

Speculative Attacks and Defenses as Wars of Attrition:

Theory and an Example*

by

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Abstract

Given that a high interest rate can be a double-edged sword, we argue that the battle between speculators and the government can be well modeled as a war of attrition game under asymmetric information. We 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, we are 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 we 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.

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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.¹ Also, a high interest rate may signal the government's ability and willingness to defend the peg.² 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.³ In our model, maintaining the peg has value to the government, while the collapse of the peg has value to the speculators. Both values are private

¹ See Kraay (2003) for a discussion of the conventional and contrarian view.

² See Drazen (1999, 2000).

³ Our paper builds from an observation made by Bensaïd 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).

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.⁴ 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.

⁴ 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. 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.⁵ 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.⁶ 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,

⁵ See Krugman (1979) and Flood and Garber (1984).

⁶ See Obstfeld (1994).

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 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.

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.⁷

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. 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

⁷ 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.

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.

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.⁸ 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 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

⁸ 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.

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.⁹ 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 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

⁹ 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.

$T_g = \beta_g(V_g)$ or $T_s = \beta_s(V_s)$.¹⁰ 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.¹¹ If we ignore discounting, the government's expected utility at time 0 is

$$EU_g(T_g) = -kT_g \text{prob}[T_s \geq T_g] + \text{prob}[T_s < T_g]E[(V_g - kT_g) | T_s < T_g] \quad (1)$$

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 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.¹²

¹⁰ 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.

¹¹ 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 , $t < \min\{T_g, T_s\}$.

¹² The government's utility function and speculators' utility function are assumed to be concave and twice differentiable everywhere.

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

$$EU_g(T_g) = -kT_g[1 - H(\phi_s(T_g))] + H(\phi_s(T_g))E[(V_g - kT_g) | V_s < \phi_s(T_g)] \quad (2)$$

$$\text{Substituting } H(\phi_s(T_g))E[(V_g - kT_g) | V_s < \phi_s(T_g)] = \int_0^{\phi_s(T_g)} [V_g - k\beta_s(V_s)]h(V_s)dV_s$$

into (2), we obtain

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

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

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

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

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

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

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

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

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

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

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

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

(See Appendix for Proof)

From conditions (4) and (5), it is easy to see that, in the equilibrium, a high interest rate cannot guarantee a successful defense.¹³ Given the winning prizes, it is really the relative cost $k(i)$ that matters and there is no reason to believe $k(i)$ decreases in i .¹⁴

This fact suggests there may exist a non-monotonic relationship between the interest rates

¹³ “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.

¹⁴ One can immediately get $\partial T_g / \partial k < 0$ by substituting equation (4) into equation (5).

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.

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 1998.¹⁵ 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.

¹⁵ See Kraay (2003) for a detailed discussion on the identification of speculative attacks.

To measure waiting costs we use the size of the country's foreign reserves as a 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 Reinhart 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. In this sample the range is 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.

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

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

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

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

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

From (12) and (13) we know that

$$[\phi_g(T)\phi_s(T)]' = k + 1 \quad (14)$$

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

$$[\phi_g(T)\phi_s(T)] = (k + 1)T \quad (15)$$

Equation (13) and equation (15) imply that

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

The solution to the differential equation is

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

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

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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