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Shu Lin
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THREE ESSAYS ON CURRENCY CRISES

A Dissertation APPROVED FOR THE

DEPARTMENT OF ECONOMICS

BY

Dr. Kevin Grier (Chairperson)

Dr. Chitru Fernando

Dr. Robin Grier

Dr. Jiandong Ju

Dr. Aaron Smallwood

Dr. Daniel Sutter

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ABSTRACT

This dissertation studies the roles of interest rates in currency crises. Existing studies in the literature suggest that high interest rates can play two different roles. The first role is an attack deterrent: a monetary authority can potentially deter a speculative attack at the first place by raising interest rates ex ante to reveal its willingness and ability to defend the currency. The second role is a weapon of defense: once an attack has already been launched, a monetary authority can possibly defend the currency by raising interest rates to increase speculators' costs. A graphical illustration of the roles of interest rates is presented in Figure 1.

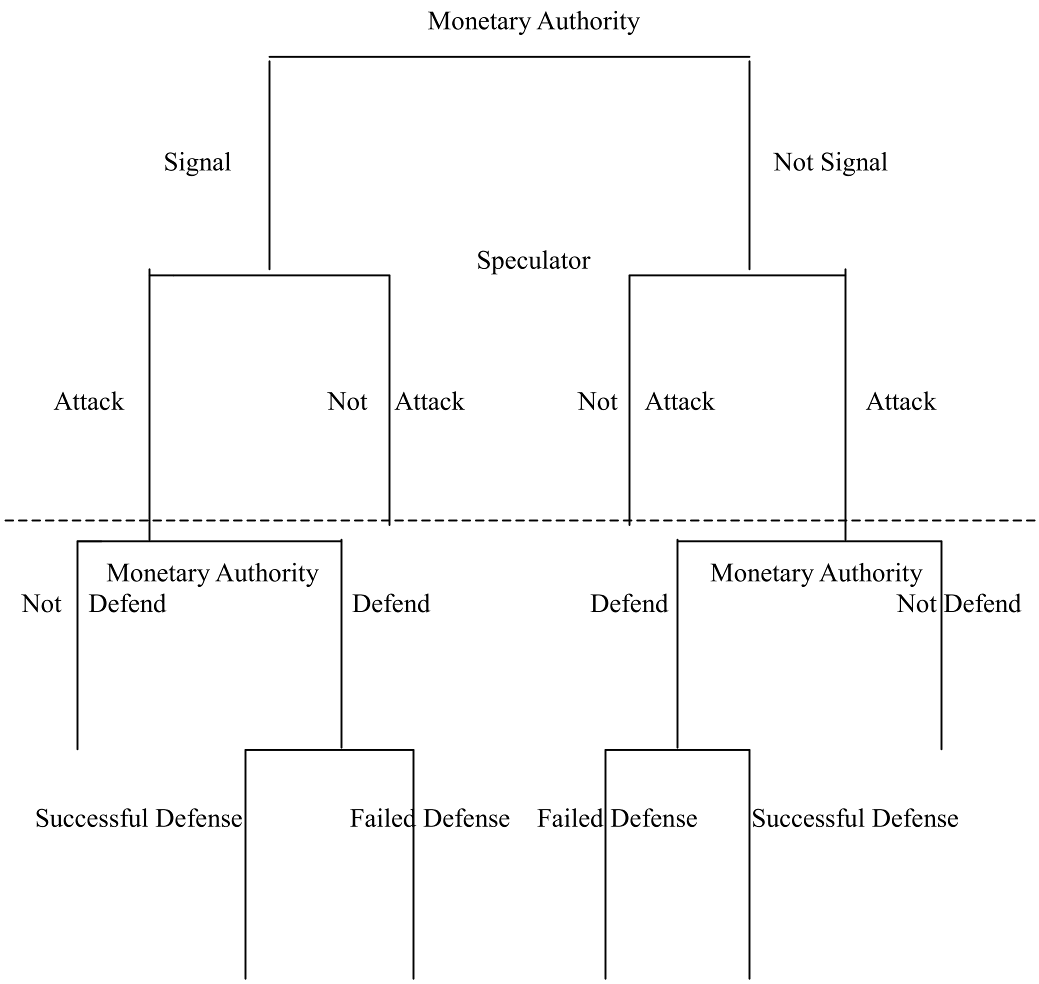
The first chapter of my dissertation studies the attack deterrence effect of high interest rates. In this chapter, I present a signaling model of raising the interest rate as a deterrent to speculative attacks and then test the model using a dataset that covers 54 countries from March 1964 through December 2000. Incorporating uncertainty over the speculator's type into a standard signaling model, I am able to show that unsuccessful signaling can be equilibrium behavior in either a pooling equilibrium or a semi-separating equilibrium. The model also implies that, although it is still possible for a weak monetary authority to hide his type in a pooling or semi-separating equilibrium, in both cases, the weak monetary authority faces a higher probability of an attack. In the empirical part of this paper, I find evidence that raising interest rates in advance has significantly different impacts in different country groups. It significantly reduces the probability of attacks in countries that have a de facto hard peg but increases it in de facto soft-pegging countries. This finding is

robust to alternative measure of monetary policy and to different specifications and samples. These results clearly support the predictions of the theoretical model.

The second chapter presents a theoretical model of interest rate defenses against speculative attacks. Given that a high interest rate can be a double-edged sword, I argue that the battle between speculators and the government can be well modeled as a war of attrition game under asymmetric information. I then solve for a pure strategy weak perfect Bayesian equilibrium in which each party's time until concession depends on their benefits from winning and their costs of fighting. Using this model, I am able to produce results that are novel for the speculative attack literature. First, the model shows that failed defenses (attacks) can be ex-ante rational for governments (speculators). Second, the model predicts systematic variations in the durations of interest rate defenses and I find some support for these predictions in the context of attacks in 1997 and 1998. Finally, the model suggests that the relation between interest rates and the outcome of a defense is likely to be nonlinear, which is consistent with existing empirical evidence.

Chapter three empirically tests the effectiveness of interest rate defenses against speculative attacks. It is shown that previous empirical studies on this issue suffer a classic sample selection problem by restricting their sample observations to crisis periods only. To correct this selectivity bias, I employ the full information maximum likelihood method to a large unbalanced panel dataset that covers both crisis periods and peaceful periods. I also develop a rare-events-corrected probit model with sample selection that can be used to correct a second bias that is created by the rare events data used to estimate the selection equation. My empirical results show there is no significant statistical relationship between the interest rate and the outcome of a speculative attack.

Figure 1 A Graphical Illustration of the Roles of Interest Rates



Chapter One

Do High Interest Rates Deter Speculative Attacks?
----Theory and Evidence

1.1 Introduction

Can raising interest rates ex-ante deter speculative attacks? Is the effect of interest rate signaling the same for all monetary authorities? If interest rate signaling is costly, why do we seem to see monetary authorities often use it to no effect?

Recent work (Drazen (1999), Drazen (2001), Angeletos et al. (2003)) emphasizes the signaling effect of high interest rates as a deterrent. In these papers, a monetary authority can potentially deter a potential attack at the first place by raising short-term interest rates ex ante to signal its willingness and ability to defend the currency.[1]

These papers make important contribution to the literature by correctly pointing out the signaling effect of high interest rates. However, there is still some room for further progress. First of all, none of these models is able to justify the failed signaling observed in reality without relying on out-of-equilibrium beliefs.[2] More importantly, they predict that the signal sent by different types of government will be equally effective, which, as we will see, is an idea that is strongly rejected by the empirical evidence we present below.

In the theoretical part of this paper, we introduce the uncertainty over the speculator's characteristics to the standard signaling model. This simple modification

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[1] Many other papers study the effectiveness of an interest rate defense once an attack has been launched, which is a different issue than what we study here. See for example, Bensaid and Jeanne (1997), Flood and Jeanne (2000), Lahiri and Vegh (2003), and Grier and Lin (2005).

[2] Failed signaling can be justified in a semi-separating equilibrium in other standard signaling models.

generates novel results. It allows us to show that a monetary authority can be attacked in either a pooling equilibrium or a semi-separating equilibrium even if he signals. Therefore, ex ante rationality of failed signaling (also attacks) can be justified in our model without relying on any out-of-equilibrium beliefs. Furthermore, it enables us to show explicitly that signaling is more effective for countries that have a strong commitment to exchange rate stability. This prediction is strongly supported by the evidence found in the empirical part of our paper.

Existing empirical studies in the literature have focused on testing whether raising interest rates influences the outcome of a speculative attack.[3] In this paper we present the first empirical evidence on whether raising interest rates ex-ante can deter a speculative attack. Drawing evidence from a large unbalanced panel dataset that includes 54 countries over the period from March 1964 through December 2000, we find robust evidence that high rates do reduce the probability of a potential speculative attack in countries that have a credible *de facto* fixed exchange rate regime but not in soft-pegging countries. This evidence supports the predictions of our theoretical model.

The paper proceeds as follows: Section 2 provides a review of the literature. In Section 3, we fix ideas by studying a simple theoretical model. Section 4 discusses data issues, especially how to measure attacks. Section 5 contains our results, and section 6 concludes.

1.2 The Literature

The signaling hypothesis was first formalized by Allan Drazen. In a series of papers (Drazen 1999, 2001), he argues that a major effect of high interest rates is as a

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[3] These studies include Kraay (2003), Hubrich (2000), and Drazen and Hubrich (2003).

signal of the government's willingness or ability to defend the exchange rate. Given imperfect information about the government characteristics, speculators use observed government policies to update the probability they assign to future devaluation. Thus, a high interest rate can signal the government's high value of the peg or strong fiscal position and can potentially deter a speculative attack.

Angeletos et al. (2003) study the effectiveness of signaling in environments where market participants play a global coordination game with information heterogeneity. In their model, signals are received by speculators with idiosyncratic noise and government policy is endogenous. There is an inactive-policy equilibrium in which speculators coordinate on "ignoring" any attempt of the government to affect market behavior and the government chooses not to signal. This happens when the fundamentals are either very strong or very weak. If the fundamentals are neither too weak nor too strong, there exists a continuum of active-policy equilibria in which the government chooses to signal. Upon observing the signal, the speculators coordinate on either an aggressive or a lenient course of action. In an "active-policy" equilibrium, the government has to raise the interest rate to a certain level, which is determined by arbitrary aggressiveness of speculators, to meet the market expectation and thus avoid attacks.

As discussed earlier, these models all have difficulty allowing failed signaling, which seems to be often observed in reality, without relying on any out-of-equilibrium beliefs.

While direct empirical testing of this issue has not been done, there are related empirical studies which investigate whether high interest rates help defend currencies during speculative attacks. Kraay (2003) is probably the first and most influential examination of this issue. Drawing on large sample evidence, he finds no evidence that high interest rates help defend exchange rates, nor can he find evidence that high interest rates have any significant perverse effects.

Following Kraay's approach, Hubrich (2000) employs the same type of data but using simpler statistical methods to reinvestigate this issue. He argues that Kraay's result is due mainly to how he defines the policy variable. Using variations of Kraay's policy variables, he finds significant, but contradictory, results. In his paper, raising discount rates significantly lowers the chances of a successful defense but reducing domestic credit significantly helps defend the exchange rate.

Drazen and Hubrich (2003) argue that such direct tests of the effectiveness of interest rate defenses are likely to get inconclusive results due to offsetting effects. By disaggregating the impact of interest rate defense into the effects on future interest rates differentials, expectation of future exchange rates, and risk premia, they find that raising the interest rates strengthens the exchange rate over the short-run but leads to an expected depreciation and an increase in the risk premium at a horizon of a year and longer.

Furman and Stiglitz (1998) use daily data on interest rates and exchange rates of nine emerging economies from January 1992 to June 1998 to test whether high interest rates help defend the domestic currency. They find a negative relationship between either the magnitude of the interest rate hike or its duration and the eventual outcome of the exchange rate. Using daily data for five Southeast Asian countries, Goldfajn and Baig (1998) fail to find any significant impacts of monetary policy on exchange rates. Using weekly data from Indonesia, Korea, Malaysia, the Philippines, Thailand, and Mexico, Gould and Kamin (2000) find that credit spreads and stock prices have significant impacts on exchange rates during financial crises, while interest rates do not.

In sum, evidence that interest rate increases significantly help monetary authorities win speculative attacks is mixed at best, while do date, there is no existing evidence on our question of interest: can ex-ante interest rate increases deter attacks?

1.3 A Simple Model of Signaling

To fix ideas and directly motivate our empirical tests, we present a simple two-stage signaling model. We show that, in both a pooling and a semi-separating equilibrium, both types of monetary authorities would signal, but one type of monetary authority can more effectively deter an attack than the other. In a separating equilibrium, only one type signals and deters attacks successfully.

A. Setup of the Model

There are two risk-neutral agents, a monetary authority and a representative speculator in the model. The monetary authority has two possible types: Strong ($\theta = 1$) and Weak ($\theta = 2$). The strong monetary authority has a higher level of commitment on exchange rate stability than does the weak monetary authority. There are also two types of speculator: an informed speculator who can directly observe the monetary authority's type and an uninformed speculator who cannot. The speculator's type is private information to both types of monetary authority while by construction the monetary authority's type is only private to the uninformed speculator. Uncertainty over the speculator's type turns out to be crucial for generating ex ante rational, but unsuccessful, signaling in a pooling equilibrium or in a semi-separating equilibrium. We will let s denote the prior probability that the monetary authority is strong and p denote the prior probability that the speculator is informed.

The model has two stages. At the first stage, the monetary authority chooses the interest rate. At the second stage, the speculator makes his attack decision upon observing the rate.[4] Although the observed interest rate is not informative to the informed speculator, it can still be used by the uninformed speculator to update his prior belief, $\mu(\theta = 1) = s$.

Assuming no discounting, a monetary authority's loss function can be written as:

$$L_\theta = C(r) + ZV_\theta \qquad \theta = 1; 2$$

where Z takes on the value one if a speculative attack occurs at the second stage and zero otherwise. $C(r)$ is strictly increasing for any $r \geq 0$ and $C(0) = 0$. It can be considered as the cost of signaling (the cost associated with deviating from the optimal interest rate). For simplicity, the optimal interest rate is normalized to be zero and the cost of signaling is assumed to be the same for both types of monetary authorities. V_θ can be interpreted as the expected cost (weighted cost conditional on the outcome) of defending the peg after an attack. To make our model interesting, we assume that $V_1 > V_2$.

Both types of speculators share a common payoff function:

$$U = Z(\pi M - K)$$

[4] Allowing speculator to signal its own type before the monetary authority moves will not change the results of our model for there is no need for the informed speculator to reveal or hide its type.

where Z is the indicator variable defined above. K can be interpreted as a fixed cost associated with launching a speculative attack. M is the potential benefit to the speculator if an attack turns out to be successful and is assumed to be greater than K. π is the probability of a successful attack. Without loss of generality, the probability is assumed to be zero if the monetary authority is strong and one if the monetary authority is weak... Therefore, an informed speculator always attacks weak types but never attacks strong types. $C(r)$, V_1, V_2, K, M, p and s are all assumed to be common knowledge.

B. Solving for Equilibria

First, we solve for the separating equilibria of the model. A separating equilibrium is the one where the two types of monetary authorities choose different actions at the first stage. The weak monetary authority will choose not to raise the interest rate because it is too costly for him to imitate the strong monetary authority. As a result, upon observing the interest rate any speculator can correctly infer the type of the monetary authority. Therefore, the conditions for a separating equilibrium are:

$$(1-p)V_1 \geq C(r^*) \geq (1-p)V_2, \quad \mu(\theta = 1 \mid r = r^*) = 1 \;, \; \mu(\theta = 1 \mid r \neq r^*) = 0$$

The first condition states that, for a strong monetary authority, the cost of raising the interest rate to r^* at the first stage is less than the expected cost of not doing so. The second condition ensures that it does not pay for a weak monetary authority to imitate a strong monetary authority because the expected total loss conditional on signaling ($pV_2 + C(r^*)$) exceeds the expected loss of no signaling (V_2).[5] Upon observing the interest rate, the uninformed speculator will assign a probability, $\mu(\theta = 1 \mid r = r^*) = 1$

[5] Note that the existence of a potential informed speculator at the second stage reduces both types of monetary authorities' incentive to signal.

and $\mu(\theta = 1 \mid r \neq r^*) = 0$ to the monetary authority's type.

It is easy to see that, for certain functional forms of $C(r)$ and values of V_1, V_2, K and M, there exists a continuum of separating equilibria in which a strong monetary authority chooses an interest rate r^*, $r^* \in [r_2, r_1]$, where $r_2 = C^{-1}((1-p)V_2)$ and $r_1 = C^{-1}((1-p)V_1)$, and a weak monetary authority chooses the optimal interest rate at the first stage. Both types of speculator would attack (not attack) the weak (strong) type.

Next, we solve for the pooling equilibria of the model. In a pooling equilibrium, both types of monetary authority would choose to signal at the first stage so the signal does not help an uninformed speculator update his prior belief. Therefore, there exists a continuum of pooling equilibria if:

$r^* \in [0, r_2]$, and $\mu(\theta = 1 \mid r = r^*) = \mu(\theta = 1) = s > (M - K)/M$, $\mu(\theta = 1 \mid r \neq r^*) = 0$

The first condition states that both types of monetary authority would find it profitable to signal. The next one ensures that an uninformed speculator would not attack at the second stage upon observing the signal. Note that in our pooling equilibrium the weak monetary authority will be attacked with probability p, the probability that the speculator is informed, even he signals. However, signaling is still rational ex ante. Therefore, our model allows unsuccessful signaling in equilibrium.

No pooling equilibrium exists when $s < (M - K)/M$. However, there is a continuum of semi-separating equilibria in which the strong monetary authority signals and the weak monetary authority and the uninformed speculator play mixed strategies. The weak monetary randomly signals with probability q to make the uninformed speculator indifferent between attacking and not attacking in equilibrium and the uninformed speculator randomly attacks with a probability t so that the weak monetary authority will find itself indifferent between signaling and not signaling. The strong monetary authority still signals. The uninformed speculator updates his belief upon observing the monetary authority's action according to Bayes rule. Therefore, the conditions for having these equilibria are:

$s < (M-K)/M$, $r^* \in (0, r_2]$, $q = Ks/[(M-K)(1-s)]$,

$t = [(1-p)V_2 - C(r^*)]/(1-p)V_2$, $\mu(\theta = 1 \mid r = r^*) = s/[s+(1-s)q]$,

$\mu(\theta = 1 \mid r \neq r^*) = 0$

In a semi-separating equilibrium, both types can be attacked. The probability of attack for a strong monetary authority is $(1-p)t$ while the probability of attack for a weak monetary authority is $p+(1-p)t$.

This model, though simple, has important implications that are not found in the existing literature. In particular, our model allows for ex ante rational failed signaling without relying on any out-of-equilibrium beliefs. The other novel feature of the model is that it gives an explicit prediction on the relative effectiveness of signaling. We show that in either a pooling equilibrium or a semi-separating equilibrium, the probability of attack for a weak monetary authority who signals is greater than that for a strong monetary authority who signals.

This is exactly what we want to test in the following empirical part of our paper: do countries with strong preferences for exchange rate stability deter attacks by raising rates more effectively than countries with less strong preferences?

1.4 Data Issues

A. Sample Coverage and Data Sources

The unbalanced panel dataset that we created for this study covers 54 countries, both developed and developing, from March 1964 to December 2000. The data are drawn from the International Monetary Fund's *International Financial Statistics on CD-ROM* (IFS) (February 2004 version), Penn World Tables 6.1, and the Polity 4 database. Detailed data sources are listed in the data appendix.

B. Identifying Speculative Attacks

In order to test the signaling hypothesis, we first have to identify speculative attacks. There are two methods to identify speculative attacks in the literature. One is proposed by Eichengreen, Rose, and Wypolz (1985) and the other is proposed by Kraay (2003). Our identification method follows that of Kraay (2003). We identify successful attacks and failed attacks separately, though the outcome of a speculative attack is not the focus of this study.

We do three things that make our sample differ from Kraay's. First, we include lower income countries, as well as middle and upper income countries, into our sample for we do not see any obvious benefit in excluding these countries. Second, our sample covers a longer period, from March 1964 to December 2000. Third, we restrict our sample to countries that can reasonably be considered to have a fixed exchange rate to defend, which Kraay does not explicitly do.[6]

Theoretically, the exchange rate is not a policy objective of the monetary authority under a freely floating exchange rate regime. It is determined by the market.

[6] He restricts his sample to countries that have relatively stable nominal exchange rates 12 months prior to an attach though. However, his method is far from perfect and he does identify some attacks in periods during which a country's exchange rate regime was freely floating. For example, Kraay identifies a successful attack in South Africa in July 1998 even though that country has had a freely floating regime ever since March 1995, according to Reinhart and Rogoff's *de facto* classification.

The monetary authority is not obligated to maintain the exchange rate at a certain level. In our view, it only makes sense to speak about speculative attacks and crises prevention in fixed exchange rate regimes. This issue is complicated, as recent research shows that the official classification of exchange rate regimes reported by the IMF's *Annual Report on Exchange Rate Arrangements and Exchange Restrictions* often fails to describe actual country practice.[7] In particular, countries that have a *de facto* peg or crawling peg are often classified as floaters. To avoid this problem, we use Reinhart and Rogoff (2003)'s *de facto* classification of exchange rate regimes.[8] They classify different exchange rate arrangements into five broad categories, hard peg, soft peg, managed floating, freely floating and freely falling, according to their flexibility. We focus our attention primarily on the first two regimes. But we do extend our sample to including managed floating later as a robustness check.

Following above rules, we identify a total of 38 successful attacks and 60 failed attacks in countries whose exchange regime is either a hard peg or a soft peg. All identified speculative attacks are listed in Table 1. Table 1 also lists speculative attacks that are identified in countries whose exchange rate regime is managed floating. There are 15 successful attacks and 24 failed attacks that fall into this category. These additional attacks will be used later as a robustness check of our empirical results.

C. Measures of Monetary Policy Signals and Policymaker Type

[7] See Calvo and Reinhart (2002), Levy-Yeyati and Sturzenegger (2003) and Reinhart and Rogoff (2003).

[8] We use Levy-Yeyati and Sturzenegger (2003)'s classification for Bangladesh, Rwanda and Trinidad and Tobago because they are not available in Reinhart and Rogoff (2003). We treat a regime as hard peg, soft peg, or managed floating if it is classified as fixed, dirty floating/crawling peg, or dirty floating in Levy-Yeyati and Sturzenegger (2003). None of our results on interest rate signaling changes if we simply drop these three countries from the sample and use only Reinhart-Rogoff classified countries.

We use the monthly change in the central bank discount rate (*DIR*) as our primary measure of changes in monetary policy. These nominal discount rates are expressed as spreads over German (U.S.) nominal interest rates for the European (non-European) countries. In order to check the robustness of our empirical results, we also create an alternative measure of monetary policy. It is constructed as the monthly change in domestic credit growth (*DDCG*).

As developed above, our model predicts that, on average, interest rate signaling will affect attack decisions differently depending on whether the signal comes from a strong or weak monetary authority, where in this context strong means a greater commitment to the fixed exchange rate regime. We operationalize the theoretical policymaker types by dummy variables for whether the country has a "hard" peg (corresponding to the strong type) or "soft" peg (the weak type) according to the Reinhart-Rogoff classification.[9] The test of our model will be whether ex-ante signaling by *de facto* hard peggers is more effective in deterring attacks than when the signal is sent by a soft pegger.

D. Economic and Political Control Variables

We have discussed how we measure attacks and how we measure signaling. We wish to estimate an equation where the probability of an attack is affected by policy signaling, and the effect differs by the value each monetary authority places on maintaining the peg, which we measure by whether their peg is "hard" or "soft".

We also want to include other control variables in the models. Our first such variable (*REROV*) is a measure of real exchange overvaluation constructed as the

[9] Given how we make the policymaker type operational, it would be fair to say that in our model, an informed speculator could be one that has read Calvo and Reinhart and Reinhart and Rogoff (or always knew the information contained therein), while the uninformed speculator is one that only had access to the official IMF listings.

growth rate of the real effective exchange rate in the previous 12 months. This variable should have a positive influence on the probability of an attack as overvalued exchange rates are ultimately unsustainable.

The second control variable that we employ is a measure of adequacy of reserves (*RESIMP*). It is defined as total non-gold reserves relative to monthly import values. We expect *RESIMP* to have a negative effect on attack probabilities. Other things equal, higher reserves should discourage attacks.

The third control variable is defined as deviation of real per capita GDP growth in a country from its average in the five preceding years (*DGROWTH*). This variable is used to capture where a country is in any business cycle prior to the speculative attack.[10] We create this variable because the cost of adopting tight monetary policies during a recession can be much higher than during a boom. The variables should have a negative effect on the probability of an attack.

The fourth control variable that we consider is a dummy variable for capital controls (*KAPCON*). This dummy variable takes on the value one if a country has restrictions on capital account transactions and zero otherwise. The effect of capital control on currency crisis is controversial in the literature. According to conventional wisdom, capital control reduces the probability of attacks by limiting volatile short-term capital flows and helping government buy time to improve the fundamentals.[11]

Beyond economic aggregates, political factors may have significant effects on

[10] Since GDP data is only available annually, we use lagged variable in our regression. Using interpolated data does not significantly change our results.
[11] Glick et al. (2004) show that countries without controls have a lower likelihood of currency crisis after controlling for self-selection bias using a matching and propensity score methodology.

speculators' attack decision or the monetary authority's cost of signaling. For these reasons, we also include a measure of democracy ($DEMOC$) in our statistical models.[12] It is an eleven-point index that ranges from 0 to 10. A high index number represents a high level of democracy. The idea captured with this variable is that countries where the government can be removed by voters can less easily afford to defend against attacks, as defense measures are often stringent and generally unpopular with the electorate. Therefore, they are more likely to be attacked.

Due to publication lags or other information imperfection, contemporaneous information on the fundamentals is often unavailable for potential speculators in reality. Therefore, we use lagged control variables rather than contemporaneous control variables in our statistical model.[13] Table 2 provides the summary statistics of all the variables used in this study.

1.5 Empirical Results

A. The Baseline Model

As a first step, we consider the following simple baseline model:

$$ATTACK^{*}_{i\,t} = \alpha_0 + \alpha_1 DMP_{it-1} + \alpha_2 F_{i\,t-1} + \upsilon_{i\,t} \qquad (1)$$

where $ATTACK^{*}_{i\,t}$ is a latent variable. We cannot not observe $ATTACK^{*}_{i\,t}$, but we do observe an indicator variable $ATTACK_{it}$ which equals one if $ATTACK^{*}_{i\,t} > 0$ and zero otherwise. In this case, $ATTACK^{*}_{i\,t} > 0$ if an attack occurs. DMP is a measure of change in monetary policy. Since our goal is to test the signaling

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[12] We have also considered other political characteristics such as partisanship and policy decisiveness. We did not include them in our statistical models because we cannot find any significant impacts of these variables.

[13] Since observations on GDP, capital control, and democracy score are only available annually. We use the variables obtained in year t-1 for year t in our regressions.

hypothesis, we are interested in the effects of monetary policies prior to a potential attack. For this reason, we use lagged changes in monetary policy in equation (1). F is a vector representing our economic and political control variables. υ is a random error term with zero mean and variance σ^2, which might be either logistically or normally distributed.

Since the dependent variable is a binary choice variable, a standard methodology would be to run a probit or logit model. This standard methodology, however, is not appropriate for this particular case. As is well known, standard finite sample maximum-likelihood estimates of probit or logit are biased. This bias vanishes as the sample size gets larger. However, King and Zeng (2001 a, b) show that this finite sample bias can be greatly exaggerated when one observed choice occurs rarely in the data. They develop a method called "rare-events-logit" to correct this enlarged bias due to the rare events data. Our sample contains a total of 6845 observations. The dependent variable takes on the value of one in only 98 out of these 6845 total possibilities. We, therefore, apply the rare-events-logit approach here.

The first panel of Table 3 shows the regression results for the baseline model using standard logit model.[14] The two Wald Chi-square statistics are 55.46 and 55.56, respectively, indicating that the overall models are significant at 1% level. All control variables have expected signs. $REROV$, $RESIMP$, and $DEMOC$ are significant, meaning that countries that have low reserves, high real exchange overvaluation, or a more democratic political system are more likely to be attacked. $KAPCON$ has a positive but insignificant effect.

[14] We also estimate equation (1) using the probit model. The results are very close to those from the standard logit model and thus not reported here.

In terms of the monetary policy variables, the change in the discount rate is positive and statistically significant at 1% level. This evidence suggests that raising discount rates in advance actually increases the probability of a speculative attack. The estimated marginal effect is shown in brackets. Holding other variables at their means, a one percent increase in discount rate from its mean increases the probability of a speculative attack roughly from 0.82% to 0.85%. The change in domestic credit growth is positive but insignificant.

As discussed earlier, given the nature of our data, the logit estimates can be largely biased towards zero. In order to correct the downward bias due to rare events, we re-estimate equation (1) using the rare-events-logit model. The second panel of Table 3 reports the results from the rare-events-logit regression.[15] We get similar results for both the control variables and the monetary policy variables. The change in the discount rate is positive and significant while the change in domestic credit growth is still insignificant. In this model, raising the discount rate from its mean by one standard deviation (percent) increases the probability of a speculative attack roughly from 0.82% to 0.94% (0.86%). Clearly, this initial evidence does not show any general beneficial effects of tight monetary policy.

B. Testing our model's prediction

The baseline model shows the overall effects of tight monetary policy on speculators' attack decision but we are more interested in testing the conditional effects in different country groups.

Our simple model predicts that high rates should be more effective in deterring

[15] The models are estimated using the relogit program written by Tomz et al. (1999) for Stata. It does not report the overall significance of the model.

speculative attacks for countries that have strong commitment on exchange rate stability. We have argued that countries with hard pegs care more about exchange rate stability than those with soft pegs. Therefore, if our model is correct, we expect to find a larger deterrent effect of high rates in these countries. To test this idea, we split the full sample into two subsamples according to their exchange rate regimes. We then run a rare-events-logit regression of equation (1) for each subsample.[16] The results are shown in the first two rows of Table 4. The two panels in Table 4 correspond to the two measures of monetary policy. To save space, we only report the coefficients, standard errors and marginal effects of monetary policy variables.

An interesting result stands out: The effects of high rates are found to be significant but opposite in these two groups. In the hard peg subsample (*HARDPEG*), the coefficient on the discount rate is negative and the coefficient on domestic credit growth is positive. They are also both statistically significant. This result suggests that raising the discount rate or reducing domestic credit growth in advance lowers the probability of speculative attacks in countries that have *de facto* hard pegs. The estimated marginal effects show that, holding other independent variables at their means, raising discount rate (lowering domestic credit growth) by one standard deviation from its mean can lower the probability of a speculative attack from roughly 0.57% (0.56%) to 0.47% (0.44%). By contrast, the effect of high rates is significantly different in the soft peg (*SOFTPEG*) subsample in that raising the interest rate increases the probability of being attacked. Thus we find initial support here for the predictions of our model.

C. Decomposing the Overall Effect in the Full Sample

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[16] Exchange regime dummy is dropped for these regressions to avoid perfect multicollinearity.

The above subsample evidence suggests that an effective signaling effect exists in countries that have *de facto* hard pegs. As a formal test, in this section we re-estimate equation (1) using the full sample and replacing the monetary policy variable with two interaction terms of monetary policy and exchange rate regimes. This specification allows us to investigate the decomposed effect of high rates for each exchange rate regime. Table 5 reports the results. The interaction term between the discount rate and a *de facto* hard peg regime, $DIR * HARDPEG$, is negative and significant at 1% level. This evidence, again, suggests that high rates can effectively reduce the probability of a potential speculative attack in countries that have a *de facto* hard peg regime. The interaction term of discount rate and the soft peg exchange rate regime is also significant but with a positive sign, indicating that raising interest rates increases the probability of speculative attacks.[17] Overall, the above evidence shows that signaling has different effects for hard peggers and soft peggers. Specifically, hard pegger signaling deters attacks while soft pegger signaling does not.

D. Robustness Checks

This section checks the robustness of our empirical results and their sensitivity to different specifications and samples. Since it could be argued that speculative attacks can possibly occur in countries that have a managed floating regime, our first robustness check is to extend our sample to including these countries. This extended sample contains 9917 observations with 137 attacks. The rare-events-logit regression results are reported in Table 6.

[17] The two interaction terms between domestic credit growth variable and exchange rate regimes also reflect the idea that tight policy is a credible signal only in the hard pegging regimes, though the coefficients in this case are not significant.

The evidence remains strong in the extended sample as both $DIR * HARDPEG$ and $DDCG * HARDPEG$ are significant and show that tight policy deters attacks in hard peg countries. It is also interesting to note that raising rates in managed floating countries increases the probability of attack even more than it does in soft peg countries. The general pattern is, the less commitment to the exchange rate regime, the less effective is interest rate signaling.

In section 4, we use different threshold values for OECD and non-OECD countries to identify speculative attacks, following Kraay (2003). One may suspect that the results may possibly be driven by this identification methodology. To show the robustness of our results, we divide the full sample into two subsamples. One subsample contains only OECD countries and the other contains only non-OECD countries. We run the same regressions for both subsamples. The results from these two subsamples are shown in Table 7 and Table 8.

These results are quite similar to those from the full sample as in both cases raising the interest rate significantly reduces the probability of attacks in the *de facto* hard peg countries but increases the probability in the soft peg countries. When comparing the two sets of results, it is interesting to note that a one standard deviation increase in the interest rate has a bigger deterrent effect in the OECD country sample, and that democracies are more prone to attacks only in the non-OECD sample.

All in all, the results here tell a very consistent story: countries with a high degree of commitment to their fixed exchange rate regime can help deter an attack via interest rate signaling in a way that other countries cannot.

1.6 Conclusion

This paper presents and tests a simple signaling model of high interest rates as a deterrent to speculative attacks. The theoretical model produces outcomes that are novel to in the literature. Assuming both agents have two possible types, our model is able to rationalize failed signaling in a pooling equilibrium or a semi-separating equilibrium without relying on any out-of-equilibrium beliefs. Our model also shows that, although it is still possible for a weak monetary authority to hide his type in a pooling or semi-separating equilibrium, the effectiveness of signaling for weak types, however, is much less effective than that for strong types. In both equilibria, the weak monetary authority faces a higher probability of attack. In the empirical part of our paper, we find strong evidence that raising interest rates in advance has significantly different impacts in different country groups. It reduces the probability of attacks in hard-pegging countries but increases it in soft-pegging countries. This finding is robust to alternative measure of monetary policy and to different specifications and samples. Our results lend support to the hypothesis proposed by our theoretical model.

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Data Appendix

Variable	Source	Description
Nominal Exchange Rate	IFS	local currency units per US dollar
Non-gold Reserves	IFS	in US dollar
Money Market Rate	IFS	
Discount Rate*	IFS	
Domestic Credit	IFS	in local currency units
Monthly Imports	IFS	in US dollar
CPI	IFS	
Real GDP per capita	Penn World Table 6.1	in US dollar
SOFT/HARDREG*/ MANAGEDFLOATING	Reinhart and Rogoff (2003)	*de facto* exchange rate regimes
DEMOC*	POLITY 4	an index of democracy ranges from 0 to 10
KAPCON	IMF's Annual Report on Exchange Rate Arrangements and Exchange Restrictions	a dummy variable takes on the value one if a country has restrictions on capital account transactions

Notes: We use Bank of England base rate for United Kingdom because its discount rate is not available in IFS after February 1981.
We use Levy-Yeyati and Sturzenegger (2003)'s exchange rate regime classification for Bangladesh, Rwanda and Trinidad and Tobago because they are not available in Reinhart and Rogoff (2003). We treat a regime as hard peg, soft peg, or managed floating if it is classified as fixed, dirty floating/crawling peg, or dirty floating in Levy-Yeyati and Sturzenegger (2003).
Hong Kong's economic data are drawn from the Hong Kong Monetary Authority. We use Singapore's democ score as a proxy for Hong Kong because it is not available in POLITY4.

Country List

COUNTRIES			
Bangladesh	Denmark	Latvia	Rwanda
Belgium	Ecuador	Malaysia	South Africa
Benin	Egypt	Mauritius	Spain
Bolivia	Finland	Mexico	Sweden
Botswana	France	Morocco	Thailand
Brazil	Ghana	Nepal	Trinidad and Tobago
Bulgaria	Greece	Netherlands	Tunisia
Burundi	Hong Kong	Nigeria	Turkey
Cameroon	Indonesia	Norway	United Kingdom
Canada	Ireland	Pakistan	Uruguay
Chile	Israel	Peru	Venezuela
Colombia	Italy	Philippines	Zimbabwe
Costa Rica	Kenya	Poland	
Croatia	Korea	Portugal	

Table 1.1 Identified Successful and Failed Attacks

A. Identified Successful Attacks

Country	Time	Country	Time	Country	Time
Botswana	1992M7	Indonesia	1997M9	Rwanda	1990M11
Brazil	1999M1	Israel	1989M1	South Africa*	1975M10
Burundi	1983M12	Italy	1992M11	South Africa*	1984M7
Canada	1992M11	Korea*	1971M7	South Africa*	1985M7
Costa Rica*	1981M1	Korea	1974M12	Spain	1967M11
Denmark	1993M8	Korea	1980M1	Spain	1982M12
Ecuador	1982M5	Korea	1997M11	Spain	1995M3
Ecuador*	1985M11	Malaysia*	1981M10	Sweden	1977M9
Egypt*	1989M8	Mauritius	1979M11	Sweden	1982M11
Egypt*	1991M2	Mauritius	1981M10	Sweden	1992M11
Finland	1967M10	Mexico	1994M12	Thailand	1984M11
Finland	1977M4	Mexico*	1998M9	Thailand	1997M7
Finland	1982M10	Nigeria*	1986M10	Trinidad and Tobago	1993M4
Finland	1991M11	Nigeria*	1999M1	Uruguay	1982M12
Finland	1992M9	Norway*	1986M5	United Kingdom	1992M9
Ghana	1967M7	Peru	1967M8	Venezuela*	1984M3
Ghana*	1972M1	Philippines	1970M3	Venezuela*	1986M12
Greece*	1983M1	Philippines	1997M8		

Notes: * denotes the attack is identified in countries that have a *de facto* managed floating exchange rate regime. __ indicates that this attack is also identified in Kraay (2003).

B. Identified Failed Attacks

Country	Time	Country	Time	Country	Time
<u>Brazil</u>	1997M11	<u>Greece</u>	1997M10	Philippines	1990M1
Brazil	1998M9	Hong Kong	1998M8	<u>Portugal</u>	1985M1
<u>Canada</u>	1976M3	<u>Indonesia</u>	1991M3	<u>Portugal</u>	1990M10
<u>Canada</u>	1978M2	Ireland	1997M4	<u>South Africa*</u>	1975M3
<u>Canada</u>	1981M7	Italy*	1980M2	<u>South Africa*</u>	1976M8
Canada	1982M2	<u>Italy*</u>	1981M5	<u>South Africa*</u>	1980M7
<u>Canada</u>	1984M6	<u>Italy</u>	1986M1	<u>South Africa*</u>	1981M9
<u>Canada</u>	1990M5	<u>Italy</u>	1990M12	South Africa*	1982M3
<u>Colombia*</u>	1995M12	<u>Korea</u>	1980M6	<u>South Africa*</u>	1982M9
<u>Costa Rica</u>	1979M8	<u>Korea</u>	1983M1	South Africa*	1983M3
<u>Denmark*</u>	1975M3	Korea	1986M1	South Africa*	1988M7
<u>Denmark*</u>	1976M9	<u>Korea</u>	1989M11	<u>Spain</u>	1987M5
Denmark*	1977M12	<u>Korea</u>	1996M8	<u>Sweden</u>	1976M4
Denmark	1980M2	<u>Malaysia*</u>	1980M9	Sweden	1976M10
Denmark	1984M12	Malaysia*	1986M8	<u>Sweden</u>	1980M2
<u>Denmark</u>	1987M2	<u>Mauritius</u>	1976M8	<u>Sweden</u>	1988M5
<u>Denmark</u>	1993M2	Mexico		<u>Sweden</u>	1990M2
Finland	1976M2	Morocco*	1980M8	<u>Sweden</u>	1991M11
Finland	1979M11	Morocco*	1982M9	<u>Thailand</u>	1978M2
Finland	1980M11	Morocco*	1985M4	<u>Thailand</u>	1984M1
Finland	1986M8	Netherlands	1976M7	<u>Thailand</u>	1985M3
Finland	1990M11	<u>Netherlands</u>	1979M12	<u>Thailand</u>	1990M9
Finland	1991M5	<u>Netherlands</u>	1981M8	<u>Thailand</u>	1992M9
France	1968M10	<u>Norway*</u>	1976M4	<u>Thailand</u>	1994M6
France	1969M10	<u>Norway*</u>	1979M6	<u>Trinidad and Tobago</u>	1988M1
<u>France</u>	1979M9	<u>Norway*</u>	1992M11	<u>Trinidad and Tobago*</u>	1994M5
<u>Greece</u>	1988M3	Pakistan	1991M3	<u>Tunisia</u>	1991M4
<u>Greece</u>	1989M5	<u>Philippines*</u>	1983M2	<u>Uruguay</u>	1998M9

Notes: * denotes the attack is identified in countries that have a *de facto* managed floating exchange rate regime. __ indicates that this attack is also identified in Kraay (2003).

Table 1.2 Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ATTACK	6845	0.0140	0.1176	0	1
DIRt-1	6845	-0.0690	2.4959	-84.2000	95.0000
DDCGt-1	6845	-0.2969	12.2017	-185.3830	90.2631
DGROWTH	6845	-0.0386	4.8054	-34.7229	52.2454
REROV	6845	0.0523	2.8515	-35.3055	82.7842
RESIMP	6845	4.0526	4.6304	0.0071	46.5559
DEMOC	6845	6.3644	4.0553	0	10
KAPCON	6845	0.7313	0.4433	0	1
HARDPEG	6845	0.4383	0.4962	0	1
SOFTPEG	6845	0.5617	0.4962	0	1

Table 1.3 The Baseline Model

	LOGIT		RARE-EVENTS-LOGIT	
	DMP=DIR	DMP=DDCG	DMP=DIR	DMP=DDCG
CONSTANT	-4.8557***	-4.8554***	-4.8038***	-4.8040***
	(0.5327)	*(0.5307)*	*(0.5320)*	*(0.5300)*
DMPt-1	0.0418***	0.0013	0.0527***	-0.0002
	(0.0148)	*(0.0038)*	*(0.0148)*	*(0.0038)*
	[0.0003]	[0.00001]	[0.0012]	[0.00002]
DGROWTH	-0.0313	-0.0309	-0.0331	-0.0328
	(0.0223)	*(0.0222)*	*(0.0223)*	*(0.0222)*
	[-0.0003]	[-0.0003]	[-0.0013]	[-0.0012]
REROV	0.2506***	0.2491***	0.2484***	0.2471***
	(0.0458)	*(0.0458)*	*(0.0457)*	*(0.0458)*
	[0.0020]	[0.0020]	[0.0088]	[0.0088]
RESIMP	-0.1104**	-0.1105**	-0.1025**	-0.1026**
	(0.0460)	*(0.0457)*	*(0.0459)*	*(0.0456)*
	[-0.0009]	[-0.0009]	[-0.0032]	[-0.0033]
KAPCON	0.1720	0.1804	0.1605	0.1758
	(0.1897)	*(0.1883)*	*(0.1895)*	*(0.1881)*
	[0.0014]	[0.0014]	[0.0014]	[0.0015]
DEMOC	0.1033**	0.1034**	0.0993**	0.0994**
	(0.0496)	*(0.0494)*	*(0.0495)*	*(0.0493)*
	[0.0008]	[0.0008]	[0.0009]	[0.0009]
HARDPEG	-0.6475	-0.6521	-0.6282	-0.6368
	(0.4071)	*(0.4059)*	*(0.4066)*	*(0.4054)*
	[-.0052]	[-0.0052]	[-0.0051]	[-0.0052]
Wald Chi2(7)	55.46***	50.56***		
TOTAL OBS	6845	6845	6845	6845

Notes: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors and estimated marginal effects are in parenthesis and brackets, respectively. *p<0.10. **p<0.05. ***p<0.01. Marginal effects are estimated using the relogitq program written by Tomz et al. (1999) for Stata. They are estimated as change in the probability of a speculative attack for a one standard deviation change in continuous independent variables, a one unit change in the variable democ, and a zero to one change in the dummy variables holding all other variables at their means.

Table 1.4 Subsample Evidence

		DISCOUNT RATE			DOMESTIC CREDIT GROWTH		
SUBSAMPLES	OBS	COEF	STD.E	MGE	COEF	STD.E	MGE
HARDPEG	3000	-0.1423***	*(0.0405)*	[-0.0010]	0.0160*	*(0.0089)*	[0.0012]
SOFTPEG	3845	0.0532***	*(0.0150)*	[0.0021]	-0.0013	*(0.0042)*	[-0.0002]

Note: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors and estimated marginal effects are in parenthesis and brackets, respectively. $^{*}p<0.10$. $^{**}p<0.05$. $^{***}p<0.01$. The hard peg dummy is dropped for these regressions to avoid perfect multicollinearity.

Table 1.5 Decomposing the Signaling Effect

	DIR	DDCG
CONSTANT	-4.8050***	-4.8196***
	(0.5322)	*(0.5306)*
DMPt-1*HARDPEG	-0.1128***	0.0141
	(0.0359)	*(0.0096)*
	[-0.0007]	[0.0009]
DMPt-1*SOFTPEG	0.0530***	-0.0015
	(0.0153)	*(0.0044)*
	[0.0011]	[-0.0001]
DGROWTH	-0.0333	-0.0324
	(0.0222)	*(0.0223)*
	[-0.0012]	[-0.0012]
REROV	0.2483***	0.2465***
	(0.0457)	*(0.0457)*
	[0.0086]	[0.0089]
RESIMP	-0.1028**	-0.0998**
	(0.0461)	*(0.0457)*
	[-0.0032]	[-0.0031]
KAPCON	0.1620	0.1827
	(0.1897)	*(0.1881)*
	[0.0014]	[0.0014]
DEMOC	0.0994**	0.1000**
	(0.0495)	*(0.0493)*
	[0.0009]	[0.0009]
HARDPEG	-0.6238	-0.6174
	(0.4077)	*(0.4069)*
	[-0.0051]	[-0.0052]
TOTAL OBS	6845	6845

Note: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors and estimated marginal effects are in parenthesis and brackets, respectively. $^{*}p<0.10$. $^{**}p<0.05$. $^{***}p<0.01$.

Table 1.6 Results from the Extended Sample

	DIR	DDCG
CONSTANT	-4.9832***	-4.9914***
	(0.4603)	*(0.4594)*
DMPt-1*HARDPEG	-0.1245***	0.0173*
	(0.0352)	*(0.0098)*
	[-0.0007]	[0.0009]
DMPt-1*SOFTPEG	0.0498***	-0.0009
	(0.0153)	*(0.0040)*
	[0.0009]	[-0.0001]
DMPt-1*MNFLOATING	0.1352**	0.0035
	(0.0565)	*(0.0095)*
	[0.0012]	[0.0002]
DGROWTH	-0.0267	-0.0263
	(0.0220)	*(0.0219)*
	[-0.0010]	[-0.0010]
REROV	0.1789***	0.1779***
	(0.0406)	*(0.0396)*
	[0.0119]	[0.0113]
RESIMP	-0.1593**	-0.1588***
	(0.0607)	*(0.0604)*
	[-0.0042]	[-0.0043]
KAPCON	0.2808	0.2980
	(0.1923)	*(0.1916)*
	[0.0023]	[0.0023]
DEMOC	0.0945***	0.0954***
	(0.0352)	*(0.0351)*
	[0.0009]	[0.0009]
HARDPEG	-0.2070	-0.2043
	(0.4548)	*(0.4566)*
	[-0.0017]	[-0.0016]
SOFTPEG	0.3915	0.3895
	(0.3066)	*(0.3072)*
	[0.0036]	[0.0036]
TOTAL OBS	9917	9917

Note: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors and marginal effects are in parenthesis and brackets, respectively. *p<0.10. **p<0.05. ***p<0.01.

Table 1.7 Results from the OECD Subsample

	DIR	DDCG
CONSTANT	-3.8041***	-3.9405***
	(0.7800)	*(0.7295)*
DMPt-1*HARDPEG	-0.7885***	0.1289**
	(0.2360)	*(0.0649)*
	[-0.0029]	[0.0057]
DMPt-1*SOFTPEG	0.3093***	-0.0005
	(0.0596)	*(0.0034)*
	[0.0053]	[-0.0001]
DGROWTH	-0.0394	-0.0458
	(0.0385)	*(0.0374)*
	[-0.0013]	[-0.0016]
REROV	0.2401***	0.2370***
	(0.0512)	*(0.0494)*
	[0.0103]	[0.0112]
RESIMP	-0.2413**	-0.1860**
	(0.0962)	*(0.0811)*
	[-0.0046]	[-0.0042]
KAPCON	0.1743	0.2353
	(0.1845)	*(0.1636)*
	[0.0022]	[0.0034]
DEMOC	0.0331	0.0388
	(0.0835)	*(0.0705)*
	[0.0004]	[0.0006]
HARDPEG	-0.9221*	-0.9284*
	(0.5228)	*(0.5105)*
	[-0.0105]	[-0.0113]
TOTAL OBS	3109	3109

Note: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors and estimated marginal effects are in parenthesis and brackets, respectively. *p<0.10. **p<0.05. ***p<0.01.

Table 1.8 Results from the Non-OECD Subsample

	DIR	DDCG
CONSTANT	-5.4651***	-5.5176***
	(0.7972)	*(0.7985)*
DMPt-1*HARDPEG	-0.1514***	0.0003
	(0.0317)	*(0.0075)*
	[-0.0008]	[0.00003]
DMPt-1*SOFTPEG	0.0545*	-0.0306***
	(0.0296)	*(0.0101)*
	[0.0010]	[-0.0009]
DGROWTH	-0.0319	-0.0257
	(0.0342)	*(0.0339)*
	[-0.0010]	[-0.0008]
REROV	0.2581***	0.2660***
	(0.0855)	*(0.0861)*
	[0.0072]	[0.0074]
RESIMP	-0.0424	-0.0343
	(0.0306)	*(0.0299)*
	[-0.0012]	[-0.0010]
KAPCON	-0.1455	-0.1408
	(0.4740)	*(0.4734)*
	[-0.0008]	[-0.0007]
DEMOC	0.1364**	0.1322**
	(0.0598)	*(0.0597)*
	[0.0008]	[0.0008]
HARDPEG	0.0360	0.0734
	(0.6093)	*(0.6105)*
	[0.0005]	[0.0004]
TOTAL OBS	3736	3736

Note: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors and estimated marginal effects are in parenthesis and brackets, respectively. $^{*}p<0.10$. $^{**}p<0.05$. $^{***}p<0.01$.

Chapter Two

Speculative Attacks and Defenses as a War of Attrition:
Theory and an Example

2.1 Introduction

Countries often use high interest rates or other tight monetary policies to defend their currencies against speculative attacks. In the recent currency crisis literature, there has been growing interest in further understanding the nature of an interest rate defense. According to conventional economic wisdom, a government can always defend its peg by raising interest rates, as a very high interest rate can make it prohibitively costly for a speculator to attack the peg.[18] Also, a high interest rate may signal the government's ability and willingness to defend the peg.[19] On the other hand, the contrarian view suggests that raising interest rates to a very high level can be prohibitively costly for the government as well. The argument that a high interest rate can signal the government's willingness and ability to defend the peg is not so convincing to a contrarian either because a high interest rate can weaken the government's fiscal position, thus making the signal less and less credible over time.

In this paper, we argue that an interest rate defense during speculative attacks can be well modeled as a war of attrition game between speculators and the government under asymmetric information.[20] In our model, maintaining the peg has value to the government, while the collapse of the peg has value to the speculators. Both values

[18] See Kraay (2003) for a discussion of the conventional and contrarian view.
[19] See Drazen (1999, 2000).
[20] Our paper builds from an observation made by Bensaid and Jeanne (1997), who state that an interest rate defense during a speculative attack is a war of attrition between the two sides. However, they do not develop this statement in the paper (that is, they do not solve a war of attrition model, nor do they consider the empirical implications of such a model).

are private information. In addition, an interest rate defense by the government is assumed to be costly to both sides. In a pure strategy weak perfect Bayesian equilibrium of the game, each party's optimal concession time depends on its reward for winning and its relative waiting cost. The higher (lower) one's value for winning (waiting cost) is, the later one concedes. Of course, she who concedes last wins the war!

Our modeling choice is motivated by three stylized facts of interest rate defenses to be discussed in section 3. Though the war of attrition game is standard in applied game theory and has been widely used in other settings, we are able to use it here to make significant contributions to the currency crisis literature.[21] In particular, our model has the following features: 1) The model shows that an ex-ante rational interest rate defense can be either successful or unsuccessful. Existing models have difficulty explaining why, if defenses are costly, governments undertake them when the outcome is going to be failure; 2) We show that, in a pure strategy weak perfect Bayesian equilibrium, an agent's optimal time until conceding depends on her value of winning and her relative waiting cost. Therefore, the model makes explicit predictions about variations in the duration of interest rate defenses, which we find to be supported in at least one important historical instance. 3) The model implies that even a very high interest rate cannot guarantee a successful defense. The relation between the level of interest rates and the outcome of a defense is likely to be nonlinear.

[21] There is a long tradition of borrowing models in the literature. For example, the model in Krugman (1979) is based on the model of Salant and Handerson (1978), and one of the models in Obstfeld (1994) follows that of Barro and Gordon (1983).

The rest of this paper is organized as follows: Section 2 reviews some relevant literature and Section 3 provides some stylized facts about interest rate defenses. Section 4 models an interest rate defense as a war of attrition under asymmetric information and solves for a pure strategy weak perfect Bayesian equilibrium. Section 5 presents an example of how the model can be tested, and Section 6 concludes.

2.2 Literature Review

Theoretical studies on currency crises originate from Krugman's 1979 seminal paper. In a Krugman style first-generation BOP crisis, the government does not act strategically.[22] It responds passively to a speculative attack on the currency peg. As has been noted, the passive government assumption seems to be unrealistic because, in practice, governments often defend pegs aggressively by raising interest rates. In second-generation currency crisis models, the government responds actively to a speculative attack.[23] It makes a strategic decision between maintaining and abandoning the peg by comparing the two costs imposed on its welfare. These early models do not focus explicitly on the role of interest rates during speculative attacks.

Existing theoretical studies on interest rate defenses can be divided into two categories. The first group includes work by Drazen (1999), Drazen (2000), and Angeletos et al. (2003). These studies make important contributions to the literature by correctly pointing out the possible signaling effects of high interest rates. In these models, given imperfect information about the government's characteristics, speculators use observed policies to update their beliefs. Thus, under some circumstances, a tough government may find it optimal to raise interest rates prior to

[22] See Krugman (1979) and Flood and Garber (1984).
[23] See Obstfeld (1994).

a potential attack to reveal its type. What is ignored in these models, however, is that the "direct" effects of high interest rates. Governments often raise interest rates simply because they can directly increase the demand of domestic assets and speculators' costs as well.

The second group of studies focuses on these direct asset demand effects. These studies include Flood and Jeanne (2000), and Lahiri and Vegh (2003). These papers study the effects of high interest rates on the timing of speculative attacks in a Krugman first-generation currency crisis model framework. In these models, raising interest rates makes domestic assets more attractive, but it increases the government's future fiscal cost as well. They show that it is not always feasible to raise interest rates in advance to delay a potential speculative attack.

Although this literature contains many excellent papers, there are still some important things missing. In the following section, we discuss three stylized facts about speculative attacks and defenses that, in our view, a successful model must be able to reproduce.

2.3 Some Stylized Facts of Interest Rate Defenses

A. There are both successful defenses and unsuccessful defenses. This is well illustrated by two well-known historical examples: Hong Kong's successful defense during the 1997 Asian crisis and Sweden's failed defense in the 1992 EMS crisis. Both monetary authorities had fought fiercely to defend their currencies. In Hong Kong, the Hong Kong Government (HKMA) raised the overnight HIBOR to 280% on Oct. 23 1997 to defend its currency board system. It also raised interest rates, though to a much less substantial level, during the next two waves of speculative attacks in January and June 1998. In August 1998, the HKMA mounted operations in both the stock market and the money market to counteract speculators' activities. The currency board system was eventually successfully defended. In the Swedish case, the Riksbank initially took a very tough stance when the speculative attacks first hit the Krona peg in August 1992. By September 16, the Riksbank raised its overnight interest rate to over 500 percent annum. The first wave of speculative attack was defeated. Yet when a new wave of attacks came two months later, the Riksbank surprisingly floated the Krona shortly after a minimal defense. As these examples illustrate, an acceptable theoretical model must be able to explain this uncertain outcome of interest rate defenses and, perhaps more importantly, it must be able to admit a failed defense or attack as being ex-ante rational. In our view, this requires incorporating asymmetric information into the theoretical analysis.

B. The duration of the battle between the government and speculators varies widely in different cases. For example, soon after the Asian financial turmoil hit Indonesia in July 1997, its monetary authority widened the Rupiah trading band from 8% to 12%. On August 14, the monetary authority further replaced the managed floating exchange rate regime with a freely floating regime. The attack on the Rupiah lasted about a month. On the other hand, the battle between speculators and Hong Kong described above lasted about a full year, during which the HK dollar experienced four separate waves of attacks.[24]

In our view, an acceptable theoretical model should be able to explain the systematic variation of the duration of speculative attacks and interest rate defenses.

[24] It is also the case that there are both long and short successful defenses and long and short unsuccessful defenses. See Section 5 below for more details.

Unfortunately, no existing model in the literature is able to provide a good explanation of this fact. Most of these models focus on the relationship between interest rates and the outcome of a defense.

C. Empirical studies of interest rate defenses show that there is no clear statistical relationship between interest rates and the outcome of speculative attacks. Kraay (2003) is probably the most influential study on this topic. Drawing on large sample evidence, he finds no systematic relationship between interest rates and the outcome of speculative attacks. Using high frequency data for five Southeast Asian countries, both Goldfajn and Baig (1998) and Kamin (2000) fail to find any significant impacts of monetary policy on exchange rates. Though Hubric (2000) finds the nominal discount rate is negatively correlated with the outcome of a defense, he also finds that his measure for domestic credit is positively correlated to the outcome of a defense. The overall effect of tight monetary policy is ambiguous. This fact suggests that there probably exist a non-monotonic or nonlinear relationship between interest rates and the outcome of a defense. An acceptable theoretical model should be able to allow for this nonlinearity.

In summary, given these stylized facts of interest rate defenses, an adequate model must be able to (1) explain the possible outcomes of interest rate defenses and allow ex ante rational unsuccessful attacks and unsuccessful defenses; (2) explain the systematic variation in the duration of a defense; (3) allow a non-monotonic or nonlinear relationship between interest rates and the outcome of a defense.

2.4 An Interest Rate Defense as a War of Attrition

In this section, we model an interest rate defense during a speculative attack as a war of attrition game between the government and speculators under asymmetric information. We consider an economy in which there is a domestic government and a group of homogenous speculators. The assumption of homogenous speculators allows us to consider only one representative speculator in our model. Time is continuous. At time 0, the government announces a commitment to a pegged exchange rate, which has a value V_g to the government. There are three main reasons why the peg is valuable to the government. First, a pegged exchange rate reduces the uncertainty of future exchange rates, thus facilitating trade and foreign investment, which is an important source of outside funding for many developing countries who have only limited access to the international financial markets. Second, a credible peg serves as a nominal anchor that helps keep the domestic inflation rate under control. Third, for some countries who have heavy foreign debt, a pegged exchange rate help reduce the debt in terms of domestic currency.

We assume that, prior to a speculative attack, the government can maintain the peg at zero cost by setting the interest rate at its optimal level, which we normalize to zero.[25] If there is an attack, however, the government has to raise interest rate to i^d to defend the peg.

A high interest rate imposes a cost, $C_g(i^d)$ to the economy. Specifically high interest rates hurt the economy through three main channels. First, a high interest rate weakens the domestic government's fiscal position by increasing its interest payments on the public debt. Second, a high interest rate often has negative effects on economic

[25] In reality, of course, it may require a different interest rate to maintain the peg even when there is no speculative attack. However, for our analysis, the level of this interest rate is not important. What is important is, in order to maintain the peg, the interest rate under speculative attack is more costly to the government than the interest rate when there is no attack.

activities because it makes private investment less profitable and consumer durables less affordable. Third, a high interest rate hurts the banking sector, which is a fragile sector in many developing countries. Therefore, keeping the benefits and costs in its mind, the government minimizes a loss function by choosing whether or not to maintain the peg.

If a speculator attacks the peg successfully, her reward is V_s, which can be interpreted as the potential profit (loss) that can be earned (avoided) from a successful attack. Since a speculator attacks the peg by selling short the domestic currency, raising interest rates increases her opportunity cost of selling the domestic currency. If she borrows domestic currency from banks and trades it for foreign currencies, a high interest rate also increases her financial costs. We therefore assume raising the interest rate from zero to i^d increases the speculator's cost by $C_s(i^d)$. For simplicity, we normalize $C_s(i^d)$ to 1 and define $k = C_g(i^d)/C_s(i^d)$ to be the relative cost.[26] The values of V_g and V_s are assumed to be private information. The cumulative distribution functions of V_g and V_s, $F(V)$ and $H(V)$, and the corresponding density functions, $f(V)$ and $h(V)$, are assumed to be common knowledge.

So in a speculative attack, speculators take a costly position gambling that the government will devalue the currency, while the government also bears a cost due to the high interest rates it chooses in an attempt to save the peg. During the battle, each party updates its knowledge about the distribution of its rival's winning prize at any

[26] For simplicity, i^d is assumed to be exogenous in the model, though in principle the government can be seen as solving a broader optimization by choosing both i^d and its optimal concession time. This assumption is justified if the government has knowledge of k. It would then choose an i^d to minimize k since, as we shall show later, k is negatively related to its expected utility.

point of time based on available information. The battle will keep going until one party realizes her rival has more at stake and concedes. The model is solved by deriving each party's optimal concession time, at which her waiting cost is equal to her value to winning times the probability that the other party will concede at the next instant.

We denote the optimal concession times, by $T_g = \beta_g(V_g)$ and $T_s = \beta_s(V_s)$. We solve this game by deriving a pure strategy weak perfect Bayesian equilibrium in which one party's concession behavior is described by a strictly increasing function $T_g = \beta_g(V_g)$ or $T_s = \beta_s(V_s)$.[27] In this equilibrium, if the government behaves according to $\beta_g(V_g)$, speculators will find it optimal to concede according to $\beta_s(V_s)$ and vice versa. Since each party's information updating process is perfectly predictable, their optimal concession times can be solved at the beginning of the battle.[28] If we ignore discounting, the government's expected utility at time 0 is

$$EU_g(T_g) = -kT_g prob[T_s \geq T_g] + prob[T_s < T_g]E[(V_g - kT_g) \mid T_s < T_g] \qquad (1)$$

The first term on the right hand side is the government's expected total waiting cost, which is equal to its total waiting cost times the probability that it concedes earlier than the speculator. The second term on the right hand side is the government's expected benefit, which is equal to probability that the speculator concedes first times

[27] In fact, in the model there is a continuum of equilibria. The continuum is obtained by picking either one of the two sides in the war of attrition and letting an (arbitrary) interval of the highest waiting cost (lowest winning prize) of that side to concede immediately at time 0. By varying the size of the conceding interval, one can get the continuum. That is, the equilibrium we consider is obtained by using implicitly the selection criterion that no side concedes at time 0 with positive probability. See Martinelli and Escorza (2004) for details.

[28] Given that the distributions of V_g and V_s at time 0 are known, one can calculate the truncated distributions at any time t, $t < \min\{T_g, T_s\}$.

the differential between its winning prize and its total waiting cost conditional on having a longer optimal concession time. The government's objective is to find an optimal concession time $T_g = \beta_g(V_g)$ to maximize its expected utility.[29]

Denoting $V = \beta^{-1}(T) = \phi(T)$ and using the fact that $prob[T_s < T_g] = prob[V_s < \phi_s(T_g)] = H(\phi_s(T_g))$, we have

$$EU_g(T_g) = -kT_g[1 - H(\phi_s(T_g))] + H(\phi_s(T_g))E[(V_g - kT_g) \mid V_s < \phi_s(T_g)] \tag{2}$$

Substituting $H(\phi_s(T_g))E[(V_g - kT_g) \mid V_s < \phi_s(T_g)] = \int_0^{\phi_s(T_g)} [V_g - k\beta_s(V_s)]h(V_s)dV_s$ into (2), we obtain

$$EU_g(T_g) = -kT_g[1 - H(\phi_s(T_g))] + \int_0^{\phi_s(T_g)} [V_g - k\beta_s(V_s)]h(V_s)dV_s \tag{3}$$

Taking the first derivative of (3) with respect to T_g and setting it equal to zero gives us the corresponding first order condition

$$k = \phi_g(T_g)[\frac{h(\phi_s(T_g))}{1 - H(\phi_s(T_g))}\phi_s'(T_g)] \tag{4}$$

The first order condition states that concession occurs when the marginal cost of waiting equals the expected marginal benefit from waiting. The left hand side of (4) is the cost of waiting one more instant to concede. The right hand side is the expected gain from waiting another instant to concede, which is the product of the winning prize and the conditional probability that the speculator concedes in the next instant.

The second order sufficient condition requires that

$$\partial[\phi_g(T_g)\frac{h(\phi_s(T_g))}{1 - H(\phi_s(T_g))}\phi_s'(T_g)] / \partial T_g < 0 \tag{5}$$

[29] The government's utility function and speculators' utility function are assumed to be concave and twice differentiable everywhere.

Similarly, the speculator's optimization problem and its first and second order conditions are

$$EU_s(T_s) = -T_s[1 - F(\phi_g(T_s))] + \int_0^{\phi_g(T_s)} [V_s - \beta_g(V_g)] f(V_g) dV_g \tag{6}$$

$$1 = \phi_s(T_s)[\frac{f(\phi_g(T_s))}{1 - F(\phi_g(T_s))} \phi_g'(T_s)] \tag{7}$$

$$\partial[\phi_s(T_s) \frac{f(\phi_g(T_s))}{1 - F(\phi_g(T_s))} \phi_g'(T_s)] / \partial T_s < 0 \tag{8}$$

Therefore, the solutions to the differential equation system (4) and (7) give us the equilibrium.

Proposition 1 There exists a pure strategy weak perfect Bayesian equilibrium with each player's optimal behavior described by conditions (4) and (7). In particular, if both V_g and V_s have an exponential distribution with $\lambda = 1$, the concession functions $T = \beta(V)$, are defined by

$$T_g = \beta_g(V_g) = (\frac{V_g}{\sqrt{2}})^{k+1} \tag{9}$$

$$T_s = \beta_s(V_s) = (\frac{\sqrt{2}V_s}{k+1})^{\frac{k+1}{k}} \tag{10}$$

(See Appendix for Proof)

From conditions (4) and (7), it is easy to see that, in the equilibrium, a high interest rate cannot guarantee a successful defense.[30] Given the winning prizes, it is really the relative cost $k(i)$ that matters and there is no reason to believe $k(i)$

[30] "Guaranteeing a successful defense" means that, ex ante, the government's calculated optimal concession time is longer. Ex post, both parties would concede at the same time in equilibrium for it would not be a best response for the winner to wait any longer after its rival concedes.

decreases in i.[31] This fact suggests there may exist a non-monotonic relationship between the interest rates and a successful defense. Therefore, our results are consistent with the empirical evidence. A very high interest rate does not guarantee a successful defense. The equilibrium of the game is such that, even though attacking (defending) is ex-ante rational, the loser of the war will experience regret. Therefore, our model justifies rational unsuccessful defenses and attacks. Also, notice that in the equilibrium, nobody concedes immediately as long as their value for winning is positive. Each agent's concession time increases with his winning prize and decreases with his waiting cost. Our model thus implies that the durations of speculative attacks will vary systematically across specific circumstances and one should be able to predict these variations with variables measuring waiting costs and benefits of winning.

2.5 An example of the model at work

Here we give a simple illustration of how the war of attrition model can predict variations in the duration of speculative attacks. We consider the 11 countries that were hit with speculative attacks according to the standard definition in the literature during 1997 and 1998.[32] They are Brazil, Greece, Hong Kong, Indonesia, Korea, Malaysia, the Philippines, Russia, Singapore, Thailand, and Taiwan. We assume that during this time period, speculators faced the same ratio of waiting costs to benefits of winning so that variations in the duration of these attacks are due solely to variations in the countries cost – benefit ratios.

To measure waiting costs we use the size of the country's foreign reserves as a

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[31] One can immediately get $\partial T_g / \partial k < 0$ by substituting equation (4) into equation (5).

[32] See Kraay (2003) for a detailed discussion on the identification of speculative attacks.

percentage of GDP and a Democracy dummy variable that equals 1 if the country is rated higher than 5 (on a 10 point scale) according to the Polity IV database. The ideas captured with these variables are that countries with higher reserves can more easily afford to defend against attacks, and that countries where the government can potentially be removed by voters can less easily afford to defend against attacks, as defense measures often cause reserve losses and are also generally unpopular with the electorate.

To measure the benefits of successfully defending against an attack, we use a dummy variable for whether the country has a hard peg exchange rate regime (as opposed to a soft peg) according to the de facto classifications of Reinhardt and Rogoff (2003). A country that has made a strong public commitment to its peg most likely values it more strongly than a country that has not made such a commitment. We also use the size of the export sector relative to GDP as a second benefit measure. As export promotion is often given as a reason for pegging, a larger export sector would make the peg more valuable to any given country.

We then use a variety of sources (see Appendix 2 for details) to measure the duration (in days) of each of the speculative attacks on each country. These data range from about a week to almost a full year. The war of attrition model, along with our interpretation of the variables described above predicts that being a democracy is negatively correlated with duration, while high reserves, having a hard peg, and having a large export sector are all positively correlated with the duration of the attack. Panel A of Table 1 reports simple pair-wise correlation coefficients between our 4 variables and attack duration. For democracy the correlation coefficient is -.34, for a hard peg, .41, for reserves, .41 and for exports .49. As shown in Panel B, a multiple regression using the two dummy variables (democracy and hard peg) to explain duration has an R^2 of .42 with each variable correctly signed (i.e. democracy is negative and hard peg is positive) and significant at the 0.10 level.

While this is only a small illustrative example, it does show that the war of attrition model has some empirical bite and hints that a larger study of the variations in attack lengths may prove to be a fruitful undertaking.

2.6 Conclusion

This paper argues that an interest rate defense during speculative attacks can be well modeled as a war of attrition between the government and speculators under asymmetric information. We show that, in a pure strategy weak perfect Bayesian equilibrium, each party's fighting time strictly increases with its value to winning and decreases with its waiting costs.

We show for the first time in the literature, the ex-ante rationality of unsuccessful defenses (attacks). We also show that, in our model raising interest rates to a high level may not necessarily defend the peg if it is more costly to the government than the speculator. There may exist a non-monotonic relationship between the level of interest rates and achieving a successful defense. Finally we show that the predictions of the war of attrition model for the duration of speculative attacks are supported by data from the 11 countries that endured such attacks in 1997-98.

Appendix 1

Proof of Proposition 1:

It is clear that the solutions to (4) and (7) are an equilibrium pair. In order to have closed form solutions, we need specify the forms of the cumulative distribution functions F and H. Suppose both V_g and V_s have an exponential distribution with $\lambda = 1$, we have

$$1 - F(V) = 1 - H(V) = f(V) = h(V) = e^{-V} \tag{11}$$

Substituting (11) into (4) and (7) gives us

$$\frac{k}{\phi_g(T)} = \phi_s'(T) \tag{12}$$

$$\frac{1}{\phi_s(T)} = \phi_g'(T) \tag{13}$$

From (12) and (13) we know that

$$[\phi_g(T)\phi_s(T)]' = k + 1 \tag{14}$$

We also know that $\phi_g(0) = \phi_s(0) = 0$. Therefore

$$[\phi_g(T)\phi_s(T)] = (k+1)T \tag{15}$$

Equation (13) and equation (15) imply that

$$\frac{\phi_g'(T)}{\phi_g(T)} = \frac{1}{(k+1)T} \tag{16}$$

The solution to the differential equation is

$$\ln(\phi_g(T)) = \frac{1}{(k+1)}\ln(T) + c \tag{17}$$

$$\phi_g(T) = AT^{\frac{1}{k+1}} \tag{18}$$

where c and $A = e^c$ are two constants. To determine the value of A, note that we have a symmetric equilibrium, if $k = 1$. Let $k = 1$, the symmetric solution to (4) and (7) is

$$V = \phi(T) = \sqrt{2T} \tag{19}$$

Thus, $AT^{\frac{1}{k+1}}$ should equal to $\sqrt{2T}$ when $k = 1$. This gives us $A = \sqrt{2}$. Substituting (18) into (12), (13) and using the fact $A = \sqrt{2}$, we obtain (9) and (10).   Q.E.D.

Appendix 2

Data Sources

The reserves, exports, and GDP data employed in Section 4 are drawn from the International Financial Statistics (Feb. 2004) of the International Monetary Fund. The exchange rate regime classification used in Section 4 is based on Reinhart and Rogoff (2003)'s natural classification. The democracy scores are drawn from Polity IV.

We use a variety of sources to identify the duration (in days) of each of the speculative attacks on each country. Our identification of the durations of Brazil, Hong Kong, Indonesia, Korea, Malaysia, the Philippines, Russia, and Thailand are based on "the Chronology of the Asian Currency Crisis and its Global Contagion" available on Nouriel Roubini's Global Economics Monitor website. For Greece, Singapore, and Taiwan, we identify their durations based on movements in their discount rates and reserves.

Taiwan's data are drawn from the Central Bank of China's website.

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Table 2.1: An Illustrative Mini-test of the War of Attrition model

A: correlation between our value of winning and waiting cost variables and attack duration in 1997-98

Value of Winning

Hard Peg dummy:	0.41
Export Share:	0.49

Waiting Costs

Reserves	0.41
Democracy dummy	-0.34

B. A modest 11 observation, 2 variable regression:

$$\text{Duration(in days)}_i = \underset{(2.3)}{89.3} + \underset{(2.03)}{111}*(\text{Hard Peg dummy})_i - \underset{(-1.84)}{97.7*}(\text{Democracy dummy})$$

$R^2 = .42$, numbers in parentheses are T-statistics.

Chapter Three

A Reinvestigation of Interest Rate Defense against Speculative Attacks

3.1 Introduction

Following a new wave of currency crises in the 1990's, there has been growing interest in further understanding the role of interest rate defense against speculative attacks in the literature. According to conventional economic wisdom, a high interest rate helps defend the currency.[33] It makes domestic currency denominated interest-bearing assets more attractive and increase speculators' borrowing cost as well. Furthermore, raising the interest rate before an attack can signal the government's willingness and ability to defend its currency.[34] The contrarian view, however, emphasizes that a high interest would worsen a country's fiscal position, and, therefore, may hasten a speculative attack and make it self-fulfilling.

Theoretical models in the literature often incorporate both views. For example, according to Lahiri and Vegh (2000), raising the interest rate can delay the crisis but only up to a point. Otherwise it may actually hasten the crisis for a higher interest rate increases the government's fiscal liability and imply higher future inflation. The model of Flood and Jeanne (2000) also shows that raising the interest rate makes domestic assets more attractive, but increases public debt service as well. Therefore, if a speculative attack is motivated by underlying fiscal fragility, raising the interest rate can hasten the attack. Drazen (2000) shows that the outcome of an interest rate

[33] See Kraay (2003) for a more detailed discussion of the conventional view and the contrarian view.
[34] See Drazen (1999), Drazen (2001), and Grier and Lin (2004).

defense depends on speculators' information about the government's fiscal position. If the fiscal position is known, raising the interest rate may increase the probability of devaluation. Otherwise, it can decrease the probability. In Angeletos et al (2003), the government is willing to take a costly policy action only for a small region of moderate fundamentals, and this region shrinks as the information in the market becomes precise. Grier and Lin (2005a) model interest rate defense as a war of attrition game. A high interest rate is not sufficient to guarantee a successful defense. The consensus conclusion one can draw from these models is that an interest rate defense is a double-edged sword. It cuts both ways.

The effectiveness of interest rate defense is ultimately an empirical issue. Empirical evidence in the literature on this issue is mixed. Using daily data, Furman and Stiglitz (1998) find that high interest rates are followed by exchange rate depreciations. Drawing on large sample evidence, Kraay (2003) finds no systematic association between the interest rate and the outcome of a speculative attack. Looking at the same type of data but using simpler statistical methods, Hubrich (2000) finds that different measures of tight monetary policies could have different impacts on the outcome of defenses. Discount rates have an unconventional impact on the exchange rate while domestic credit has conventional results. Drazen and Hubric (2003) find that raising the interest rate strengthens the exchange rate over the short-run but leads to an expected depreciation at a horizon of a year and longer.

The objective of this paper is to empirically test whether raising the interest rate during a speculative attack can help defend the currency peg. This study is distinguished from previous ones in two aspects. First, previous empirical studies on this issue look at sample observations drawn from the crisis periods. As I shall show later, these studies suffer a classic sample selection problem, and their estimation results are, therefore, biased. They confuse the effects of interest rate defenses conditional on speculative attacks with the unconditional effects. To correct this selectivity bias, I employ the full information maximum likelihood method to my sample which contains both the crisis periods and the tranquil periods. The empirical model that I estimate is following that of Van de Ven and Van Praag (1981) and Maddala (1983), in which both the selection equation and the attack outcome equation have binary dependent variables. Second, I develop a rare-events-corrected probit model with sample selection to correct a second bias that is created by the rare events data used to estimate the selection equation. After controlling for other factors, I find empirical evidence that supports neither the conventional nor the contrarian view. Raising the interest rate during speculative attacks does not have significant effect on the outcome of a speculative attack.

The rest of this paper is organized as follows: Section 2 discusses the empirical models and the methodology. Section 3 addresses data issues. Section 4 provides my empirical results. Section 5 concludes.

3.2 Empirical Models

A. A Probit Model with Sample Selection

The statistical model can be specified as follows:

$$SF_i^* = \alpha' X_i + U_{1i} \tag{1}$$

$$ATK_i^* = \beta' Z_i + U_{2i} \tag{2}$$

where $U_1 \quad N(0,1)$, $U_2 \quad N(0,1)$, and $corr(U_1, U_2) = \rho$. The first equation regresses the outcome of a speculative attack on a vector of monetary policy variable and other factors affecting the outcome. SF_i^* is an unobserved latent variable. What we observe is an indicator variable SF_i, which equals one if $SF_i^* > 0$ and zero otherwise. In this case, $SF_i^* > 0$ if an attack turns out to be successful and $SF_i^* < 0$ if an attack fails. The second equation is the selection equation. A speculative attack occurs ($ATK_i = 1$) if the underlying latent variable ATK^* is greater than zero. Otherwise, there is no speculative attack ($ATK_i = 0$). Equation (1) and equation (2) are related because one observes SF_i only if $ATK_i = 1$ and the two error terms U_{1i} and U_{2i} are assumed to be jointly normally distributed with correlation coefficient ρ.

Heckman (1979) shows that a direct estimation of equation (1) would produce biased estimate as long as ρ is nonzero. I suspect that this sample selection problem exists in my statistical environment because the unobserved characteristics, which can affect the speculators' attack decision, captured by the error term of equation (2) are also likely to affect the outcome of a speculative attack. After all, rational speculators attack a currency only if they believe that their attack is likely to be successful. Since both equation (1) and equation (2) have binary dependent variables, one can estimate them using either the two-step approach developed by Van de Ven and Van Praag (1981) or the full information maximum likelihood method. Under the assumption that the error terms are jointly normally distributed, the log likelihood function can be written as

$$L = \sum_{ATK=0} \ln[1-\Phi(\beta' Z_i)] + \sum_{ATK=1}^{SF=1} \ln[\Phi_2(\alpha' X_i, \beta' Z_i, \rho)] + \sum_{ATK=1}^{SF=0} \ln[\Phi_2(-\alpha' X_i, \beta' Z_i, \rho)] \quad (3)$$

Where $\Phi_2(\,)$ is the cumulative bivariate normal distribution function with zero means and $\Phi(\,)$ is the standard cumulative normal distribution function. The first term in the log likelihood function is the probability of speculators choosing not to attack, the second term is the probability of speculators choosing to attack with success, and the last term is the probability of speculators choosing to attack with failure.

B. Rare Events Corrected Probit Model with Sample Selection

As is known, standard finite sample maximum-likelihood estimates of probit or logit are biased. This bias vanishes as sample size becomes larger. However, King and Zeng (2001 a, b) show that this finite sample bias can be greatly exaggerated when one observed choice occurs rarely in the data. The sample that I used to estimate the selection equation contains 6765 total observations. The dependent variable takes on the value of one in only 96 out of these 6765 total possibilities. Therefore, maximum likelihood estimate of the selection equation can result in a large bias due to the nature of my data. King and Zeng (2001 a, b) develop a method called rare-events-logit to correct the bias. However, their method is not applicable in this study because it would violate the jointly normal assumption of the error terms. [35] To address this problem, I shall develop a rare-events-corrected probit model with sample selection in the following part of this section.

The rare events corrected probit model with sample selection can be developed

[35] An alternative method would be to apply the rare-events-logit technique to the second equation, and then use the generalized two-step selection bias correction method, which does not require the bivariate normal assumption, introduced by Lee (1982). However, this method requires tedious computation and is much more difficult to apply.

based on traditional two-step approach proposed by Van de Ven and Van Praag (1981), and Maddala (1983). It is a three-step approach. The first step is to estimate the selection equation using probit. The second step is to correct the rare events bias in the probit estimate. McCullagh and Nedler (1989) show that the bias can be estimated by the following weighted least-square expression:

$$b = E[\hat{\beta} - \beta] = (Z'WZ)^{-1} Z'W\xi \tag{4}$$

where $(Z'WZ)$ is the Fisher information matrix. ξ is a $N \times 1$ vector with $\xi_i = Q_{ii}\eta_i / 2$. Q_{ii} are the diagonal elements of matrix $Q = Z(Z'WZ)^{-1} Z$, and $W = diag\{\phi^2(\beta' Z_i)/[\Phi(\beta' Z_i)\Phi(-\beta' Z_i)]\}$. Thus, the unbiased and consistent estimate, β_u, can be obtained from subtracting the estimated bias from the probit estimate $\hat{\beta}$, $\beta_u = E[\beta] = \hat{\beta} - b$. Also according to McCullagh and Nedler (1989), the variance of β_u can be approximately estimated as $V(\beta_u) = [N/(N+K)]^2 V(\hat{\beta})$ for small β.

The last step corrects the sample selection bias. Maddala (1983) shows that, under the assumption that the error terms are jointly normally distributed, the conditional mean of the error term in equation (1) equals the correlation coefficient ρ times the inverse Mills ratio, λ_i.[36]

$$E[U_{1i} \mid X_i, ATK_i^* > 0] = \rho\lambda_i \tag{5}$$

where $\lambda_i = \phi(-\beta' Z_i)/\Phi(\beta' Z_i)$ is the inverse Mills ratio, ϕ and Φ are the density

[36] This is only true when the variance of the error term is normalized to one. Otherwise, $E[U_{1i} \mid X_i, ATK_i^* > 0] = \sigma\rho\lambda_i$.

and distribution function for a standard normal variable.

The selectivity-bias-free estimates, therefore, can be obtained by maximizing the following log-likelihood:

$$L(\alpha) = \sum_{ATK=1} [SF_i \ln \pi_i(\alpha) + (1 - SF_i)\ln(1 - \pi_i(\alpha))] \tag{6}$$

where $\pi_i = \Phi[(\alpha' X_i + \rho\lambda_i) / \sqrt{\tau_i^2}]$, and

$\tau_i^{\ 2} = Var[SF_i \mid X_i, ATK_i > 0] = 1 + \rho^2(-\beta' Z_i \lambda_i - \lambda_i^{\ 2})$.

The unbiased estimate β_u will be used to construct the inverse Mill's ratio in equation (6). Notice that a direct estimation of equation (1) with the inverse Mill's ratio as an additional regression using probit is invalid for the new error term is heteroskedastic by construction.

3.3 DATA

The dataset used in this study is an unbalanced panel comprised of monthly data for 49 countries, both developed and developing, from March 1964 to December 2000.[37] For some countries, there are some time periods excluded from the sample either due to their absence of pegged exchange rate regimes or due to data availability. Much of the data are drawn from Grier and Lin (2005b), including those identified speculative attacks and their outcomes.[38] Table 1 lists all the identified attacks, including 36 successful attacks and 60 failed attacks.

Following Kraay (2003), I consider two measures of monetary policy response in equation (1): a change in central bank discount rate (DIR) and a change in

[37] I actually started looking at a dataset that include all countries in the world. Those countries that are excluded from the sample are countries that had not had fixed exchange rate during those period or whose data are not available.
[38] See Grier and Lin (2005b) for a detailed description of the identification methodology.

domestic credit growth (DDCG). If the conventional view is correct, one would expect to see negative and significant coefficient on DIR and a positive and significant coefficient on DDCG. In equation (2), I replace a monetary policy variable with a lagged monetary policy variable. Lagged monetary policy variables are used because they are observable to speculators prior to attacks and are expected to have import impacts on speculators' attack decisions.[39]

Four control variables are included in equation (1). The first control variable is a measure of real exchange overvaluation (REROV) constructed as the growth rate of the real CPI weighted exchange rate versus the US in the previous 12 months. The second control variable I consider is a measure of reserves adequacy (RESIMP), which is calculated by dividing a country's total non-gold reserves with its monthly import values. The third control variable is a measure of the point in the business cycle prior to the speculative attack (DGROWTH) defined as deviation of real per capita GDP growth in a country from its average in the five preceding years. The last control variable is a dummy variable for capital control (KAPCON). The control variables I consider in equation (2) include all the above 4 control variables and one additional variable NOA, which is defined as number of attacks occurred in history and is used to capture the historical vulnerability of a currency. Table 2 shows some basic summary statistics of the data. Detailed data sources and variable descriptions are available in the data appendix.

3.4 Results

A. Results from Simple Probit Regressions

Table 3 reports the results of simple probit regressions of equation (1) without

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[39] See Grier and Lin (2005b).

correcting for the selectivity bias. The two panels in Table 3 correspond to my two measures of monetary policy. The two Wald χ^2 statistics are 41.92 and 47.40, indicating that both models are statistically significant at 1% level. Change in discount rate has a negative sign and change in domestic credit growth is positive, neither of which is significant. This evidence suggests that there is no significant statistical relationship between imposing tight monetary policy and the outcome of an attack. In terms of the control variables, DGROWTH, REROV, and KAPCON have expected signs and are statistically significant, meaning that speculative attacks are less likely to be successful in countries that either experience high growth, or have low real exchange rate overvaluation, or impose restrictions on their capital account transactions. RESIMP is insignificant, suggesting that a large reserve does not have the significant impact on the outcome of a speculative attack as one usually believes.

B. Results from Maximum Likelihood

Due to the selectivity bias, previous results of simple probit model cannot be taken seriously. One way to correct the selectivity bias is to jointly estimate both equation (1) and equation (2) using full information maximum likelihood.

The maximum likelihood estimation results are shown in Table 4. The first column of each panel reports the results of the selection equation and the second column of each panel reports the results of the attack outcome regression. The results are quite similar to those reported in Table 3. Even after correcting for selectivity bias, the overall evidence still shows no significant relationship between monetary policy variables and the outcome of a speculative attack. The coefficients on DIR and DDCG are still insignificant. There is also some evidence that lagged monetary policy increases the probability of attacks.[40] In terms of the control variables, NOA is always significant and positive, indicating that countries that have been attacked more are more likely to be attacked in the future. Real exchange rate overvaluation has significant and consistent impacts in both the selection equation and the main equation. A high real overvaluation not only increases the probability of attacks but make these attacks more likely to be successful as well. A large reserve reduces the probability of attacks but does not have significant impact on the outcome of attacks. On the contrary, high economic growth and capital control both help defend the peg though they do not seem to have significant impacts on the probability of attacks. The two estimated correlation coefficients, ρ , are -0.792 and -0.694, both of which are significant. The first Wald χ^2 statistics (with 5 degree of freedom) show that the two statistical models are significant at 1% level. Finally, the second Wald χ^2 statistics (with one degree of freedom) can be used to test the independence of equation (1) and equation (2). For both models, the null hypothesis that these two equations are independent can be rejected at 1% level. Severe sample selection problem does exist in the data.

C. Results from Rare Events Corrected Probit with Sample Selection

As discussed earlier, the finite sample bias of maximum likelihood estimate of the selection equation can be largely exaggerated because of the rare events data used to estimate the selection equation. The three-step approach developed earlier in Section 2 part B can be used to correct both the rare-events bias and the selectivity bias. The first step is to correct the rare-events bias. This can be done by using

[40] See Grier and Lin (2005b) for a detailed discussion of this perverse effect of raising the interest rate before attacks.

McCullagh and Nedler's method. The first column and the third column of Table 5 provide the estimation results of equation (2) from the standard probit model and the same columns of Table 6 report the rare-events-corrected probit model. It seems that bias is quite small. These two estimation procedures produce similar coefficients and standard errors, which are also close to the joint maximum likelihood estimators reported in Table 4. The only exception is the coefficients on DDCG. Compared to the simple probit estimate and maximum likelihood estimate, the rare-events-corrected probit model produces a much smaller coefficient on DDCG.

The next step is to construct the inverse Mills ratio using the unbiased and consistent rare-events corrected probit estimates. Finally, after including the inverse Mills ratio as an additional regressor and taking care of the heteroskedasticity in the error term, equation (6) can be estimated using the probit model. The results are shown in column 2 and column 4 of Table 6 and the results from traditional two-step probit sample selection aer shown in the same columns in Table 5. The results are similar and are also close to those reported in the second column of each panel in Table 4. All control variables remain the same signs. The coefficients on DIR and DDCG are again found to be insignificant, suggesting that imposing tight monetary policies has no significant impact on the outcome of an attack. Furthermore, strong sample selection problem is once again identified in the data. The estimated ρ s are found to be significant in both models.

3.5 Conclusion

This paper empirically tests the effectiveness of interest rate defense against speculative attacks in a large unbalance panel dataset that covers 49 countries over the time period from March 1964 through December 2000. My empirical evidence shows that there is no significant statistical relation between the interest rate (or domestic credit) and the outcome of a speculative attack.

This paper makes two important contributions to the literature. First, it shows that previous empirical studies suffer a classic sample selection problem that could result in biased estimation results. Severe sample selection problem is identified in the data and is corrected by jointly estimate the equations using full information maximum likelihood. Second, I develop a rare-events-corrected probit model with sample selection that can be used to correct both the rare-events bias and the selectivity bias for datasets in which the selection equation is characterized by rare events.

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Data Appendix

Variable	Source	Description
Nominal Exchange Rate	IFS	local currency units per US dollar
Non-gold Reserves	IFS	in US dollar
Money Market Rate	IFS	
Discount Rate*	IFS	
Domestic Credit	IFS	in local currency units
Monthly Imports	IFS	in US dollar
CPI	IFS	
Real GDP per capita	Penn World Table 6.1	in US dollar
Exchange Regimes	Reinhart and Rogoff (2003)	*de facto* exchange rate regimes
KAPCON	IMF's Annual Report on Exchange Rate Arrangements and Exchange Restrictions	a dummy variable takes on the value one if a country has restrictions on capital account transactions

Notes: I use Bank of England base rate for United Kingdom after February 1981 because its discount rate is not available in IFS since then.
I use Levy-Yeyati and Sturzenegger (2003)'s exchange rate regime classification for Bangladesh, Rwanda and Trinidad and Tobago because they are not available in Reinhart and Rogoff (2003). I treat a regime as hard peg, soft peg, or managed floating if it is classified as fixed, dirty floating/crawling peg, or dirty floating in Levy-Yeyati and Sturzenegger (2003).

Table 3.1 Identified Successful and Failed Attacks

A. Identified Successful Attacks

Country	Time	Country	Time	Country	Time
Botswana	1992M7	Indonesia	1997M9	Rwanda	1990M11
Brazil	1999M1	Israel	1989M1	Spain	1967M11
Burundi	1983M12	Italy	1992M11	Spain	1982M12
Canada	1992M11	Korea	1974M12	Spain	1995M3
Denmark	1993M8	Korea	1980M1	Sweden	1977M9
Ecuador	1982M5	Korea	1997M11	Sweden	1982M11
Finland	1967M10	Mauritius	1979M11	Sweden	1992M11
Finland	1977M4	Mauritius	1981M10	Thailand	1984M11
Finland	1982M10	Mexico	1994M12	Thailand	1997M7
Finland	1991M11	Peru	1967M8	Trinidad and Tobago	1993M4
Finland	1992M9	Philippines	1970M3	Uruguay	1982M12
Ghana	1967M7	Philippines	1997M8	United Kingdom	1992M9

B. Identified Failed Attacks

Country	Time	Country	Time	Country	Time
Brazil	1997M11	France	1969M10	Pakistan	1991M3
Brazil	1998M9	France	1979M9	Philippines	1990M1
Canada	1976M3	Greece	1988M3	Portugal	1985M1
Canada	1978M2	Greece	1989M5	Portugal	1990M10
Canada	1981M7	Greece	1997M10	Spain	1987M5
Canada	1982M2	Hong Kong	1998M8	Sweden	1976M4
Canada	1984M6	Indonesia	1991M3	Sweden	1976M10
Canada	1990M5	Ireland	1997M4	Sweden	1980M2
Costa Rica	1979M8	Italy	1986M1	Sweden	1988M5
Denmark	1980M2	Italy	1990M12	Sweden	1990M2
Denmark	1984M12	Korea	1980M6	Sweden	1991M11
Denmark	1987M2	Korea	1983M1	Thailand	1978M2
Denmark	1993M2	Korea	1986M1	Thailand	1984M1
Finland	1976M2	Korea	1989M11	Thailand	1985M3
Finland	1979M11	Korea	1996M8	Thailand	1990M9
Finland	1980M11	Mauritius	1976M8	Thailand	1992M9
Finland	1986M8	Mexico	1994M5	Thailand	1994M6
Finland	1990M11	Netherlands	1976M7	Trinidad and Tobago	1988M1
Finland	1991M5	Netherlands	1979M12	Tunisia	1991M4
France	1968M10	Netherlands	1981M8	Uruguay	1998M9

Table 3.2 Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ATK	6765	0.014	0.118	0	1
SF	96	0.375	0.487	0	1
DIR	6765	-0.117	3.803	-231.400	21.940
DIRt-1	6765	-0.070	2.510	-84.200	95.000
DDCG	6765	0.004	10.504	-106.099	90.263
DDCGt-1	6765	-0.158	11.179	-146.237	90.263
DGROWTH	6765	-0.034	4.829	-34.723	52.245
REROV	6765	0.057	2.865	-35.305	82.784
RESIMP	6765	4.045	4.644	0.007	46.556
KAPCON	6765	0.736	0.441	0	1
NOA	6765	1.660	2.129	0	11

Table 3.3 Results From Simple Probit Regressions

	DMP=DIR	DMP=DDCG
CONSTANT	-1.193* (0.631)	-1.171* (0.615)
DMP	-0.070 (0.094) [-0.018]	0.014 (0.011) [0.004]
DGROWTH	-0.213** (0.093) [-0.054]	-0.220** (0.090) [-0.053]
REROV	0.428*** (0.097) [0.109]	0.439*** (0.099) [0.106]
RESIMP	0.013 (0.129) [0.003]	-0.023 (0.104) [-0.006]
KAPCON	-0.816** (0.379) [-0.171]	-0.829** (0.342) [-0.164]
LOG-LIKELIHOOD	-19.659	-19.772
Wald $\chi^2(5)$	41.92***	47.40***
TOTAL OBS	96	96

Notes: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors and estimated marginal effects are in parenthesis and brackets, respectively. $^{*}p<0.10$. $^{**}p<0.05$. $^{***}p<0.01$.

Table 3.4 Results from Full Information Maximum Likelihood

	DMP=DIR		DMP=DDCG	
	ATK	SF	ATK	SF
CONSTANT	-2.357*** (0.089)	1.272*** (0.501)	-2.357*** (0.089)	0.904* (0.499)
DMP		-0.034 (0.058)		0.012 (0.008)
DMPt-1	0.026** (0.012)		0.001 (0.023)	
NOA	0.077*** (0.014)		0.077*** (0.014)	
DGROWTH	-0.010 (0.009)	-0.115* (0.060)	-0.010 (0.009)	-0.145*** (0.052)
REROV	0.093*** (0.021)	0.211** (0.090)	0.092*** (0.021)	0.270*** (0.075)
RESIMP	-0.040** (0.019)	0.017 (0.084)	-0.040** (0.019)	-0.002 (0.085)
KAPCON	0.038 (0.074)	-0.610* (0.320)	0.042 (0.073)	-0.676** (0.335)
RHO	-0.792*** (0.102)		-0.694*** (0.156)	
Log-Likelihood	-445.962		-447.43	
Wald $\chi^2(5)$	12.72**		17.67***	
Wald $\chi^2(1)$	15.34***		8.11***	
TOTAL OBS	6765	96	6765	96

Notes: DMP denotes a certain measure of policy change. Cluster adjusted robust standard errors are in parenthesis. *p<0.10. **p<0.05. ***p<0.01. Equations are jointly estimated using STATA heckprob command.

Table 3.5 Two-Step Probit with Sample Selection

	DMP=DIR		DMP=DDCG	
	ATK	SF	ATK	SF
CONSTANT	-2.356*** (0.089)	1.499*** (0.545)	-2.355*** (0.089)	1.138** (0.555)
DMP		-0.030 (0.038)		0.011 (0.036)
DMPt-1	0.024** (0.011)		0.001 (0.002)	
NOA	0.077*** (0.014)		0.076*** (0.014)	
DGROWTH	-0.010 (0.009)	-0.103 (0.079)	-0.010 (0.009)	-0.133*** (0.080)
REROV	0.093*** (0.021)	0.183*** (0.040)	0.092*** (0.021)	0.243*** (0.041)
RESIMP	-0.040** (0.019)	0.016 (0.047)	-0.040** (0.019)	0.0003 (0.047)
KAPCON	0.039 (0.074)	-0.569 (0.392)	0.042 (0.074)	-0.637 (0.402)
RHO		-0.851*** (0.161)		-0.760*** (0.162)
LOG-LIKELIHOOD	-426.944	-18.943	-428.025	-19.363
TOTAL OBS	6765	96	6765	96

Notes: DMP denotes a certain measure of policy change. The Huber/White robust standard errors are reported in parenthesis for the main equation. Cluster adjusted robust standard errors are reported for the selection equations. $^{*}p<0.10$. $^{**}p<0.05$. $^{***}p<0.01$. The Huber/White robust standard error are estimated using the SAS IML. The maximum likelihood estimates of the main equations are estimated using Eviews. Codes are available upon request.

Table 3.6 Rare-Events-Corrected Two-Step Probit with Sample Selection

	DMP=DIR		DMP=DDCG	
	ATK	SF	ATK	SF
CONSTANT	-2.352*** (0.089)	1.533*** (0.538)	-2.351*** (0.089)	1.538** (0.547)
DMP		-0.028 (0.038)		-0.029 (0.036)
DMPt-1	0.027*** (0.011)		0.0005 (0.011)	
NOA	0.076*** (0.014)		0.076*** (0.014)	
DGROWTH	-0.011 (0.009)	-0.100 (0.079)	-0.010 (0.009)	-0.100*** (0.081)
REROV	0.092*** (0.021)	0.177*** (0.039)	0.091*** (0.021)	0.177*** (0.040)
RESIMP	-0.036* (0.019)	0.013 (0.048)	-0.037* (0.019)	0.013 (0.047)
KAPCON	0.036 (0.074)	-0.559 (0.392)	0.042 (0.074)	-0.557 (0.401)
RHO		-0.861*** (0.157)		-0.862*** (0.158)
LOG-LIKELIHOOD	---	-18.895	---	-19.363
TOTAL OBS	6765	96	6765	96

Notes: DMP denotes a certain measure of policy change. The Huber/White robust standard errors are reported in parenthesis for the main equation. Cluster adjusted robust standard errors are reported for the selection equations. *p<0.10. **p<0.05. ***p<0.01. The unbiased rare-events-corrected probit estimates and the Huber/White robust standard error are estimated using the SAS IML. The maximum likelihood estimates of the main equations are estimated using Eviews. Codes are available upon request.