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# Sterilised central bank intervention in the foreign exchange market

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## Abstract

We have studied the signalling role of sterilised foreign exchange intervention using a market micro-structure framework. We have assumed that the monetary authorities intervene in the foreign exchange market in order to target the value of a foreign currency. Since the fundamentals of the foreign currency are not necessarily equal to this objective, the central bank does not have an incentive to reveal its intervention operations and no announcement on its activity will be credible. Under these circumstances, secret sterilised intervention can be used to influence agents' expectations and exchange rates, as the central bank possesses private information on these fundamentals. A surprising result of our analysis is that while announcements on the objective of intervention are not credible, they are not even desirable. In fact, the foreign exchange market is more efficient when this objective is secret than when it is common knowledge, because in the former case the central bank is more aggressive and reveals more of its private information. © 1999 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

Conventional wisdom of the early 1980s suggests that central bank intervention

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in the foreign exchange market does not represent an independent policy tool, because sterilised intervention has no impact on exchange rates. Nevertheless, the experience of the past 10 years of foreign exchange policy has suggested that co-ordinated or isolated intervention operations by the central banks of the G-5 have coincided with changes in the trend of the exchange rates of the main currencies. Therefore, a new strand of empirical investigations (see Edison (1993) for a survey) has tried to assess whether sterilised intervention may actually influence exchange rates. These investigations have generally concluded that foreign exchange intervention is a useful instrument to alter exchange rates.

A possible channel through which sterilised purchases and sales of foreign currencies by the monetary authorities may influence market expectations and the exchange rate has been considered by Mussa (1981). According to his 'signalling hypothesis' operations in the foreign exchange market by the central bank may be used to signal future changes in the monetary policy. Sales (purchases) of foreign exchange should signal a forthcoming monetary contraction (expansion) more effectively than a simple announcement, because the central bank stakes its own capital in support of the future policy and hence 'buys credibility'. In fact, when a sale of foreign assets is followed by a monetary expansion, that forces a devaluation of the domestic currency, the central bank incurs in a net loss.

A series of empirical studies has attempted to assess the signalling role of sterilised intervention. In particular, Dominguez and Frankel (1993b,c), using survey data on market expectations and daily data on central bank intervention, find a significant effect of sterilised operations on expectations of exchange rates. Results by Klein and Rosengren (1991), Dominguez (1992), Watanabe (1994) and Kaminsky and Lewis (1996) generally suggest that central bank intervention is informative of future changes in the monetary policy, even if a clear link has not been established.

In this paper, we suggest a different interpretation of the signalling role for sterilised central bank intervention. As Mussa, we claim that the monetary authorities may possess some private information on the fundamental value of a foreign currency, that they can exploit to influence market expectations and consequently alter the exchange rate. By buying (selling) the foreign currency the central bank passes signals to the market on the fundamental value and hence conditions the market expectations. However, while for Mussa central bank intervention should be aimed at revealing the fundamental value, we suggest that its objective might be different. We show that when this objective is not equal to the fundamental value, the monetary authorities pass 'wrong signals' to the market.

In effect, Kaminsky and Lewis (1996), considering the period 1985–1991, find that in most cases in the United States the relation between foreign exchange intervention and future movements in the money supply does not correspond to the 'signalling hypothesis' popularised by Mussa (1981). It has often been the case that in the presence of an intervention operation in the foreign exchange market

the money supply did not move in the direction indicated by the operation, so that the Federal Reserve was actually passing ‘wrong signals’ to the market. Similar conclusions are also drawn by Dominguez (1992).

Another important aspect of central bank intervention that we intend to address is its secrecy: in effect, most central banks conceal their operations in the market for foreign exchange. Several economists, such as Dominguez, Frankel, Kaminsky and Lewis, have questioned this practice on the ground that, in order to signal effectively future movements in the money supply, operations should be visible and therefore announced. Likewise, objectives of the central bank operations, such as target levels or target zones, should be declared. Anyway, some justifications for this practice, both practical and theoretical, have been given (see Cukierman and Meltzer, 1986; Stein, 1989).

In our analysis we suggest that secrecy of intervention may be desirable for the central bank, when it intends to target the value of the exchange rate. In this case, in fact, the target level and the fundamental value might not be equal and the central bank’s attempt to ‘fool’ the market is more successful when its activity is concealed. This also implies that no announcement on its operations will be credible.

However, using a market micro-structure model of the foreign exchange market, we show that even secret operations can alter exchange rates. In particular, we formulate a model of the foreign exchange market in which a dealer (market maker) transacts a foreign currency with a group of private customers and with a central bank. The dealer uses his flow of orders to up-date his expectation of the fundamental value of the exchange rate, while the central bank places market orders in an attempt to target the value of the currency. Since the central bank possesses private information on the fundamental value, it can influence the dealer’s expectations and alter the exchange rate.

In a related though independent paper, Bhattacharya and Weller (1997) conduct a similar analysis of sterilised intervention and suggest, as we do, that the central bank should keep its intervention operations concealed, if its objectives are not equal to the fundamental value of the foreign currency. However, they also conclude that under certain conditions the monetary authorities prefer to reveal their objectives.

On the contrary, our analysis suggests that the goals of sterilised intervention should never be disclosed. Not only the central bank prefers to conceal its target level, but also the efficiency of the market benefits from this secrecy. This is because the central bank trades more aggressively when the dealer is ignorant of this target level, so more information on the fundamental value is revealed. This result is surprising and challenges the general opinion that the objectives of sterilised intervention should be clearly declared.

This paper is structured as follows. In the next section, we present a market micro-structure framework for the analysis of the foreign exchange market, that permits assessing the signalling role of central bank intervention. In the following

section, we describe the equilibria of the model, while in Section 4 we use them to discuss the consequences of intervention on the characteristics of the market, such as its liquidity and efficiency. A conclusion completes the paper, while proofs of the Propositions are given in Appendix A.

## 2. A market micro-structure framework

In Bhattacharya and Weller a model of the foreign exchange market is developed along the lines of the classical rational expectations literature and resembles the analytical framework of Grossman (1976). The model we consider draws instead from the more recent market micro-structure theory and leads to rather different conclusions. Differently from the rational expectations literature, in which the functioning of the market is proxied by a fictional auctioneer, market micro-structure models take into account the actual organisation of trading of financial markets. Within this new literature, several authors (Glosten and Milgrom, 1985; Kyle, 1985, etc) have analysed dealer markets in which some agents possess some private information. In particular, Kyle has proposed a batch framework in which important characteristics of the market (such as its liquidity and efficiency) are endogenously determined. In what follows we will consider a model for the market for foreign exchange based on this framework.

The structure of the foreign exchange market does not correspond to that of the auction market considered by Kyle, but there are several reasons that can justify its use in the present context. First, his framework is elegant and powerful. In fact, simple analytical solutions are easily derived and have intuitive interpretations. Moreover, crucial characteristics of the market are naturally defined and the effects of sterilised intervention on the market performance can be easily established. Finally, the batch framework captures the most important aspect of the foreign exchange market: its lack of transparency. In fact, in both these markets dealers cannot observe all market orders and prices cannot immediately incorporate all private information contained in individual trades.<sup>1</sup> This ‘opaqueness’ is fundamental for the functioning of any dealer market and consequently the batch framework, despite its abstraction, is a valid approximation for the study of sterilised intervention in the foreign exchange market.

In the model it is assumed that a single foreign currency is traded before some news on its fundamental value,  $f$ , is announced. A simple interpretation of this assumption is that this news concerns the money supply. For instance, in the United States decisions of intervention in the domestic monetary market are taken at the meetings of the Federal Open Market Committee. While actions immediately follow the meetings, communiqués on their conclusions are released 1 week later

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<sup>1</sup>See Madhavan (1992), Biais (1993) and Pagano and Röell (1996) for extensive discussions of issues related to market transparency. Lyons (1996) and Perraudin and Vitale (1996) discuss these issues in the context of the foreign exchange market.

(Stein (1989)) and actual data on monetary aggregates are disclosed with a two-week lag (Tabellini, 1987). Assuming that monetary variables affect the fundamental value,<sup>2</sup> uncertainty on the fundamental value can be a consequence of uncertainty on the current monetary policy.<sup>3</sup>

In the foreign exchange market a dealer transacts the foreign currency with a group of liquidity traders and a central bank. The dealer filters the order flow he observes to extract information on the fundamental value of the foreign currency and sets the exchange rate according to a semi-strong form efficiency condition. The liquidity traders represent a group of agents which trade for hedging reasons and place unpredictable market orders, while the central bank knows the value of  $f$  and tries to exploit its informational advantage in order to target the exchange rate.

As the market maker modifies the exchange rate in response to the movements in the order flow, central bank intervention can influence the exchange rate only by altering the dealer's expectations. In other words, because its intervention does not modify the fundamental value, provided that it is fully sterilised, the central bank influences the exchange rate simply by affecting the informational content of the order flow. Therefore, we can say that assuming the central bank just buys and sells the foreign currency in this market permits isolating the signalling channel of sterilised intervention.

The hypothesis that when the central bank intervenes it has to take the fundamental value as given implies that there exists a separation between foreign exchange intervention and other policy-making tools. In effect, both in Japan and in the United States foreign exchange and monetary policies fall under the jurisdiction of different institutions.<sup>4</sup> Furthermore, it is common opinion that while monetary policy is mainly concerned with internal objectives (such as inflation and employment), foreign exchange policy is devoted to external goals (such as reducing trade and current account imbalances).

Nevertheless, even if sterilised intervention and open market operations are not coordinated, the former might have a feedback effect on the latter. It would certainly be interesting to investigate how sterilised intervention affects the monetary policy and how these two policy instruments interrelate. Though, if we

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<sup>2</sup>Lewis (1995), applying Granger Causality tests, finds that non-borrowed reserves influence the exchange rate, while Ito and Roley (1987) find a similar result for news on monetary variables.

<sup>3</sup>In a simple monetary model the fundamental value of the exchange rate will be given by:

$$f_t = \sum_{j=0}^{\infty} \phi^j E[m_{t+j} | I_t],$$

where  $\phi$  is a function of the semi-elasticity of the money demand with respect to the interest rate. Assuming that the money supply follows an AR(1) process,  $f_t = \mu m_t$  and therefore the uncertainty about the fundamental value corresponds to the uncertainty about the money supply.

<sup>4</sup>The Minister of Finance in Japan and the Treasury in the United States have the authority over the foreign exchange policy, that is actually carried out by the respective central banks. Moreover, they also possess special foreign reserves funds (the Foreign Exchange Fund Special Account and the Exchange Stabilization Fund, respectively) to implement their intervention policies.

considered the influence of sterilised intervention on the monetary policy, it would no longer be possible to isolate the signalling effect of this intervention. In fact, purchases (sales) of foreign assets would alter exchange rates by influencing not only agents' expectations, but also the fundamental value of currencies. Since we are interested in assessing the signalling role of intervention, we leave the analysis of this feedback effect to future research.

We assume that foreign exchange intervention targets the exchange rate to some predetermined level. In effect even if foreign exchange policy could pursue other objectives, such as smoothing the exchange rates and reducing turbulences in the market, the experience of the period 1985–1991 clearly indicates that in many circumstances massive intervention operations were brought about by the desire to reach some target level. In particular, according to Funabashi (1988), at the Plaza meeting of September 1985 the G-5 agreed to some co-ordinated foreign exchange intervention to depreciate the dollar with respect to the yen and the D-mark: target levels were set close to 215 for the yen–dollar rate and 2.60 for the D-mark–dollar rate. Likewise, at the Louvre meeting of February 1987, when the dollar had experienced a large devaluation since the Plaza, new reference levels were fixed at 153.5 and 1.825, respectively. These figures were then repeatedly adjusted in the following year (see Dominguez and Frankel, 1993a).

In what follows we assume that the central bank aims at minimising a loss function that depends on the distance between the exchange rate and a target level,  $\bar{s}$ , and on the cost of intervention. Given this formulation of the loss function the objective of the central bank can embrace both a purely speculative motive and a purely targeting one. In the first case the central bank just follows Milton Friedman's prescription, according to which the central bank should behave as a stabilising speculator: selling when the exchange rate is high, buying when it is low. Conversely, if the commitment of the central bank to the target level is infinite, it will accept any intervention cost to target the exchange rate.

As we have already suggested, a central bank may prefer to conceal its intervention operations. This is possible if its market orders are placed by a commercial bank that transacts on its behalf. However, the transactions of this commercial bank will be interpreted as noisy signals of intervention operations and hence the central bank will be able to exploit the signalling channel even if its intervention is secret. The batch framework put forward by Kyle captures this aspect of foreign exchange intervention, because the market maker cannot observe the identity of his clients and therefore cannot distinguish between informed and uninformed traders. However, the market orders he receives still convey information on the fundamental value.

Not only does sterilised intervention not need to be visible to alter exchange rates, but even operations of limited scale can be effective. In fact, despite the massive volume of trading of the foreign exchange market, the activity of a single dealer remains within limited dimension. Lyons (1995) reports statistics on the transaction data of a large dealer. In the week 3–7 August 1992, in which

particular events were not reported in the press, the average daily volume of transactions with clients of this large dealer in D-marks for dollars was around \$1 billion, while their average size was close to \$4 million. These figures indicate that with a relatively small market order the central bank can affect the quotes of a single market maker. Then, if this market maker has the reputation of receiving market orders from the central bank, inter-dealer transactions will propagate this effect on the quotes of the other dealers.<sup>5</sup>

### 3. Equilibrium exchange rates

In this section, we derive the equilibrium exchange rate in the presence of sterilised intervention. In this respect we need to introduce the following assumptions.

The fundamental value is a normal random variable with mean  $s_0$  and variance  $\Sigma_0^f$  realised at time 0, that initially only the central bank observes. At time 1, the market maker calls an auction for the currency, so that the central bank and the liquidity traders place their respective market orders,  $x$  and  $\epsilon$ . Customer market orders are batched and the total market order,  $x + \epsilon$ , is passed to the market maker. Then, the dealer will fix the exchange rate and execute the market orders. Considering that in the foreign exchange market there exists a large number of dealers and assuming that market makers are risk neutral, competition should enforce zero-expected profits for our dealer inducing a semi-strong form efficiency condition for the exchange rate. Therefore we have that:

$$s_1 = E[f|I_m],$$

where  $I_m$  indicates the information the dealer possesses at time 1. Finally at time 2 the uncertainty on the fundamental value is resolved and the market maker will fix the exchange rate equal to this value.

The total market order of the liquidity traders at time 1,  $\epsilon$ , is a normal random variable independent of  $f$ , with mean 0 and variance  $\sigma_\epsilon^2$ . At the same time, given that at time 1 the exchange rate is  $s_1$ , the central bank will choose its market order,  $x$ , minimising the expected value of its loss function:

$$c = (s_1 - f)x + q(s_1 - \bar{s})^2.$$

The parameter  $q$  is non negative and indicates the degree of commitment to the target level,  $\bar{s}$ . The first term in the loss function, instead, indicates the capital

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<sup>5</sup>In a recent empirical study Peiers (1997) confirms that certain commercial banks stand as market leaders during periods of central bank intervention. On the theoretical side, Montgomery and Popper (1997) show that dealers are better off if they share information on the activity of central banks, while Lyons (1996) and Perraudin and Vitale (1996) study the process of diffusion of information among dealers in the foreign exchange market.

commitment or cost of intervention. As  $q$  may vary between 0 and infinite, this definition of the loss function encompasses all possible motives of intervention between *purely speculative*, for  $q=0$ , and *purely targeting*, for  $q \uparrow \infty$ , ones. Notice, in the end, that while others market participants may not know the target level,  $\bar{s}$ , the degree of commitment of the central bank,  $q$ , is common knowledge.<sup>6</sup>

As we have already anticipated, trading in foreign exchange is not conducted as in the auction market described here. However, our market maker can represent a typical dealer in the foreign exchange market. This dealer cannot directly observe the total flow of orders that external customers place with all foreign exchange dealers, but can gather information on this flow of orders by trading with his clients and with other dealers and by observing brokered inter-dealer transactions. In this way he can form an estimate of the total flow of external orders that reach the foreign exchange market. Since external customers comprise both liquidity traders and the central bank, we could assume that the quantity  $\epsilon$  contains both a measure of liquidity trading and an error term for the estimate of the total flow of orders. For simplicity we abstract from this second component.

Given the form of its loss function, it is clear that the central bank cannot reveal its intervention operations and its target level. If it did it, a rational market maker would be able to extract the fundamental value and no attempt to target the exchange rate would be effective. On the contrary, the central bank might attempt to ‘fool’ the market maker by giving false announcements on its activity. This shows that in the present context no official declaration should be made, because in any case it would not be credible. However, this conclusion depends crucially on the assumption that the fundamental value  $f$  is given. Indeed, if the objective of the monetary policy was to target the exchange rate too, an announcement would be credible and desirable. In the prosecution of our discussion we will not consider this possibility and will concentrate only on the analysis of secret intervention.

Given the structure of the model, it is very simple to derive linear Nash equilibria for the model.<sup>7</sup> However, the characteristics of these equilibria will vary according to the dealer’s perception of the objective of the central bank intervention. We start our analysis of these equilibria by discussing the case in

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<sup>6</sup>Bhattacharya and Weller consider a completely different structure of trading for the foreign exchange market, in that traders place limit orders and a market clearing condition defines the spot rate. Moreover, a continuum of rational price-taker speculators replace our liquidity traders. This implies that, differently from our model, the central bank is not uncertain about the effect of its intervention on the spot rate, that the market collapses in some circumstances and that it is not possible to study the relation between market liquidity and central bank intervention. Finally, while the analysis of the multi-period extension of our formulation is relatively simple, it would be particularly challenging within their model.

<sup>7</sup>We should make clear that in the use of the Nash equilibrium concept, we implicitly assume that the dealer tries to minimise the expectation of the square value of the difference between the exchange rate and the fundamental value. Because of the properties of conditional expectations, this corresponds to the use of a semi-strong form efficiency condition.



which the central bank can commit to reveal the true value of its target level,  $\bar{s}$ . Despite what we have just said, we have analysed this case because it is a useful starting point and because economists have for a long time discussed the opportunity to declare officially the objectives of foreign exchange intervention.

### 3.1. Common knowledge of the target level

In the simplest situation the market maker knows the target level of the central bank. Then, the following Proposition holds.

**Proposition 1.** *If the target level of the central bank is common knowledge, the market possesses a unique linear Nash equilibrium, in which the central bank cannot target the value of the foreign currency. In equilibrium, the market order of the central bank is a linear function of the domestic currency misalignment,  $f - s_0$ , and of the deviation of the exchange rate from the target level,  $\bar{s} - s_0$ :*

$$x = \beta(f - s_0) + \gamma(\bar{s} - s_0). \quad (1)$$

The market maker filters out the ‘false signal’ component of the central bank market order,  $\gamma(\bar{s} - s_0)$ , so that the variation in the exchange rate is a function only of the ‘true signal’ component  $\beta(f - s_0)$  and the market order of the liquidity traders:

$$s_1 = s_0 + \lambda[\beta(f - s_0) + \epsilon]. \quad (2)$$

The liquidity coefficient,  $\lambda$ , that determines the sensitiveness of the exchange rate to the order flow, is the unique positive root of the following equation:

$$4\lambda^2(1 + \lambda q)^2 \sigma_l^2 = (1 + 2\lambda q) \sum_0^f, \quad (3)$$

while the trading intensities,  $\beta$  and  $\gamma$ , are given by the following expressions:

$$\beta = \frac{1}{2\lambda(1 + \lambda q)}, \quad \gamma = 2q.$$

From this Proposition it is quite evident that *common knowledge* of the target level of the central bank is detrimental to its interests. In effect, sterilised central bank intervention represents an effective instrument to target the exchange rate only if it can permit surprising the market. This is the case if the central bank objective is secret.

Notice that Bhattacharya and Weller draw a different conclusion. In fact, they find that, while intervention operations should always be secret, the central bank prefers to reveal the objectives of its intervention under some parametric configurations. Moreover, under the same circumstances the effect of sterilised intervention is ‘perverse’, in that the domestic currency depreciates when the central bank purchases it.

### 3.2. Secret target level

Suppose the market maker knows the form of the loss function, but not the exact value of the target level. Since no announcement is made, he assumes that the value  $\bar{s}$  is extracted from some distribution independent of  $f$  and  $\epsilon$ . In particular, this distribution is assumed normal with mean  $\bar{s}_0^e$  and variance  $\Sigma_0^s$ . In this *secret target level* case, the market equilibrium is described by the following Proposition.

**Proposition 2.** *If the target level of the central bank is secret, the market possesses a unique linear Nash equilibrium, in which the central bank can target the value of the foreign currency. In equilibrium, the market order of the central bank comprises three components: a linear function of the domestic currency misalignment,  $f - s_0$ , and two ‘false signal’ components (one predictable and the other unpredictable), which are linear functions, respectively of  $\bar{s}_0^e - s_0$  and  $\bar{s} - \bar{s}_0^e$ :*

$$x = \beta(f - s_0) + \gamma(\bar{s}_0^e - s_0) + \theta(\bar{s} - \bar{s}_0^e). \quad (4)$$

The market maker is only partially able to filter out the ‘false signal’ components of the market order of the central bank and the exchange rate is also influenced by the unpredictable ‘false signal’ component,  $\theta(\bar{s} - \bar{s}_0^e)$ :

$$s_1 = s_0 + \lambda[\beta(f - s_0) + \theta(\bar{s} - \bar{s}_0^e) + \epsilon]. \quad (5)$$

The liquidity coefficient,  $\lambda$ , is now the unique positive root of the following equation:

$$4\lambda^2[(1 + \lambda q)^2 \sigma_i^2 + \Sigma_0^s] = (1 + 2\lambda q) \Sigma_0^f, \quad (6)$$

while the trading intensities,  $\beta$ ,  $\gamma$  and  $\theta$ , are given by the following expressions:

$$\beta = \frac{1}{2\lambda(1 + \lambda q)}, \quad \gamma = 2q, \quad \theta = \frac{q}{1 + \lambda q}.$$

Proposition 2 proves that the central bank prefers to conceal its target level. In fact, in this case part of the ‘false signal’ components of the central bank market order is not filtered out.<sup>8</sup> Thus, when  $\bar{s}$  is secret, for any cost of intervention incurred by the monetary authorities, the second moment of the deviation of the exchange rate from the target level,  $E[(s_1 - \bar{s})^2 | \bar{s}]$ , is smaller and so is the expected value of the loss of the central bank. This also confirms that no announcement on the target level will be credible.

Assume, in fact, that the monetary authorities declare that  $\bar{s} = s_0$ , while in effect  $\bar{s} > s_0$ , and that the dealer believes in this announcement. In this case the dealer

<sup>8</sup>For  $s_0 = \bar{s}_0^e$  we also see that, differently from Bhattacharya and Weller, sterilised intervention can have a ‘perverse’ effect on the spot rate only in the presence of a very large liquidity market order with opposite sign with respect to that of the central bank.

will assume that  $\bar{s} = s_0$  is common knowledge and will up-date his expectation of the fundamental value as in Proposition 1, using the information he believes is contained in the order flow for  $\bar{s} = s_0$ . Then, his pricing rule becomes as follows:

$$s_1 = s_0 + \lambda(x + \epsilon),$$

where  $x$  is the order of the central bank and  $\lambda$  is as in Proposition 1. Now, the central bank can completely fool the dealer. In fact, by placing the order  $x = (\bar{s} - s_0)/\lambda$  it can target the exchange rate with great success and little cost. A similar argument would prove that any imprecise announcement cannot be credible.

Notice that if the objective of the central bank were that of revealing the fundamental value, an announcement would be credible and there would not be a need for sterilised intervention. On the contrary, it is exactly when the objective of the central bank is not consistent with the fundamental value and announcements are not credible that sterilised intervention is mostly needed. In effect, since sterilised intervention is expensive, the central bank can buy credibility and alter exchange rates by purchasing and selling foreign exchange.

To see this, suppose that in the context of our model  $f > s_0 > \bar{s}$ . In this case, if the monetary authorities sell foreign exchange in an attempt to revalue the domestic currency they will eventually incur in an expected loss proportional to  $f - s_0$ , as in the second period  $s_2 = f$ . As a consequence, in equilibrium the order placed by the central bank contains the component  $\beta(f - s_0)$  and hence sterilised intervention is informative. This component would not appear if intervention were not costly. In that case, the dealer would completely disregard the order flow he observes and the central bank could not influence his expectations and the exchange rate.

We can now use Propositions 1 and 2 to assess the consequences of sterilised intervention on the exchange rate and the market characteristics.

#### 4. Market efficiency and liquidity

The efficiency and liquidity of the foreign exchange market can be analysed employing two simple measures. Using the projection theorem for normal distributions we can easily derive the conditional variance of the fundamental value, given the information set of the market maker,  $\Sigma_1^f \equiv E[(f - s_1)^2 | I_m]$ . Its inverse is a natural indicator of the efficiency of the market, because  $\Sigma_1^f$  measures the proportion of private information that is not incorporated in the exchange rate at time 1. The conditional variance  $\Sigma_1^f$  respects the following equation in both the types of equilibrium:

$$\Sigma_1^f = \frac{1 + 2\lambda q}{2(1 + \lambda q)} \Sigma_0^f. \quad (7)$$

The inverse of  $\lambda$  represents the market depth, that is the minimum market order required to move the exchange rate by one. Thus,  $\lambda$  is a direct measure of the cost of trading and its inverse is a simple indicator of the liquidity of the foreign exchange market. Then, using Propositions 1 and 2, and these measures of market liquidity and efficiency, we can derive the following important result.

**Proposition 3.** *For any  $q > 0$  and for any choice of the other parameters, the foreign exchange market is more efficient and more liquid when the central bank conceals its target level, than when it commits to reveal it.*

Despite Proposition 3 does not seem very intuitive, its explanation is relatively straightforward. In fact, when the target level is secret, the market maker uses the order flow to up-date his estimates of both the fundamental value and the target level. This implies that his filtering problem is more complicated and that the central bank can place a larger market order to target the exchange rate, while this market order will convey more information to the dealer. The liquidity is also increased, because the ‘false signal’ component of the central bank market order is greater when the target level is secret.

In synthesis, the secrecy of the target level is preferable on different accounts: it benefits the central bank and improves the efficiency and the liquidity of the market. Notice, that this result carries over to a dynamic version of the model, in which several rounds of trading occur before the fundamental value of the currency is revealed to the market maker. We cannot discuss this dynamic version here and refer the reader to an earlier version of this paper (Vitale, 1997).

This result challenges the usual thesis that the foreign exchange market would be more efficient if the central bank could commit to reveal its targets. On the other hand, it justifies a practice that seems to have been in place in the eighties. As we already said, between 1985 and 1987 the monetary authorities of the G-5 set target levels for the main exchange rates and, despite massive intervention operations were undertaken by their central banks, these target levels were never disclosed.

We now consider some comparative statics for the two types of equilibrium. This exercise provides some further interesting results. In particular, let us start from the following Proposition.

**Proposition 4.** *Irrespective of the market maker knowledge of the target level,  $\bar{s}$ , and for any choice of the other parameters, an increase in the volatility of liquidity trading,  $\sigma_i^2$ , augments the liquidity of the market. When  $q > 0$ , an increase in  $\sigma_i^2$  also augments the market efficiency. In the limit, when  $\sigma_i^2 \uparrow \infty$ , the liquidity of the market becomes infinite and its efficiency reaches a maximum, in that:*

$$\Sigma_1^f \downarrow \frac{1}{2} \Sigma_0^f \text{ for } \sigma_i^2 \uparrow \infty.$$

Once again this result does not seem very intuitive. In particular, while a rise in the liquidity trading reduces the adverse selection problem of the market maker and hence justifies a reduction of  $\lambda$ , that is an increase in the market liquidity, it is not quite obvious why a larger volume of liquidity trading should bring about a reduction of  $\Sigma_1^f$  and hence an improvement of the market efficiency. This result again derives from the reaction of the central bank to the change in  $\sigma_t^2$ . Because of the larger volume of uninformative orders from liquidity traders, the central bank can better hide its activity and it will trade more aggressively. Even in this case, it will end up passing a more informative market order to the dealer. In the limit, the level of efficiency of the market corresponds to that implied by  $q=0$ , that is to the case in which the central bank simply speculates.

Notice that if we believe the interpretation that  $\epsilon$  contains an error term of the estimate of the total flow of orders of external customers, this result suggests some important consequence of the structure of the foreign exchange market. In fact, in this case the variance  $\sigma_t^2$  might be considered as a measure of the lack of transparency of the foreign exchange market. The greater  $\sigma_t^2$  the more opaque the market. Then, the conclusion we derive from Proposition 4 may well be that a less transparent market turns out to be more efficient in the presence of sterilised intervention. This contrasts with the standard conclusion of the market micro-structure theory, that opaque markets are less efficient than transparent ones (Madhavan, 1995).

In Fig. 1 the consequences of changes in  $\sigma_t^2$  on the equilibrium of the market are represented graphically. To obtain Fig. 1 we assume that  $s_0=0$  and  $\bar{s}=1$ . This corresponds to a normalisation. We also choose  $\bar{s}_0^e$  equal to 0, while  $\Sigma_0^f$ ,  $\Sigma_0^s$  and  $q$  are set equal to 1. The choice of these values is substantially arbitrary, but inconsequential for the conclusions of our analysis, since most of our results are obtained analytically. Yet we use Fig. 1 for illustrative purposes. In the simulation of the exchange rate  $f$  is equal to  $-0.6389$  and  $\epsilon$  is equal to  $0.3973$ . In this scenario the target level is not equal to the fundamental value and hence the central bank is trying to force the exchange rate in the ‘wrong’ direction. In fact, in the United States there have been disagreements between the Federal Reserve and the Treasury on the risk of passing ‘wrong signals’ to the market.

The top panels represent  $\lambda$  and  $\Sigma_1^f$ , while the bottom ones show the effect of changes in  $\sigma_t^2$  on the exchange rate and the expected loss of the central bank,  $E[c|\bar{s}]$ . As claimed in Proposition 3 the market is more liquid and efficient if the target level is secret: in the figures this result is represented by the smaller values of  $\lambda$  and  $\Sigma_1^f$ . Moreover, as indicated by Proposition 4, an increase in the volume of liquidity trading (or a reduction in the transparency of the market) improves the liquidity and efficiency of the market, reducing the values of  $\lambda$  and  $\Sigma_1^f$ . We also observe that the exchange rate moves closer to the fundamental value for larger values of  $\sigma_t^2$ . Since  $\lambda \downarrow 0$  it is not difficult to see that in the limit the mis-pricing of the currency halves. In fact,  $(s_1 - f) \rightarrow (s_0 - f)/2$  with probability one, for  $\sigma_t^2 \uparrow \infty$ , in both the *common knowledge* and *secret target level* cases.

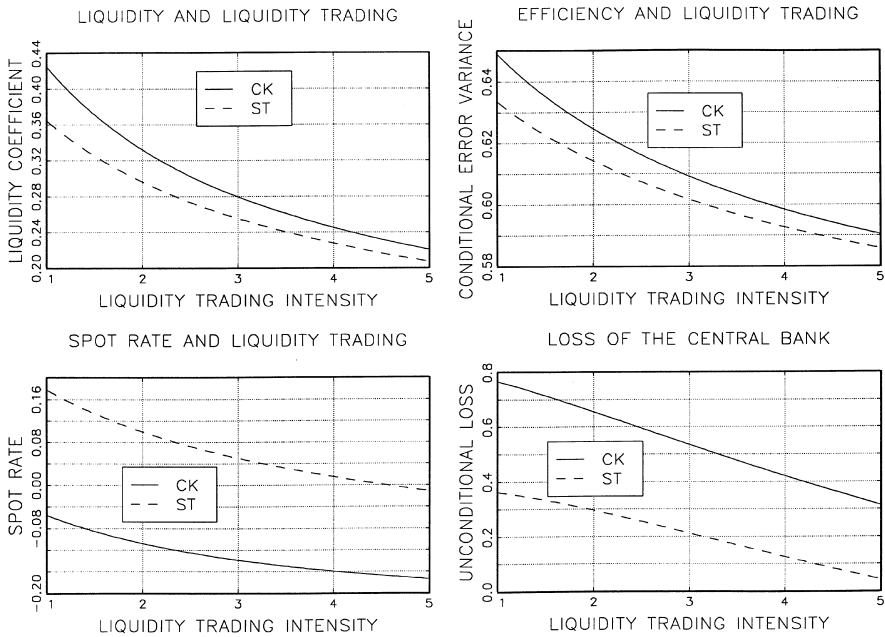


Fig. 1. Market characteristics as functions of  $\sigma_1^2$ . The continuous line indicates the *common knowledge* case, while the dotted one the *secret target level* case.

Finally, a rise in the volatility of liquidity trading seems to reduce the expected loss of the central bank. This is true for  $q$  relatively small, because the monetary authorities can hide better their market orders. On the other hand, for a greater commitment to the target level, the central bank suffers for the rise in the volatility of  $s_1$  brought about by an increase in  $\sigma_1^2$ .

Increases in the uncertainty of the market maker on the target level  $\bar{s}$  have also interesting consequences.

**Proposition 5.** *If the target level is secret, an increase in the uncertainty of the market maker on the target level, that is an increase in  $\Sigma_0^s$ , augments the liquidity and the efficiency of the market for any choice of the other parameters. When  $\Sigma_0^s \uparrow \infty$ , the liquidity of the market becomes infinite and its efficiency reaches a maximum, in that:*

$$\Sigma_1^f \downarrow \frac{1}{2} \Sigma_0^f \text{ for } \Sigma_0^s \uparrow \infty .$$

This result follows by continuity from the proof of Proposition 3. Nevertheless, it is interesting to see that when the uncertainty of the market maker on  $\bar{s}$  becomes very large, the efficiency of the foreign exchange market does not differ

substantially from the level reached when the activity of the central bank is purely speculative. Moreover, notice that once again in the limit the mis-pricing of the currency halves. In fact  $(s_1 - f) \rightarrow (s_0 - f)/2$  with probability one, for  $\Sigma_0^s \uparrow \infty$ . In synthesis, Proposition 5 points in favour of the secrecy of the central bank's objective too.

Once again, Bhattacharya and Weller propose rather different results with respect to the effect of sterilised intervention on the efficiency of the market. In particular, for some parametric specifications the market is most efficient if the objectives of the intervention are announced. Moreover, even if for other parametric values some uncertainty on these objectives is desirable, it is never the case that the market is most efficient when such uncertainty is infinite.

Finally, in our comparative statics exercise we consider the effects of a rise in the level of commitment to the target level of the central bank,  $q$ .

**Proposition 6.** *Irrespective of the market maker knowledge of the target level,  $\bar{s}$ , and for any choice of the other parameters, an increase in the level of commitment to the target level of the central bank, that is an increase in  $q$ , augments the market liquidity and reduces its efficiency. In the limit, when  $q \uparrow \infty$ , the liquidity of the market becomes infinite and  $\Sigma_1^f$  reaches  $\Sigma_0^f$  when the target level is common knowledge and the following maximum*

$$\bar{\Sigma} = \frac{2\Sigma_0^s + (1 + \Delta)\Sigma_0^f}{4\Sigma_0^s + (1 + \Delta)\Sigma_0^f} \Sigma_0^f, \text{ with } \Delta = (1 + 4\Sigma_0^s/\Sigma_0^f)^{1/2},$$

when the target level is secret.

The first part of the Proposition contains probably the unique unsurprising result of our analysis. A rise in the degree of commitment of the central bank to defend the target level reduces the informativeness of its market orders and hence the sensitiveness of the exchange rate and the efficiency of the market. The second part, instead, still stresses the superiority of the secrecy of the target level, indicating that even when  $\bar{s}$  is secret and the degree of commitment approaches infinite the order flow contains information on the fundamental value. On the contrary, in the *common knowledge* case, no information on  $f$  is revealed by the order flow.

In Fig. 2 the consequences of changes in  $q$  on the equilibrium of the market are represented graphically.<sup>9</sup> The top panels confirm the conclusions of Proposition 6, while the bottom ones suggest that the exchange rate converges to a limit for  $q \uparrow \infty$ .

Indeed, it is not difficult to show that for a level of commitment approaching infinite the exchange rate converges to its unconditional expected value,  $s_1 \rightarrow s_0$ , in

<sup>9</sup>To obtain Fig. 2 we use the same selection of the parameters of the model used for Fig. 1, but now  $q$  is free to change and  $\sigma_{\tau}^2$  is set equal to 1.

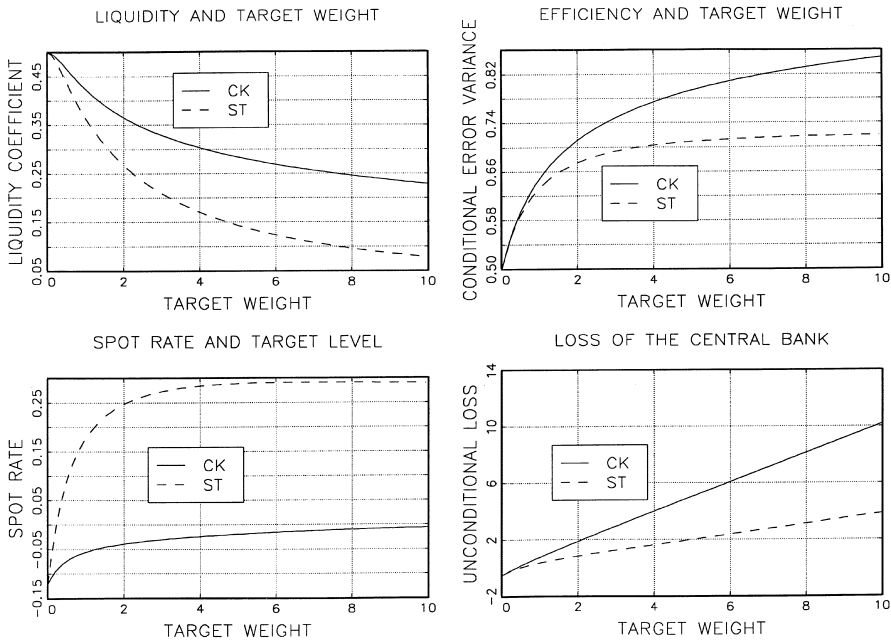


Fig. 2. Market characteristics as functions of  $q$ . The continuous line indicates the *common knowledge* case, while the dotted one the *secret target level* case.

the *common knowledge* case. Instead, in the *secret target level* case and for  $s_0 = \bar{s}_0^e$  the exchange rate converges to the following limit:

$$s_1 - s_0 \rightarrow \frac{4 \sum_0^s}{4 \sum_0^s + (1 + \Delta) \sum_0^f} (\bar{s} - s_0) - \frac{2 \Sigma_0^s}{4 \sum_0^s + (1 + \Delta) \sum_0^f} (f - s_0).$$

Then, when the level of uncertainty of the dealer on the target level also approaches infinity, that is when  $q, \Sigma_0^s$  and  $\Delta \uparrow \infty$ ,  $s_1 \rightarrow \bar{s} - (f - s_0)/2$  with probability 1.

Clearly the case  $q \uparrow \infty$  raises the question of the sustainability of intervention. In this case, in fact, the central bank might lose all its foreign reserves in an attempt to target the exchange rate, so that we should interpret this result as referring only to very large degrees of commitments. On the other hand, Fig. 2 suggests that the convergence to the asymptotic values is quick.

### 5. Conclusions and extensions

In this paper we have proposed an analysis of the signalling role of sterilised intervention, based on a micro-structural model of the foreign exchange market.



This model captures the lack of transparency of the foreign exchange market and presents several interesting properties. In particular, it permits defining endogenously the liquidity and efficiency of the market, and studying the effects of sterilised intervention on the market expectations and on the exchange rate. Assuming the monetary authorities possess private information on the fundamental value of a foreign currency and aim at targeting its exchange rate, we can provide a rationale for several aspects of sterilised central bank intervention.

Intervention operations can convey a signal on the fundamental value even if they are conducted anonymously and in limited amounts. Moreover, when the central bank targets the value of the exchange rate, it prefers to conceal its activity and it may pass ‘wrong signals’ to the market. Our analysis also suggests that announcements on the activity and the objectives of sterilised intervention are not credible, if this activity is not consistent with the fundamental value of the exchange rate. In effect, any announcement would mis-represent the activity of the monetary authorities in an attempt to ‘fool’ the market. Finally, we find that while these announcements are not credible, they are not even desirable. In fact, the market is more efficient and more liquid when all market participants are ignorant of the target level chosen by the central bank than when this value is common knowledge.

Our comparative static exercise suggests that a less transparent market, or a market with a greater volume of liquidity trading, is not necessarily less efficient. In effect, in a less transparent market, the central bank is induced to intervene more aggressively, revealing a greater proportion of its private information. Likewise, when the uncertainty on the objective of foreign exchange intervention is particularly severe, the monetary authorities may target the exchange rate more successfully, while revealing more of their information on the fundamental value of the foreign currency.

The limits of our analysis already suggest several possible extensions of the study of foreign exchange intervention. In particular, we have chosen to consider as given the fundamentals of the foreign exchange. Yet, monetary and foreign exchange intervention may be coordinated in an attempt to target the exchange rate. In a few cases in the eighties this seems to have been the case for the currencies of the main industrialised countries. We have not studied the question of feedback effects of sterilised intervention on open market operations to isolate the signalling role of foreign exchange intervention, but we consider it a natural and important extension of our analysis.

Other extensions of our analysis would comprise a study of a dynamic version of the model we have considered here. This has been partially covered in Vitale (1997) suggesting that most of the results provided in a static formulation carry over to a dynamic one. A more interesting line of research should consider a macroeconomic model, in which monetary and foreign exchange intervention coordinate in an attempt to stabilise prices and achieve full employment. We conjecture that this analysis would reveal all the potential implications of foreign exchange intervention. While we hope to follow these lines of research in future,

we believe that this paper represents another step towards a full understanding of the role of foreign exchange intervention.

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### Appendix A

**Proof of Proposition 1.** In order to find a Nash equilibrium we need to find two strategies which are mutually consistent. Let us start from the central bank's problem. Consider that the central bank minimizes the expected value of its loss function,  $(s_1 - f)x + q(s_1 - \bar{s})^2$ , and suppose that it conjectures that the dealer's pricing rule is as follows:

$$s_1 = s_0 + \lambda[x + \epsilon - h(\bar{s} - s_0)],$$

where  $h$  is a positive constant. Plugging this expression in the loss function of the central bank, taking the expectation of  $\epsilon$  and minimising it with respect to  $x$ , it follows that the market order of the central bank is as follows:

$$x = \beta(f - s_0) + \gamma(\bar{s} - s_0),$$

with

$$\beta = \frac{1}{2\lambda(1 + \lambda q)}, \quad \gamma = \frac{2q(1 + \lambda h) + h}{2(1 + \lambda q)},$$

and second order condition  $\lambda(1 + \lambda q) > 0$ .

Now, let us consider the dealer's problem and assume he receives the total order  $x + \epsilon$ , where  $x = \beta(f - s_0) + \gamma(\bar{s} - s_0)$ . He will fix the spot rate  $s_1$  equal to the conditional expectation of the fundamental value. To obtain this expectation we can apply the projection theorem for normal distributions and find that:

$$s_1 = s_0 + \lambda[x + \epsilon - \gamma(\bar{s} - s_0)],$$

where

$$\lambda = \frac{\beta \sum_0^f}{(\beta)^2 \sum_0^f + \sigma_l^2}.$$

Notice that the initial conjecture of the central bank is consistent with the pricing rule of the dealer only if  $\gamma=h$ , that is only if  $h=2q$ . Thus, given  $\lambda$ , there is a unique linear Nash equilibrium. Hence, substituting  $x$  in the expression for the spot rate, we have:

$$s_1 = s_0 + \lambda[\beta(f - s_0) + \epsilon].$$

Finally, plugging the formula for  $\beta$  into the expression for  $\lambda$  we obtain after some manipulation the quartic Eq. (3). It is easy to see that this equation possesses two roots: one positive and one negative. The negative one is such that  $1 + \lambda q > 0$ . Then, the second order condition for the central bank is respected only by the positive root, proving that the linear Nash equilibrium is unique.  $\square$

**Proof of Proposition 2.** We follow the same steps of the proof of Proposition 1. Consider the central bank’s problem and assume now that it conjectures that the dealer’s pricing rule is as follows:

$$s_1 = s_0 + \lambda[x + \epsilon - h(\bar{s}_0^e - s_0)],$$

where  $h$  is still a positive constant. Repeating the same calculations of Proposition 1 we find that:

$$x = \beta(f - s_0) + \gamma(\bar{s}_0^e - s_0) + \theta(\bar{s} - \bar{s}_0^e),$$

with the same expressions for  $\beta$ ,  $\gamma$  and the second order condition of the proof of Proposition 1, and with  $\theta = q/(1 + \lambda q)$ .

Consider now the filtering problem of the dealer. Given the expression for  $x$ , the application of the projection theorem for normal distributions will imply that:

$$s_1 = s_0 + \lambda[x + \epsilon - \gamma(\bar{s} - s_0)]$$

with

$$\lambda = \frac{\beta \sum_0^f}{(\beta)^2 \sum_0^f + (\theta)^2 \sum_0^s + \sigma_l^2}.$$

Again, the initial conjecture of the central bank is correct only if  $h = \gamma$ , that is if  $h = 2q$ . Moreover, inserting the expression for  $x$  into the pricing rule of the dealer we find that:

$$s_1 = s_0 + \lambda[\beta(f - s_0) + \theta(\bar{s} - \bar{s}_0^e) + \epsilon]. \tag{8}$$

Finally, plugging the formulae for  $\beta$  and  $\theta$  into the expression for  $\lambda$  we obtain after some manipulation the quartic Eq. (6). It is easy to see that even this equation

possesses only one root, positive, that satisfies the second order condition for the central bank, proving again the unicity of the linear Nash equilibrium.  $\square$

**Proof of Proposition 3.** For any choice of the parameters with  $q$  positive, let  $\lambda^{CK}$  be the value of the liquidity parameter that solves Eq. (3). If we plug this value in both sides of Eq. (6), we see that the left hand side is necessarily larger than the right hand side. This proves that the value of the liquidity parameter satisfying this second equation,  $\lambda^{ST}$ , is smaller. Then, the market turns out to be more liquid in the *secret target level* case. For the second part of the Proposition consider that from Eq. (7) the conditional variance of  $f$ ,  $\Sigma_1^f$ , is increasing in  $\lambda$ . Thus, for  $\lambda$  smaller we have a smaller conditional variance of  $f$  and hence a more efficient market.  $\square$

**Proof of Proposition 4.** Assume that for some choice of the parameters  $\lambda^{CK}$  is the positive root of Eq. (3). If now  $\sigma_1^2$  augments the left hand side of the equation becomes greater than the right hand side. Therefore, we need a reduction of  $\lambda^{CK}$  to find a root of Eq. (3). Given Eq. (7) this proves that for  $q > 0$  the efficiency of the market is increasing in  $\sigma_1^2$  in the *common knowledge* case. Notice also from Eq. (3) that in the limit, for  $\sigma_1^2 \uparrow \infty$ ,  $\lambda^{CK}$  converges to zero. Then, for  $\lambda^{CK} \downarrow 0$ , the conditional variance of the fundamental value reaches the minimum  $\Sigma_0^f/2$ . A similar proof shows the same results in the *secret target level*.  $\square$

**Proof of Proposition 5.** The proof of this Proposition follows the same argument as that of Proposition 4. Consider, in fact, that an increase in  $\Sigma_0^s$  has substantially the same effect of a rise in  $\sigma_1^2$ . In fact, assume that for some choice of the parameters  $\lambda^{ST}$  is the positive root of Eq. (6). If now  $\Sigma_0^s$  augments, then the left hand side of the equation becomes greater than the right hand side. Therefore, we need a reduction of  $\lambda^{ST}$  to find a root of Eq. (6). Given Eq. (7) this proves that in the *secret target level* case for  $q > 0$  the efficiency of the market is increasing in  $\Sigma_0^s$ .  $\square$

**Proof of Proposition 6.** We start this proof by showing that both in the *common knowledge* and *secret target level* cases the following holds:

$$\frac{\partial \lambda}{\partial q} < 0 \text{ and } \frac{\partial \lambda q}{\partial q} > 0. \quad (9)$$

To show this, let us consider the *common knowledge* case and define the following function:

$$G(\lambda, q) \equiv 4\lambda^2(1 + \lambda q)^2\sigma_1^2 - (1 + 2\lambda q)\sum_0^f.$$

Given  $q$ , a positive root of the equation  $G(\lambda, q) = 0$  corresponds to the liquidity coefficient,  $\lambda^{CK}$ . By the implicit function theorem we have:

$$\frac{\partial \lambda}{\partial q} = - \frac{\partial G / \partial q}{\partial G / \partial \lambda} .$$

Applying this formula we find:

$$\frac{\partial \lambda}{\partial q} = \frac{\lambda^2 [\Sigma_0^f - 4\lambda^2(1 + \lambda q)\sigma_l^2]}{4\lambda^2(1 + \lambda q)(1 + 2\lambda q)\sigma_l^2 - \lambda q \Sigma_0^f} .$$

It is not difficult to see that when  $\lambda$  solves Eq. (3) the numerator of the fraction on the right hand side is negative, while the denominator is positive: thus  $\partial \lambda / \partial q < 0$ . Consider, then, that:

$$\frac{\partial \lambda q}{\partial q} = \frac{\partial \lambda}{\partial q} q + \lambda .$$

Therefore, plugging the expression for  $\partial \lambda / \partial q$  and with some manipulation you can check that:

$$\frac{\partial \lambda q}{\partial q} = \frac{[2\lambda(1 + \lambda q)]^2 \sigma_l^2}{4\lambda(1 + \lambda q)(1 + 2\lambda q)\sigma_l^2 - q \Sigma_0^f} .$$

Again, for  $\lambda$  solving Eq. (3) both numerator and denominator are positive. The proof for the *secret target level* case is very similar. We leave the details to the reader. To complete the proof of the first part of the Proposition notice that from Eq. (7)  $\Sigma_1^f$  is increasing in  $\lambda q$ .

Consider now what happens when  $q \uparrow \infty$ . Let us define  $y \equiv \lambda q$ . We know from what we have just proved that in the *common knowledge* and in *secret target level* cases  $y$  is increasing in  $q$ . We now want to know if  $y$  converges to some limit or not. To do it consider that we can express Eqs. (3) and (6) in terms of  $y$  and  $q$ . Let us consider Eq. (3) first. We have:

$$\frac{4y^2(1 + y)^2 \sigma_l^2}{q^2} = (1 + 2y) \Sigma_0^f . \tag{10}$$

Since there is only one positive  $\lambda$  that solves Eq. (3) for any  $q$ , likewise there will be a unique positive  $y$  that solves Eq. (10). Now, suppose that for  $q \uparrow \infty$  the positive root of Eq. (10) converges to a finite limit  $k$ . In this case, in the limit the left hand side of Eq. (10) disappears. Then, we should have:  $(1 + 2k)\Sigma_0^f = 0$ . This implies that  $k < 0$ , that is a contradiction. Thus, the limit of  $\lambda q$  must be infinite. Given Eq. (7) we have proved that in the limit  $\Sigma_1^f \uparrow \Sigma_0^f$ .

Finally, consider the same exercise for the *secret target level* case. We have:

$$\frac{4y^2(1 + y)^2 \sigma_l^2}{q^2} + 4y^2 \Sigma_0^s = (1 + 2y) \Sigma_0^f . \tag{11}$$

Suppose that for  $q \uparrow \infty$  the positive root of Eq. (11) converges to a finite limit  $k$ . In this case, Eq. (11) converges to  $4\Sigma_0^s k^2 = (1+2k)\Sigma_0^f$ . The positive root of this equation is:

$$k = \frac{1}{4}(1 + \Delta) \frac{\Sigma_0^f}{\Sigma_0^s}, \text{ with } \Delta = \sum (1 + 4\Sigma_0^s / \Sigma_0^f)^{1/2}.$$

Since Eq. (11) possesses just one root we have proved the convergence of  $\lambda q$  to a finite limit. Plugging this limit in Eq. (7) we obtain Eq. (8).  $\square$

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