The Scandinavian
Journal of Economics

Scand. J. of Economics 116(2), 506–538, 2014
DOI: 10.1111/sjoe.12044

"Large" versus "Small" Players: A Closer Look at the Dynamics of Speculative Attacks*

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Abstract

What is the role of "large players" (e.g., hedge funds) in speculative attacks? Recent work suggests that large players move early to induce smaller agents to attack. However, many observers argue that large players move late in order to benefit from interest-rate differentials. We propose a model in which large players can do both. Using data on currency trading by foreign (large) and local (small) players, we find that foreign players moved last in three attacks on the Norwegian krone during the 1990s. During the attack on the Swedish krona after the Russian moratorium in 1998, foreign players moved early. Gains by delaying attack were small, however, because interest rates did not increase.

Keywords: Currency crises; foreign exchange trading; large players; microstructure

JEL classification: *F*31; *F*41; *G*15

I. Introduction

Currency crises often appear to be only loosely connected to economic fundamentals. This observation has encouraged a large and growing body

*We thank Paul De Grauwe, Chris D'Souza, Øyvind Eitrheim, Michael Moore, Erling Steigum, and two anonymous referees for constructive comments. The data were kindly provided by Norges Bank and Sveriges Riksbank. Any mistakes remain our own. The views expressed here do not necessarily reflect those of Norges Bank.

of literature on why, when, and how currency crises occur. The role of large players is often emphasized in the public debate. Many observers and politicians have denounced hedge funds and other highly leveraged institutions, especially foreign ones, for manipulating exchange rates during speculative pressure. This interest has also been reflected in the academic literature. A key contribution has been made by Corsetti *et al.* (2004) (hereafter CDMS). They have extended the model of Morris and Shin (1998) by introducing a single large player who might have superior information. The work by CDMS has inspired a number of contributions, both theoretical (Bannier, 2005) and experimental (Taketa *et al.*, 2009).

In the model of CDMS, the large player will move early in order to signal his/her information to the small players, thereby inducing an attack. However, this is in contrast to the experiences from the European-wide Exchange Rate Mechanism (ERM) crisis of 1992–1993 and the Asian currency crisis of 1997–1998. In these cases, Tabellini (1994) and IMF (1998) have argued that the large players moved late because they wanted to benefit from positive interest-rate differentials.

We extend the CDMS model by adding the possibility of a late attack in the analysis. An early attack by the large player might induce the small players to attack the currency, but it also involves the cost of moving to a currency with a lower interest rate. If the interest-rate differential is large, the large player might prefer to delay some or all of his/her speculation to the last stages of the attack. In contrast, if early speculation is sufficiently cheap (because of a small interest-rate differential), or if the effect on the small players is crucial for the success of the attack, the large player will attack early.

In order to study position-taking during speculative attacks, we use a unique dataset on weekly spot and forward trading by foreigners and local non-bank customers in the Norwegian and Swedish markets. The foreign exchange (FX) market is almost completely unregulated, lacking, for example, the trade disclosure requirements seen in equity markets. Therefore, it is difficult to obtain detailed data on trading in FX data. Norges Bank and Sveriges Riksbank (the central banks of Norway and Sweden, respectively) collect data from banks on their buying and selling with foreigners and locals. Exactly who is behind these trades is only known to the reporting banks, but evidence by Lindahl and Rime (2012) from a detailed dataset on the trading of Swedish banks suggests that foreign customers, in general, trade larger volumes than local customers. This is true for several different types of customers: foreign financial customers, for example, typically trade larger volumes than local financial customers.

Armed with these data, we explore the implications of the model empirically on three cases of speculative pressure on the Norwegian krone (NOK), and one case for the Swedish krona (SEK). The Norwegian cases are (i) the attack during the ERM crisis in December 1992, (ii) the NOK-specific attack in January 1997, and (iii) the attack during the crisis that followed the Russian moratorium in August 1998. The third crisis is also our Swedish case. Norway had a fixed exchange rate in 1992, while the exchange rate was a managed float in 1997 and 1998. Sweden had an inflation target with a floating exchange rate in 1998, but the Riksbank had nevertheless intervened on several occasions since the ERM crisis of 1992–1993 (see Aguilar and Nydahl, 2000). Even under floating or dirty-floating regimes, speculators can take currency positions in the belief that monetary authorities will change the monetary regime, or at least allow for a considerable change in the exchange rate, in the near future.[1] Such beliefs might be triggered by economic developments making a (implicit) dual mandate of price stability and macroeconomic stability unsustainable.

The dataset employed here is unique for the study of speculative attacks. First, anecdotal evidence from the two central banks suggests that the dataset covers almost the total market for the currencies under investigation. Second, the dataset is very detailed in that it covers the trading of both foreign and domestic players. Finally, the dataset is sufficiently long to cover several speculative attacks. The study by Carrera (1999) of the Mexican crisis of 1994 is also very detailed, but it covers only one crisis. Corsetti *et al.* (2002) and Cai *et al.* (2001) have studied the role of large players during the Asian crisis of 1997–1998 using the US Treasury Bulletin reports. However, these data are aggregate data and the authors simply assume that the data reflect the trading of large players. Furthermore, while the above-mentioned studies have focused on emerging markets, we focus on two European economies.[2] To the best of our knowledge, we are the first to be able to study speculative attacks using data on the trading of both foreign and local traders.

Our results suggest that the behavior of foreign and domestic players differs before and during speculative attacks. We find that foreign players moved last during the three attacks on the NOK. This is in line with the observations made by Tabellini (1994) and IMF (1998) about the ERM and Asia currency crises. We also find that it is the trading of foreign players that is most important when the depreciation takes place (i.e., they move late). This is consistent with our theoretical model, given an assumption that the foreign players represent the large player. The model predicts that the large players can choose to move late if there is some gain from

[1] Calvo and Reinhart (2002) have argued that even if countries officially adopt a "flexible" exchange rate, they often tend to limit the fluctuations of the exchange rate.
[2] The two datasets used here have previously been studied by Rime (2000) and Bjønnes *et al.* (2005) for Norway and Sweden, respectively.

waiting (e.g., a high interest-rate differential). However, during the attack on the Swedish krona in 1998, it was the foreign players who moved early. This is also consistent with our model, because in this case interest-rate differentials did not increase during the attack, so for the foreign players there was little to gain by a delayed attack.

Early work on currency crises focused on models with a multiplicity of equilibria and coordination problems (e.g., Obstfeld, 1996). Morris and Shin (1998) and CDMS used a global games framework, where the assumption of a small amount of noise in the signals of the players entails the existence of a unique equilibrium. This work has spurred a number of contributions. One strand of the literature explores the implications of endogenizing the aggregate information that is available to the agents (see Angeletos *et al.*, 2006, 2007; Angeletos and Werning, 2006; Hellwig *et al.*, 2006).[3] We remain closer to the CDMS framework, focusing on the interplay between large and small players.

In Section II, we present the model and discuss some empirical implications. Section III contains a description of our data and the institutional framework of the exchange-rate regimes. In Section IV, we describe the empirical methodology and our results. We conclude in Section V.

II. The Model

We consider a stylized economy where the central bank aims to keep the exchange rate within a certain interval, either a well-defined, publicly known, narrow target zone or a less-explicit dirty-float policy. The basic model follows CDMS, but we add several extensions, which we describe as we go along.

The central bank has two measures to defend the exchange-rate target: the policy interest rate and interventions. The interest rate should be used at an early stage, because a high interest rate raises the alternative costs for speculators selling the currency, which might deter speculation (CDMS do not discuss interest-rate setting in their model). In contrast, interventions are used as a response to speculation, because the central bank must take the other side of the speculative pressure to avoid a devaluation or depreciation of the currency. To capture these strategic considerations, we assume that the interest rate is set prior to the speculation, in period 0, while intervention takes place together with the speculation in periods 1 and 2. Following CDMS, we consider a reduced form of the central-bank

[3] Bannier (2005) has shown that, by adding a public signal in a model otherwise close to the model of CDMS, large players are more important when public signals are weak. Guimarães and Morris (2007) have explored the effects of the risk attitudes and wealth of market participants on the incidence of currency attacks.

reaction function for the interventions as a function of economic fundamentals and central-bank preferences. We allow an exogenous random variable θ to indicate the quantity of reserves the bank is willing, and able, to use in its defense of the exchange rate. If the fundamentals support the current regime (i.e., are strong), the central bank is willing to use more reserves in the defense. If the fundamentals are weaker, the central bank might be less willing to use reserves, or it might be subject to borrowing constraints in foreign currency, implying a lower θ.

The FX traders consist of two types, one large player and a continuum of small players indexed to $[0, 1]$. We want to capture the fact that, in reality, there are important differences across traders.[4] Some have large resources, in the form of expensive information systems and personnel resources. They will follow the market closely and be able to interpret various features of market activity. Thus, they will be able to react fast to changes in the market. Other traders are smaller, or trade only as part of other business activities. They spend fewer resources on following the market, and will consequently not be able to react as fast. We refer to the former type as the large player, and the latter type as small players. Note that the model can also be modified to allow for several large players; this is discussed later in this section.

The players can attack the currency by (short) selling the currency in periods 1 and 2. The small players taken together have a combined limit to short selling the domestic currency normalized to 1, while the large player has access to credit, allowing him to take a short position up to the limit $L > 0$ (where L might or might not be larger than 1). There is a cost $t \in (0, 1)$ per unit of short selling, reflecting the interest-rate differential and other trading costs. The costs are normalized so that the pay-off to a successful attack on the currency, leading to a devaluation/depreciation of the currency, is given by 1, and the pay-off from refraining from attack is 0. Thus, the net pay-off for small players of a successful attack on the currency is $1 - t$, while the pay-off to an unsuccessful attack is $-t$. All players are assumed to be risk-neutral, because this facilitates the analysis, but the assumption is of no qualitative importance.

In contrast to CDMS, we assume that if the trading in periods 1 and 2 results in a successful attack, it might also be possible to join the attack at a late stage, which we refer to as period 3. This strategy requires that one follows the market closely, to be able to move rapidly at the right moment. In line with the description above, we assume that this option is only available to the large player, and not to the small players.[5] The

[4] For example, see the surveys by Cheung and Wong (2000) and Cheung and Chinn (2001).
[5] In the model, the difference between the two types of players can be motivated by the assumption that a player must incur a fixed cost $z > 0$, which is independent of the size

benefit from waiting until this late stage is that the speculation period is much shorter, implying lower costs associated with the interest-rate differential under speculation. For notational simplicity, without affecting the qualitative results, we set the unit trading costs in period 3 to zero. However, waiting also involves disadvantages. First, by postponing the speculation to a very late stage, there is a risk that the speculative attack will fail and that other players will withdraw their position. We capture this aspect by assuming that in period 3 it is too late to affect whether the attack succeeds. Second, there is a risk that the exchange rate will fall earlier than expected, so that no gain is possible in the late speculation. We assume that waiting involves an exogenous probability $q > 0$ that the attack is too late, after the exchange rate has fallen, resulting in zero profit.

The assumption that the speculation in period 3 is too late to affect whether the attack succeeds simplifies the analysis considerably, because it implies that there is no need for other players to make forecasts about the large player's behavior in period 3. This is a strong assumption, because it rules out the possibility that a late attack from the large player might be decisive in making the exchange rate fall. Yet the assumption also captures an important element of realism: if an attack is seen not to succeed, many players might withdraw their positions, and it would be too late for the large player to induce a successful attack by increasing his speculation.

As noted by CDMS, there is no gain for small players from speculating in period 1, because each of them is too small to affect the behavior of the others. For the large player, speculation in period 1 is better than speculation in period 2, because speculation in period 1 encourages speculation by the small players. For the large player, there is nothing to learn from waiting until period 2, because the small players will not speculate in period 1. However, the large player can also postpone some or all of his speculation to period 3.

Under these assumptions, whether a speculative attack is successful depends on the speculation in periods 1 and 2, relative to the strength of the economic fundamentals. More specifically, if the speculators sell more

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of the speculation, to have the option of speculating in period 3. Such fixed costs can be subscription to necessary trading systems, or the cost of maintaining a relationship with a bank that gives "hot-line" access to the trading room. We assume that the large player incurs these costs for other business purposes, so the fixed cost can be neglected for the large player. However, the small players are too small to profit from incurring the fixed costs. Another reason for assuming that only the large player can speculate late is that, in a crisis situation, liquidity of the market dries up, and the banks can typically only honor the trade request by their most valuable customers at pre-attack levels. These will typically be large financial customers.

domestic currency than the central bank is willing or able to buy, the exchange rate falls and the speculators gain from the depreciation of the exchange rate. Let ξ denote the mass of small players that speculate, and let λ denote the speculation of the large player in period 1. Then, the exchange rate will fall if and only if[6]

$$\xi + \lambda \geq \theta. \tag{1}$$

If $\theta < 0$, the exchange rate will depreciate irrespective of whether a speculative attack takes place. Therefore, we restrict attention to the case where $\theta > 0$.

Information

The small players observe a private signal that yields information about the fundamentals as well as the amount of early speculation of the larger player. A typical small player i observes

$$x_i = \theta - \lambda + \sigma\varepsilon_i, \tag{2}$$

where $\sigma > 0$ is a constant and the individual-specific noise ε_i is distributed according to a smooth symmetric and single-peaked density $f(\cdot)$ with mean zero, and $F(\cdot)$ as the associated cumulative distribution function (CDF). The noise ε_i is assumed to be independent and identically distributed (i.i.d.) across players.

Equation (2) implies that the small players cannot distinguish the information they obtain about the fundamentals from the information about the speculation of the larger player. This departs from the assumption in CDMS, who have assumed that the players in period 2 can observe the actions taken by the large player in period 1. The assumption of CDMS is strong given the decentralized trading (compared to centralized trading at an exchange) and very opaque trading institutions, which characterize FX markets. A lack of regulations on FX trading means that there are no disclosure requirements as there are in most equity markets.[7] This means that small players cannot know the extent of a large player's trade. Rumors

[6] An important simplification in the model of CDMS, which we have retained, is that there is no rationing among the small traders. Thus, if the attack succeeds, all speculators gain to the full extent, even if the amount of speculation exceeds the interventions made by the central bank. One heuristic interpretation of this is that there also other, unmodeled, traders who do not speculate, and who are on the other side of the speculative trades as long as the exchange rate has not fallen. If we were to explicitly include the possibility of rationing among the small traders, then this would complicate the model immensely, with no clear implications for the qualitative results. However, we do include the possibility that speculation in period 3 by the large player is too late to be profitable.

[7] The data we use in our empirical analysis are published with a considerable lag.

can give the small players strong indications about whether large players are trading. However, because a large player might have an incentive to encourage the belief that he is trading, in order to induce speculation by others, the small players should be careful when interpreting such loose information. Our approach strikes a balance between the perfect observability of CDMS and the opaqueness of actual markets. Even if the small players cannot observe the large player's action in period 1, and thus cannot let their trading depend on this action, the large player can still affect the trading of the small players by affecting their signals via the choice of early speculation. Furthermore, our assumption simplifies the analysis considerably.

The larger player observes

$$y = \theta + \tau\eta, \tag{3}$$

where $\tau > 0$ is a constant, and the random term η is distributed according to a smooth symmetric and single-peaked density $g(\cdot)$ with mean zero, and $G(\cdot)$ as the associated CDF. For tractability, we assume that $g(\cdot)$ is strictly increasing for all negative arguments, and strictly decreasing for all positive arguments. We assume that the noise in the information is sufficiently large so that the probability of a successful attack, as seen by the large player, always is strictly positive.

We do not include any learning from the interest-rate setting of the central bank. In principle, a high interest rate could signal weak fundamentals that had to be defended, but it could also indicate that the central bank thought that the exchange rate could be maintained.[8] We return to interest-rate setting later in this section.

Analysis

As usual in such models, we solve by using backwards induction. Because the likelihood that the attack will be successful is determined in period 2, we start by considering the action of the small players in this period, given the prior decision of the large player in period 1. Then, we consider the decision of the large player about whether to initiate an early attack. An eventual late attack by the large player will be the residual of his credit L after any early speculation.

Following CDMS, we assume that the small players follow trigger strategies in which players attack the currency if the signal falls below a critical value x^*.[9] As in the analysis of CDMS, the unique equilibrium of the

[8] Holden and Vikøren (1996) have shown that the central bank can build up credibility for a fixed-exchange-rate regime by abstaining from a devaluation in spite of a high interest-rate differential. They also found supporting evidence for Norway.

[9] CDMS have shown that there are no other equilibria in more complex strategies.

model is characterized by two critical values: x^* and a critical value for the fundamental without the early speculation of the large player, $(\theta - \lambda)$. If $\theta - \lambda \leq (\theta - \lambda)^*$, then the currency will fail.

These critical values can be derived in the same way as in the analysis of the benchmark case in section 2.2.1 of CDMS. First, we consider the equilibrium given the trigger strategies, and then we consider the optimal trigger strategies. Given the trigger strategy, a small player i will attack the currency if his signal $x_i \leq x^*$. The probability that this will occur is a function of the true state of the economy, $\theta - \lambda$, as follows

$$\begin{aligned} prob\,[x_i \leq x^* | \theta - \lambda] &= prob\,[\theta - \lambda + \sigma\varepsilon_i \leq x^*] \\ &= prob\left[\varepsilon_i \leq \frac{x^* - (\theta - \lambda)}{\sigma}\right] = F\left[\frac{x^* - (\theta - \lambda)}{\sigma}\right]. \end{aligned}$$

Because there is a continuum of small players, and because their noise terms are independent, there is no aggregate uncertainty as to the behavior of the small agents. Thus, the mass of small players attacking, ξ, is equal to this probability. Because $F(.)$ is strictly increasing, it is apparent that the incidence of the speculative attack is strictly decreasing in $\theta - \lambda$; the weaker the strength of the economic fundamentals less the early speculation of the large player, the more small players attack.

A speculative attack will be successful if the mass of small players who speculate exceeds the strength of the economic fundamentals, less the early speculation of the large player, that is, if

$$F\left[\frac{x^* - (\theta - \lambda)}{\sigma}\right] \geq \theta - \lambda.$$

Thus, the critical value $(\theta - \lambda)^*$, for which the mass of small players who attack is just sufficient to cause a devaluation, is given by the equality

$$F\left[\frac{x^* - (\theta - \lambda)^*}{\sigma}\right] = (\theta - \lambda)^*. \tag{4}$$

For lower values, where $\theta - \lambda \leq (\theta - \lambda)^*$, the incidence of speculation (i.e., the left-hand side of equation (4)) is larger, and the strength of the fixed exchange rate (i.e., the right-hand side of equation (4)) is lower, implying that an attack will be successful. Correspondingly, for higher values, where $\theta - \lambda > (\theta - \lambda)^*$, the incidence of speculation is smaller and the strength of the fixed exchange rate is larger, implying that an attack will not succeed.

Let us then derive the optimal trigger strategies of the small players. A player observes a signal x_i and, given this signal, the success probability of an attack is given by

$$\begin{aligned} prob\left[\theta - \lambda \leq (\theta - \lambda)^* \,|x_i\right] &= prob\left[x_i - \sigma\varepsilon_i \leq (\theta - \lambda)^*\right] \\ &= prob\left[\varepsilon_i \geq \frac{x_i - (\theta - \lambda)^*}{\sigma}\right] \\ &= 1 - F\left[\frac{x_i - (\theta - \lambda)^*}{\sigma}\right] = F\left[\frac{(\theta - \lambda)^* - x_i}{\sigma}\right], \end{aligned}$$

where the last equality follows from the symmetry of $f(.)$, $F(\nu) = 1 - F(-\nu)$. Thus, the expected pay-off from attacking the currency for player i, per unit of speculation, is

$$\begin{aligned} (1-t)F\left[\frac{(\theta - \lambda)^* - x_i}{\sigma}\right] - t\left\{1 - F\left[\frac{(\theta - \lambda)^* - x_i}{\sigma}\right]\right\} \\ = F\left[\frac{(\theta - \lambda)^* - x_i}{\sigma}\right] - t. \end{aligned}$$

In an optimal trigger strategy, the expected pay-off from attacking the currency must be zero for the marginal player, that is, the optimal cut-off x^* in the trigger strategy is given by

$$F\left[\frac{(\theta - \lambda)^* - x^*}{\sigma}\right] = t. \tag{5}$$

To solve for the equilibrium, we rearrange equation (5) to obtain $(\theta - \lambda)^* = x^* + \sigma F^{-1}(t)$. Substituting into equation (4), we obtain

$$(\theta - \lambda)^* = F\left\{\frac{x^* - \left[x^* + \sigma F^{-1}(t)\right]}{\sigma}\right\}$$

or

$$(\theta - \lambda)^* = F[-F^{-1}(t)] = 1 - F[F^{-1}(t)] = 1 - t.$$

Thus, the critical values are

$$(\theta - \lambda)^* = 1 - t, \tag{6a}$$

and

$$x^* = 1 - t - \sigma F^{-1}(t). \tag{6b}$$

These critical values correspond to the critical values in CDMS, the only novelty being the addition of the early speculation of the large player λ.

We then consider the decision of the large player about whether to speculate in period 1, and if so, by how much. There is no uncertainty in the aggregate behavior of the small players, so the large player can anticipate their speculation perfectly, except for the noise in his own signal. From equations (6a) and (6b), a devaluation will take place if the fundamental $\theta \leq \theta^* \equiv 1 - t + \lambda$.

The probability that an attack will succeed can be written as

$$\begin{aligned} prob\,[\theta \leq 1 - t + \lambda | y] &= prob\,[y - \tau\eta \leq 1 - t + \lambda | y] \\ &= prob\left[\frac{y - \lambda - (1 - t)}{\tau} \leq \eta | y\right] \\ &= G\left(\frac{1 - t + \lambda - y}{\tau}\right), \end{aligned}$$

where we again use the symmetry of the distribution. If the attack succeeds, the large player will also want to speculate in period 3, so that total speculation is L. However, there is also a risk, occurring with probability q, that the speculation in period 3 comes too late, so that the large player only profits from his early speculation λ. Thus, the expected pay-off from attacking in the amount $\lambda \geq 0$ at an early stage is

$$E\pi = G\left(\frac{1 - t + \lambda - y}{\tau}\right)[L\,(1 - q) + \lambda q] - t\lambda,$$

The first-order condition for an interior solution λ^* is

$$\begin{aligned} \frac{\partial E\pi}{\partial \lambda} = g\left(\frac{1 - t + \lambda^* - y}{\tau}\right)\frac{1}{\tau}[L\,(1 - q) + \lambda^* q] \\ + G\left(\frac{1 - t + \lambda^* - y}{\tau}\right) q - t = 0. \end{aligned} \tag{7}$$

Because $E\pi$ is a continuous function of λ, defined over the closed interval $[0, L]$, we know that there exists an optimal amount of early speculation λ, that maximizes the expected profits. However, the optimal λ is not necessarily unique, nor is it necessarily interior. In fact, if the costs of early speculation, t, are sufficiently small, the optimal early speculation is equal to the credit constraint L.

Proposition 1. *The conditions for early speculation by a large player are as follows.*

- *(i) For given values of the other parameters, there exists a critical value for the costs of early speculation $\underline{t} > 0$ such that if $0 < t < \underline{t}$, then the optimal early speculation is equal to the upper constraint, $\lambda = L$.*
- *(ii) For given values of the other parameters, there exists a critical value for the costs of early speculation $\overline{t} > 0$ such that if $t > \overline{t}$, then the optimal early speculation is zero, $\lambda = 0$.*

The proof is given in Appendix A. The intuition for these results is as follows. If early speculation is very cheap (i.e., t is very small), early speculation that induces small players to attack is clearly the more profitable alternative. Because the large player is risk-neutral, he will then speculate to his limit L. However, if early speculation is sufficiently expensive, it will never be profitable to speculate early.[10]

If the solution is interior, the second-order condition is

$$\frac{\partial^2 E\pi}{\partial\lambda^2} = g'\left(\frac{1-t+\lambda^*-y}{\tau}\right)\frac{1}{\tau^2}\left[L(1-q)+\lambda^* q\right] \\ +2g\left(\frac{1-t+\lambda^*-y}{\tau}\right)\frac{q}{\tau} < 0. \tag{8}$$

The second term in equation (8) is positive, implying that first term must be negative (i.e., that $g'(.) < 0$ in an interior solution). To explore the effect of increased speculation costs t on the optimal early speculation, given an interior solution, note that equation (7) can be written as $H(\lambda, t) = 0$, which implicitly defines the optimal early speculation λ^* as a function of the speculation costs. Differentiating with respect to t, we obtain $H_1(d\lambda^*/dt) + H_2 = 0$, or $d\lambda^*/dt = -H_2/H_1$, where $H_2 \equiv (\partial^2 E\pi)/(\partial\lambda\partial t)$ and $H_1 \equiv (\partial^2 E\pi)/(\partial\lambda^2) < 0$ from the second-order condition. Thus, it follows that the sign of $d\lambda^*/dt$ is equal to the sign of $H_2 \equiv (\partial^2 E\pi)/(\partial\lambda\partial t)$. We differentiate the first-order condition (equation (7)) with respect to t, which gives us

$$\frac{\partial^2 E\pi}{\partial\lambda\partial t} = -g'\left(\frac{1-t+\lambda^*-y}{\tau}\right)\frac{1}{\tau^2}\left[L(1-q)+\lambda^* q\right] \\ -g\left(\frac{1-t+\lambda^*-y}{\tau}\right)\frac{q}{\tau} - 1. \tag{9}$$

An increase in speculation costs t affects the optimal early speculation via three mechanisms, corresponding to the three terms in equation (9). The second and third terms are both negative; the second term captures the reduced speculation of small traders because of higher speculation costs. This reduces the probability that the attack will succeed, which reduces the expected profitability of early speculation. The third term captures the direct effect of higher speculation costs, which makes it more expensive to speculate, leading to less early speculation.

[10] In practice, it might be difficult or impossible for the central bank to increase the interest rate sufficiently, and in particular to keep it high for a sufficiently long period to prevent speculation completely.

For the first term, however, we know that it is positive in an interior solution, because $g'(.) < 0$. Because higher speculation costs reduce the speculation of the small traders, the expected effect of increased early speculation by the large trader on the success probability increases. The mechanism induces the large player to increase early speculation. In fact, we cannot rule out that this effect dominates for some interval of t, implying that an increase in speculation costs might lead to increased speculation by the large player, and indeed increased total speculation in periods 1 and 2, thus increasing the risk of a fall in the exchange rate. However, in view of Proposition 1, it is clear that, in general, higher speculation costs will reduce the extent of speculation, and thus also decrease the risk of a fall in the exchange rate.

The model could be modified to allow for $N > 1$ large players in the following way. First, for reasons of tractability, we would neglect any information asymmetries among the large players, assuming that they all observe the same signal y. These are firms that spend a large amount of resources on following the market, and they have access to the same sources of information. Thus, neglecting information asymmetries might be a plausible approximation.[11] Second, we assume that the costs of funds for speculation are convex, so that the costs of early speculation λ_j for player j are $tc(\lambda_j)$, where $c(.)$ is strictly positive and strictly convex. The expected pay-off from the early speculation of player j would be

$$E\pi_j = G\left(\frac{1-t+\lambda-y}{\tau}\right)[L_j(1-q)+\lambda_j q] - tc(\lambda_j),$$

where $\lambda = \Sigma_j \lambda j$, and L_j is the credit limit of player j. From standard arguments, it follows that there exists a Nash equilibrium in mixed strategies for the early speculation of the large players, but uniqueness is not ensured (see Fudenberg and Tirole, 1991, Chapter 1.3). Yet, we can derive results similar to Proposition 1, implying that there will be no early speculation if the costs t are above a critical value. The first-order condition for the optimal interior early speculation λ_j^* of player j is

$$\begin{aligned}\frac{\partial E\pi}{\partial \lambda_j} &= g\left(\frac{1-t+\lambda^*-y}{\tau}\right)\frac{1}{\tau}[L_j(1-q)+\lambda_j^* q] \\ &\quad + G\left(\frac{1-t+\lambda^*-y}{\tau}\right)q - tc'(\lambda_j^*) = 0. \qquad (10)\end{aligned}$$

[11] The microstructure approach to FX is concerned with the nature of information asymmetries. There are reasons to believe that the critical asymmetries are between small and large players, and less within the group of large players (e.g., Bjønnes *et al.*, 2011).

In an interior equilibrium in pure strategies, which might or might not exist, all the large players would speculate early in the amount given by equation (10). If an interior equilibrium in pure strategies does exist, the remainder of the analysis would be essentially the same as with only one large player. In particular, an increase in the speculation costs would have a direct negative effect on the speculation of both small and large players. This would reduce the probability of a successful attack, which would also lead to less early speculation. The opposing effect would still apply (i.e., the first term in equation (9)); however, it would be less important because each of the large players are now smaller than the single large player, implying that the possible but counterintuitive result that higher speculation costs increase the total speculation is less likely.

Finally, we consider the interest-rate decision of the central bank in period 0. From equation (6b), it is clear that the critical value of the small players, x^*, decreases in the costs of speculation t, and thus also decreases in the central-bank interest rate. Thus, a higher interest rate will lead to less speculation by the small players. As discussed above, a higher interest rate will, in general, also imply less early speculation by the large player (i.e., lower λ^*). Rewriting equation (6a) as $\theta^* = 1 - t + \lambda^*$, it is clear that θ^* falls if t increases and λ^* falls. Thus, in general, a higher interest rate reduces the critical value for the fundamentals, implying that the exchange rate will survive for weaker fundamentals.[12] Now, as noted by CDMS, the model makes use of the assumption that θ has an (improper) uniform prior distribution, so the *ex ante* probability that θ is above the critical value θ^* is not well defined. However, as also discussed by CDMS, if we assume that the signals to the players are very precise relative to the information in the prior, a uniform distribution serves as a good approximation in generating the conditional beliefs of the players. This implies that the equilibrium obtained under the uniform prior distribution will be a good approximation to the true equilibrium. It then follows that the *ex ante* probability that the exchange rate falls is given approximately by $P(\theta^*)$, where $P(.)$ is the prior distribution function for θ. Because $P(.)$ is strictly increasing, it follows that an increase in the interest rate, which increases t and reduces the critical value θ^*, also leads to a reduction in the (approximate) probability of a fall in the exchange rate. Thus, by raising the interest rate, the central bank can reduce the amount of currency speculation and increase the likelihood that the regime survives.

The central bank does not know the signal or the credit limit L of the large player, so the central bank cannot solve for the critical value θ^*. Thus, the central bank does not have sufficient information about θ^* to

[12] However, as noted above, we cannot rule out that for some intervals of t, an increase in t might, in fact, raise λ^* more than t falls, so that θ^* increases.

be able to set t exactly at the level that will prevent a successful attack. Because the focus of the model is the speculation of the large and small traders, and the relationship between these, we discuss the decision of the central bank only informally. When the fundamentals weaken, the central bank must decide whether to raise the interest rate in an attempt to prevent speculation and defend the exchange rate. In this decision, the central bank will weigh the gains from maintaining the exchange rate (i.e., avoiding the costs of a fall in the exchange rate), against the costs of a rise in the interest rate. The costs of raising the interest rate will depend on the state of the economy. For example, in a severe downturn, a rise in the interest rate might have a severe negative impact on the economy, with large political costs for the central bank. If it is viewed as important to maintain the exchange rate, central banks will typically incur the associated costs of increasing the interest rate. Interestingly, the empirical episodes we explore in the following differ considerably along these aspects, allowing us to evaluate the predictions of the theoretical model.

III. Data and Description of Crises

In order to empirically test the implications of the model, we would need data on position-taking by large and small players in the FX markets. In general, this is difficult because the FX market is almost completely unregulated, lacking, for example, the disclosure requirements of equity markets. Although some interbank trading platforms (e.g., Reuters and EBS) sell transaction data, these are aggregated data that do not distinguish between large and small players.

Fortunately, Norges Bank and Sveriges Riksbank collect data from market-making banks on net spot and forward transactions (measured in billions of local currency) with different counterparties. From Norges Bank, we have weekly observations starting in 1991 on the trading of Norwegian market-making banks with foreigners, locals, and the central bank. In the dataset from Sveriges Riksbank, we have weekly observations starting in 1993 on the trading of both Swedish and foreign market-making banks with non-market-making foreign banks and with Swedish non-bank customers. The net trading of the different counterparties is comparable to "order flow" in the body of literature on FX microstructure (e.g., Evans and Lyons, 2002), because non-bank customers always act as initiators when trading with banks, and because these banks are the main market-makers in these currencies when trading in the interbank market.[13]

[13] Interested readers are referred to Rime (2000) and Bjønnes *et al.* (2005) for further descriptions on the Norwegian and Swedish datasets, respectively. Descriptive statistics for

In general, we would expect there to be large and well-informed players among both the local and foreign traders. However, evidence given by Lindahl and Rime (2012) from a detailed dataset of the (non-bank) customers of major Swedish banks over the period 2001–2004 shows that foreign customers are, on average, more than three times as large as the local customers.[14] To some extent, this difference reflects the fact that foreign customers of the Nordic currencies are mostly financial, whereas the great majority of the local customers are non-financial. Both anecdotal evidence and the detailed Swedish data indicate strongly that financial customers are typically larger than non-financial customers. In addition, the Swedish dataset shows that foreign customers are, on average, considerably larger than local customers, even for a given type of customer. Thus, it seems reasonable to proceed as if the foreign traders can represent the large player, while the local traders represent the small players, even if we readily acknowledge that the distinction is not as clear-cut as we would wish. We return to this issue in Section V.

A further difference between the foreign and local traders concerns the means of speculation. When there is a risk of depreciation/devaluation, local traders will typically sell the currency spot. However, foreign traders do not have the available local currency, and will instead sell the currency forward. We return to this in Section IV.

Because the reporting banks are the main market-makers in their local currencies, they primarily intermediate the trades of their customers, rather than taking overnight positions themselves, in line with evidence on market-making (e.g., Lyons, 1995; Bjønnes and Rime, 2005). This is true even in the speculative attacks that we study (described in more detail in the following subsection) where Norges Bank is typically the final counterpart during the attacks on NOK, and the foreigners and locals trade with each other (via reporting banks) in the crisis in Sweden covered by our data.

Three Crisis Periods in Scandinavia

The three crisis periods that we analyze are (1) the ERM crisis and the depreciation of the NOK in December 1992, (2) the appreciation of the NOK in January 1997, and (3) the crisis in both Norway and Sweden following the Russian moratorium in August 1998. Figure 1 shows the NOK/euro and SEK/euro exchange rates, together with the Norwegian sight

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the Norwegian transactions are shown in Table A1 in Appendix A, both for the whole period with data and for the specific crises.

[14] The average trade by foreign customers is 2.2 billion euros, compared to 0.6 billion euros for Swedish customers. Furthermore, the medians and the eighth deciles are, respectively, 0.5 and 2 billion for foreign customers, compared to 0.2 and 0.5 billion for Swedish customers.

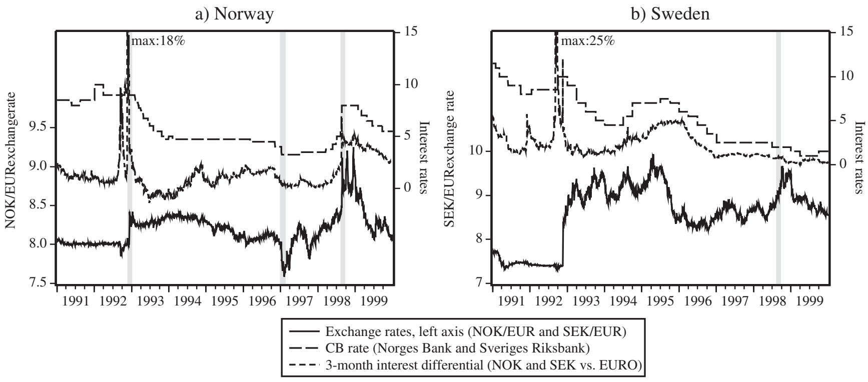

Fig. 1. Exchange rate, central-bank rate, and three-month interest-rate differential for (a) Norway and (b) Sweden
Notes: Daily observations on exchange rates (left axis), and the central-bank rate and interest-rate differential (right axis). Exchange rates are local currency per euro, using the European Central Bank (ECB) conversion rate for the Deutsche mark versus the euro. Interest-rate differentials are the local interbank interest rate minus the German interbank interest rate. Shaded areas indicate the crises.

deposit rate and the Swedish discount rate (the two key policy rates) and the three-month interest-rate differential against Germany for the two countries, from the beginning of 1990 until the end of 2000.[15] The three crises are indicated by gray areas. The key dates for the attacks can be identified, for example, from the financial press.[16] The descriptive statistics on trading given in Table A1 confirm that there are major movements in the expected direction during the identified events.

Figure 2 shows some series on the state of the macroeconomy in Norway and Sweden during the 1990s. The vertical lines mark the crises. The two plots for Norway illustrate that two of the crises in Norway coincided with a downturn in the economy (1992 and 1998), and one coincided with a peak (1997).

Prior to the ERM crisis of 1992, the NOK was pegged to the European Currency Unit (ECU), with fluctuation bands of ± 2.5 percent. However, the pressure within the ERM, combined with the downturn in Norway, led markets to expect a devaluation of the NOK. During the fall of 1992, Finland, Italy, the UK, and finally Sweden were forced to abandon their fixed pegs. During this period, Norges Bank repeatedly increased its key rate to

[15] Before January 1, 1999, we adjust the NOK/DEM and SEK/DEM exchange rates for the DEM/euro conversion.
[16] The three periods are also identified in a crisis index (for a description, see Eichengreen *et al.*, 1995), which takes into account the fact that speculative pressure might materialize through interest-rate changes instead of exchange-rate changes (results available on request).

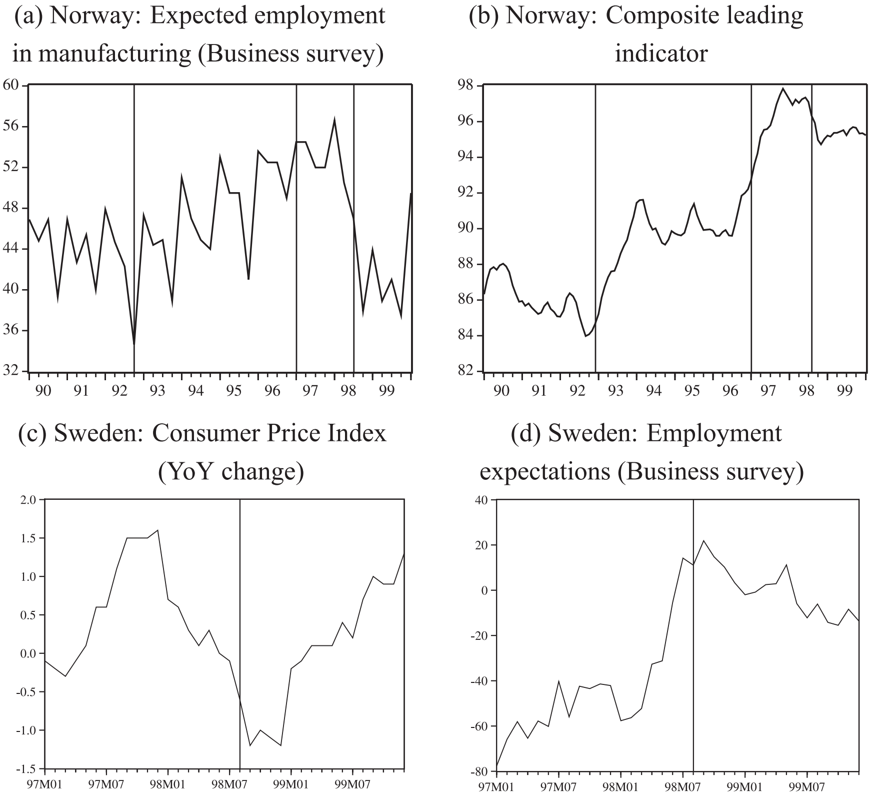

Fig. 2. Illustrative macro series for the Norwegian and Swedish economies
Sources: (a) Statistics Norway; (b) OECD; (c) Statistics Sweden; (d) DG ECFIN.
Notes: Panel (a) is a diffusion index, where an index above 50 indicates increasing growth. The composite index in Panel (b) contains the following components: retail sales, job vacancies, judgment on capacity utilization, new export orders, share prices, and yield on government bonds. Positive numbers in Panel (d) indicate that more people have replied that the variable in question will increase. The vertical lines indicate the crises.

reduce capital outflows. However, on December 10, 1992, Norges Bank was forced to abandon the fixed ECU rate. The exchange rate eventually stabilized at a 10 percent weaker level.

In the aftermath of the ERM crisis, Norway chose a managed float regime with an obligation to stabilize the exchange rate in a medium-term sense. During the fall of 1996, there was pressure for an appreciation of the NOK. The Norwegian financial press reported that foreigners were speculating in a Norwegian appreciation, in the belief that the strong Norwegian economy and emerging inflationary pressure would force the

Norwegian government to adopt an inflation-targeting regime.[17] Inflation targeting would allow Norges Bank to raise interest rates in order to fight inflation and to dampen a potential boom, but it was also expected to involve a potentially steep appreciation of the NOK. The pressure peaked in January 1997 and the NOK cost of a deutsche mark (DEM) fell by more than 5 percent over a period of 14 days (with the largest changes on January 8–10). However, the regime was not changed and Norges Bank continued to defend the exchange rate by lowering its key rate and intervening in the market.

The 1998 crisis was a joint crisis in Norway and Sweden, and it took place at the same time as the Russian moratorium crisis. When Russia, in August 1998, first announced a possible devaluation of the rouble and then a week later, on August 24, a moratorium on all debt payments, this triggered massive international uncertainty. Investors withdrew from small currencies, including NOK and SEK.

During the spring of 1998, Norway experienced a slowdown in growth, and many commentators argued for monetary and fiscal stimuli in order to spur growth. Again, market participants had for some time expected a switch to inflation targeting, but this time to stimulate growth with lower interest rates. However, when the NOK/DEM exchange rate depreciated in July and August, Norges Bank increased its key rate to defend the domestic currency (see Figure 1).

In Sweden, inflation had been falling for some time and was far below the inflation target of 2 percent (adopted in 1993; see Figure 2(c)). Hence, Sveriges Riksbank did not adjust its key rate in response to the changes in the exchange rate during this period (cf. Figure 1), in spite of more positive employment expectations (see Figure 2(d)).

Let us summarize the key features of the four episodes we have explored. Because Norway had an exchange-rate target, Norges Bank used the interest rate actively to defend the exchange-rate target in all three Norwegian episodes. However, the active use of the interest rate also involved costs. In 1992 and 1998, the interest-rate hike had a negative impact on an already weak economy, while the reduction of the interest rate in 1996 amplified the boom. In contrast, Sveriges Riksbank, which had an inflation target, chose not to use the interest rate to prevent exchange-rate volatility. This difference in monetary policy meant that there was a potential gain from a delayed attack in Norway (because of the increase in the interest-rate differential), but not in Sweden.

[17] For instance, on November 5, 1996, the leading business newspaper in Norway (*Dagens Næringsliv*) reported that foreign analysts "believe in stronger NOK" (Mathiassen, 1996). On November 6, Norges Bank lowered its key rate.

IV. Results

The model presented in Section II is stylized, with the aim of illustrating a mechanism for delayed speculation, and it does not lend itself easily to structural estimation. For example, we cannot observe the signals of the players, and data on the macroeconomy cannot be used as empirical proxies for the signals because they do not vary sufficiently over the rather short calendar time-span of a typical crisis. Instead, we focus on the following two issues: (i) the sequence of moves of the large (foreign) and small (local) players; (ii) which players speculate when the change in the exchange rate takes place.

This choice is based on the key predictions of the model. If a large interest-rate differential makes early speculation costly, large players might delay speculation in order to reap the interest-rate benefit. Small players will move early in order to avoid being too late to benefit from the attack. If the interest-rate benefit is small, large players might move early as well, which will induce small players to join the attack. If early speculation is sufficiently cheap (e.g., because of a small interest-rate differential), then the large player might only speculate early. In the case where large players only speculate early, it will be the small players who are most active when the exchange rate changes.

As noted above, the important difference between the episodes relates to the difference in monetary regime between Norway and Sweden. Norway had an exchange-rate target to be reached in the medium term and, in all three attacks, Norges Bank used the policy rate and interventions to defend the exchange rate. In contrast, Sweden had an inflation target. The speculation against SEK coincided with low and falling inflation, and Sveriges Riksbank did not raise the interest rate. Thus, there was no benefit to be reaped from postponing speculative sales of Swedish currency.

To test for the sequence of moves of the large and small players during the speculative attacks, we use the statistical concept of Granger causality. Granger causality is not an economic definition of causality, but might be useful to identify which group of players moves first or last. Granger causality is tested by running regressions such as

$$y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i y_{t-i} + \sum_{i=1}^{k} \beta_i x_{t-i} + \varepsilon_t. \tag{11}$$

There is absence of Granger causality from x to y if the estimation of y on lagged values of y and lagged values of x is equivalent to an estimation of y only on lagged values of y (i.e., the joint hypothesis of $\beta_1 = \cdots = \beta_k = 0$ is not rejected). If this hypothesis is rejected for x in the equation for y, while it is not rejected in case of y in a similar equation for x, we say we have one-way Granger causality from x to y.

We distinguish between Granger causality during the crises and in normal (pre-crisis) periods. When choosing the crisis periods for the Granger causality test, we take the crisis dates as our starting point. We end the crisis period as soon as there are any signs that the exchange rate has stabilized (i.e., when the crisis is over). The beginning of the crisis period is determined in the following way. We go backwards in time from the end of the crisis until before the signs of turmoil begin. Then, we add observations in the beginning, if needed, in order to ensure that the sample is sufficiently long for statistical analysis. The number of crisis observations and the exact dates are reported in Table 1.

The pre-crisis periods are defined as the 40 observations prior to the crisis period defined above. This balances the need for a sufficient number of observations without mixing crisis periods and calm periods. With this approach, we capture the position-taking of the players that will eventually elicit the interest-rate and exchange-rate changes that are captured by the crisis index.

The results from the Granger causality tests are shown in Table 1. We regress the net trading (order flows) used in the attack on lags of locals' and foreigners' net trading (see Figures 3 and 4). We use dummies to differentiate between crisis and pre-crisis periods. The numbers of lags are determined from the Schwarz and Akaike information criteria.[18] In Table A2, we present a similar system using net trading in all instruments, which confirms the results.[19]

For the three Norwegian crises, we see that lagged speculation of local players during the crisis period has a significant positive effect on the speculation of foreign players, while the lagged speculation of foreign players has no significant effect on the speculation of local players. Thus, locals Granger-cause foreigners, but foreigners do not Granger-cause locals. This is in line with the model because in all three cases, interest-rate differentials changed in such a way as to make it more costly to speculate early. This implies that large players (foreigners) might gain from delaying the attack. Furthermore, the coefficients on the local's lagged trading for the foreign trading are positive during the crises. This is as one would expect from the model if the locals move first in an attack.

[18] We have chosen lags based on the shortest positive lag selected by these two criteria. The weekly frequency employed makes us prefer shorter lags because we do not believe that behavior during a crisis exhibits long lag-dependence.
[19] A summary of other results for the crisis and pre-crisis periods, for different lag-structures and VAR formulations, and for the method robust to outliers, indicates that the results are rather robust (available upon request).

Table 1. *Granger causality test for net trading: crisis and pre-crisis*

	Norway						Sweden	
	1992		1997		1998		1998	
	Foreigners	Locals	Foreigners	Locals	Foreigners	Locals	Foreigners	Locals
Constant	0.352	0.177	−0.305	−1.092	−0.441	0.789	0.010	−0.244
	(0.09)	(0.44)	(0.13)	(0.07)	(0.33)	(0.14)	(0.92)	(0.00)
Crisis: foreigners, lagged	0.357	0.098	0.573	−0.721	0.030	−0.009	−0.153	0.350
	(0.02)	(0.71)	(0.00)	(0.11)	(0.91)	(0.98)	(0.41)	(0.03)
Crisis: locals, lagged	0.208	−0.420	0.184	−0.401	0.341	−0.379	−0.190	0.332
	(0.00)	(0.00)	(0.04)	(0.03)	(0.00)	(0.00)	(0.39)	(0.13)
Crisis: locals, second lag					0.316			
					(0.01)			
Pre-crisis: foreigners, lagged	−0.208	−0.021	−0.268	−0.136	−0.080	0.017	0.388	−0.263
	(0.01)	(0.82)	(0.00)	(0.33)	(0.39)	(0.94)	(0.07)	(0.05)
Pre-crisis: locals, lagged	0.014	−0.124	0.077	−0.315	0.141	−0.403	0.094	0.048
	(0.91)	(0.22)	(0.03)	(0.00)	(0.34)	(0.00)	(0.75)	(0.83)
Pre-crisis: locals, second lag							0.490	
							(0.00)	
Adj. R^2	0.23	0.13	0.21	0.12	0.03	0.11	0.07	0.06
Durbin–Watson	2.17	2.23	1.91	1.80	1.88	2.29	2.08	2.06
Number of observations	81		70		71		71	
Crisis observations	41		30		31		31	
Crisis period	May 1, 1992– Feb 2, 1993		Aug 9, 1996– Feb 28, 1997		May 8, 1998– Dec 4, 1998		May 8, 1998– Dec 4, 1998	

Notes: Net trading by foreigners (large players) and locals (small players) estimated within a system on lagged trading of large and small players, with dummies for pre-crisis and crisis periods. Net trading measured in billions of local currency. The p-values based on robust standard errors are given in parentheses. All equations use one lag, except for both Norway and Sweden in 1998 where we use two lags of local's trading in the foreigners specification during the crisis and pre-crisis periods, respectively. In Norway, locals always speculate in spot trading, while foreigners speculate with spot trading in 1997 and with forward trading in 1992 and 1998. For the Swedish 1998 crisis, we use net spot trading for foreigners and net forward trading for locals.

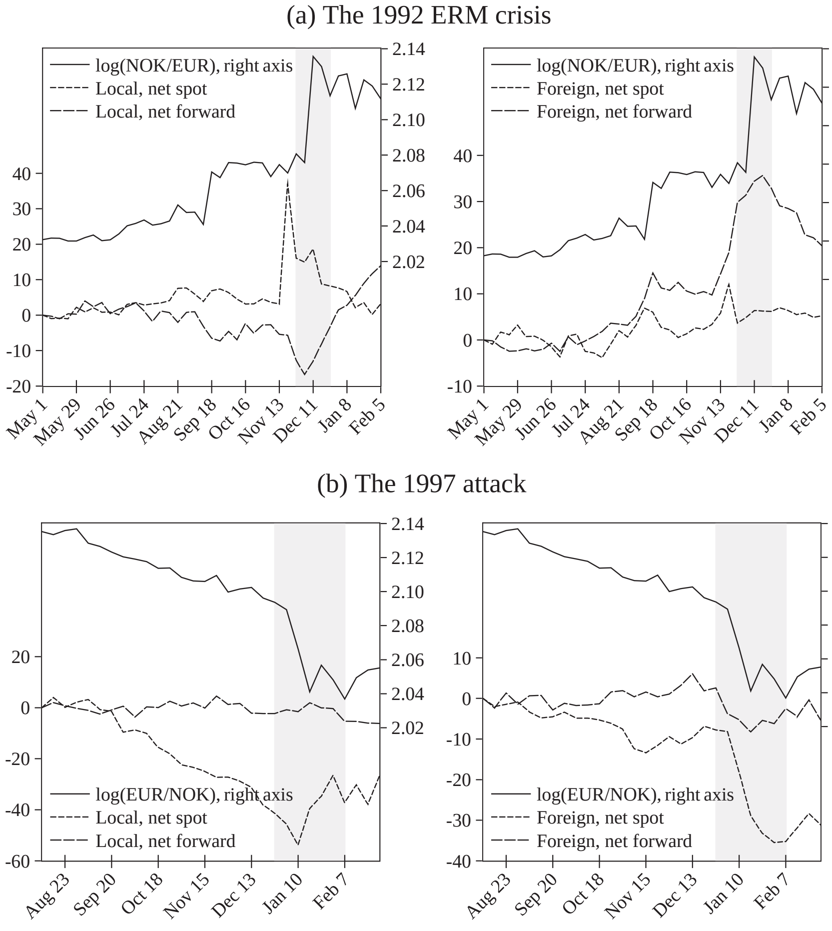

Fig. 3. Exchange rate and level of net positions: Norway during the 1992 ERM crisis (a) and the 1997 attack (b)
Sources: Norges Bank and Ecowin.
Notes: Exchange rates (solid lines) measured along the right axis and positions (dotted lines) on the left axis. A negative position indicates a net holding of NOK, implying that an increasing curve indicates selling of NOK. Positions are created as the cumulative sum of the net trading used for estimation (indexed to zero at the beginning of the sample period), measured in billions of NOK. Gray areas indicate the crises: November 27–December 25, 1992, and December 27, 1996–February 7, 1997. The positions of locals are in the left column. Weekly data and date information represent Friday dates.

Figures 3 and 4 visualize the results from the Granger causality analysis. In Figure 3(a), we see the levels of net position in spot and forward trading for local and foreign players in the period from May 1992 to January 1993 (cumulative sum of net trading). The first sign of any changes is when

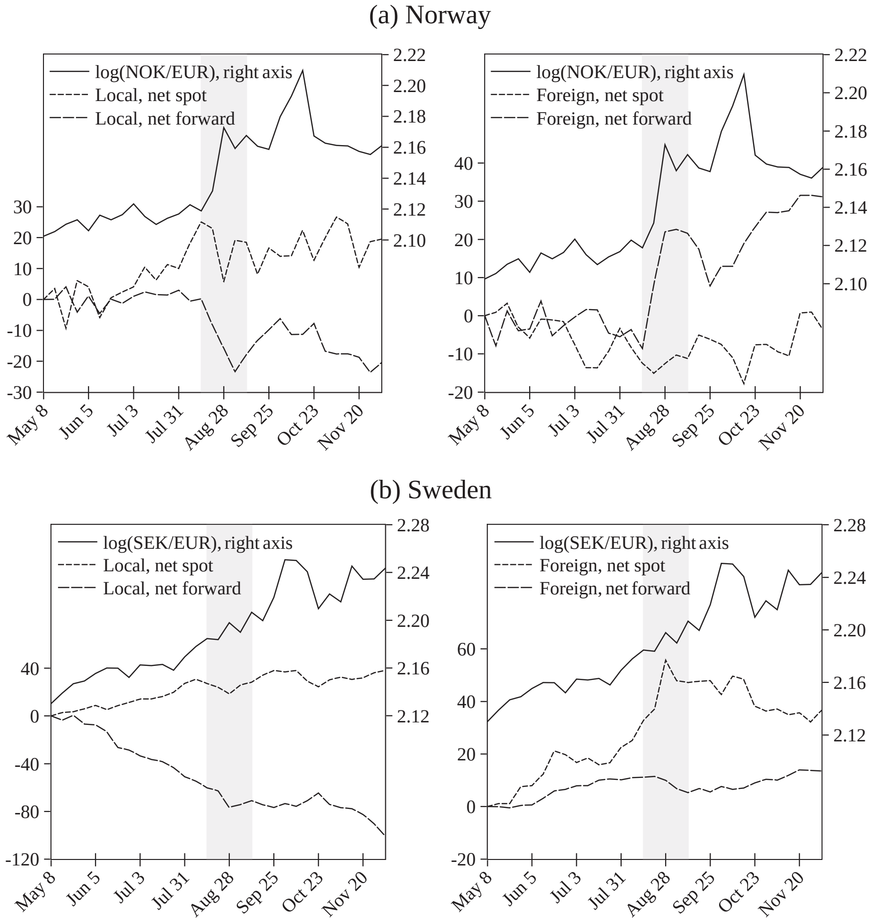

Fig. 4. Exchange rate and level of net positions: 1998 Russian moratorium crisis in Norway (a) and Sweden (b)

Sources: Norges Bank, Sveriges Riksbank, and Ecowin.

Notes: Exchange rates (solid lines) measured along the right axis and positions (dotted lines) on the left axis. A negative position indicates a net holding of local currency (i.e., NOK or SEK), implying that an increasing curve indicates selling of NOK or SEK. Positions are created as the cumulative sum of the net trading used for estimation (indexed to zero at the beginning of the sample period), measured in billions of NOK or SEK, respectively. Gray areas indicate the crisis: August 14–September 11. The positions of locals are in the left column. Weekly data, and date information represents Friday dates.

foreigners start selling NOK forward from early August 1992. At this time, the interest-rate differential was very small. In November 1992, speculative activity emerged in two forms: local players sold NOK spot and foreigners sold NOK forward.

Figure 3(b) shows the 1997 crisis from August 1996 to February 1997. At this time, the issue was a potential appreciation of NOK, and in the period from September to December 1996 local players accumulated NOK spot, while foreigners did not change their net positions. However, during the speculative attack in the first weeks of 1997 – the central dates of the attack were January 8–10, 1997 – it was the foreigners who were buying NOK spot, while this was accommodated by locals who were selling NOK spot.

For the Swedish 1998 crisis, there is some evidence that foreigners Granger-cause locals, because lagged speculation of foreigners is significant in the local player regression. This result is also consistent with the model (i.e., there was no gain in delaying the speculation, because Sveriges Riksbank did not increase interest rates). In other words, in the speculative attack in Sweden, where interest rates were low, we would expect more early speculation by the large player.

Figures 4(a) and 4(b) show NOK/DEM and SEK/DEM exchange rates and the level of net positions during the period from May to December, 1998. Again, we see that in Norway, locals were selling NOK spot during the summer. When the foreigners attacked in August, they did so in the forward market. This sale of NOK was matched by locals buying NOK forward. In Sweden, the foreigners were selling SEK in July and August, with a peak around the Russian moratorium. However, locals were taking the other side, because there was no intervention by Sveriges Riksbank.

Finally, from Table 1, we can see that the crisis pattern discussed above is not representative for the pre-crisis periods. The coefficient on lagged trading of foreign players is negative in the pre-crisis period of all three attacks on the NOK, while it is positive during the crisis periods. In 1997, there is positive feedback from the locals to the foreigners in the pre-crisis period; however, because the foreigners' own lagged trading is negative, we cannot call this speculative herding. This is consistent with the idea of the model that trading sequences during an attack are different from non-crisis periods.

At the beginning of this section, we put forward two issues to focus on, the second of which was to identify which group was most active during the actual crisis. To address this question, we regress log changes in the exchange rate on contemporaneous net trading (order flows) and macro variables, with dummies for the crises. The dummies are selected so that the focus is on what happens during the actual speculative attack. Hence, the dummy is set equal to one for the week prior to the attack, the week of the attack, and any following week with large changes in the exchange rate. This gives us three crisis observations (dummy equals one) for 1992 and 1998, and four for 1997. Because of problems of multicollinearity, we run separate regressions for locals and foreigners. The results are given in Table 2.

Table 2. *Crisis regressions*

	NOK/EUR		SEK/EUR	
	Foreigners	Locals	Foreigners	Locals
Constant	−0.013	0.046	0.048	−0.009
	(−0.17)	(0.50)	(1.02)	(−0.20)
Interest-rate differential	−0.062	−0.240	1.743	1.887
	(−1.07)	(−3.77)***	(5.24)***	(5.56)***
Oil price	−2.894	−3.162	−1.746	−1.799
	(−1.45)	(−1.47)	(−1.99)**	(−2.01)**
1992 crisis, spot	0.839	−0.147		
	(3.75)***	(−1.39)		
1992 crisis, forward	0.687	0.432		
	(4.29)***	(1.68)		
1997 crisis, spot	0.226	0.088		
	(3.31)***	(1.10)		
1997 crisis, forward	0.034	−0.903		
	(0.23)	(−2.50)**		
1998 crisis, spot	0.238	−0.183	0.033	0.027
	(1.15)	(−4.01)***	(0.66)	(0.18)
1998 crisis, forward	0.167	−0.152	−0.078	−0.070
	(4.44)***	(−2.20)**	(−0.29)	(−0.71)
Spot	−0.053	0.056	0.079	−0.058
	(−1.76)	(3.00)***	(5.82)***	(−4.18)***
Forward	0.026	−0.007	0.067	−0.037
	(0.82)	(−0.20)	(5.59)***	(−2.70)***
AR(1)	−0.22184	−0.067	−0.183	−0.151
	(−2.06)**	(−0.59)	(−4.11)***	(−3.41)***
Adj. R^2	0.41	0.35	0.14	0.12
Durbin–Watson	2.11	2.04	2.00	1.99

Notes: Regression of NOK and SEK return (log changes multiplied by 100 to measure in percent) on net trading, interest-rate differential, and first-difference log oil price. Net trading measured in billions of NOK or SEK, respectively. Robust (Newey–West) *t*-values are given in parentheses below coefficient estimates. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. Trading effects during crises are constructed using a dummy on the trading variables.

In the regressions, we have included the three-month interest-rate differential against Germany and the log differenced oil price as macroeconomic variables. The rows labeled "Spot" and "Forward" report the coefficients and t-values for net trading outside the actual crisis, while the other rows are the effect of net trading in the different crisis.

From the analysis above, we would expect that foreigners were instrumental in the three Norwegian crises because the foreigners delayed their attack towards the end. This should be reflected in significant and positive coefficients when the speculation is successful, because players buy currency (positive net trading) when speculating on a depreciation (positive change in the exchange rate) and sell (negative net trading) when speculating on an appreciation (negative change in the exchange rate). In the 1992 and 1998 crises, foreigners speculated forward (because they had less spot available), while they used spot in the 1997 appreciation crisis. We would also expect that the locals' trading is insignificant in all three crises in the case of Norway, or at least not positive, because a negative coefficient would imply provision of liquidity to foreigners. From Table 2, we see that these expectations are largely substantiated.

For Sweden, we do not find any significant effects during the 1998 crisis. Given the evidence that foreigners Granger-caused locals, we would at least expect the locals' flows to be positive and significant. However, Figure 4 seems to suggest that it is the foreigners who are most active in the crisis week, and that the period when SEK actually jumped was somewhat later.

The impact of net trading in the crisis is also of economic significance. For the 1992 case, we find that the size effect of forward trading on the NOK/DEM exchange rate is 0.69 percent per billion NOK sold, or about 5 percent per one billion USD equivalent.[20] The comparable numbers for the 1997 and 1998 events are about 1.6 percent per one billion spot USD for 1997 and about 1.2 percent per one billion forward USD for 1998. By comparison, Evans and Lyons (2002) have reported an effect from order flows to the DEM/USD exchange rate of about 0.5 percent per one billion USD equivalent. The larger effect of currency trade that we find seems reasonable, given that the periods we are studying here involve higher uncertainty than the more normal period studied by Evans and Lyons. The lower numbers for 1997 and 1998, compared to 1992, might be a result of increased liquidity over time and less rigid monetary regimes.

V. Conclusion

We have studied the dynamics of speculative attacks. The problem of connecting currency crises to fundamentals has led to a discussion of the possible manipulation of exchange rates, especially by large foreign players, such as hedge funds and other highly leveraged institutions. To analyze this, we have extended the model of CDMS by incorporating the costs and benefits of early versus late speculation by the large player. The model of CDMS predicts that large players might move early in an attack in order to induce small players to attack. However, Tabellini (1994) and IMF (1998) have argued that large players move late in currency crises in order to reap the benefits of higher interest-rate differentials.

In our model, the large player can choose to speculate early. This incurs trading and interest-rate costs, but it also provides a signal to the small players, possibly inducing them to speculate. However, the large player can also choose to delay speculation, reaping the benefit of a positive

[20] The average NOK/USD rate over the period 1992–2000 was 7.4.

interest-rate differential while waiting, but also missing the opportunity to influence the smaller players, as well as risking being too late to join the attack. The smaller players will not speculate as early as the large player, because they cannot affect the behavior of other players. The smaller players are also less informed and less capable of successfully delaying speculation until the final stage of the attack.

The theoretical model is used as a framework for an empirical analysis of four speculative attacks in Norway and Sweden during the 1990s: the ERM attack in 1992 on the NOK; the 1997 appreciation crisis in Norway; the August 1998 crisis in both Norway and Sweden following the Russian moratorium. The latter event is especially interesting, because in this case we can compare the effects of an international event on two similar neighboring countries, but where the monetary regimes differed.

We have data for net currency trading of foreign and local traders in Norway and Sweden. Foreigners trade, on average, larger volumes than locals. Furthermore, foreign traders are typically financial, whereas the large majority of the local traders are non-financial. Therefore, we believe that the large player in the model can be represented by the foreign traders, and the small players by local traders, even if this distinction is not at all clear-cut. The results indicate a significant difference in behavior between locals and foreigners, consistent with foreigners representing the large player.

In the theoretical model, we show that the large player will speculate early, thus inducing speculation among the small traders, if the costs of early speculation in the form of the interest-rate differential are sufficiently small. In contrast, if early speculation is costly, because of a high interest-rate differential, the large player might postpone speculation to a later stage. The sequence of trading is tested with Granger causality tests, while the triggering of the attacks is tested with regression analysis. We find that local players lead the foreign players in all cases, except for the 1998 crisis in Sweden. This is in line with the model because the Norwegian central bank used the interest rate to defend the NOK in all cases. The resulting interest-differential made it profitable for those able to attack at short notice to postpone the attack to a late stage, which, as we argue, applies to more of the foreign traders. In contrast, the Swedish central bank did not change its interest rate during the depreciation crisis in 1998, which implies that there was no gain from delaying the attack in Sweden. The regression analysis shows that the foreigners were active during the final stage of the attack in all cases.

By comparing the Norwegian and Swedish episodes, we can see that the Norwegian central bank managed to delay the speculation of the foreign traders by raising the interest rate. This was nevertheless not sufficient to avoid a forced change in the exchange rate, which occurred in all the Norwegian episodes (although only temporarily in 1997). A likely reason for this is that the required interest-rate adjustment had an adverse effect on the domestic economy, because the interest-rate hikes in 1992 and 1998 depressed an already weak economy, while the interest-rate reduction in 1996/1997 amplified the boom. Thus, the central bank was prevented from using the interest rate even more vigorously than it did. The experience from these episodes was probably important for the subsequent formal adoption of an inflation target in 2001.

Appendix

Proof of Proposition

(i) Consider the pay-offs from three levels of the early speculation, which are zero, full or the optimal interior solution:

$$E\pi(0) = G\left(\frac{1-t-y}{\tau}\right) L(1-q),$$

$$E\pi(L) = G\left(\frac{1-t+L-y}{\tau}\right) L - tL,$$

and

$$E\pi(\lambda^*) = G\left(\frac{1-t+\lambda^*-y}{\tau}\right) [L(1-q)+\lambda^* q] - t\lambda^*.$$

(The latter will not exist for all values of t.) Because $G(.)$ is strictly increasing, it is clear that for $t = 0$, we find that $E\pi(L) > E\pi(\lambda)$ for all $\lambda < L$. Thus, for $t = 0$, $\lambda = L$ is optimal. By continuity of $E\pi$, it follows that $\lambda = L$ is also optimal for t close to zero. Now, increase t from below until $E\pi(L) = \max[E\pi(0), E\pi(\lambda^*)]$, and let $\underline{t}$ denote t for which this condition holds. (If $E\pi(\lambda^*)$ does not exist, it is when $E\pi(L) = E\pi(0)$.) It follows that $\lambda = L$ is optimal for all $t < \underline{t}$.

(ii) This is similar to the proof of (i). Observe that for sufficiently large t, early speculation is clearly unprofitable (both $E\pi(\lambda)$ and $\partial E\pi/\partial\lambda$ converge to minus infinity when t goes to infinity). Now, decrease t from above until $E\pi(0) = \max[E\pi(L), E\pi(\lambda^*)]$, and let $\bar{t}$ denote t for which this condition holds. It follows that $\lambda = 0$ is optimal for all $t > \bar{t}$.

Table A1. *Descriptive statistics and correlations matrices for Norwegian net trading*

			Large		Small	
			Spot	Forward	Spot	Forward
Whole sample	(a)	Mean	−0.04	0.05	0.03	−0.16
		Median	−0.28	−0.07	0.04	−0.06
		Maximum	21.05	16.58	33.87	15.80
		Minimum	−22.25	−20.06	−20.97	−10.38
		Standard deviation	3.78	4.03	5.45	3.05
		Observations	469	469	469	469
	(b)	Large spot	1			
		Large forward	−0.128	1		
		Small spot	−0.254	−0.308	1	
		Small forward	0.098	−0.336	−0.090	1
1992	(a)	Mean	0.09	0.49	0.18	0.40
		Median	−0.13	−0.17	−0.13	0.73
		Maximum	6.22	**10.95**	**33.87**	4.84
		Minimum	−8.37	−4.77	−20.97	−7.05
		Standard deviation	2.46	2.79	6.76	2.90
		Observations	41	41	41	41
	(b)	Large spot	1			
		Large forward	−0.071	1		
		Small spot	0.630	−0.094	1	
		Small forward	0.084	−0.601	0.105	1
1997	(a)	Mean	−0.98	−0.25	−0.97	−0.16
		Median	−0.67	0.10	−1.96	−0.19
		Maximum	3.47	4.14	14.23	4.65
		Minimum	**−10.81**	−6.38	**−10.61**	−4.95
		Standard deviation	3.27	2.72	5.71	2.32
		Observations	30	30	30	30
	(b)	Large spot	1			
		Large forward	0.165	1		
		Small spot	−0.371	−0.372	1	
		Small forward	−0.130	−0.395	0.214	1
1998	(a)	Mean	−0.21	1.07	0.54	−0.56
		Median	−0.94	0.50	0.80	0.06
		Maximum	11.25	**16.58**	**15.37**	5.45
		Minimum	−6.87	−9.70	−17.08	−9.04
		Standard deviation	4.58	5.93	8.07	4.49
		Observations	31	31	31	31
	(b)	Large spot	1			
		Large forward	0.076	1		
		Small spot	−0.597	−0.523	1	
		Small forward	0.055	−0.372	−0.211	1

Notes: Descriptive statistics for net trading (panels a), and correlation matrix (panels b), over the whole sample, and for each of the crisis periods as defined in Table 1. The numbers in bold indicate the variables discussed in Section III.

Table A2. *Granger causality test on all flows: Norway, 1992, 1997, and 1998*

		Small spot		Small forward		Large spot		Large forward	
1992									
	Constant	0.359	(0.18)	0.339	(0.09)	0.649	(0.01)	0.284	(0.14)
Crisis	Small spot	−0.631	(0.00)	−0.153	(0.04)	−0.241	(0.00)	0.186	(0.01)
	Small forward	−0.505	(0.09)	0.009	(0.97)	0.009	(0.95)	−0.159	(0.16)
	Large spot	0.968	(0.17)	0.185	(0.49)	0.196	(0.23)	0.113	(0.66)
	Large forward	−0.197	(0.67)	−0.363	(0.05)	−0.102	(0.45)	0.273	(0.10)
Pre-crisis	Small spot	0.031	(0.78)	0.240	(0.24)	0.295	(0.21)	−0.365	(0.00)
	Small forward	0.117	(0.25)	−0.437	(0.00)	0.022	(0.90)	−0.150	(0.14)
	Large spot	−0.140	(0.12)	−0.040	(0.77)	−0.160	(0.34)	0.331	(0.00)
	Large forward	−0.003	(0.99)	0.191	(0.20)	−0.004	(0.99)	−0.267	(0.01)
	Adj. R^2	0.19		0.15		0.06		0.26	
	Durbin–Watson	2.29		2.14		2.03		2.19	
1997									
	Constant	−1.195	(0.03)	−0.342	(0.25)	−0.320	(0.12)	0.056	(0.84)
Crisis	Small spot	−0.328	(0.00)	−0.130	(0.02)	0.241	(0.01)	0.276	(0.00)
	Small forward	−0.188	(0.51)	−0.446	(0.02)	0.060	(0.78)	0.086	(0.47)
	Large spot	−0.771	(0.12)	−0.107	(0.06)	0.545	(0.00)	0.101	(0.13)
	Large forward	0.543	(0.15)	−0.254	(0.06)	0.538	(0.03)	−0.243	(0.00)
Pre-crisis	Small spot	−0.425	(0.00)	0.209	(0.11)	0.035	(0.55)	−0.082	(0.49)
	Small forward	−0.519	(0.01)	−0.013	(0.92)	−0.218	(0.03)	−0.061	(0.68)
	Large spot	−0.199	(0.29)	0.090	(0.68)	−0.266	(0.16)	−0.297	(0.32)
	Large forward	−0.113	(0.46)	0.067	(0.45)	−0.015	(0.93)	−0.373	(0.12)
	Adj. R^2	0.14		0.10		0.29		0.13	
	Durbin–Watson	1.86		1.95		1.84		1.89	
1998									
	Constant	0.995	(0.12)	−0.079	(0.87)	−0.582	(0.18)	−0.115	(0.86)
Crisis	Small spot	−0.513	(0.03)	0.093	(0.48)	−0.013	(0.96)	0.312	(0.02)
	Small forward	−0.486	(0.09)	−0.257	(0.22)	0.136	(0.64)	−0.396	(0.35)
	Large spot	0.127	(0.67)	0.011	(0.96)	−0.083	(0.66)	0.056	(0.71)
	Large forward	−0.289	(0.53)	−0.371	(0.00)	0.067	(0.84)	−0.073	(0.73)
Pre-crisis	Small spot	0.118	(0.53)	−0.119	(0.37)	−0.381	(0.00)	0.187	(0.52)
	Small forward	0.159	(0.58)	−0.047	(0.67)	−0.247	(0.22)	0.036	(0.90)
	Large spot	1.075	(0.00)	−0.012	(0.95)	−0.897	(0.00)	0.125	(0.66)
	Large forward	0.353	(0.00)	−0.114	(0.37)	−0.178	(0.07)	−0.008	(0.95)
	Small spot, second lag							0.412	(0.03)
	Adj. R^2	0.22		0.11		0.14		−0.01	
	Durbin–Watson	2.20		1.84		1.99		1.99	

Notes: Difference of net position (flows), both spot and forward, for large and small players, estimated within a system on lagged flows of large and small players, with dummies for pre-crisis and crisis periods. The p-values are given in parentheses. All equations use one lag, except in 1998 where we use two lags of small players' spot trading in the large specification during the crisis period.

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First version submitted February 2011;
final version received October 2012.