Can Secret Intervention Be Compatible with a Non-Profitmaking Central Bank and a Fundamental-Consistent Target?

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Abstract

The coexistence of secret intervention operations and "the signaling channel" (Mussa, 1981) seems confusing. Vitale (1999) resolves this puzzle by employing an asymmetric information framework and an assumption of a fundamental-inconsistent target for the exchange rate. Ferré and Manzano (2009) follow Vitale's (1999) microstructure framework and argue that the central banks' profitability motivation offers a rationale for their secret intervention even under a target consistent with the fundamentals. However, that the authority uses its superior information to obtain speculative profits through secret intervention in the market is not a typical goal for central banks. To theoretically explain the opaqueness in non-profitmaking central banks' exchange rate policies, we employ a model of a central bank's optimization by considering that no bank really knows the exact fundamental rate and they take into account the possible bad consequences of announcing the intervention. We also show that, in passing the bank's private information to market participants, a bank's announcement of the intervention size is equivalent to revealing its target rate.

JEL Code: E58, F39

Keywords: Signal extraction; secrecy; fundamental consistency; non-profitability

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* E-mail: ecdsyl@ccu.edu.tw. The author thanks all participants at the 4th Conference of Money, Exchange Rates, and Dynamic Equilibrium in Taiwan for their valuable comments. A grant from the NSC of Taiwan (NSC 98-2752-H-194-001-PAE) is also gratefully acknowledged.

1. Introduction

One unique characteristic of a foreign exchange market is its official manipulation. As the IMF (2009, pp. 37) points out, “A member should intervene in the exchange market if necessary to counter disorderly conditions, which may be characterized *inter alia* by disruptive short-term movements in the exchange rate of its currency.” Moreover, most central bank interventions are conducted silently, even though a minority of industrialized countries provides intervention data *ex post*. The vagueness in announcing an exchange rate target and intervention size is a common phenomenon in both developed and developing economies and deserves more study.

The purpose of this article is to theoretically explain the intended opaqueness of exchange rate policies. Regarding how an intervention operation functions to affect the exchange rate in a foreign exchange market, Mussa’s (1981) signaling effect channel (an indirect channel) is often mentioned, rather than the induced excess supply of foreign exchange (a direct channel). Unlike the old signaling channel claiming that the current intervention forecasts future money supply, Vitale (1999) justifies the signaling effect channel through information extraction.[1] As new shocks come into the economy, central banks have private information that the public is not aware of. Yet, this begs the question: given that transparency generally improves efficiency, why doesn’t a bank share its private information with the market?

One rationale for secret interventions in the literature is the government’s exchange rate target not being consistent with the fundamentals.[2] Nonetheless, a

[1] The literature currently does not have such a monetary rule reacting to past official intervention. The study of Kaminsky and Lewis (1996) even finds results contrary to the sign of the signaling effect.

[2] For instance, Japan’s Ministry of Finance makes the decision to intervene, while the Bank of Japan

fundamental-inconsistent exchange rate target can not be sustained for a very long time either in theory or in reality. It is hard to explain with rational expectations models why a government should set a fundamentally inconsistent target rate in a rational market. The public will "learn" to know the true policy rule so as to form correct predictions and can therefore cancel the effect of the policy. In practice, if a target that is inconsistent with fundamentals continues, it leads to a constant imbalance of international payments and eventually needs a re-alignment or else results in a collapsing of the intermediate exchange rate regime.

It is worthwhile providing an alternative explanation for the secrecy of the central banks' intervention by building a theoretical framework with a fundamentals-consistent exchange rate target. Neely (2001), Chiu (2003), and Mihaljek (2005) have conducted a survey of the central banks' foreign exchange intervention in advanced/emerging market countries and have concluded that the motivation behind intervention is to correct misalignment, to return exchange rates to "fundamental values," as well as to calm disorderly markets. Neely (2008) further points out that a successful foreign exchange authority acts consistently with fundamentals.

It should also be noted that the fundamentals in the foreign exchange market are mostly abstract and unclear, and theories dealing with them lack empirical support (Meese and Rogoff, 1983). When a bank announces something it is not exactly sure about and makes the intervention public, the intervention potentially creates opportunities for market participants to reap profits and lowers the effectiveness of the operation on the exchange rate. Furthermore, a record of failed intervention in turn conjures up an image of an incompetent central bank and damages the authority's

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acts as an agent for it. The two may not have the same target all the time.

credibility. Maintaining secrecy or being vague can reduce the possibility of these bad outcomes.

This article considers an optimizing central bank that takes intervention cost into account when reducing the departure of the exchange rate from its fundamental. Moreover, the bank has private but imperfect information regarding the foreign exchange market and is concerned about the risks associated with announcing its intervention operations. Even though secret interventions in reducing the exchange rate departure and the intervention cost are not as efficient as open ones, they can avoid such risk from openness.

Our contribution to the literature is that we provide a theory-based complement for the intended vagueness of the central bank's intervention. Under the practical assumption of fully sterilized intervention, we simultaneously derive the intervention reaction function and the exchange rate process under two intervention modes (secret vs. open). We also find that the following conditions contribute to a bank's decision to conduct a secret intervention: (i) non-fundamental shocks are minor in explaining the total disturbances of the exchange rate; (ii) the bank is less aware of the fundamental shocks; and (iii) the bank considers the departure of the exchange rate from its target as being less important relative to openness risk.

The remainder of this article is organized as follows. The related literature on intervention secrecy is reviewed in Section 2. Section 3 provides a rational expectations model of exchange rate determination under intervention. With assumptions of the exchange rate target being consistent with its fundamentals, Section 4 proves that the announcement of the exchange rate target is equivalent to revealing the amount of intervention, and derives the solutions for models both with secret and announced targets. Section 5 discusses several simulation results of official intervention implied by our models. Section 6 finishes with conclusions and some discussion.

2. Literature review on intervention and its secrecy

2. 1 Main channels for intervention to influence the exchange rate

The relation between the exchange rate and the central bank's interventions is not as clear as the one between the inflation and the money supply/some basic nominal interest rates. Open macro-economic models such as those based on Mundell-Fleming frameworks consider that the central bank's interventions change the excess supply of foreign exchange and thus have an impact on the exchange rate. Following Dominguez and Frankel (1993), recent research often discusses three channels of intervention affecting exchange rates: the monetary/interest rate channel (emphasizing non-sterilized intervention), the portfolio channel (emphasizing imperfect substitution of assets and sterilized intervention), and the signaling effect channel (emphasizing the perfect substitution of assets and sterilized intervention). As shown in Mihaljek's (2005) survey on central banks, every channel has its own supporters.

Among the three channels, the monetary channel is rarely mentioned except for the currency board system, because non-sterilized interventions are less common nowadays.[3] An earlier survey by Canales-Kriljenko (2003) indeed finds that interventions of central banks in developing and transition economies are more effective in affecting exchange rates because of incomplete sterilization. However,

[3] That advanced economies sterilize their intervention is mentioned in Lecourt and Raymond (2006). Many emerging market countries, such as Korea (Kim, Kim and Wang, 2004), Taiwan (Lee and Lai, 2011), Indonesia, Thailand, and Malaysia (Fane, 2005), and the Czech Republic, Hungary, Romania, Slovakia, and Turkey (Égert, 2007), also sterilize their intervention.

whether foreign exchange operations are transparent or not does not affect much the way in which this channel works (Chiu, 2003).

The empirical evidence on the portfolio channel is mixed.[4] Disyatat and Galati (2005) argue that the portfolio channel is more relevant for emerging markets than for advanced countries due to their lower degree of asset substitutability and larger intervention transactions. Although information transmission is not crucial for the portfolio channel, the return of the foreign exchange depends on the expected depreciation rate and whether interventions are overtly or covertly conducted will thus lead to different expectations of the future exchange rate and, in turn, give rise to different influences on the spot rate.

The signaling effect channel is more popular due to the global financial integration since the 1980s. The uncovered interest parity (UIP) implies that, given the unchanged interest rate differential (as under a fully-sterilized intervention case), the expectation of the future exchange rate is the only variable that can change the spot exchange rate. Nevertheless, the degree of capital mobility and the degree of sterilization are inversely related, and it is impossible to completely sterilize an infinite excess supply of foreign exchange in perfect capital mobility circumstance (Mundell, 1963, and Swoboda, 1972). Even though the signal channel can work under perfect capital mobility without complete sterilization and a variety of capital mobility (but not a perfect one) with full sterilization, it is still the most mysterious channel since there is no clear theoretical explanation for the transmission mechanisms.[5]

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[4] See Breedon and Vitale (2010) and Fatum (2010), for example.

[5] Mussa (1981) explains the signaling channel by contradiction: interventions give monetary authorities open positions in foreign currencies that would result in losses if they failed to validate their

The old signaling channel suggests that sterilized foreign exchange interventions have to be publicly known to be effective. The newer signaling channel is based on an asymmetric information assumption that market participants believe that the central bank has superior information on the foreign exchange market and they extract the bank's private information from observed trade orders as well as the bank's announcement about its intervention (if any). This channel is advocated by the literature on a market microstructure approach (see, Hung, 1997; Vitale, 1999; and, recently, Jang, 2007). Hung (1997) points out that secret intervention can have an effect on the trading rules followed by noise traders and thus reinforce the effect of intervention. Obviously, whether interventions are openly or secretly conducted will lead to different market expectations regarding the exchange rate and result in different spot rates through the signaling channel.

2.2 Interaction between intervention and other macroeconomic policies

Policy tools are interdependent and intervention itself is not isolated from other macro policies. The impossible trinity or policy trilemma is a curse for policy makers. The existence of interactions between monetary policy and intervention in order to peg a fixed exchange rate under different degrees of capital mobility and various proportions of sterilization is made clear in the traditional Mundell-Fleming type models in textbooks. In the extreme case of perfect capital mobility, a central bank can not concurrently control the quantity of its money aggregate/the level of the basic interest rate (referring to traditional monetary policy) and the relative price of its currency to the foreign one(s) (referring to intervention), even over a very limited period of time. In practice, however, intervention has been used as a policy tool in addition to traditional monetary policy because the capital mobility is not as perfect as

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signal.

in theory.[6]

According to the "Tinbergen (1956) principle," the government must have at least as many instruments as objectives. Mundell (1962) further provides a "principle of effective market classification," which states that a system works best if variables respond to the markets on which they exert the most direct influence. Since an interest rate policy is the most traditional and common instrument of monetary policy used to stabilize business cycles and control the price level, intervention is employed as an instrument to affect the exchange rate. At least after the 2008 global financial crisis, it has been more popular for central banks to use their interest rate policy to pursue internal goals while using foreign exchange market intervention to pursue external goals.[7]

Intervention by central banks in the foreign exchange market is a direct operation which can affect the exchange rate. It appears to be helpful in underlining the intervention effects by assuming that the monetary policy is in a broad sense implemented recursively. That is, to smooth the inflation/business cycles, an interest rate policy is implemented before the exchange rate policy and the interest rate in turn affects the exchange rate as a foreign exchange market fundamental. A fully-sterilized intervention is then conducted to affect the exchange rate. The effects of the intervention can therefore be separately identified from changes in

[6] That many authorities in advanced economies, such as the Fed, the European Central Bank, and the Bank of Japan, enjoy a high degree of monetary autonomy and engage in intervention to influence the exchange rate at the same time is a fact that justifies the assumption of finite (although high) capital mobility.

[7] For example, China is facing inflationary pressure and has increased its interest rate several times, even though it does not like the Reminbi's appreciation (a side-effect of the higher interest rate policy).

interest rates/monetary aggregates.[8] Previous studies, for instance Mussa (1981) (the old signaling effect approach), Vital (1999) (the market microstructure framework), Humpage (2003) (the asset market approach), and Ghosh (2002) (the Mundell-Fleming framework), implicitly adopt this approach. For analytical simplification, this article follows this approach in elucidating the intended secrecy of a central bank's intervention operations.

The interest rate as a fundamental surely changes the exchange rate but it does not necessarily respond to the exchange rate. Incorporating the departure of the exchange rate from its target into the interest rate reaction function as a "Taylor's rule for open economies" has attracted a lot of attention while giving rise to controversial conclusions (see, for instance, the review by Osawa, 2006). The essence of Taylor's rule is to control inflation. Professor John B. Taylor (2001) points out that, once the interest rate responds to inflation, adding the exchange rate to the policy equation does not help in improving the performance of monetary policy.

In addition, even if the central bank lets its interest rate policy be responsible for controlling inflation while intervention responsible for controlling exchange rate, it is infeasible to sterilize the long-term imbalance of international payments resulting from intervention. Lee (2011) theoretically proves that the stationarity of a central bank's intervention is determined by the fundamental-consistency of its exchange rate target. Geršl and Holub (2006) assess a managed floater's consistency of intervention with its inflation-targeting monetary policy based on the Czech 1998-2002 experience and judge that most intervention episodes are consistent. A

[8] Neely (2001) states that "[t]he crucial distinction between sterilized and unsterilized intervention is that the former constitutes a potentially useful independent policy tool while the latter is simply another way of conducting monetary policy."

sustainable and credible exchange rate target should be a rate consistent with economic fundamentals, which essentially include monetary policy stances. This article adopts this approach.

2.3 The secrecy of central banks' foreign exchange intervention

The IMF (2000) identifies two key benefits of a transparent policy framework, namely, the enhancement of policy effectiveness through promoting public understanding of the goals and instruments of policy, and the strengthening of governance by promoting accountability.[9] However, the Fund's code on policy transparency "does not deal with issues related to the transparency of foreign exchange operations" and central banks can "choose the degree of transparency of foreign exchange intervention that makes it more effective" (Canales-Kriljenko, 2003).[10]

Based on surveyed economies (7 advanced economies and 3 Asian little dragons) Chiu (2003) notes that, compared with central banks' activities in the money market (in which the bank is the sole supplier of base money or the authority that determines certain benchmark interest rates), banks face much greater uncertainty in operating in

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[9] For an interesting comparison, the reader can refer to Goodfriend (1986)'s discussion about five questionable arguments of the Federal Open Market Committee for justifying the secrecy in monetary policy operations: unfair speculation, inappropriate market reaction, harm to the government's commercial interest, undesirable pre-commitment, and more difficult interest rate smoothing.

[10] While embracing a general transparent environment, the IMF (2000) states that "extensive disclosure requirements about internal policy discussion on money and exchange market operations might disrupt markets, constrain the free flow of discussion by policy makers, or prevent the adoption of contingency plans." Canales-Kriljenko, Cuimarães and Karacadağ (2003) further suggest that, in order to achieve the intervention objective most efficiently, the tactics of intervention should never be revealed.

the foreign exchange market. The author further suggests that "…one can probably conclude that the relationship between transparency in monetary policy and that in foreign exchange intervention is by no means straightforward," and gives several practical examples.[11]

Sarno and Taylor (2001) review the theory and evidence on official intervention and reach the conclusion that "most actual intervention operations in the foreign exchange market have been—and still are—largely secret, not publicly announced by monetary authorities." At the present time, those authorities seldom intervene in the FX markets, such as the central banks of Canada, Japan, the U.S. and the Eurozone, mostly confirming their operations after intervention has taken place and providing some details with a certain time lag. By contrast, others, such as Asian emerging markets, actively intervene, but do not have regular channels to disclose their interventions (except for Hong Kong).

Canales-Kriljenko's (2003) survey is based on the IMF's 2001 Survey on Foreign Exchange Market Organization, and covers a large number of developing and transition economies. It shows 40% of respondents "Not Announcing or Reporting Foreign Exchange Intervention (Table 25)," only 13% of respondents "Announcing *Ex Ante* Foreign Exchange Intervention (Table 26)," and 19% of respondents "Publishing Foreign Exchange Intervention Figures (sometimes with a lag) (Table 27)."

Central banks intervene secretly in the foreign exchange market because they believe such kinds of intervention are more effective. In Mihaljek's (2005) emerging

[11] For instance, the Bank of Korea has high (low) transparency in explaining its monetary policy (foreign exchange operations), while the Bank of Canada adopts a relatively open (less transparent) approach in its foreign exchange intervention (monetary policy framework).

markets survey of central banks' views, which is based on the extensive 2004 survey of the Bank for International Settlements, half of the 20 respondents intervening confirm the effectiveness of secret interventions (others either do not intervene or do not intervene secretly).

Dominguez and Frankel (1993) mention a couple of rationales for intervention secrecy by observing the intervention practice. In circumstances where fundamentals are inconsistent with the intervention and/or there is poor track record, central banks prefer intervening secretly to openly to avoid damaging credibility. In other circumstances (which are excluded from a narrow perspective of intervention) a foreign exchange purchase or sale is conducted secretly, merely because it is for client transactions or portfolio adjustments rather than to influence the exchange rate.[12]

Also noted by Chiu (2003), one major worry for the risk of increasing transparency in foreign exchange market interventions is the possible erosion of credibility if the intervention fails to achieve its objective. The intuitive explanation for secrecy is that, when the market cannot distinguish the source of the problem, a failed intervention policy may be less likely to damage central bank credibility. When fundamentals are unclear, central banks may misjudge the market conditions and openness causes the public to recognize this mistake.

Another concern about announcing an intervention emphasizes that it may make speculators take advantage of such predictable behavior and profit from the bank's intervention operations. Sarno and Taylor (2001) further conjecture that the secrecy of central bank's intervention may be an attempt to affect the exchange rate without

[12] For example, since 2004 the Czech authority has intervened to systematically decumulate its reserves to mitigate the valuation loss on its euro-denominated reserve assets (Dominguez, Fatum and Vacek, 2010).

triggering a self-fulfilling attack on the currency.

2.4 Some useful papers about intervention secrecy/transparency

There are several theoretical studies that are devoted to explaining the intended vagueness of the central bank's interventions. Bhattacharya and Weller (1997) and Vitale (1999) provide a reason for secret interventions, claiming that, when the central bank's exchange rate target is inconsistent with its fundamentals, the announcement of the target is not convincing and interventions are operated secretly in order to fool the public. Popper and Montgomery (2001) provide another theoretical explanation by a model of information sharing among heterogeneously informed agents. Central banks adopt secret intervention because they interact with only some dealers, not all.

Among them, Vitale (1999) uses a market microstructure framework to study a central bank's secret interventions. The author simulates the central bank's loss under the fundamental-inconsistent target assumption and finds that official purchases with a secret target result in less loss than with a target that is public knowledge. Barnett and Ozerturk (2007) extend Vitale (1999) by allowing for a second central bank and show that the first central bank's selectively, as opposed to publicly, disclose target improves the effectiveness of the intervention.

Although Neely's (2008) survey of monetary authorities' beliefs finds modest agreement for "inconsistency" as a factor that increases the likelihood of keeping an intervention secret, targeting a fundamental-inconsistent exchange rate is not a normal policy. Lecourt and Raymond (2006) in a survey on central banks in industrialized countries question the main reason for their interventions being conducted secretly and find, among 9 respondents, that the majority of them answers neither "to minimize the effect in the market," nor "to counter speculative attacks," but "other (undefined reasons)."

Ferré and Manzano (2009) extend Vitale's (1999) framework by adding a fundamental exchange rate target. They show that if the intervention is consistent with the fundamentals (where the variance of the non-fundamental part of the target is zero), secrecy will provide a higher expected profit, so that the central banks' profitability motivation can offer a rationale for their secret intervention.[13] However, that an authority uses its superior information to obtain profits through secret intervention in the market is not a typical intervention motive of a central bank in practice, either. In the survey by Neely (2001) on 22 monetary authorities that participated in the Bank for International Settlements' 1999 survey on foreign exchange practices (of which 9 were in emerging markets) and the European Central Bank, for the factor "to profit from speculative trades," 100% of the monetary authorities answered "Never." For the factor "to resist short-term trends in exchange rates" in the questionnaire, 42.1% and 47.4% of monetary authorities respectively answered "Sometimes" and "Always." Moreover, 66.7% of monetary authorities answered that they intervene "to correct long-run misalignments of exchange rates from fundamental values."

Beine and Bernal (2007) empirically investigate the main determinants of secret interventions in the foreign exchange market of Japan, while also providing a literature survey. They define a secret intervention as an "intervention that has not been reported to market participants by the involved central bank or banks on the day it was carried out." Their binary response logit model estimation shows that, during the 1991-2004 period, the probability that the Bank of Japan would conduct an

[13] An interesting finding detected by Neely (2008) is that the central banks of floating rate economies believe that they can profit from intervention but seem to be concerned about the risk, while fixers are less optimistic about profiting from intervention.

intervention secretly (rather than publicly) is positively related to the misalignment of the exchange rate (inconsistent target case), negatively related to the previous 5 days' failure record of reported interventions, while negatively but insignificantly related to "leaning-against-the-wind" operations. The second finding goes against the view of Chiu (2003).

Beine et al. (2009) employ a three-level nested logit model in estimating the same period of Japanese data but find that inconsistency, previous reported successes and "leaning-against-the-wind" operations are all significantly and positively related to the probability of a public intervention (rather than a secret one). These findings are surprisingly inconsistent with those in Beine and Bernal (2007).

Due to data limitations, most of the empirical evidence is based on several advanced economies that have hardly intervened since the beginning of the 21st century.[14] As for those countries that intervene in their foreign exchange markets almost every day, empirical study that investigates the determinants of their secret interventions is a lack. Chiu (2003) points out that the data problem is the main hindrance in empirical studies related to intervention transparency. Identifying a secret intervention from an open one is not so clear-cut in practice.

3. An environment of an official intervention with asymmetric information

To focus our study, we assume complete sterilization, so that the fundamentals of the foreign exchange market are independent of the central bank's intervention.[15] We begin with the following definition of the foreign exchange market:

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[14] Regarding emerging markets exception, Geršl and Holub (2006) investigate the Czech authority's intervention.

[15] This is because the central bank sterilizes fully the change in money supply induced by intervention in the foreign exchange market.

$$\mathrm{CA}_t + \mathrm{FA}_t = \mathrm{BOP}_t, \tag{1}$$

where CA_t denotes the balance of the current account, FA_t denotes the balance of the capital and financial accounts, and BOP_t denotes the balance of payments. Equation (1) is an essential market constraint for any open macroeconomic model, including models built on a micro-foundation: the market constraint is also a country's budget constraint — the country's change in foreign reserves (the right-hand side variable) is equal to its net exports plus investment income inflows and the accumulation of foreign assets owned by its private sector (summarized by the left-hand side variables). Moreover, $\mathrm{BOP}_t = INT_t$ and the latter is the central bank's intervention (net buying in foreign reserves) at time *t*. As in Humpage (2003), "intervention" refers to official purchases or sales of foreign exchange undertaken to influence exchange rates.

Let e_t be the logarithm of the exchange rate (defined as the domestic currency price of foreign currency). Regarding the current account, the exchange rate has a predominant influence on it through a relative price effect, while in the case of the financial account the expected devaluation rate $(E_t e_{t+1} - e_t)$ has a decisive effect on the flow of international capital. The term E_t denotes the market expectations based on the available information at time *t*. Aside from the exchange rate, there are fundamental factors (f_t) as well as non-fundamental disturbances (d_t) that give rise to purchases or sales in the foreign exchange market.

Following the Mundell-Fleming specification for the current account and the capital/financial account, the analytical framework for the exchange rate behavior can be described by the following constraint in the foreign exchange market:

$$f_t + d_t + (\delta + \gamma) e_t - \gamma E_t e_{t+1} = INT_t, \tag{2}$$

where δ captures the price elasticity of the current balance and γ is the interest semi-elasticity of the capital and financial accounts. Although Equation (2) appears to be a reduced-form equation, γ and δ are structural parameters even in more general models due to their economic interpretation and are irrelevant to a central bank's attitude regarding intervention secrecy. In addition, Equation (2) can include the extreme case of perfect capital mobility implied by many microstructure models ($\gamma \to \infty$) Moreover, Equation (2) provides a simple way of displaying the forward-looking feature of the exchange rate, which is the most important characteristic of asset prices that has been disregarded in many empirical studies.

Note also that f_t is a linear combination of fundamental factors influencing the foreign exchange market, which may contain technology shocks, the physical capital stock, financial assets, price differentials between a home country and its foreign counterpart, as well as interest differentials (entering f_t with a coefficient γ). To make the model tractable while capturing the persistence of foreign exchange market fundamentals, this article assumes that fundamentals follow a random walk with drift — that is, $f_t = \lambda + f_{t-1} + u_t$, in which u_t is a normally distributed white noise with mean zero and variance σ_u^2. On the other hand, we assume that a non-fundamental factor d_t captures temporary noises, such as seasonal demand, fads, speculative attacks, and even political disruption that affect this market. In addition, we assume that it is a normally distributed white noise with mean zero and variance σ_d^2. Since d_t represents non-fundamental factors, it is obvious that u_t and d_t are orthogonal.

In Equation (2), $E_t x_{t+i} \equiv E[x_{t+i} \mid \Omega_t]$ is the market expectation of variable x_{t+i} for time $t+i$, given the information set for time t, Ω_t . Although market participants cannot observe the realized shocks at time *t*, they do know all historical variables (that is, $\{f_{t-i}, d_{t-i}\}_{i=1}^{\infty}$) and can extract information based on the observed total market orders of foreign exchange. We assume that people are rational in performing information extraction and forming the market expectations regarding the exchange rate.

By substituting the random walk fundamentals into Equation (2), we obtain:

$$\lambda + f_{t-1} + u_t + d_t + (\delta + \gamma)e_t - \gamma E_t e_{t+1} = INT_t . \qquad (2')$$

Market participants can observe total trading volume and then obtain the combination of $u_t + d_t - INT_t$, but not each component of it, until the end of time *t*.

There is one distinct difference between the microstructure framework of Vitale (1999) and Ferré and Manzano (2009) and the rational-expectations macroeconomic model of this article. In the former, the total market order is the sum of orders from the central bank and noise traders, respectively, and has no influence on the fundamental exchange rate. Even more extreme, the market order of the private sector is independent of the exchange rate. The only way for the market order to change the exchange rate is through changing the market makers' expectations of the fundamental rate. In this article all market participants (the public and the central bank) trade the items in the current account and/or the financial account based on the exchange rate and its expectations. The demand for foreign exchange and the supply of it together turn out to determine the exchange rate.

For the investigation of the optimal intervention decision we have to specify the objective function of the central bank. Let β denote the central bank's discount factor. Suppose the central bank minimizes the following loss function:

$$\mathrm{L} = E_0^b \sum_{t=0}^{\infty} \beta^t \left[\phi(e_t - e_t^*)^2 + (\mathrm{INT}_t)^2 + cI_t\right], \qquad (3)$$

where $E_t^b x_{t+i} \equiv E[x_{t+i} \mid \Omega_t^b]$ is the central bank's expectation of variable x_{t+i} at time $t+i$, based on the information set available to the bank at time t (Ω_t^b), ϕ is the relative weight on the exchange rate's instability, e_t^* is the target of the exchange rate which is set as the best forecast of the fundamental exchange rate by the bank ($e_t^* \in \Omega_t^b$),[16] I_t is an indicator function which equals one (zero) if the bank intervenes in the foreign exchange market with (without) an announcement, and the term c denotes the cost of announcing the exchange rate target.

There are three sources of the central bank's loss in Equation (3): one comes from the instability of the exchange rate, a second is from intervention, and the third arises from an announcement of the exchange rate target before the bank knows the exact market fundamentals/non-fundamentals. The first loss is defined as a departure of the exchange rate from its target and is commonly noted in the previous literature (e.g., Almekinders and Eijffinger, 1996; Miller and Zhang, 1996; Bhattacharya and Weller, 1997; Vitale, 1999; Im, 2001; Ito and Yabu, 2007; and Lee, 2011).

The second loss is caused by the intervention operation itself, as argued by Miller and Zhang (1996), Im (2001), Ghosh (2002), Ito and Yabu (2007), and Lee (2011). A central bank that intervenes must use foreign reserves for exchanging domestic currency and vice versa, and must buy or sell treasury bills for sterilization. Except for the transaction cost, in the case of intervention characterized by "leaning against the wind" which partially alleviates the appreciating/depreciating trend, central banks suffer losses from the new foreign exchange transactions (expressed in

[16] Because the loss function is of the exchange rate departure squared, the "certainty equivalence" principle of the optimization problem is applied and there is no difference whether the bank targets the fundamental rate or the prediction of the rate.

the value of the domestic currency). Bhattacharya and Weller (1997) note that "the central bank… seeks to balance expected losses on currency transactions against its success in achieving its targeting objective." Moreover, reluctance to adjust the exchange rate leads to a deterioration in the balance of payments and affects the domestic economy through spillover effects.

The last cost arises from an openness risk as the central bank reveals *ex ante* its exchange rate target or intended intervention size, without yet knowing the exact fundamental/non-fundamental of the foreign exchange market. There is a possibility that an announcement will provoke the market into gambling on the intervention operation, and the realized exchange rate may differ significantly from the target rate of the bank and result in unpredictable consequences. The market may question the government's ability to affect the exchange rate and maintain market order, and doubt the accountability of the government. These results can have economic repercussions on future exchange rate policies and even influence the election outcomes in a democratic society. Withholding information or being vague can reduce this kind of openness risk.

Vitale (1999) and Ferré and Manzano (2009) assume that the bank intervenes under a trade-off between gaining speculative profits and stabilizing the exchange rate. The two extremes of their intervention consideration are the pure speculator and the pure target. This article assumes that the bank intervenes under a trade-off between stabilizing the exchange rate and saving on intervention costs. The two extremes of our intervention consideration are the peg (pure target) and the clean float.

We assume that central banks have more information than is publicly available in the foreign exchange market. Let $u_t = u_t^b + \varepsilon_t$, in which u_t^b is a normally distributed white noise with mean zero and variance σ_b^2, and which is known at the beginning of time *t* by the central bank before it sets its exchange rate target, while ε_t is an unobservable white noise and is normally distributed with mean zero and variance σ_ε^2, and is orthogonal to u_t^b. Thus, $\sigma_u^2 = \sigma_b^2 + \sigma_\varepsilon^2$ and $\Omega_t \subset \Omega_t^b$. Due to the banks' imperfect information, the expected loss of their open interventions is increasing in σ_ε^2.

We substitute the fundamental shock equation $u_t = u_t^b + \varepsilon_t$ into Equation (2') to further obtain:

$$\lambda + f_{t-1} + u_t^b + (\varepsilon_t + d_t) + (\delta + \gamma)e_t - \gamma E_t e_{t+1} = INT_t\,. \tag{2''}$$

Given the market's expected exchange rates, the government achieves optimization by setting its intervention strategy to minimize the expectations of the loss function, (3), subject to the constraint of the foreign exchange market, Equation (2) or (2").

4. Solutions of models with and without announcements

The assumption that a central bank chooses a fundamental-consistent exchange rate target ensures the intertemporal solvency.[17] The fundamental rate of the foreign exchange is defined as an equilibrium exchange rate in the absence of non-fundamental disturbances ($d_t = 0$) and intervention ($INT_t = 0$), and can be solved forwards for any finite, positive capital mobility (i.e., $0 < \gamma < \infty$).[18] The central bank's exchange rate target (e_t^*) is set at its best predicted fundamental rate as:

[17] In that case the possibility of the bank selling so much as to hit the reserve limit is very slight.

[18] The UIP hypothesis is a common presumption in microstructure models while it is very much disputed in empirical studies (see Adolfson et al., 2008, for example). We thus make the realistic assumption of finite mobility for cross-border capital.

$$e_t^* = -\frac{\lambda + f_{t-1} + u_t^b}{\delta} - \frac{\theta^b}{\delta}(\varepsilon_t + d_t) - \frac{\lambda\gamma}{\delta^2}, \tag{4}$$

where $\theta^b \equiv \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \sigma_d^2}$ is implied by the projection theorem for a normal distribution. The second term in Equation (4) is obtained from the bank's information extraction, which arises from the inseparable-observed part ($\varepsilon_t + d_t$) in Equation (2"). Readers can refer to Appendix 1 for the details of the derivations.

In the framework of asymmetric information, the participants in a foreign exchange market try to filter out the central bank's private information from the observable market orders traded. Suppose that market participants conjecture the optimal intervention of the central bank to be a linear function of the bank's private information (u_t^b) and of the bank's observed sum of concurrent shocks ($\varepsilon_t + d_t$):

$$INT_t = a(\varepsilon_t + d_t) + bu_t^b. \tag{5}$$

The participants therefore engage in information extraction by filtering out the private information of the central bank with observed trading amounts (O_t) of the foreign exchange market in Equation (2"):

$$\begin{aligned} O_t &\equiv u_t^b + \varepsilon_t + d_t - INT_t \\ &= (1-b)u_t^b + (1-a)(\varepsilon_t + d_t). \end{aligned} \tag{6}$$

Note that in this article announcing the exchange rate target is equivalent to revealing the amount of intervention. If the central bank announces the exchange rate target, then through simultaneously solving the private information of the central bank (u_t^b) and the bank's observed sum of concurrent shocks ($\varepsilon_t + d_t$) by Equations (4) and (6), market participants are led to know INT_t through Equation (5). Conversely, if INT_t is known through an official announcement, then by simultaneously solving Equations (5) and (6), one can obtain u_t^b and $\varepsilon_t + d_t$, too. Market participants can substitute them into Equation (4) and can then be aware of the bank's target rate. Hereinafter, we explain the intervention secrecy by considering whether the bank *ex ante* reveals the exchange rate target can make less loss. In what follows, we discuss the minimization of the expected loss function under secret intervention and open intervention, respectively.

Through information extraction, together with the definition of O_t, the application of the projection theorem for normal distributions provides the market with expectations of (i) the central bank's private information on fundamental shocks (u_t^b), (ii) fundamental shocks that the central bank does not know (ε_t), and (iii) non-fundamental shocks (d_t). The optimal intervention and the exchange rate in the foreign exchange market which is consistent with rational expectations assumptions can be solved as:

$$INT_t = -\frac{\phi}{\delta + \gamma}\left[1 + \frac{\gamma(\theta_1 + \theta_2)}{\delta}\right](e_t - e_t^*), \qquad (7)$$

and

$$e_t = -\frac{\lambda\gamma}{\delta^2} - \frac{\lambda + f_{t-1}}{\delta} - \frac{1 + \frac{\gamma(\theta_1 + \theta_2)}{\delta}}{\delta + \gamma}\left[(1-b)u_t^b + (1-a)(\varepsilon_t + d_t)\right], \qquad (8)$$

where θ_1 and θ_2 are functions of the variances of each shock and the underdetermined coefficients, *a* and *b*, which in turn are solved using the method for resolving undetermined coefficients.

By inserting Equation (7) into the bank's loss function, (3), together with Equations (4) and (8), the central bank's conditional expectation of the loss under its secret intervention (L_t^s) is:

$$\mathrm{L}_t^s = \varphi\left\{1+\frac{\varphi[\delta+\gamma(\theta_1+\theta_2)]^2}{(\delta+\gamma)^2\delta^2}\right\}\left\{\left[\frac{\gamma(1-\theta_1-\theta_2)+b[\delta+\gamma(\theta_1+\theta_2)]}{\delta(\delta+\gamma)}\right]^2\sigma_b^2\right.$$

$$\left.+\left[\frac{\delta(\theta^b-1)+\gamma(\theta^b-\theta_1-\theta_2)+a[\delta+\gamma(\theta_1+\theta_2)]}{\delta(\delta+\gamma)}\right]^2(\sigma_\varepsilon^2+\sigma_d^2)\right\}. \quad (9)$$

On the other hand, the central bank can alternatively share its information with the market, instead of adopting a concealment approach. If the bank announces its exchange rate target or reveals the extent to which it is going to intervene, then market participants will forecast the exchange rate more accurately, while the bank will bear the openness risk (the cost c in Equation (3)).

The exchange rate in the foreign exchange market and the optimal intervention consistent with the rational expectations assumption are solved as:

$$e_t = -\frac{\lambda\gamma}{\delta^2}-\frac{\lambda+f_{t-1}}{\delta}-\frac{\gamma+\delta(1-b)}{\delta(\delta+\gamma)}u_t^b-\frac{\gamma\theta^b+\delta(1-a)}{\delta(\delta+\gamma)}(\varepsilon_t+d_t), \quad (10)$$

and

$$INT_t = -\frac{\phi}{\delta+\gamma}\left[1+\frac{\gamma\theta^b}{(1-a)\delta}\right](e_t-e_t^*). \quad (11)$$

The central bank's conditional expectation of the loss under its open intervention (L_t^o) becomes:

$$\mathrm{L}_t^o = \phi\left[1+\frac{\phi\left(\delta+\frac{1}{1-a}\gamma\theta^b\right)^2}{\delta^2(\delta+\gamma)^2}\right]\left(\frac{1-a-\theta^b}{\delta+\gamma}\right)^2(\sigma_\varepsilon^2+\sigma_d^2)+c. \quad (12)$$

A central bank will compare the loss under its secret intervention in Equation (9) with that under its open intervention in Equation (12) to decide whether or not to reveal its private information. Therefore, a fundamental-inconsistent target of the exchange rate is not necessary to justify a central bank's secret intervention. That a central bank endogenously chooses opaqueness in its intervention operations can realize from the bank's calculations that opaqueness gives rise to less of a loss.

5. Simulation experiments

To answer the question as to why some central banks basically keep their interventions secret while others make their interventions public, we compare the central bank's loss from secret intervention with its loss from open intervention. Since the model is highly non-linear, we investigate the determinants of a central bank's attitude in revealing its exchange rate target through simulation experiments.

First, we fix the elasticity of price (δ) in the current account at a value of one. The semi-elasticity of the interest rate (γ) in the financial account is then set to be 0.1, 1, 10, and 100 to investigate an economy with relatively low international capital mobility, intermediate mobility, high mobility, and close-to-perfect mobility, respectively. Second, the weight of the intervention costs in the central bank's loss function is fixed at one. In order to analyze how the central bank values the stability of the exchange rate, we set the weight of the deviation in the exchange rate from its target (ϕ) as 0.1, 1, and 10, respectively. Third, we normalize the variance of the fundamental shocks (σ_u^2) to be one. We then assume the variance of the non-fundamental disturbance to be $\sigma_d^2 = \lambda\sigma_u^2$ and $\log\lambda = [-2, 2]$. Therefore, both cases of relatively small and relatively large irregular disturbances may be analyzed. Fourth, in terms of variance decomposition, we further assume that the relative importance of u_t^b and ε_t in the fundamental disturbance (u_t) is α and $1-\alpha$, respectively. That is, $\sigma_b^2 = \alpha\sigma_u^2$ and $\sigma_\varepsilon^2 = (1-\alpha)\sigma_u^2$. Lastly, the expected cost from the bank's revealing its exchange rate target *ex ante* is specified as $c = 0.1\sigma_\varepsilon^2 / \delta^2$.[19]

[19] From Equation (4), it is easy to show that the expected variation in the difference between the

This section uses several numerical simulations to depict the determinants of a central bank's secrecy. Let α be 0.5 at first. The consequence of changes in $\log(\sigma_d^2)$ on the logarithm of the expected loss under open intervention ($\log(\mathrm{L}_t^o)$) is represented graphically in Figure 1, while that on the logarithm of the expected loss under secret intervention ($\log(\mathrm{L}_t^s)$) is depicted in Figure 2. Recall that, given $\sigma_u^2 = 1$, $\log(\sigma_d^2)$ reflects the relative importance of irregular disturbances to fundamental shocks in explaining the exchange rate. Other things being equal, a higher $\log(\sigma_d^2)$ leads to a more volatile exchange rate and thus a central bank's private information is less helpful in predicting the fundamental exchange rate.

There are three panels in Figure 1 and Figure 2, with each corresponding to a ϕ in which the central bank values the stability of the exchange rate. From Figures 1 and 2, some interesting findings are worth noting: (i) (A higher $\log(\sigma_d^2)$ in each panel) A more volatile irregular disturbance always increases the bank's loss. This is obvious, since the loss is an increasing function of the variance of prediction errors. (ii) (Comparisons of each line in Figure 1 and its counterpart in Figure 2) If the central bank reveals rather than conceals its private information, then the loss driven by more volatile irregular disturbances would on average increase to a small extent. This finding is consistent with the established wisdom that more perfect information lowers uncertainty and increases efficiency and, in most instances, welfare as well.[20]

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central bank target and the fundamental rate equals $\sigma_\varepsilon^2 / \delta^2$. Assume first that the risk from intervention openness results in a cost equal to an additional 10 percent of the expected variation, i.e., $c = 0.1\sigma_\varepsilon^2 / \delta^2$.

[20] However, there are at least two examples where more information harms welfare: the heterogeneous agent model of Rudin (1988) and the sticky price model of Ghosh (2002).

(iii) (A higher γ in each panel) Economies with higher international capital mobility have lower loss, regardless of whether the central bank reveals its private information or not. It is well known that a high degree of international capital mobility limits the ability of a central bank to move its exchange rate away from the equilibrium rate. Because our model assumes that central banks target their exchange rate to a fundamental rate, high international capital mobility helps the central banks' efforts. (iv) (A higher ϕ in lower panels) If the bank cares more about the stability of the exchange rate, it has to accept a greater loss due to heavier intervention.

Let $\Delta \mathrm{L} = \mathrm{L}_t^o - \mathrm{L}_t^s$ be the difference between sharing the central bank's information with market participants and not sharing it. A positive $\Delta \mathrm{L}$ means that maintaining secrecy is a better strategy for the bank than revealing its private information. However, since a different openness risk cost (c) shifts the $\Delta \mathrm{L}$ line upward or downward, the sign of the intercept of $\Delta \mathrm{L}$ is determined by the assigned risk cost under open intervention (here, $0.1\sigma_\varepsilon^2 / \delta^2$). We should therefore focus on the evolution of $\Delta \mathrm{L}$ (how the advantage of open intervention changes in some parameters) rather than on its sign.

In Figure 3 the consequences of changes in $\log(\sigma_d^2)$ on $\Delta \mathrm{L}$ are represented graphically as a negative-slope curve. Intuitively, when the fundamental shock explains most of the unpredictable changes in the exchange rate, the bank considers the cost of risk from announcing an indeterminate fundamental exchange rate to be more serious. In this case, concealing the private information results in reducing the central bank's loss and secret intervention is thus a better choice for the bank. Nonetheless, as the variance of irregular disturbances increases (a higher $\log(\sigma_d^2)$), the information on the economic fundamentals becomes less valuable in predicting exchange rates, and the role of openness risk drops. When the variance of the irregular disturbances is large enough, ΔL becomes negative. Revealing the exchange rate target lowers the central bank's loss and thus open intervention turns out to be a better choice for the bank.

Figure 3 plots three panels, each corresponding to a ϕ in which the central bank values the stability of the exchange rate. In the central bank's loss function, a higher ϕ indicates that an openness risk is relatively unimportant to exchange rate instability, where the bank would be prone to openly intervene. This conjecture is confirmed by comparing the ΔL's in the upper panels with those in the lower panels since most ΔL's with low ϕ's are positive, while those ΔL's with higher ϕ's rapidly turn negative as $\log(\sigma_d^2)$ increases by a sufficient amount.

The influence of international capital mobility (γ) on the choice between open and secret intervention is less obvious and is not independent of the other parameters. From the upper panel of Figure 3 we see that, as the variance of non-fundamental shocks ($\log(\sigma_d^2)$) increases, central banks allowing for greater capital mobility prefer secret intervention while those allowing less capital mobility prefer open intervention. It can be seen from the lines in the middle panel of Figure 3 that this relationship changes. Moreover, from the lower panel of Figure 3, it turns out that central banks which allow for higher capital mobility prefer open intervention, while those which allow for less capital mobility prefer secret intervention.

A rough but intuitive explanation is as follows. Relative to the variance of the fundamental shock (normalized to be one), if the variance of the non-fundamental shock ($\log(\sigma_d^2)$) is large enough, the expected fundamental shocks that can be extracted from observable trades, either by central banks or by markets, are very minor. In addition, as the capital mobility is nearly perfect, optimal intervention coefficients approach zero and central banks do not intervene in the foreign exchange market. The intervention costs then vanish as a result. In this case, the second loss (intervention cost) in the loss function declines to zero while the first cost (the exchange rate instability) and the third cost (openness risk) remain. On the one hand, when the central bank is not very concerned about the exchange rate instability (a low ϕ), the openness risk is the main concern. Because only open intervention causes this additional loss, the central banks that allow for high capital mobility favor secret intervention. On the other hand, when the central bank is highly concerned with exchange rate stability (a high ϕ), both the instability of the exchange rate as well as openness risk are determinants of the optimal choice of the bank. Since open intervention usually causes a greater reduction in the exchange rate instability, central banks which allow high capital mobility are prone to engage in open intervention.

The above findings are robust to the variance proportion of fundamental shocks known by central banks. In contrast to the simulation experiments of $\alpha = 0.5$, we conduct $\alpha = 0.9$ as well as $\alpha = 0.1$ simulation experiments. Figure 4 and Figure 5 graph ΔL's with different α's, while data for $\log(\mathrm{L}_t^o)$ and $\log(\mathrm{L}_t^s)$ are not plotted to save space, but are available upon request. Recall that the proportion of fundamental shocks known by central banks is denoted by $\alpha = \sigma_b^2 / \sigma_u^2$. A higher α means that a central bank is more aware of fundamentals. The bank which knows more about the fundamental shocks is better able to lower the cost of the exchange rate instability and is prone to open interventions. As α decreases from 0.9 (Figure 4) to 0.5 (Figure 3) and then to 0.1 (Figure 5), a higher proportion of fundamental shocks is out of the central bank's control. As α decreases, the efficiency gains in terms of stabilizing the exchange rate and saving intervention transactions costs from open interventions fall relatively while the cost of openness risk rises, which leads the bank to prefer hiding the target when it intervenes.[21]

In summary, the bank is more prone to secretly intervene, when: (i) the fundamental shocks are more helpful than non-fundamental ones in explaining the total disturbances of the exchange rate; (ii) the bank is less aware of the fundamental shock; or (iii) the bank considers the departure of the exchange rate from its target to be less important. Capital mobility alone does not have an unambiguous influence on the choice between an open intervention and a secret one. As the volatility of irregular disturbances increases, the attitude toward the departure of the exchange rate from its target is important for the effects of capital mobility on the choice of secrecy.

6. Conclusions and remarks

An inference regarding the secret intervention operations of central banks can be as follows: No central bank knows exactly how much the fundamental exchange rate is or how much the rate responds to one dollar of intervention. The noted international finance economist Rudiger Dornbusch (1986) writes: "how large an intervention is required to move the $/DM rate 1 percent? To that question we have no serious answer." Therefore, central banks intervene "to smooth excess exchange rate fluctuations that *are judged to be* clearly out of line with economic fundamentals" or they intervene when "the exchange rate *is thought to be* clearly out of line with the economic fundamentals" (Chiu, 2003).

This article considers an optimizing central bank as one that takes into consideration the departure of the exchange rate from its fundamental and the cost of intervention. Moreover, it has imperfect information about the foreign exchange

[21] The results are robust even if we assume a constant cost for openness risk.

market and is concerned about the potential, bad consequences of announcing its intervention operations. Even though secret interventions are not in principle as efficient as open ones, they can avoid openness risk.

We show that the announcement of the exchange rate target is equivalent to revealing the amount of intervention, and simultaneously solve the intervention reaction function and the exchange rate process under two intervention modes (secret vs. open). It is found that the following circumstances contribute to a bank's decision to engage in secret intervention: (i) fundamental shocks are more helpful in explaining the total disturbances of the exchange rate; (ii) the central bank is less aware of the fundamental shocks; or (iii) the bank considers the departure of the exchange rate from its target as being less important. Capital mobility alone does not have an unambiguous influence on the choice between the open intervention and secret intervention of central banks.

The first implication of our model is that a more volatile non-fundamental shock makes a central bank consider the price of announcing its intervention operations to be less important and thus the bank will prefer to overtly intervene.[22] A coincident observation is that many emerging market economies that silently engage in frequent intervention in their foreign exchange markets suddenly become more willing to talk about their intervention and/or exchange rate targets when facing an unusual, speculative press (e.g., the authorities of Korea, Taiwan, Thailand, and the Philippines that have been fighting hot money since 2009Q4).

Another implication is the negative relationship between a central bank's private

[22] On the other hand, Ferré and Manzano's (2009) corollary 5 states that a more volatile volume of noise trading makes the speculative profits dominate the losses and thus the bank prefers to intervene secretly.

information about the foreign exchange market fundamentals and its intervention secrecy. In general, advanced economies have more open interventions (if they intervene), while developing and emerging market economies have more secret interventions. If advanced economies do know more about their foreign exchange market fundamentals than other economies, the second implication can be supported. In investigating the implications of official intervention secrecy, a minimum number of observations on intervention secrecy and foreign exchange market fundamentals are still needed to test these hypotheses. However, none of them can be easily measured. As for measuring the extent of the intervention secrecy, quantifying an additional important aspect — the intervention tactics — is an inevitable challenge for empirical research.

Appendix 1

The exchange rate in Equation (2) under a floating rate regime can be solved as:

$$e_t = \frac{\gamma E_t e_{t+1} - f_t - d_t}{\delta + \gamma}$$

$$= -\frac{E_t f_t}{\delta} - \frac{\lambda\gamma}{\delta^2} - \frac{E_t d_t}{\delta + \gamma}. \tag{A1}$$

The fundamental exchange rate (e_t^f) defined at no non-fundamental disturbances is:

$$e_t^f = -\frac{f_t}{\delta} - \frac{\lambda\gamma}{\delta^2}. \tag{A2}$$

Therefore the central bank's fundamental-consistent target is:

$$e_t^* = -\frac{E_t^b f_t}{\delta} - \frac{\lambda\gamma}{\delta^2}$$

$$= -\frac{\lambda + f_{t-1} + u_t^b}{\delta} - \frac{\theta^b}{\delta}(\varepsilon_t + d_t) - \frac{\lambda\gamma}{\delta^2}. \tag{4}$$

Because the irregular disturbance d_t is unpredictable, it is reasonable to make a conjecture that the market participants' rational expectation of e_{t+1} is:

$$E_t e_{t+1} = -\frac{\lambda\gamma}{\delta^2} - \frac{E_t f_{t+1}}{\delta}$$

$$= -\frac{\lambda}{\delta^2}(\gamma + \delta) - \frac{E_t f_t}{\delta}. \tag{A3}$$

In the case of secret intervention, the application of the projection theorem for normal distributions implies that the expectations of the central bank's private information about shocks, u_t^b, ε_t, and d_t are:

$$E_t u_t^b = E[u_t^b \mid \Omega_t] = \theta_1 O_t, \tag{A4}$$

$$E_t \varepsilon_t = E[\varepsilon_t \mid \Omega_t] = \theta_2 O_t, \tag{A5}$$

and

$$E_t d_t = E[d_t \mid \Omega_t] = \theta_3 O_t, \tag{A6}$$

where $\theta_1 \equiv \dfrac{(1-b)\sigma_b^2}{(1-a)^2(\sigma_\varepsilon^2+\sigma_d^2)+(1-b)^2\sigma_b^2}$, $\theta_2 \equiv \dfrac{(1-a)\sigma_\varepsilon^2}{(1-a)^2(\sigma_\varepsilon^2+\sigma_d^2)+(1-b)^2\sigma_b^2}$,

and $\theta_3 = \theta_2\sigma_d^2/\sigma_\varepsilon^2$.

From Equations (A4) and (A5), the rational expectation of concurrent fundamental f_t made by the market is as follows:

$$E_t f_t = \lambda + f_{t-1} + (\theta_1+\theta_2)O_t. \tag{A7}$$

Reorganize Equation (2") and use the definition of O_t in Equation (6), the exchange rate of the foreign exchange market then becomes:

$$e_t = \frac{1}{\delta+\gamma}\left[\gamma(E_t e_{t+1}) - \lambda - f_{t-1} - O_t\right]. \tag{A8}$$

To see the effect of intervention on the exchange rate, differentiating (A8) with respect to INT_t, together with Equations (A3), (6), and (A7), to get:

$$\frac{\partial e_t}{\partial INT_t} = \frac{1}{\delta+\gamma} + \frac{\gamma}{\delta+\gamma}\frac{\partial E_t e_{t+1}}{\partial INT_t}$$

$$= \frac{1+\frac{\gamma(\theta_1+\theta_2)}{\delta}}{\delta+\gamma}. \tag{A9}$$

Minimizing the loss function (3) by choosing optimal intervention, subject to Equation (A9), we have the following first-order condition for INT_t:

$$INT_t = -\frac{\phi}{\delta+\gamma}\left[1+\frac{\gamma(\theta_1+\theta_2)}{\delta}\right](e_t - e_t^*). \tag{7}$$

For Equation (A8), we substitute Equation (A3) for $E_t e_{t+1}$, (A7) for $E_t f_t$, and (6) for O_t, and the exchange rate of the foreign exchange market becomes:

$$e_t = -\frac{\lambda\gamma}{\delta^2} - \frac{\lambda+f_{t-1}}{\delta} - \frac{1+\frac{\gamma(\theta_1+\theta_2)}{\delta}}{\delta+\gamma}\left[(1-b)u_t^b + (1-a)(\varepsilon_t + d_t)\right]. \tag{8}$$

Taking expectations of both sides of Equation (8) at time $t+1$ confirms our initial forecast of Equation (A3).

Putting Equations (4) and (8) into (7), with the method of undetermined coefficients, the initial conjecture of optimal intervention (5) by market participants is consistent with the optimal intervention of the central bank, if and only if:

$$a = -\phi\left[\delta + \gamma(\theta_1 + \theta_2)\right]\frac{\theta^b(\delta+\gamma) - (1-a)\left[\delta + \gamma(\theta_1 + \theta_2)\right]}{\delta^2(\delta+\gamma)^2},$$

and

$$b = -\phi\left[\delta + \gamma(\theta_1 + \theta_2)\right]\frac{(\delta+\gamma) - (1-b)\left[\delta + \gamma(\theta_1 + \theta_2)\right]}{\delta^2(\delta+\gamma)^2}.$$

In this case of open intervention, $E_t^b u_t = E_t u_t = u_t^b$. From Equations (2”), (3), (A3), and (6), the exchange rate of the foreign exchange market and the optimal intervention consistent with the rational expectations assumption become:

$$e_t = -\frac{\lambda\gamma}{\delta^2} - \frac{\lambda + f_{t-1}}{\delta} - \frac{\gamma + \delta(1-b)}{\delta(\delta+\gamma)}u_t^b - \frac{\gamma\theta^b + \delta(1-a)}{\delta(\delta+\gamma)}(\varepsilon_t + d_t), \qquad (10)$$

and

$$INT_t = -\frac{\phi}{\delta+\gamma}\left[1 + \frac{\gamma\theta^b}{(1-a)\delta}\right](e_t - e_t^*), \qquad (11)$$

where $a = \dfrac{\phi\left[(1-a)\delta + \gamma\theta^b\right](1-a-\theta^b)}{(\delta+\gamma)^2(1-a)\delta}$ and $b = 0$.

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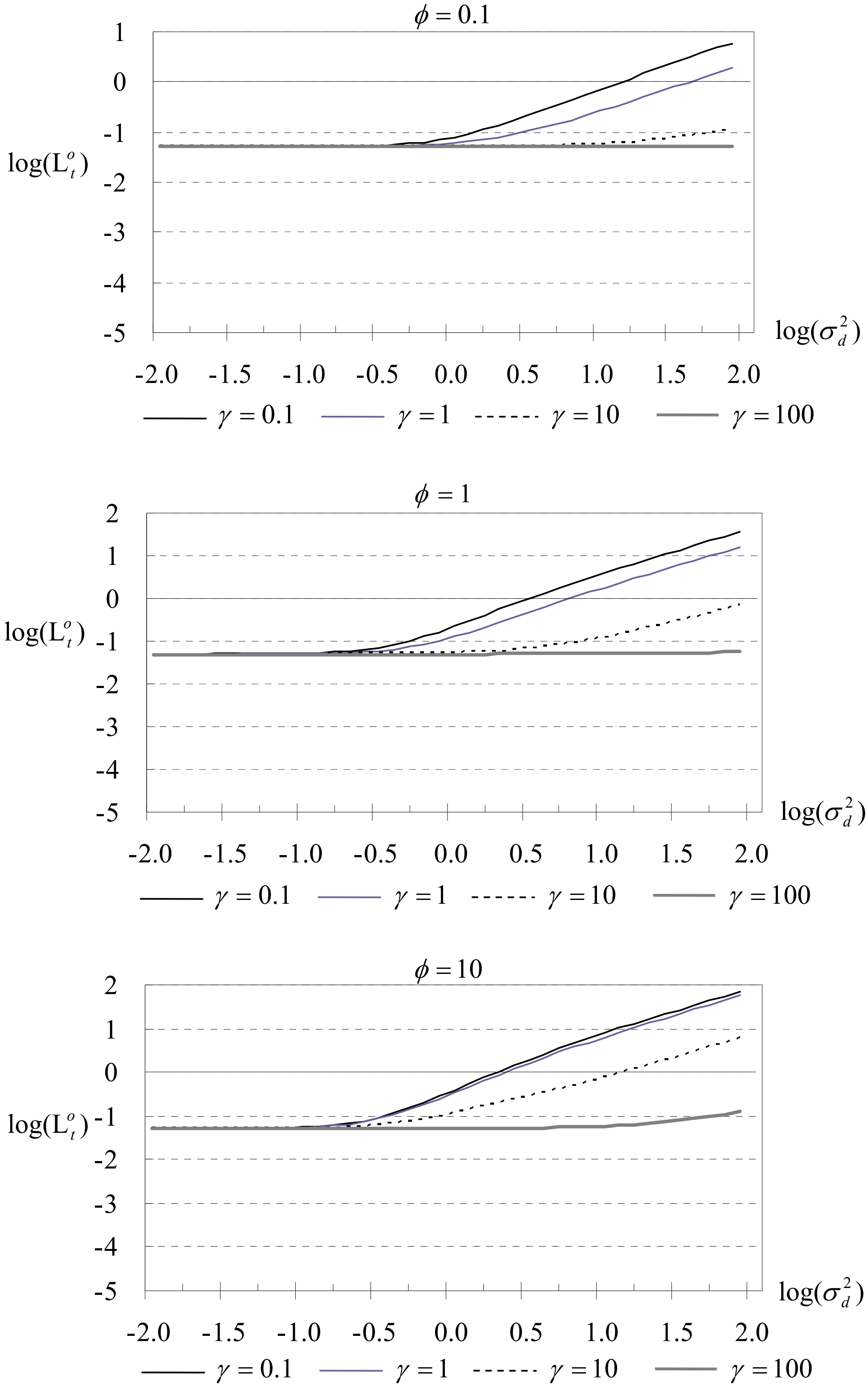

Figure 1. Expected Loss from Open Intervention

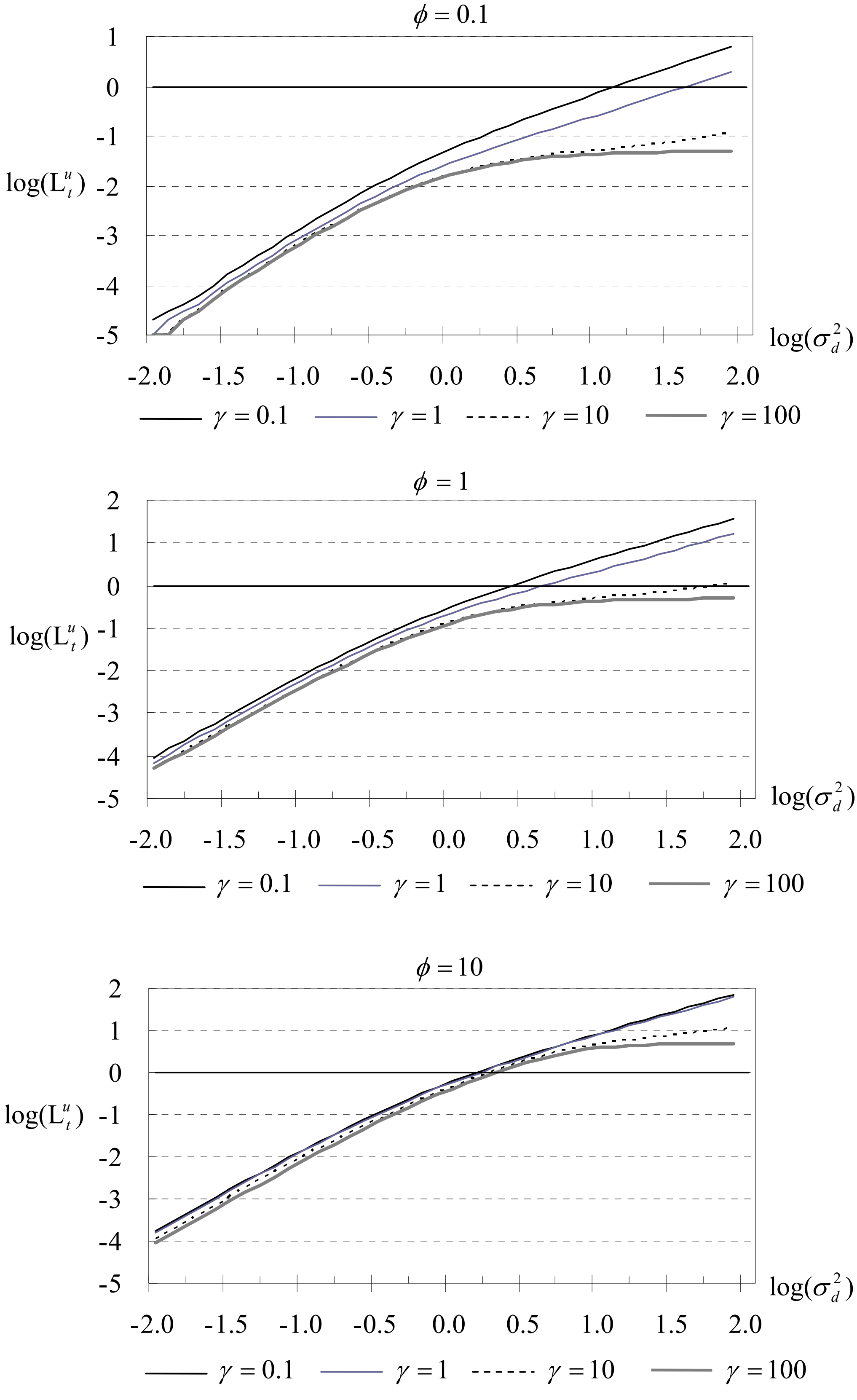

Figure 2. Expected Loss from Secret Intervention

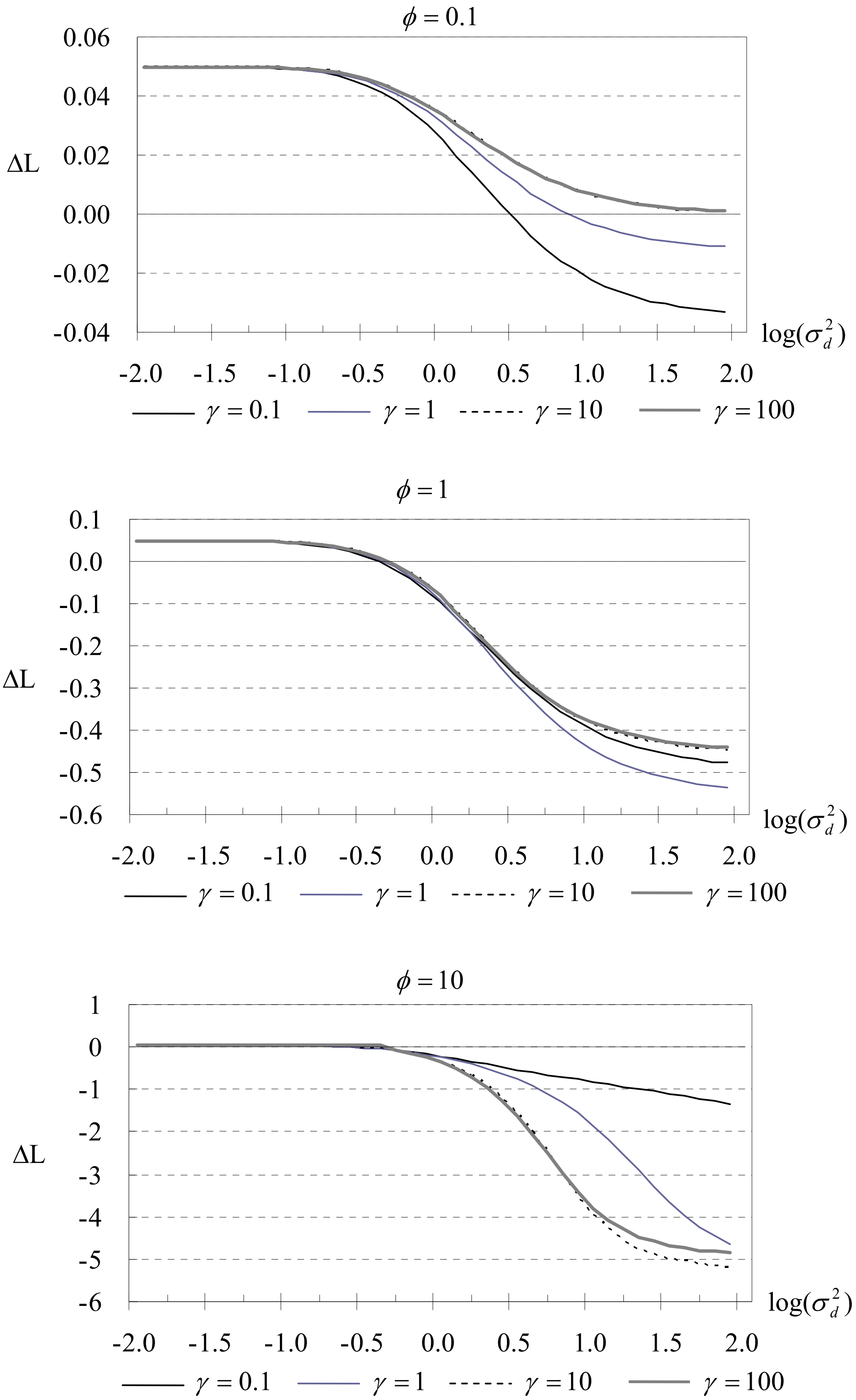

Figure 3. Expected Loss Differential ($\alpha = 0.5$)

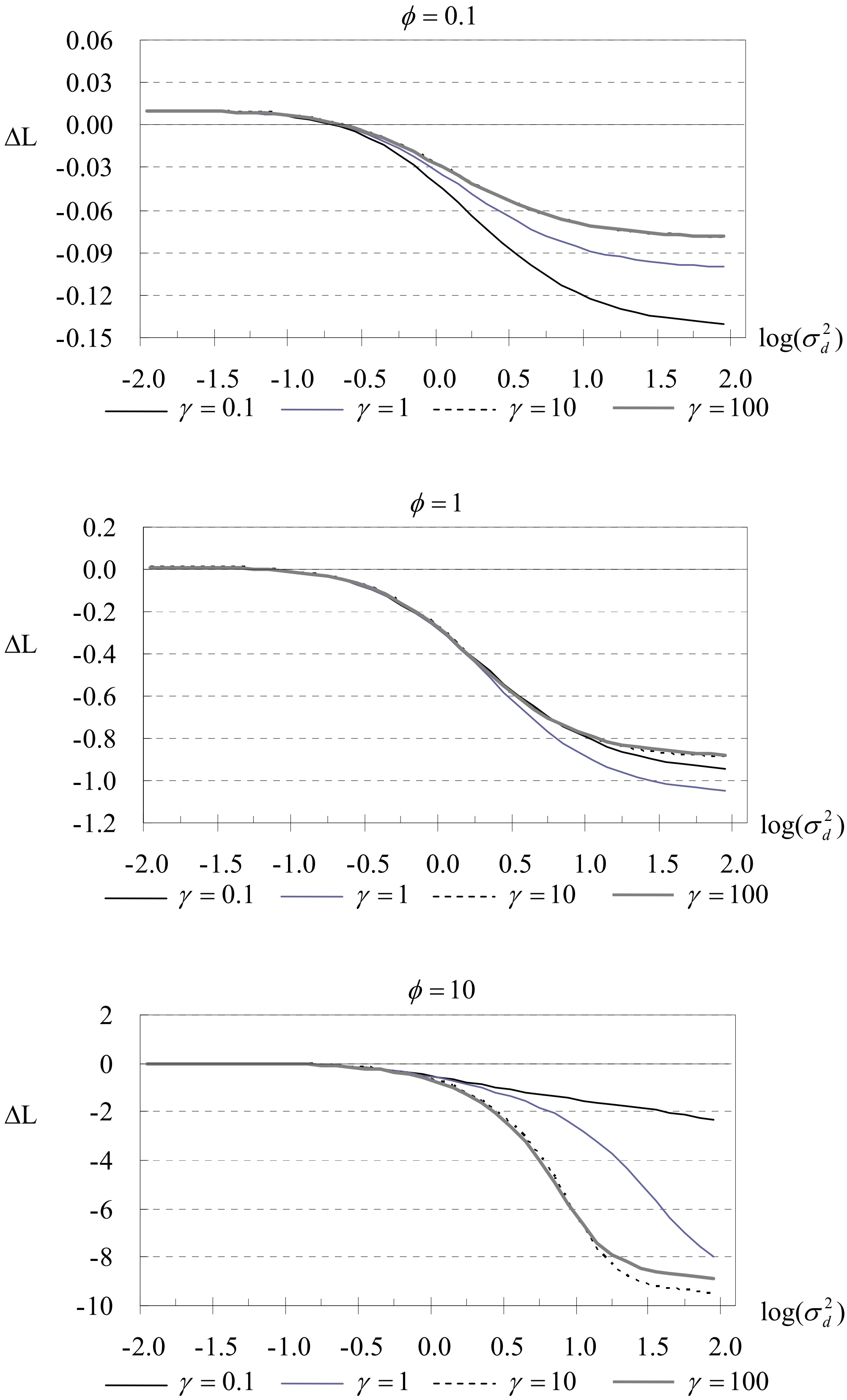

Figure 4. Expected Loss Differential ($\alpha = 0.9$)

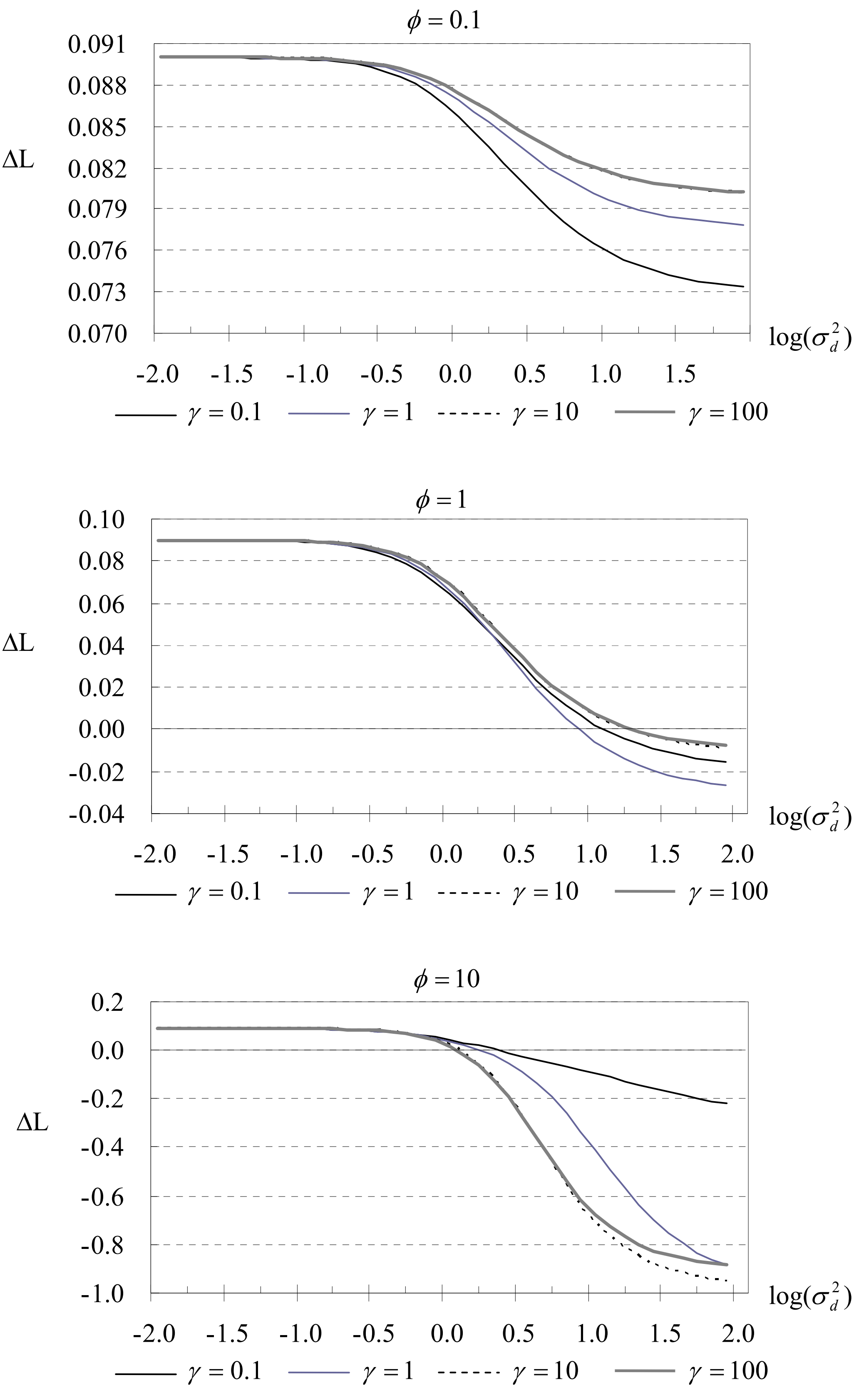

Figure 5. Expected Loss Differential ($\alpha = 0.1$)