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This is the authors’ accepted and refereed manuscript to the article published in

Scandinavian Journal of Economics, 116(2014)2: 506-538

DOI: 10.1111/sjoe.12044

Publisher’s version available at http://dx.doi.org/10.1111/sjoe.12044

‘Large’ vs. ‘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 so as to benefit from interest rate differentials. We propose a model where 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, since interest rates did not increase.

Keywords: Currency crises, FX trading, large players, microstructure
JEL Classifications: F31, F41, G15

I Introduction

Currency crises often appear only loosely connected to economic fundamentals. This observation has encouraged a large and growing literature on why, when and how currency crises occur. The role of large players is often emphasized in the public debate. Many observers and

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

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politicians have denounced hedge funds and other highly leveraged institutions, especially foreign, for manipulating exchange rates during speculative pressure. This interest has also been reflected in the academic literature. A key contribution is Corsetti, Dasgupta, Morris, and Shin (2004) (henceforth CDMS), who extend the model of Morris and Shin (1998) by introducing a single large player that might have superior information. The work by CDMS has inspired a number of contributions, both theoretical (Bannier, 2005) and experimental (Taketa, Suzuki-Lffelholz, and Arikawa, 2009).

In the model of CDMS, the large player will move early so as to signal his/her information to the small players, thereby inducing an attack. This is, however, in contrast to the experiences from the European-wide ERM crisis in 1992–93 and the Asian currency crisis in 1997–98, where Tabellini (1994) and IMF (1998) argue that the large players moved in the rear 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 may 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 may 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 (due to 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 data set 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 e.g. the trade disclosure requirements seen in equity markets. It is therefore difficult to get detailed data on trading in foreign exchange 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 data set on the trading of Swedish banks suggest 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 in 1992–93 (see Aguilar and Nydahl, 2000). Even under floating or dirty-floating regimes, speculators may 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 may be triggered by economic developments making a (implicit) dual mandate of price stability and macroeconomic stability unsustainable.

The data set employed here is unique for the study of speculative attacks. First, anecdotal evidence from the two central banks suggests it covers almost the total market for the currencies under investigation; second, it is very detailed in that it covers the trading of *both* foreign and domestic players; and finally the data is sufficiently long to cover *several* speculative attacks. Carrera's (1999) study of the Mexican crisis of 1994 is also very detailed, but covers only one crisis. Corsetti, Pesenti, and Roubini (2002) and Cai, Cheung, Lee, and Melvin (2001) study the role of large players during the Asian crisis of 1997–98 using the US Treasury Bulletin reports, but these data are aggregate data and the authors simply assume that it reflects the trading of large players. Furthermore, while the above mentioned studies have focused on emerging markets, we focus on two European economies.[2] As far as we know, our paper is the first that is able to study speculative attacks with data on the trading of both foreign and local traders.

[1] Calvo and Reinhart (2002) argue that even if a country officially adopts a "flexible" exchange rate, they often tend to limit the fluctuations of the exchange rate.

[2] The two data set used here have previously been studied by Rime (2000) (Norway) and Bjønnes, Rime, and Solheim (2005) (Sweden).

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 Norwegian krone. This is in line with the observations made by Tabellini and the IMF 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 may choose to move late if there is some gain from waiting, e.g., a high interest rate differential. However, during the attack on the Swedish krona in 1998, it was the foreign players that moved early. This is also consistent with our model, as 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, see 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, Hellwig, and Pavan (2006, 2007), Angeletos and Werning (2006) and Hellwig, Mukherji, and Tsyvinski (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. Section IV describes the empirical methodology and our results. We conclude in Section V.

II The Model

We consider a stylized economy where the central bank aims at keeping the exchange rate within a certain interval, either a well defined, publicly known, narrow target zone, or a less

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

explicit dirty float policy. The basic model follows CDMS, but we add several extensions, which will be described as we go along.

The central bank has two measures to defend the exchange rate target, namely the policy interest rate and interventions. The interest rate should be used at an early stage, as a high interest rate raises the alternative costs for speculators selling the currency, which may *deter* speculation (CDMS do not discuss interest rate setting in their model). In contrast, interventions are used as a *response to* speculation, as 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 reaction function for the interventions as a function of economic fundamentals and central bank preferences. We let an exogenous random variable θ indicate the quantity of reserves the bank is willing to, 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 may be less willing to use reserves, or it may 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 less 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 will be discussed below.

The players may 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

[4] See, e.g., the surveys by Cheung and Wong (2000) and Cheung and Chinn (2001).

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 may or may 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 payoff to a successful attack on the currency, leading to a devaluation/depreciation of the currency, is given by 1, and the payoff from refraining from attack is 0. Thus, the net payoff for small players of a successful attack on the currency is $1-t$, while the payoff to an unsuccessful attack is $-t$. All players are assumed to be risk neutral, as 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 may 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 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, one risks 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 one attacks 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, as it implies that there is no need for other players

[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 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. The small players, on the other hand, are too small to profit from incurring the fixed costs. Another reason for assuming that only the large player may 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.

to make forecasts about the large player's behavior in period 3. It is a strong assumption, as 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 succeed, many players may 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, as 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, as speculation in period 1 encourages speculation by the small players. For the large player there is nothing to learn from waiting till period 2, as the small players will not speculate in period 1. However, the large player may 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 concretely, if the speculators sell more 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 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. We therefore restrict attention to the case where $\theta > 0$.

[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, un-modeled, 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. Explicitly including the possibility of rationing among the small traders 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.

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 c.d.f. The noise ε_i is assumed to be 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 assume 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 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 large player's trade. Rumors may give the small players strong indications whether large players are trading, but since a large player may have an incentive to encourage the belief that he is trading, 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 may 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

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

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

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 c.d.f. 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 will return to interest rate setting below.

Analysis

As usual in such models, we solve by using backwards induction. Since whether the attack is 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 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 will 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 model is characterized by two critical values: x^* and a critical value for the fundamental less the early speculation of the large player, $(\theta - \lambda)$. If $\theta - \lambda \leq (\theta - \lambda)^*$, 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, 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 occurs is a function of the true

[8] Holden and Vikøren (1996) show that the central bank may build up credibility for a fixed exchange rate regime by abstaining from a devaluation in spite of a high interest rate differential.

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

state of the economy, $\theta-\lambda$, as follows

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

Since there is a continuum of small players, and 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. As $F(.)$ 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 that speculate exceeds the strength of the economic fundamentals, less the early speculation of the large player, i.e., 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 (the left-hand side of (4)) is larger, and the strength of the fixed exchange rate (the right-hand side of (4)) 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 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

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

where the last equality follow from the symmetry of $f(.)$, $F(\nu) = 1-F(-\nu)$. The expected payoff from attacking the currency for player i, per unit of speculation, is thus

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

In an optimal trigger strategy, the expected payoff from attacking the currency must be zero for the marginal player, i.e., the optimal cutoff 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 (5) to obtain $(\theta-\lambda)^* = x^*+\sigma F^{-1}(t)$. Substituting into (4), we get

$$
\begin{aligned}
(\theta-\lambda)^* &= F\left(\frac{x^*-\left(x^*+\sigma F^{-1}(t)\right)}{\sigma}\right), \text{ or} \\
(\theta-\lambda)^* &= F\left(-F^{-1}(t)\right) \\
&= 1-F\left(F^{-1}(t)\right) = 1-t.
\end{aligned}
$$

Thus, the critical values are

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

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

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 of 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 (6) a devaluation will take place if the fundamental $\theta \leq \theta^* \equiv 1 - t + \lambda$.

The probability that an attack succeeds 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. The expected payoff from attacking in the amount $\lambda \geq 0$ at an early stage is thus

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

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

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

As $E\pi$ 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 *Conditions for early speculation by large player:*

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* $\bar{t} > 0$ *such that if* $t > \bar{t}$*, then the optimal early speculation is zero,* $\lambda = 0$.

The proof is 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 inducing small players to attack is clearly the more profitable alternative. As the large player is risk neutral, he will then speculate to his limit L. On the other hand, 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 (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 (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 $H_1 \frac{d\lambda^*}{dt} + H_2 = 0$, or $d\lambda^*/dt = -H_2/H_1$, where $H_2 \equiv \frac{\partial^2 E\pi}{\partial\lambda\partial t}$ and $H_1 \equiv \frac{\partial^2 E\pi}{\partial\lambda^2} < 0$ from the second order condition. Thus, it follows that the sign of $\frac{d\lambda^*}{dt}$ is equal to the sign of $H_2 \equiv \frac{\partial^2 E\pi}{\partial\lambda\partial t}$. We differentiate the first order condition (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 (9). The second and third term are both negative: the second term captures the reduced speculation of small traders owing to higher speculation costs. This reduces the probability that the attack will succeed, which reduces the expected

[10] In practice, it may 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.

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.

For the first term, however, we know that it is positive in an interior solution, as $g'(.) < 0$. As 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, one cannot rule out that this effect dominates for some interval of t, implying that an increase in speculation costs may lead to increased speculation by the large player, and indeed increased total speculation in period 1 and 2, thus increasing the risk of a fall in the exchange rate. However, in view of Proposition 1 above, 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, so 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 is $tc(\lambda_j)$, where $c(.)$ is strictly positive and strictly convex. The expected payoff from early speculation of player j would be $E\pi_j = G\left(\frac{1-t+\lambda-y}{\tau}\right)\left(L_j(1-q)+\lambda_j q\right) - tc(\lambda_j)$ 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, e.g., Fudenberg and Tirole, 1991, Chapter 1.3). Yet one 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

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

[11]The microstructure approach to foreign exchange 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 (see, e.g., Bjønnes, Osler, and Rime, 2011).

In an interior equilibrium in pure strategies, which may or may not exist, all the large players would speculate early in the amount given by (10). If an interior equilibrium in pure strategies 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 of 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 (the first term in (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 counterintuitive result that higher speculation costs increases the total speculation is less likely.

Finally, we consider the interest rate decision of the central bank in period 0. From (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 (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. As $P(.)$ is strictly increasing, it follows that an increase in the interest rate, increasing t and reducing 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

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

currency speculation and increase the likelihood that the regime survives.

The central bank knows neither the signal nor 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 be able to set t exactly at the level that prevents a successful attack. As the focus of the model is the speculation of the large and the small traders, and the relationship between these, we will 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 may 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 below 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 foreign exchange markets. This is in general a tall hurdle since the foreign exchange market is almost completely unregulated, lacking e.g. 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 Norwegian market-making banks' trading with foreigners, locals, and the central bank. In the data set from

Sveriges Riksbank, we have weekly observations starting in 1993 on both Swedish and foreign market making banks' trading 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 literature on FX microstructure (see e.g. Evans and Lyons, 2002) since 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]

In general we would expect there to be large and well informed players both among the local and foreign traders. However, evidence by Lindahl and Rime (2012) from a detailed data set 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. In addition, the Swedish data set shows that foreign customers on average are considerably larger than local, 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, even if we readily acknowledge that the distinction is not as clear cut as we would wish. We return to this issue in the conclusion.

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. Foreign traders, on the other hand, do not have the available local currency, and will instead sell the currency forward. We come back to this in the empirical analysis.

As the reporting banks are the main market makers in their local currencies, they primarily intermediate the trades of their customers, rather taking overnight positions themselves, in line with evidence on market making (e.g. Lyons, 1995; Bjønnes and Rime, 2005). This is true even

[13]Interested readers are referred to Rime (2000) and Bjønnes et al. (2005) for further descriptions on the Norwegian and Swedish data sets, respectively. Descriptive statistics for the Norwegian transactions are shown in Table B1 in the appendix, both for the whole period with data and for the specific crises.

[14]The average trade by foreign customers are euro 2.2 bn, compared to euro 0.6 bn for Swedish customers. Furthermore, the medians and the 8th deciles are 0.5 bn and 2 bn for the foreign customers, compared to 0.2 bn and 0.5 bn for the Swedish customers.

in the speculative attacks that we will study (described in more detail below) where Norges Bank is typically 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 (*i*) the ERM crisis and the depreciation of the Norwegian krone in December 1992; (*ii*) the appreciation of the Norwegian krone in January 1997; and (*iii*) the crisis in both Norway and Sweden following the Russian moratorium in August 1998. Figure 1 shows the NOK/EUR and SEK/EUR exchange rates, together with the Norwegian sight deposit rate and the Swedish discount rate (the two key policy rates) and the 3-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 with grey areas. The key dates for the attacks can be identified e.g. from the financial press.[16] The descriptive statistics on trading in Table B1 confirm that there are major movements in the expected direction during the identified events.

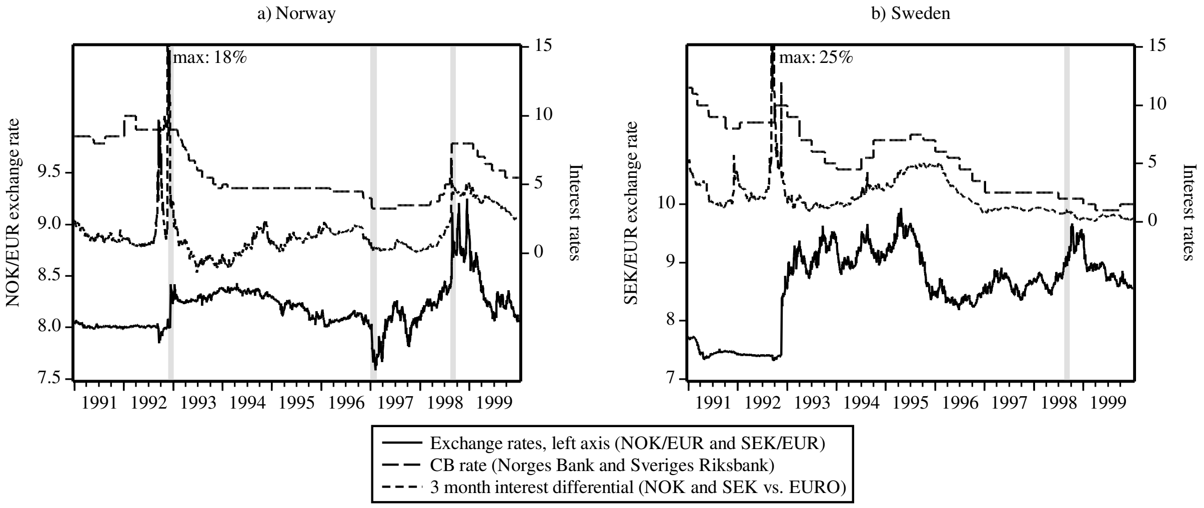
Figure 2 shows some series on the state of the macroeconomy in Norway and Sweden during the 1990s. Vertical lines mark the crises. The two graphs for Norway illustrate that two of the crises in Norway coincided with a downturn in the economy (1992 and 1998), and one with a peak (1997).

Prior to the ERM crisis of 1992 the Norwegian krone was pegged to the ECU, with fluctuation bands of $\pm$ 2.5%. However, the pressure within the ERM combined with the downturn in Norway led markets to expect a devaluation of the Norwegian krone. 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 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% weaker level.

[15]Before Jan. 1, 1999, we adjust the NOK/DMARK and SEK/DMARK exchange rates for the DMARK/EUR-conversion.

[16]The three periods are also identified in a crisis index (see e.g., Eichengreen, Rose, and Wyplosz, 1995, for a description), which takes into account that speculative pressure may materialize through interest rate changes instead of exchange rate changes (results available on request).

Figure 1
Exchange rate, central bank rate, and 3-month interest rate differential: Norway and Sweden



Note: Daily observations on exchange rates (left axis), and central bank rate and interest differential (right axis). Exchange rates are local currency pr. euro, using ECB conversion rate for Deutsche mark vs euro. Interest rate differentials are local interbank interest rate less German interbank interest rate. Shaded areas indicate the crises.

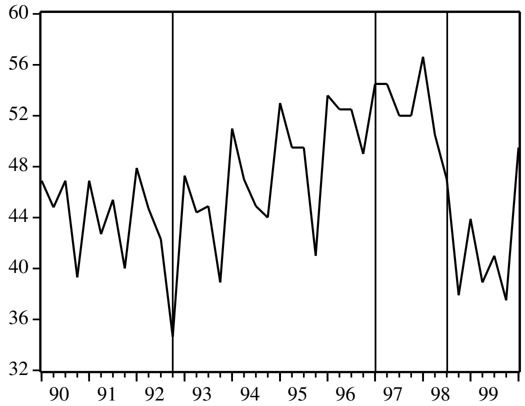
In the aftermath of the ERM crisis, Norway chose a managed float regime with an obligation to stabilize the exchange rate in a medium-term sense. During the fall of 1996 there was pressure for an appreciation of the krone. The Norwegian financial press reported that foreigners were speculating in a Norwegian 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 to fight inflation and dampen a potential boom, but it was also expected to involve a potentially steep appreciation of the krone. The pressure peaked in January 1997 and the NOK-cost of a DEM fell by more than 5% over a period of 14 days (largest changes on January 8th – 10th). 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 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,

[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.

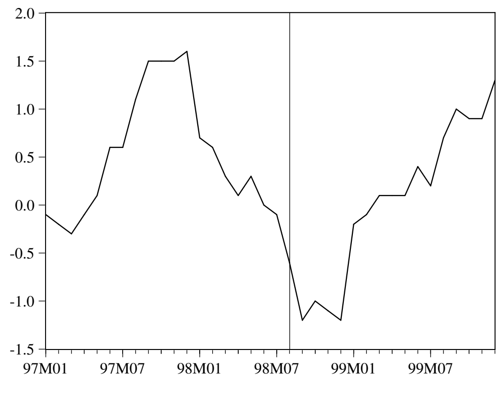
Figure 2
Illustrative macro series for the Norwegian and Swedish economy

(a) Norway: Expected employment in manufacturing (Business survey)

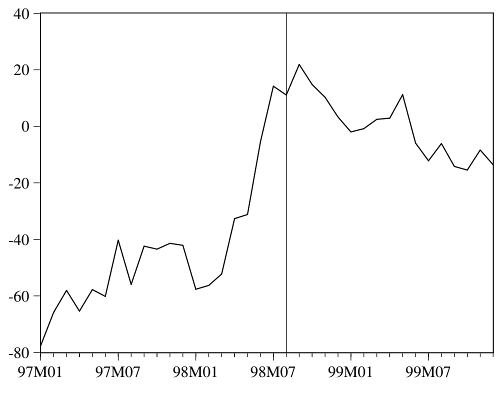


(b) Norway: Composite leading indicator

(c) Sweden: Consumer Price Index (YoY change)



(d) Sweden: Employment expectations (Business survey)



Note: Panel a) is a diffusion index, with index above 50 indicates increasing growth. The composite index in panel b) contains the following components: Retail sales; Job vacancies; Judgment on capacity utilisation; 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. Vertical lines indicate the crises. Sources: a) Statistics Norway; b) OECD; c) Statistics Sweden; d) DG ECFIN.

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 stimulus 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% (adopted in 1993), see Figure 2c. 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 2d).

Let us sum up the key features of the four episodes we explore. As 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, having 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 (due to the increase in interest rate differential), but not in Sweden.

IV Results

The model presented in Section II is stylized, with the aim of illustrating a mechanism for delayed speculation, and 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, and (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 may 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 may move early as well, which will induce small players to join in on the attack. If early speculation is sufficiently cheap, e.g., due to a small interest rate differential, the large player may 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 will 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 move first or last. Granger causality is tested by running regressions like

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

There is *absence* of Granger causality from x to y if 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 $\beta_1 = \ldots = \beta_k = 0$ is not rejected. If this hypothesis is rejected for x in the equation for y, while 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. In our view this approach is better than following a crisis index, as it may be 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 data Section). We use dummies to differentiate between crisis period and pre-crisis period. The number of lags are determined from the Schwarz and Akaike information criterions.[18] In Table B2 in the appendix we present a similar system using net trading in all instruments, which confirm 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 local players' speculation. Thus, locals Granger-cause foreigners, but foreigners do not Granger-cause locals. This is in line with the model since in all three cases interest rate differentials changed in such a way as to make it more costly to speculate early, implying 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

[18]We choose lags based on the shortest positive lag selected by these two criterions. 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 method robust to outliers, indicates that the results are rather robust, and is available upon request.

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

Note: 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 period and crisis period. Net trading measured in billions local currency. *p*-values based on robust standard errors in parenthesis. 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 period and pre-crisis period, respectively. In Norway, Locals always speculate in spot, while Foreigners speculate with spot in 1997 and with forward in 1992 and 1998. For the Swedish 1998 crisis we use net spot-trading for Foreigners and net forward-trading for Locals.

	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, 2nd 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, 2nd 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
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	

move first in an attack.

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 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 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. Now 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, as lagged speculation of foreigners is significant in the local player regression. This result is also consistent with the model since there was no gain in delaying the speculation as 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.

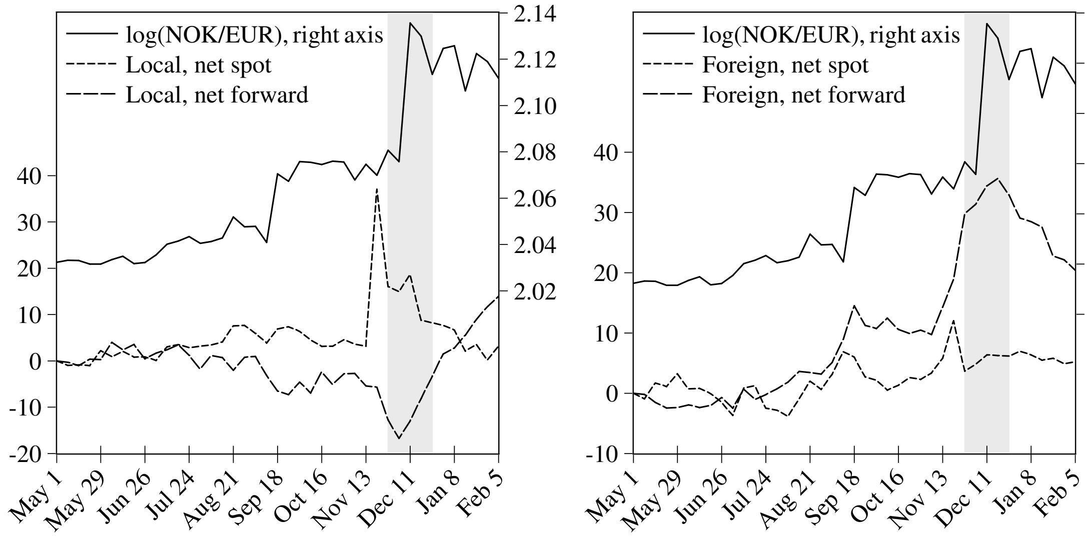
Figures 4(a) and 4(b) show NOK/DEM and SEK/DEM exchange rates and the level of net positions during the period from May 1998 to December 1998. Again we see that in Norway locals were selling NOK spot during the summer. When the foreigners attacked in August, they did so in the forward market. This sale 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. Locals, on the other hand, were taking the other side as there were no intervention by Sveriges Riksbank.

Finally, from Table 1 we 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 Norwegian krone, while it is positive during the crisis

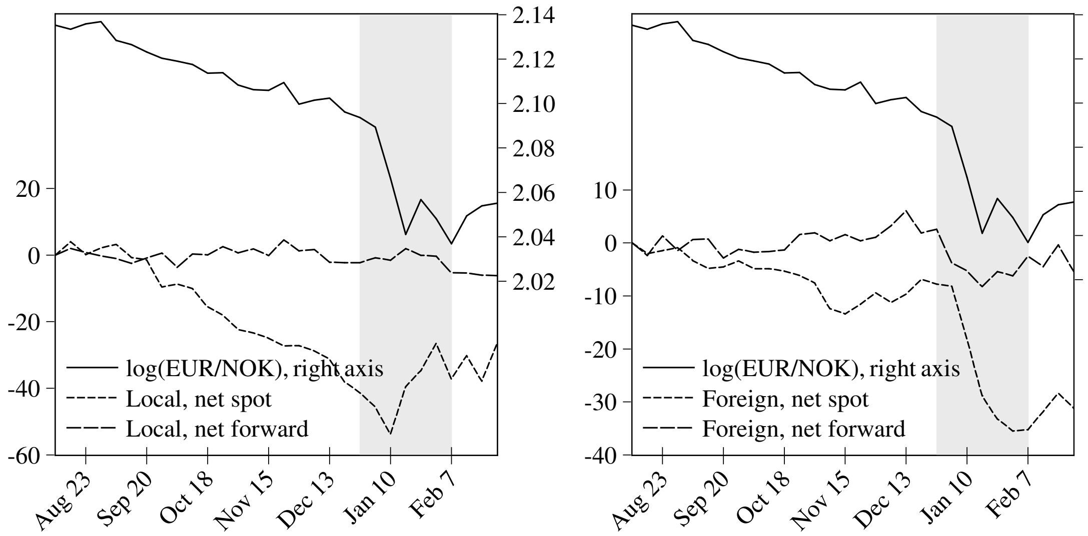
Figure 3

The exchange rate and the level of net positions: Norway during the 1992 ERM crisis (a) and the 1997 attack (b).

(a) The 1992 ERM crisis



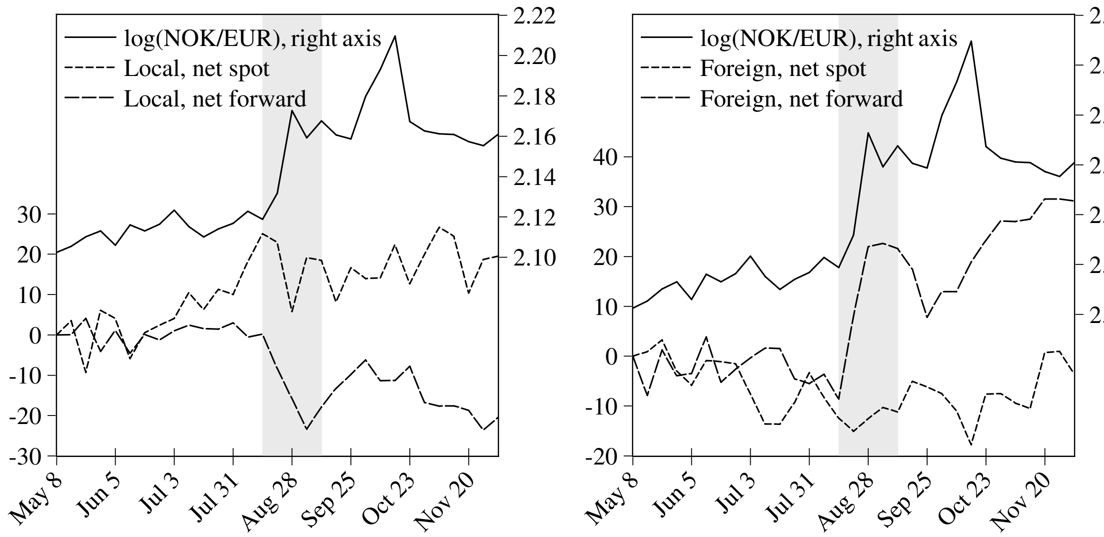
(b) The 1997 attack



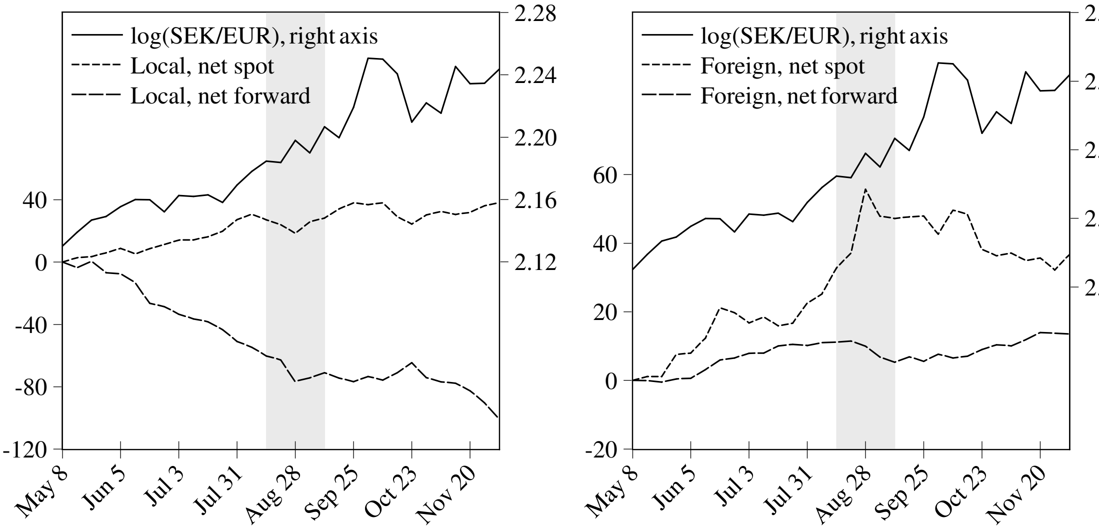
Note: Exchange rates (solid lines) measured along the right axis and positions (dotted lines) on the left axis. A negative position indicates a net holding of NOK, implying that an increasing curve indicates selling of NOK. Positions are created as the cumulative sum of the net trading used for estimation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

Figure 4
The exchange rate and the level of net positions: The 1998 Russian moratorium crisis in Norway (a) and Sweden (b).

(a) Norway



(b) Sweden



Note: 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 in beginning of the sample period), measured in billions of NOK or SEK, respectively. Grey 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. Source: Norges Bank, Sveriges Riksbank and Ecowin.

periods. In 1997 there is positive feedback from the locals to the foreigners in the pre-crisis period, but since the foreigners' own lagged trading is negative we can not 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.

The second question is 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. Due to problems of multicollinearity, we run separate regressions for locals and foreigners. The results are in Table 2.

In the regressions we include the 3-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 the foreigners were instrumental in the three Norwegian crises since the foreigners delayed their attack towards the end. This should be reflected in significant and positive coefficients when the speculation is successful, as 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 (as 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, as a negative coefficient would imply provision of liquidity to the foreigners. From Table 2 we see that these expectations are largely borne through.

For Sweden we do not find any significant effects during the 1998 crisis. Given the evidence that foreigners Granger-caused locals, we would expect that at least the locals' flows were

Table 2
Crisis regressions

Note: Regression of NOK and SEK return (log-changes multiplied by 100 to measure in %) on net trading, interest differential and first-difference log oil price. Net trading measured in billions of NOK or SEK, respectively. Robust (Newey-West) *t*-values in parenthesis below coefficient estimates. Asterisks indicate level of significance, ** for 1% significance-level and * for 5% level. Trading impact during crises are constructed using a dummy on the trading variables.

	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 diff	−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
DW	2.11	2.04	2.00	1.99

positive and significant. However, Figure 4 seems to suggest that it is the foreigners that 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% per billion NOK sold, or about 5% per 1 billion USD equivalent.[20] The comparable numbers for the 1997 and 1998 events are about 1.6% per 1 billion *spot* USD for 1997 and about 1.2% per 1 billion *forward* USD for 1998. By comparison, Evans and Lyons (2002) report an effect from order flows to the DEM/USD exchange rate of about 0.5% per 1 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 due to increased liquidity over time and less rigid monetary regimes.

V Conclusion

We study 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 extend the model of Corsetti et al. (2004) by incorporating the costs and benefits of ”early” versus ”late” speculation by the large player. The model of Corsetti et al. (2004) predicts that large players may move early in an attack in order to induce small players to attack. It has, however, been argued by Tabellini (1994) and the IMF that large players move in the rear in currency crises in order to reap the benefits of higher interest rate differentials.

In our model the large player may choose to speculate early, incurring trading and interest rate costs, but also providing a signal to the small players, possibly inducing them to speculate. However, the large player may also choose to delay speculation, reaping the benefit of a positive interest rate differential while waiting, but also missing the opportunity to influence the smaller

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

players, as well as risking being too late to join the attack. The smaller players will not speculate as early as the large player, as 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 Norwegian krone; the 1997 appreciation crisis in Norway; and the August 1998 crisis following the Russian moratorium. The latter event is especially interesting, as 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. We therefore 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, due to a high interest rate differential, the large player may 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 the 1998 crisis in Sweden. This is in line with the model since the Norwegian central bank used the interest rate to defend the krone in all cases, implying that it was profitable to delay the attack on the Norwegian krone for players with sufficient capacity to be able to enter at a late stage, 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, implying that there was no gain by delaying the attack in Sweden. The regression analysis shows that the foreigners were active during the final stage of the attack in all cases.

Comparing the Norwegian and Swedish episodes suggests that the Norwegian central bank managed to delay the speculation of the foreign traders by raising the interest rate. However, it was nevertheless not sufficient to avoid a forced change in the exchange rate, which happened 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, as the interest rate hike in 1992 and 1998 depressed an already weak economy, while the interest rate reduction in 1996/97 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.

A Proof of Proposition 1

Proof. *i.* Consider the payoffs from three values 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.) As $G(.)$ is strictly increasing, it is clear that for $t=0$, we have 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 optimal also 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 the 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 $\frac{\partial E\pi}{\partial\lambda}$ 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 the t for which this condition holds. It follows that $\lambda = 0$ is optimal for all $t > \bar{t}$. ■

B Tables

Table B1
Descriptive statistics and correlations matrixes for Norwegian net trading

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

			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
		Std. Dev.	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
		Std. Dev.	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
		Std. Dev.	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
		Std. Dev.	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

Table B2
Granger causality test on all flows: Norway, 1992, 1997 and 1998

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

		1992							
		Small spot		Small forward		Large spot		Large forward	
	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	
	DW	2.29		2.14		2.03		2.19	
		1997							
		Small spot		Small forward		Large spot		Large forward	
	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	
	DW	1.86		1.95		1.84		1.89	
		1998							
		Small spot		Small forward		Large spot		Large forward	
	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, 2nd lag							0.412	(0.03)
	adj.R^2	0.22		0.11		0.14		-0.01	
	DW	2.20		1.84		1.99		1.99	

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