBOJXR*D_{it-1} + c_2 DBOJXR*D_{it-2} + c_3 DBOJXR*D_{it-3} + c_4 DBOJXR*D_{it-4} + c_5 (i^{us}-i^{j})_{t-1} + c_6 (i^{us}-i^{j})_{t-2} + c_7 (i^{us}-i^{j})_{t-3} + c_8 (i^{us}-i^{j})_{t-4} + \varepsilon_t$$

where D_i = dollar purchases by Corporates, Mutual Funds, Hedge Funds; DBOJXR= Dummy equals one on days with Bank of Japan intervention accompanied by positive change in bank excess reserves with BOJ; $(i^{us}-i^{j})$ = London interbank interest rate differential on the dollar minus the yen. In order to eliminate heteroscedasticity we use an Exponential GARCH(1,1) model for model (1) for mutuals in the first subsample, and a Threshold GARCH(1,1) model for Corporates during both the first and the last subsamples.

Table 6: Price impact of trades by end-user segments and central banks

	7/1995 – 1/2003	1/2003 - 3/2004	1/2003 - 9/2003	10/2003 - 3/2004 (a)
Mean				
a_0	0.011 [0.44]	-0.087 [0.00]**	-0.0858 [0.02]*	-0.113 [0.00]**
a_1	-0.388 [0.04]*	-0.506 [0.15]	-0.684 [0.27]	-0.202 [0.68]
a_2	0.634 [0.00]**	0.767 [0.00]**	-0.406 [0.46]	1.28 [0.00]**
a_3	0.479 [0.00]**	1.201 [0.00]**	1.594 [0.00]**	0.954 [0.00]**
a_4	0.102 [0.00]**	0.052 [0.00]**	0.085 [0.00]**	0.064 [0.00]**
a_5	5.891 [0.00]**			
Variance				
b_0	0.005 [0.02]*	0.013 [0.26]	0.011 [0.72]	-0.69 [0.08]
b_1	0.040 [0.00]**	0.060 [0.05]	0.024 [0.48]	.0.049 [0.78]
b_2	0.949 [0.00]**	0.883 [0.00]**	0.920 [0.00]**	0.605 [0.00]**
b_3				0.253 [0.07]
Adj R^2	0.082	0.147	0.148	0.222
Log likelihood	-1995.4	-201.6	-93.7	-79.5
Q(5)	1.09 [0.95]	4.16 [0.52]	8.99 [0.11]	1.47 [0.91]
Q^2(5)	4.97 [0.42]	3.04 [0.69]	5.21 [0.39]	1.97 [0.95]

P-values in parentheses (from Bollerslev-Woolridge robust standard errors). For the period 10/2003-3/2004, we include three autoregressive coefficients.

$$\Delta e_t = a_0 + a_1 \, CORP_t + a_2 \, MUTUAL_t + a_3 \, HEDGE_t + a_4 \, BOJ_t + a_5 \, FED_t + \varepsilon_t$$

$$\varepsilon_t = (h_t)^{1/2} \zeta_t \ , \ \zeta_t \sim N(0,1)$$
$$h_t = b_0 + b_1 \, \varepsilon^2_{t-1} + b_2 \, h_{t-1}$$

(a) $h_t = b_0 + b_1 \, |\varepsilon_{t-1}|^2 + b_2 \, h_{t-1} + b_3 \, \varepsilon^2_{t-1}$ (EGARCH model)

where: Δe_t = New York open-to-close returns; CORP = dollar purchases by non-financial corporations; MUTUAL = dollar purchases by unleveraged financial institutions; HEDGE = dollar purchases by leveraged financial institutions: BOJ = dollar purchases by the Bank of Japan; FED = dollar purchases by the Federal Reserve; all in billion U.S. dollars.

Table 7: Quantitative easing and price impact of trades by central banks

	2/1999 – 1/2003	1/2003 – 3/2004	1/2003 – 9/2003	10/2003 – 3/2004
Mean				
a_0	0.003 [0.86]	-0.087 [0.00]**	-0.089 [0.00]**	-0.102 [0.02]*
a_1	-0.32 [0.26]	-0.512 [0.15]	-0.796 [0.15]	-0.846 [0.06]
a_2	0.376 [0.01]*	0.769 [0.00]**	-0.375 [0.44]	1.293 [0.00]**
a_3	0.586 [0.00]**	1.199 [0.00]**	1.694 [0.00]**	0.991 [0.00]**
a_4	0.067 [0.02]*	0.050 [0.00]**	0.049 [0.13]	0.052 [0.00]**
a_5	0.085 [0.09]	0.056 [0.00]**	0.119 [0.00]**	0.034 [0.11]
Variance				
b_0	-	0.012 [0.26]	0.011 [0.07]	0.156 [0.00]**
b_1	-	0.06 [0.04]*	0.009 [0.70]	0.231 [0.09]
b_2	-	0.883 [0.00]**	0.935 [0.00]**	-
Adj R^2	0.036	0.144	0.159	0.231
Log likelihood	-661.7	-201.6	-89.9	-81.7
Q(5)	1.89 [0.86]	4.13 [0.53]	7.56 [0.18]	1.45 [0.91]
Q^2(5)	1.59 [0.90]	2.99 [0.70]	4.11 [0.53]	1.56 [0.90]

P-values in parentheses (from Bollerslev-Woolridge robust standard errors). For the period 10/2003-3/2004, we include three autoregressive coefficients.

$$\Delta e_t = a_0 + a_1 CORP_t + a_2 MUTUAL_t + a_3 HEDGE_t + a_4 BOJDPXBK_t + a_5 BOJDMXBK_t + \varepsilon_t$$

$$\varepsilon_t = (h_t)^{1/2} \zeta_t \ , \ \zeta_t \sim N(0,1)$$
$$h_t = b_0 + b_1 \varepsilon^2_{t-1} + b_2 h_{t-1}$$

where: Δe_t = New York open-to-close returns; CORP = dollar purchases by non-financial corporations; MUTUAL = dollar purchases by unleveraged financial institutions; HEDGE = dollar purchases by leveraged financial institutions: BOJDPXBK = dollar purchases by the BOJ on days when excess bank reserves rise; BOJDMXBK = dollar purchases by the BOJ on days when excess bank reserves fall.

Table 8: Does the price impact of end-user trades depend on intervention?

	7/1995 -1/2003	1/2003 - 3/2004	1/2003 - 9/2003	10/2003 - 3/2004
Mean				
a_0	0.010 [0.47]	-0.087 [0.00]**	-0.085 [0.02]*	-0.083 [0.03]*
a_{11}	-1.146 [0.39]	-0.732 [0.09]	-0.642 [0.45]	-1.37 [0.04]*
a_{12}	-0.352 [0.06]	-0.356 [0.47]	-0.594 [0.43]	-0.027 [0.96]
a_{21}	0.034 [0.97]	0.924 [0.00]**	0.998 [0.38]	1.146 [0.00]**
a_{22}	0.650 [0.00]**	0.583 [0.07]*	-0.682 [0.24]	1.682 [0.00]**
a_{31}	0.772 [0.36]	0.959 [0.00]**	0.662 [0.14]	1.348 [0.00]**
a_{32}	0.465 [0.00]**	1.414 [0.00]**	1.979 [0.00]**	0.28 [0.60]
a_4	0.096 [0.00]**	0.051 [0.00]**	0.090 [0.00]**	0.045 [0.00]**
a_5	5.862 [0.00]**			
Variance				
b_0	0.005 [0.02]*	0.013 [0.29]	0.011 [0.60]	0.13 [0.00]**
b_1	0.040 [0.00]**	0.056 [0.06]	0.036 [0.34]	0.36 [0.00]**
b_2	0.949 [0.00]**	0.885 [0.00]**	0.907 [0.00]**	_
Adjusted R^2	0.087	0.146	0.159	0.231
Log Likelihood	-1994.1	-200.6	-91.1	-77.4
Q(5)	1.04 [0.95]	3.77 [0.58]	7.53 [0.18]	1.02 [0.96]
Q^2(5)	4.86 [0.43]	2.40 [0.79]	4.00 [0.54]	3.50 [0.62]

P-values in parentheses (from Bollerslev-Woolridge robust standard errors). For the period 10/2003-3/2004, we include three autoregressive coefficients.

$$\Delta e_t = a_0 + a_{11}\, BOJCORP_t + a_{12}\, NOBOJCORP_t + a_{21}\, BOJMUTUAL_t + a_{22}\, NOBOJMUTUAL_t + a_{31}\, BOJHEDGE_t + a_{32}\, NOBOJHEDGE_t + a_4\, BOJ_t + a_5\, FED_t + \varepsilon_t$$

$$\varepsilon_t = (h_t)^{1/2}\zeta_t\ ,\ \zeta_t \sim N(0,1)$$

$$h_t = b_0 + b_1\, \varepsilon^2_{t-1} + b_2\, h_{t-1}$$

Where: Δe_t = New York open-to-close returns; NOBOJX= dollar purchases by end-user type X on days without BOJ intervention; BOJX = dollar purchases by end-user type X on days with BOJ intervention; X = CORP, MUTUAL, HEDGE. For other variables, see Table 7.