

Does it pay to defend - The dynamics of financial crises

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Abstract

Despite major recent improvements the literature on financial crises the role of central banks as key players and the dynamics of financial crises are not well understood and have so far not been adequately analyzed. We overcome these shortfalls by explicitly modeling (A) the strategic options of market participants and policy makers and (B) the dynamics of financial crises. We analyze a global game where both speculative traders and central bank face imperfect information. In case of an attack, the central bank basically faces three alternatives. If it chooses to defend its currency, the defense can be successful or not. Each of these outcomes yields entirely different economic consequences. The empirical results strongly support the theoretical model. In our panel of 33 emerging market countries between 1990 and 2005 following stylized facts emerge: Immediate devaluation are followed by higher inflation, successful stabilization by sluggish growth while an unsuccessful stabilization implies both very high inflation and a recession. We find that the most significant predictor for the broad range of crises effects on growth, inflation and foreign trade is the type of crisis, i.e. immediate devaluation, successful defense of unsuccessful defense. Using a two-stage panel regression, we then identify crisis relevant sets of economic indicators. Taken together, intervention is risky. If a central bank chooses to defend its currency it can avoid the costs of a devaluation if its successful, however, if it is not successful it faces even higher costs, namely higher inflation and lower growth.

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1 Motivation and related literature

By opening up their capital markets countries can benefit from a deeper international division of labor. However, the advantages of financial globalization come at a price, in particular more frequent and potentially more severe financial crises (see Tornell and Westermann (2005)). The risks of financial crises have further increased in recent years because of growing global imbalances and international capital flows as well as new financial instruments and large players e.g. hedge funds. A number of countries, e.g. Mexico (1995), the Asian tiger economies (1997-98), Russia (1998), Brazil (1999), Ecuador (1999-2000) and Turkey (2000) faced sudden and unpredicted severe financial crises. These crises illustrate the large costs of inconsistent policies and the subsequent speculative attacks for both the directly affect countries as well as the international community. While financial crises have become less frequent in recent years, they are a periodic phenomenon and the next wave of crises is sure to come.

Both the likelihood of currency crises as well as the associated economic and social costs are only partially determined by fundamentals, exogenous shocks, and the strength of attacks. In addition, monetary policy reactions play a crucial role. The decisions of both speculative traders and policy makers are the result of strategic optimizations under incomplete information in a dynamic situation.

Figure 1 illustrates the stylized dynamics of a currency crisis with the order of decisions. Incorporating the decisions of both policy makers and speculative traders, there are four possible outcomes. Starting from a situation of stable exchange rates, contagion effects, changes in the fundamentals, and/or expectations might trigger (stage 1 decision) speculative traders to initiate an attack (A) or to not enter the market (B). In case of an attack, the policy maker chooses (stage 2 decision) to either devalue immediately (A1) or to defend the exchange rate (A2). This attempt can either be successful (A2b), i.e. the exchange rate remains stable, or unsuccessful (A2a), i.e. the currency depreciates despite defensive actions. Figure 1 specifies (i) the time line of the crisis as well as (ii) all nodes and outcomes with the respective stylized costs. Natural extensions to this model include preemptive defensive measures in the initial situation and the iteration of the game in stage 3 representing an ongoing attack.

The current currency crises and speculative attack models account for these dynamics and interrelations only partially. In particular, there is no approach to our

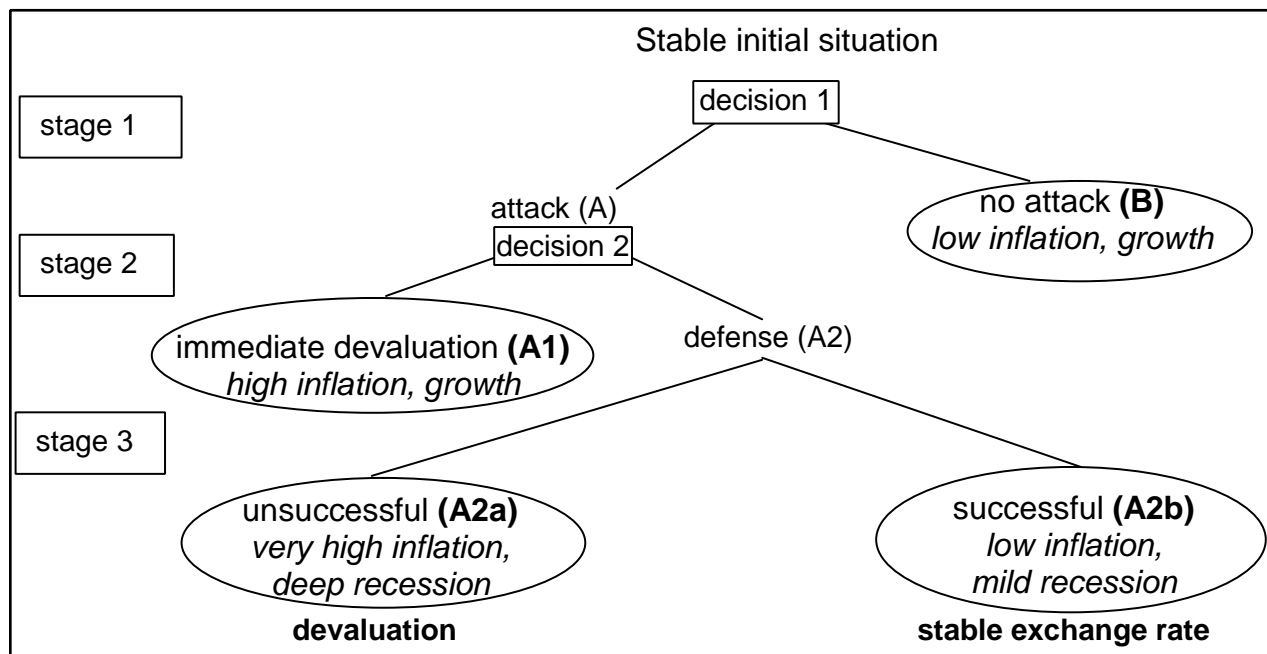


Figure 1: Multi stage decision tree of a simple speculative attack with stylized costs

knowledge that accounts for (1) the specific costs of the alternative outcomes, i.e. A1, A2a, and A2b, and (2) the strategic actions of policy makers (e.g. central banks) and investors with respect to incomplete information, lags, and inherent dynamics.

First, an adequate analysis of currency crises should differentiate the three alternative outcomes following a speculative attack as these three cases have very different economic implications for among others inflation and real growth. In the aftermath of a successful stabilization (A2b) real growth typically slows down while inflation remains low. An immediate exchange rate devaluation (A1) generally leads to higher inflation but does not reduce real growth. Unsuccessful attempts to defend the exchange rate (A2a) bear the highest costs in terms of both very high inflation and a deep recession.

Secondly, the literature on currency crises models mostly restricts the strategic calculus of policy makers to a black box. The effects of crisis outcomes and the informational position of the agents are only rudimentary represented by fixed and variable costs. An explicit dynamic analysis of the key role of central banks and their influence or even control of the course and costs of financial crises is still missing. As the decisions at the different stages are all tightly interrelated, any partial approach might explain only subgroups of outcomes and cannot solve the

endogeneity problems within this dynamic context.

Currency crises are mostly analyzed on basis of static models with dual options, i.e. only subsets of the structure presented in figure 1 are examined. First generation models (Krugman (1979), Flood and Garber (1984)) analyze the effects of changes in fundamentals. A deteriorating shadow exchange rate inevitably induces an attack of rational investors with the central bank mechanically depleting its reserves in an unsuccessful attempt to defend the currency. These models thus analyze scenario (B) - no attack, stable exchange rate - vs. (A2a) - attack, unsuccessful defense, and subsequent devaluation. Second generation models (Obstfeld (1994)) only differentiate between the alternatives (B) - no attack, stable exchange rate - and (A1) - attack and immediate devaluation - with the outcome being determined by the initial fundamentals and the self-fulfilling expectations of the speculators (see Jeanne (2000) for a literature review).

These approaches fail to analyze the empirically most relevant scenarios in which central banks initially try to defend the currency peg but devalue later in the course of an attack. Most currency crises follow this scheme, e.g. Sweden and the United Kingdom during the 1992 EWS crisis and the Asian crisis in 1997/98. In these events central banks initially defended their currency. Apparently they were unwilling or unable to correctly evaluate the strength and duration of the attack or the associated costs of defending the currency peg. Later in the crisis they revised their assessment and devalued their currency.

While the more recent global game approach, initiated by the seminal work of Morris and Shin (1998), has advanced the understanding of speculative attacks with respect to the informational position of the investors, it still lacks an adequate analysis of central bank behavior. The models formalize the attack decision in stage 1 of figure 1 but neglect the remaining elements. Based on the distribution of private information among the investors, global games solve the coordination problem, which arises in second-generation models for intermediate fundamental states. This model class analyzes the strategic calculus of traders and the role of different model parameters, e.g. fundamentals, precision of public and private information, and highly leveraged institutions such as hedge funds (e.g. Corsetti et al. (2004)). Morris et al. (2002, 2006) and Svensson (2006) discuss the social value of public information in the sense, that more information reduces the likeliness of crises. Bauer (2005) develops a stochastic calculus to apply generalized information structures to these models. Dynamic and multi period models (e.g. Chamley (2003) and Hellwig et al.

(2007)) analyze timing, signaling, front running or learning effects. In experimental studies Heinemann et al. (2004b,a) analyze the impact of strategic uncertainty on the decision process and find, that global games yield a good description of real behavior.

We expand the standard global game model by implementing the policy makers' strategic calculus to get a two stage game with imperfect information, which we can solve by backward induction and the typical global game approach. On the one side, the speculative traders simultaneously decide on an attack of the status quo based on private information about the fundamentals. They thereby maximize expected profits with respect to the expected probability and strength of the central bank's defensive action. On the other side, the central bank receives a noisy signal about the attack and chooses the strength of its defensive measures minimizing the expected costs. Costs arise first, if the regime has to be abandoned, i.e. if the attack is stronger than the defensive measures, and secondly, for the defensive measures itself. The optimal central bank reaction for a given attack is to abstain from defensive measures, if the attack appears to be very strong, and otherwise defend the currency with sufficient measures, which equal the expected strength of the attack plus some safety cushion. Thus the defense only fails, if the central bank significantly underestimates the strength and duration of the attack.

The missing distinction between the three alternative outcomes of an speculative attack is also characteristic for the empirical analysis. Two types of binary crises definitions are most common. A first crisis definition accounts for sudden and large devaluation (Frankel and Rose (1996) and Bauer et al. (2007)), i.e. it combines and therefore does not differentiate between scenarios (A1) and (A2a) while leaving out completely the case of a successful defense. The second crisis definition is based on exchange market pressure (Eichengreen et al. (1995), Prati and Sbracia (2002), Fratzscher and Bussiere (2006)). It differentiates between successful (A1 and A2a) and unsuccessful attacks (A2b) but fails to distinguish immediate devaluations (A1) and unsuccessful attempts to defend a currency (A2a). As our results indicate, the heterogeneity of the empirical results in the literature seems in part to be due to this mixing of different crises types.

The empirical results strongly support the theoretical model. First we find that the specific type of crisis, i.e. immediate devaluation, successful defense of unsuccessful defense, is the most significant predictor for a broad range of economic effects of financial crises on, e.g. growth, inflation, and trade. Secondly, using a two-stage

panel regression, we identify crisis relevant sets of economic indicators. In particular, we identify the central banks dilemma: Given weak fundamentals, e.g. declining growth, an attempt to defend the currency against an attack is most likely to fail implying recession and high inflation. However, if a weak currency is attacked a successful defense could stabilize the economy. We also relate our findings to the empirical results found in the literature based on the two standard crisis definitions, namely a significant devaluation and a rise of an exchange market pressure index. Both crises indicators mix different crises types, which should be treated separately according to our model, and therefore cannot differentiate the type specific implications of these crisis types. Our results thus indicate that this failure might be one explanation for the well-known poor performance of early warning systems.

The next section presents the theoretical model. Section 2.2 analyzes the optimal monetary policy. Section 2.3 incorporates speculative traders and section 2.4 analyzes the equilibrium. The empirical analyses in section 3 starts presenting some stylized facts, followed by a differentiated analyses of the costs of currency crises (3.1), and identification of crisis relevant sets of economic indicators (3.2). The final section concludes.

2 The model

The structure and timing of the model has already been illustrate in figure 1, so that we can focus in the following on the information structure and parameter setting. There are two types of agents: speculative traders and the central bank. The traders' aim is to maximize their expected profits, while the central bank minimizes the expected loss function which incorporates the costs of defending and abandon the exchange rate peg.

Our model extends the classical global game models with respect to the fundamentals and the reaction function of the monetary authority. Technically speaking, in typical global game models the fundamentals $\theta \in \mathbb{R}$, often denoted as strength of the regime, are equated with the ability and willingness of the policy maker to defend the exchange rate, i.e. the status quo is abandoned if and only if the measure of agents attacking is greater than or equal to θ . The underlying decision process of the central authority is treated as a black box, however. In our model the reaction function of the central bank is the result of an optimization process under incomplete

information.²

2.0.1 Time structure

Starting from a situation of stable exchange rates, nature first draws the state of the fundamentals θ , which is imperfectly revealed to the speculative traders and the central bank. The traders then decide individually and simultaneously whether to join an attack (A) or not (B). Subsequently the central bank receives a signal about the strength of the attack A and chooses to either devalue immediately (A1) or to try to defend the exchange rate (A2). In particular, the policy maker decides on defensive measure B on the basis of his information on θ and A . We assume that $B = 0$ implies an immediate abandonment of the regime regardless of the strength of the attack. The attempt to defend the regime can be either successful (A2b), i.e. the exchange rate remains stable, or unsuccessful (A2a), i.e. the currency depreciates despite the interventions. The currency peg is abandoned if and only if the measure of agents attacking A is greater than or equal to the strength of the defensive measures B .

2.0.2 Information structure

As is typical for games with incomplete information, the uncertainty of the players is restricted to a few variables, while the majority of the game structure is common knowledge. In our approach, there are two variables, which are not common knowledge, the fundamentals θ and the strength of the attack A . There is an information asymmetry between speculative traders and central bank. While the traders know the calculus of the central bank, they have only noisy information about the fundamental state of the economy. In contrast the central bank knows the fundamental state, but is not able to monitor exactly the behavior of the speculative traders. Ex ante, a central bank typically cannot exactly assess the scale of an attack and the endurance of the speculative traders.

Specifically, nature draws the state of the fundamentals θ according to the distribution function G_N and speculative traders as well as the central bank receive noisy

²In the empirical part, we focus currency crises, and thus use the notation and terminology for the theoretical model also. However, the highly stylized theoretical model may well be applied more generally in the context of financial crises (currency crises, debt crises, and bank runs) and political change.

private signals about the realization of θ . Trader i gets signal $x_i = \theta + \varepsilon_i$ where all ε_i are i.i.d. according to some distribution G . Without loss of generality, we assume that the central bank has no uncertainty about the fundamentals.³

In addition, the central bank is not able to predict perfectly the strength of the attack A . For its defense strategy, it relies on an unbiased estimate $\tilde{A} = A + \xi_{CB}$, where the noise term ξ_{CB} is Laplace distributed with standard deviation 2σ and independent from the signals on the fundamentals. The Laplace distribution with density $f(x) = \frac{1}{2\sigma} \exp\left(-\frac{|x|}{\sigma}\right)$ has several advantages: Firstly, it allows a closed form solution for the optimal monetary policy. Secondly, it is unimodal and centered around zero, i.e. the likeliness of small errors is higher than that of large estimation errors.

2.0.3 Model solution

The model is solved by backward induction. We first determine the optimal reaction of the central bank $B_{opt} = B(\tilde{A})$ as a function of its information on the fundamentals and the strength of the attack. We then modify the global game approach to model the speculative traders behavior. As is common in these models, the traders' optimal strategy is to attack whenever their private signal does not exceed a threshold x^* . In determining this threshold the optimal central bank behavior is taken into account.

2.1 Optimal monetary policy

The central bank faces the problem to decide on the optimal extent of costly stabilizing measures under imperfect information about the fundamentals and the attack. It receives private signals on the strength on the attack \tilde{A} and the state of the fundamentals x_{CB} . Its target to minimize the expected total costs of exchange rate policy C implies the following policy function

$$B_{opt} = \arg \min_B \left(\mathbb{E} \left(C | \tilde{A} \right) \right).$$

These total costs C depend on the per unit costs of stabilizing measures $\phi B(\theta)$ and the degree of stabilization B as well as the costs of a giving up the currency peg

³Both players act under imperfect information. Albeit the central bank has full information about the fundamentals, it does not perceive the strength of the attack perfectly. We thus separate the sources of uncertainty for traders and central bank thereby simplifying their calculus as to allow closed form solutions.

$R(\theta)$. As both types of costs might depend on the fundamental state θ we get

$$C = \phi(\theta) B + R(\theta) I_{A>B},$$

where $I_{A>B}$ denotes the indicator function which takes values 1 if $A > B$, i.e. if the attack succeeds, and 0 otherwise.

We make marginal assumptions on the behavior of the different cost elements. Firstly, the costs of a defense relative to the cost a devaluation, i.e. $\frac{\phi(\theta)}{R(\theta)}$, are non-increasing. Typically one would assume that the costs of exchange rate stabilization $\phi(\theta)$ are non-increasing in θ . An economy is likely to cope more easily with increasing interest rates when it is in a good fundamental state than when it is in recession. Secondly, we assume

$$\phi(\theta) < \frac{R(\theta)}{2\sigma}, \quad (1)$$

i.e. for any given fundamental θ the costs of the defense are less than the risk adjusted cost of a devaluation.⁴ If the expected costs of the stabilizing measures $\phi(\theta)$ are larger than the risk adjusted cost of giving up the currency peg $\frac{R(\theta)}{2\sigma}$, a defense would never be an optimal strategy as the costs of defensive measures would always outweigh its benefits (see Proposition 1).

The costs of abandoning the exchange rate peg could include a reputation loss or an increased risk of a debt crises, as the real value of the external debt denominated in foreign currency increases. Additionally a currency crisis with the accompanying depreciation might have a positive effect of increased exports and a negative effect of higher inflation. We generally assume, that the negative effects outweigh the positive aspects for each state of the fundamentals, so that there are effective costs. Therefore, for every state of the fundamentals it is optimal to keep the status quo if no attack is to be expected.

Proposition 1: Given our assumptions on the distribution of the central bank's signals, the expected costs of a defense B are

$$\mathbb{E}_A \left(C | \tilde{A} \right) = \begin{cases} \phi(\theta) B + \frac{1}{2} R(\theta) \exp\left(\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B \geq \tilde{A} \\ \phi(\theta) B + R(\theta) \left(1 - \frac{1}{2} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right)\right) & \text{if } B < \tilde{A} \end{cases}.$$

Proof: Appendix 1

⁴The realization of the devaluation costs is uncertain and 2σ is the standard deviation of the measurement error of the attack strength.

Proposition 2: The optimal reaction function of the central bank is

$$B_{opt} = \begin{cases} \tilde{A} + \sigma \ln \left(\frac{R(\theta)}{2\sigma\phi(\theta)} \right) & \text{if } \tilde{A} < \frac{R(\theta)}{\phi(\theta)} - \sigma \ln \frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma \\ 0 & \text{else} \end{cases}. \quad (2)$$

Proof: Appendix 2

The optimal strategy of the central bank is to abstain from defensive measures, if it perceives a signal indicating a very strong attack, i.e. there is a threshold $\frac{R(\theta)}{\phi(\theta)} - \sigma \ln \frac{R(\theta)}{\phi(\theta)} - \sigma(1 - \ln 2\sigma)$ above which the interventions to fend off the attack are more costly than to give up the currency peg without any defense.⁵

If the attack signal \tilde{A} is below the threshold, the central bank will take defensive measures which do not only offset the expected strength of the attack \tilde{A} , but additionally include some safety cushion. Note that $\sigma \ln \left(\frac{R(\theta)}{2\sigma\phi(\theta)} \right) > 0$ as $\phi(\theta) < \frac{R(\theta)}{2\sigma}$. For a given measurement error ξ_{CB} the central bank abstains from defensive measures for bad fundamentals, i.e. for $\theta < \theta_0(\xi_{CB}) = \liminf \left\{ \theta : G(x^* - \theta) + \xi_{CB} \leq \frac{R(\theta)}{\phi(\theta)} - \sigma \ln \frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma \right\}$. This approach proves very helpful in understanding the dynamics of the model. It is equivalent to ask the following question: what happens if a central bank over-/underestimates an attack by an error ξ_{CB} . If the central bank underestimates the attack, $\xi_{CB} < 0$, defensive measures are insufficient, if and only if the error is larger than the safety cushion. If the central bank overestimates the strength of the attack, $\xi_{CB} > 0$, the defense will be successful if the central bank chooses to act. However, in this situation the estimated strength of the attack is more likely to be higher than the threshold keeping the central bank from taking measures.

Finally, we compare the result with the perfect information benchmark. We obtain the optimal central bank reaction function for perfect information from equation (2) by taking the limit $\sigma \rightarrow 0$

$$B_{opt}(\sigma = 0) = \begin{cases} A & \text{if } \phi(\theta) A < R(\theta) \\ 0 & \text{else} \end{cases}, \quad (3)$$

i.e. the central bank chooses exactly the necessary amount of defensive measures to counter the attack A , if the costs of these measures $\phi(\theta) A$ are less than the cost of the devaluation, and abstains from taking defensive measures, if its costs would exceed the devaluation loss. The threshold in the perfect information case is higher

⁵For the derivation of this threshold, we assume that the status quo is abandoned if the central bank chooses $B = 0$ regardless of the realized strength of the attack.

	attack fails ($A < B$)	attack succeeds ($A \geq B$)
Attack	-c	1-c
null action	0	0

Table 1: Payoffs of speculative traders

than under imperfect information, as in the latter case the central bank faces the risk of bearing both costs, defense and regime change, if the defense fails.

In contrast to the classical global game approaches, the reaction function of the central bank is not monotonously increasing in θ . In the literature the fundamentals θ usually are identified with the strength of the status quo, which implies setting $B(\theta) = \theta$, whereas we show that it is rational to adjust costly defensive measures to the size of the expected attack. Therefore the central bank either abstains from defensive measures, if its estimates the necessary defense as too costly or adjusts the extent of its interventions to the estimated strength of the attack, which is *declining* in θ .⁶

2.2 Speculative traders

There is a continuum $[0, 1]$ of traders indexed by i . Agents decide individually and simultaneously between two actions: they can either attack the current exchange rate regime or abstain from attacking (null action). The payoff from not attacking ($a_i = 0$) is zero, whereas attacking is costly and the payoff depends on the success of the attack. The decision to join the attack ($a_i = 1$) implies costs $c \in (0, 1)$. If the attack succeeds in forcing the regime to change, there is a normalized payoff of one for each trader, who has participated in the attack. Table 1 summarizes the total payoffs.

An agent hence finds it optimal to attack if and only if the expected payoff of attacking is non-negative. This is equivalent to expecting a regime change with probability of at least c . The speculative traders' decisions might be triggered by contagion effects, changes in the fundamentals, and/or expectations which are included in the private signal on the fundamentals.

⁶Since traders actions are strategic complements, the unique monotone Nash equilibrium is a threshold strategy. Traders attack, if and only if their private signals are lower than the threshold. As the private signals are distributed around the true fundamentals θ , the less traders receive a signal below their threshold, the better the fundamentals are.

The attack is successful, i.e. the regime changes, if and only if the share of attacking agents A is greater than or equal to the strength of the defensive measures B . Agents' actions thus are strategic complements: the aggregate size of the attack increases with each agent's incentive to attack thereby increasing the incentive to attack for all other agents.

As noted above, agents have heterogeneous information about the fundamentals θ . The initial prior $G_N(\theta)$ of nature's draw is common knowledge. Then each trader receives a private signal $x_i = \theta + \varepsilon_i$, where the error term ε_i is distributed according to some commonly known distribution G .⁷

This setup allows us to use the typical reasoning of the global game approach. The c.d.f. of agent i 's posterior distribution about θ is non increasing in his private signal x_i . Therefore (if the private information is sufficiently precise relative to public information) only one monotone Bayesian Nash equilibrium survives the iterated elimination of dominated strategies.⁸ This equilibrium strategy is characterized by a threshold x^* . For a given state of the fundamentals θ , we therefore have

$$A(\theta) = \int_0^1 a_i di = \int_0^1 I_{\theta + \varepsilon_i < x^*} di = \int_0^1 I_{\varepsilon_i < x^* - \theta} di = G(x^* - \theta)$$

Following the global game approach, the equilibrium is characterized by two variable – the threshold x^* and a threshold of the fundamental state $\hat{\theta}$ – which are determined by two equations. However, in our approach a second source of uncertainty is present. The central banks can only imperfectly assess the strength of the attack. The determining equation of the fundamental threshold holds only conditional on the central banks assessment error.

Proposition 3: The attack is successful if and only if $\theta < \hat{\theta}(\xi_{CB})$ where

$$\hat{\theta}(\xi_{CB}) = \sup \{ \theta : A(\theta) > B(\theta, \xi_{CB}) \} \quad (4)$$

Depending on the central bank's signals, there are four possible situations. First, the signals are such that the attack is underestimated and the attack succeeds for all

⁷A common choice is $G_N = N(z, \frac{1}{\alpha})$ and $G = N(0, \frac{1}{\beta})$, so that the information structure can be parsimoniously parameterized with (α, β, z) , the precision of private information as well as the mean and precision of the common prior.

⁸As the decision is binary, monotone strategies, i.e. strategies that are non-increasing in x_i , are threshold strategies where the agent decides to attack if and only if his private signal is lower (or equal) to some threshold \hat{x} .

θ , i.e. $\hat{\theta}(\xi_{CB}) = \infty$. Secondly, the attack is not underestimated, however, defensive measures are too costly given bad fundamentals. Then $\hat{\theta}(\xi_{CB})$ solves the threshold in equation (2). Thirdly, the safety cushion in the central banks defense strategy is not sufficient to offset the underestimation of the strength of the attack for bad fundamentals, i.e. $\hat{\theta}(\xi_{CB})$ solves $A(\theta) = B(\theta, \xi_{CB})$. Fourthly, based on a high estimate of the strength of the attack, the central bank chooses defensive measures that are stronger than the attack for all θ , i.e. $\theta_0 = -\infty$ and $\hat{\theta}(\xi_{CB}) = -\infty$. In appendix 3, we visualize the relation of θ_0 and $\hat{\theta}(\xi_{CB})$ exemplarily.

Proposition 4: The unique threshold x^* is given by

$$\mathbb{E}_{\xi_{CB}} \left(P \left(\theta < \hat{\theta}(\xi_{CB}) \mid x_i = x^* \right) \right) = c \quad (5)$$

The threshold must satisfy the condition stated above. Agent i receiving a signal exactly at the threshold value, i.e. $x_i = x^*$, is indifferent between attacking or not. Therefore the expected payoff given this private information must equal zero or equivalently, the expected probability of a regime change conditional on $x_i = x^*$ must equal the cost of attacking, i.e. using equation (4) $\mathbb{E}_{\xi_{CB}} \left(P \left(\theta < \hat{\theta}(\xi_{CB}) \mid x_i = x^* \right) \right) = c$.⁹

Note that x^* depends on the cost and information structure of the central bank, i.e. ϕ , R , and σ . If R and ϕ do not depend on θ , θ is a pure sunspot variable, i.e. a coordination device for the speculative traders.

2.3 Equilibrium analysis

This section derives the main results regarding the influence of the various model parameters on the incidence of a currency crisis and the policy reaction function under the assumption that the conditions for uniqueness of equilibrium are satisfied. Since a devaluation takes place for all fundamental values lower than or equal to $\hat{\theta}(\xi_{CB})$, each change in a parameter that increases $\hat{\theta}(\xi_{CB})$ subsequently raises the ex ante probability of a crisis. This in turn allows the traders to act more aggressively, i.e. increases x^* . Increasing $\hat{\theta}(\xi_{CB})$ in this context means that $\hat{\theta}_1(\xi_{CB}) \geq \hat{\theta}_2(\xi_{CB}) \forall \xi_{CB}$, i.e. $\hat{\theta}(\cdot)$ increases for at least some values of ξ_{CB} and is not decreasing for any value of ξ_{CB} . To analyze the reaction of $\hat{\theta}(\xi_{CB})$ to parameter

⁹If we apply the above stated common example of normally distributed prior and error distribution, the posterior distribution is $P \left(\theta < \hat{\theta}(\xi_{CB}) \mid x_i = x^* \right) = \Phi \left(\hat{\theta}(\xi_{CB}) - \frac{\alpha}{\alpha+\beta} x^* - \frac{\beta}{\alpha+\beta} z \right)$.

changes, it is sufficient to look at B_{opt} and θ_0 . The likelihood of a regime change, i.e. $\hat{\theta}(\xi_{CB})$, decreases, if the strength of the defensive action (if taken) increases, i.e. B_{opt} increases, and the area where no defensive action is taken decreases, i.e. θ_0 decreases. Parameters with mixed effects on $\hat{\theta}(\xi_{CB})$ cannot be analyzed in this setting without choosing concrete error distributions and cost functions.

2.3.1 Behavior of the traders

Proposition 5:

The traders behave less aggressive, if the costs of a devaluation increase or the cost of defensive measures decrease.

Proof: Appendix 4

We have $\frac{d\hat{\theta}(\xi_{CB})}{dR} < 0$ and therefore $\frac{dx^*}{dR} < 0$, as well as $\frac{d\hat{\theta}(\xi_{CB})}{d\phi} > 0$ and therefore $\frac{dx^*}{d\phi} > 0$. This proposition shows that the model is consistent. The defense of the central bank becomes stronger (both the use of defensive measures is more intense, if the central bank chooses to defend the regime, and the likelihood of the central bank to take defensive measures grows), if a regime change is more costly or if defensive measures are cheaper for the central bank.

2.3.2 Policy analysis

The strength of the attack depends on the true value of the fundamentals, since $A = G(x^* - \theta)$. Speculative traders attack if they receive a signal lower than their threshold indicating sufficiently bad fundamentals. As the signals are centered around the true value, the share of signals below the threshold decreases if the true value increases. We have $\frac{dA(\theta)}{d\theta} = -g(x^* - \theta) < 0$, i.e. better fundamentals imply less strong attacks.

The policy of the central bank depends on its assessment of the strength of the attack. To infer the influence of a change in the fundamentals on the probability of a regime change, both parts of the defense strategy have to be analyzed: the effect on the defensive action if taken and the likelihood that defensive action is taken.

Strength of defensive action

If the central bank decides to take defensive actions, it chooses $B = \tilde{A} + \sigma \ln\left(\frac{R(\theta)}{2\sigma\phi(\theta)}\right)$, i.e. it intervenes more aggressively than is necessary given its estimate of the strength of the attack and applies a safety cushion against a certain amount of estimation error. The likelihood of a regime change then equals the probability

that the cushion is sufficient, i.e. $P\left(\xi_{CB} < -\sigma \ln\left(\frac{R(\theta)}{2\sigma\phi(\theta)}\right)\right)$. We have

$$\frac{d}{d\theta}\sigma \ln\left(\frac{R(\theta)}{2\sigma\phi(\theta)}\right) = \sigma \frac{2\sigma\phi(\theta)}{R(\theta)} \cdot \frac{1}{2\sigma} \cdot \frac{d\frac{R(\theta)}{\phi(\theta)}}{d\theta} = \frac{\sigma\phi(\theta)}{R(\theta)} \cdot \frac{d\frac{R(\theta)}{\phi(\theta)}}{d\theta} > 0.$$

therefore the cushion is increasing in θ and the likeliness of a regime change decreases.

To put it intuitively, for better fundamentals it is easier and cheaper to take defensive measures.

Likelihood that defensive action is taken

The likelihood that defensive action is taken depends on the absolute height of the attack signal, i.e. the sum of realized attack and estimation error, and the central bank threshold. The fundamentals change both, the size of the attack and the threshold. The probability that the central bank acts is

$$P\left(A(\theta) + \xi_{CB} < \frac{R(\theta)}{\phi(\theta)} - \sigma \ln\frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma\right).$$

Now we have

$$\frac{d}{d\theta}\left(\frac{R(\theta)}{\phi(\theta)} - \sigma \ln\frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma\right) = \frac{d\frac{R(\theta)}{\phi(\theta)}}{d\theta} - \frac{\sigma\phi(\theta)}{R(\theta)} \cdot \frac{d\frac{R(\theta)}{\phi(\theta)}}{d\theta} = \left(1 - \frac{\sigma\phi(\theta)}{R(\theta)}\right) \cdot \frac{d\frac{R(\theta)}{\phi(\theta)}}{d\theta} > 0,$$

since $\frac{\sigma\phi(\theta)}{R(\theta)} < \frac{1}{2}$ (see equation (1)). The threshold increases with better fundamentals, as the defensive measures become relatively cheaper.

In addition, the strength of the attack decreases.

For better fundamentals, both effects conjointly raise the likelihood that the central bank takes defensive actions. And if such measures are taken, they are more likely to be successful.

The precision of central bank information

The effects of the precision of central bank information on the behavior of the agents is mixed.

$$\begin{aligned} \text{Cushion} & : \quad \frac{d}{d\sigma}\sigma \ln\left(\frac{R(\theta)}{2\sigma\phi(\theta)}\right) = \ln\left(\frac{R(\theta)}{2\sigma\phi(\theta)}\right) - 1 = \begin{cases} > 0 & \text{if } \sigma < \frac{R(\theta)}{2\exp(1)\phi(\theta)} \\ < 0 & \text{if } \sigma > \frac{R(\theta)}{2\exp(1)\phi(\theta)} \end{cases} \\ \text{Threshold} & : \quad \frac{d}{d\sigma}\left(\frac{R(\theta)}{\phi(\theta)} - \sigma \ln\frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma\right) = -\ln\left(\frac{R(\theta)}{2\sigma\phi(\theta)}\right) < 0 \end{aligned}$$

A decrease in the central bank's information quality, i.e. an increase in σ , always decreases the threshold for the estimated attack strength above which no defense action is taken. However, the effect on the size of the defense measures if action is taken depends on the level of information quality. If the central authority is well informed, i.e. σ is small, an decrease of precision is compensated by an increased safety buffer. With decreasing precision the cost -utility ratio of additional safety buffer declines. If the central authority is poorly informed, i.e. σ is large, a further increase leads to a reduction of the safety cushion.

3 Empirical analysis

In the following we empirically explore the following three questions: (1) Does central bank policy matter, once international traders have initiated a speculative attack? (2) What are the economic consequences of the different types of currency crises? (3) What are determinants of these consequences? After a short discussion of the literature, we present some stylized facts, followed by a more detailed empirical analysis.

The empirical literature on currency crises typically applies dichotomic approaches and divides the samples into crises and no crises events.¹⁰ Two types of crises definitions are commonly used: (a) a significant devaluation (compare Frankel and Rose (1996) and Bauer et al. (2007)) and (b) a rise of an exchange market pressure index (EMPI) (e.g. Eichengreen et al. (1995), Prati and Sbracia (2002), Fratzscher and Bussiere (2006)). Both of these crises indicators combines different types of crises, which should be treat separately according to our model. The Frankel-Rose measure indicates a currency crisis either if the central bank chooses to surrender the regime without defensive measures or if it attempts to defend the regime and fails. Increases of the exchange market pressure index – typically a weighted sum of devaluation rate, reserves changes, and sometimes interest rate increases – always indicate an attack, i.e. this indicator combines and intermingles all three crises scenarios namely immediate devaluation, successful defense and unsuccessful defense.

Following our theoretical model, we relate the three different crises scenarios to

¹⁰Often in a second step a window around the crises events is applied to the sample to reduce the estimation bias. Assumably, periods shortly before and after a crises might be influenced by the crises and thus should not be treated as no crisis events.

	no devaluation	devaluation
no IPI increase	no crisis (B)	immediate devaluation (A1)
IPI increase	successful defense (A2b)	unsuccessful defense (A2a)

Table 2: Crisis definitions

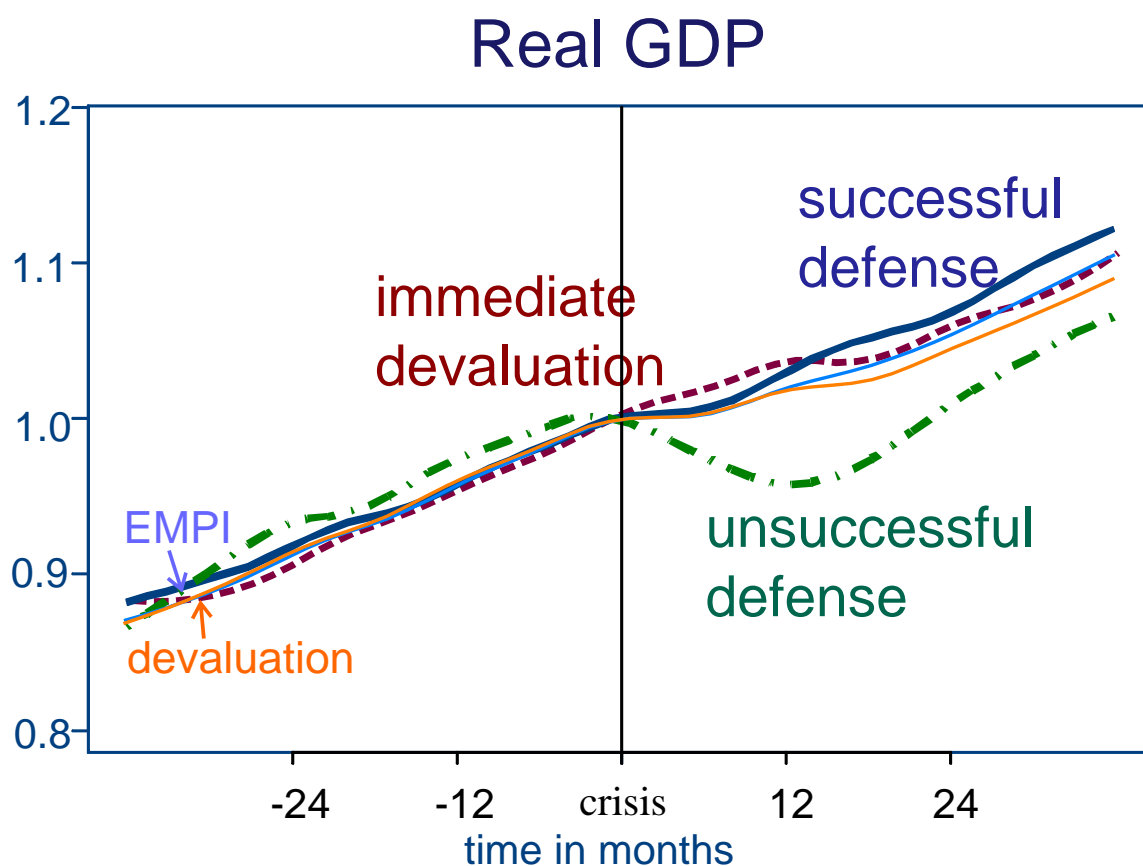
the traditional crisis indicators as displayed in figure 1. We define a devaluation as significant, if it is larger than five times the standard deviation of the previous 12 months exchange rate changes and more than 5% to include realignments in fixed exchange rates.¹¹ In addition, we define the weighted sum of the percentage drop in reserves and the interest rate increase as an intervention pressure index (IPI). The IPI measures the strength of the defensive measures taken by the central bank. In contrast to the EMPI, the IPI excludes the rate of depreciation, as we account for exchange rate changes with an separate indicator. Analogously to the devaluation variable, an increase of the IPI is defined as significant, if it exceeds 5 standard deviations of the previous 12 months changes. An immediate devaluation (A1) is defined as a significant drop in the exchange rate that is not accompanied by a strong increase in the interest rates or a decline in reserves. A successful defense (A2b) is characterized by an increase in the IPI indicating an attack while the currency does not depreciate. Finally, an unsuccessful defense (A2a) is given by both an IPI increase and an drop in the exchange rate. Table 2 summarizes these definitions.

We base our analysis on a sample of 33 emerging markets countries between 1990 and 2005. The sample contains 65 crises with 22 immediate devaluation, 24 successful and 19 unsuccessful exchange rate defenses. We use monthly data on monetary and real indicators of the Fratzscher and Bussiere (2006) data set which we have updated and supplement by data from the Joint BIS-IMF-OECD-WB External Debt Hub (see appendix 5 for a detailed description of the data).

¹¹We use a combined measure for the devaluation indicator: comparison to the average variability in the past and an absolute measure of devaluation. In contrast to most of the literature, we use monthly data, and thus have to adjust our thresholds, in order to create a comparable number of crises. In addition, monthly decreases of the exchange rate less than 5% are not seen as a devaluation, even if they exceed the five sd threshold e.g. in a strictly managed exchange rate regime.

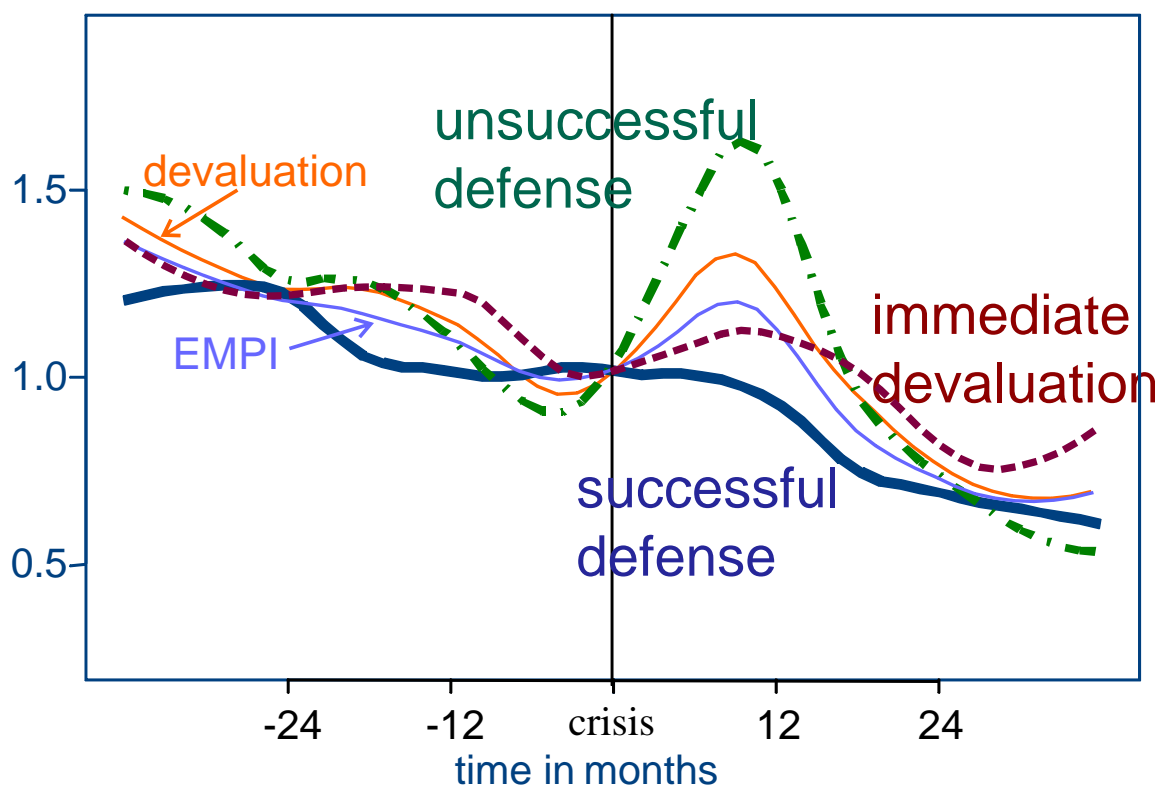
3.1 The economic consequences of currency crises: Central bank behavior matters

As a stylized fact we find that central bank behavior is a key element in the economic development after a speculative attack. Real GDP (see figure 3.1), CPI inflation (see figure ??), and deviations from the growth path (see figure 3.1) all indicate that the economic consequences of a speculative attack strongly depend on central bank behavior during the crisis, i.e. the type of crisis scenario.



Crisis type specific kernel regressions on the development of real GDP. To allow for comparability and to eliminate level effects, GDP is standardized to unity in $t=-1$.

Inflation



Crisis type specific kernel regressions on the development of CPI inflation. To allow for comparability and to eliminate level effects, inflation is standardized to unity in $t=-1$.

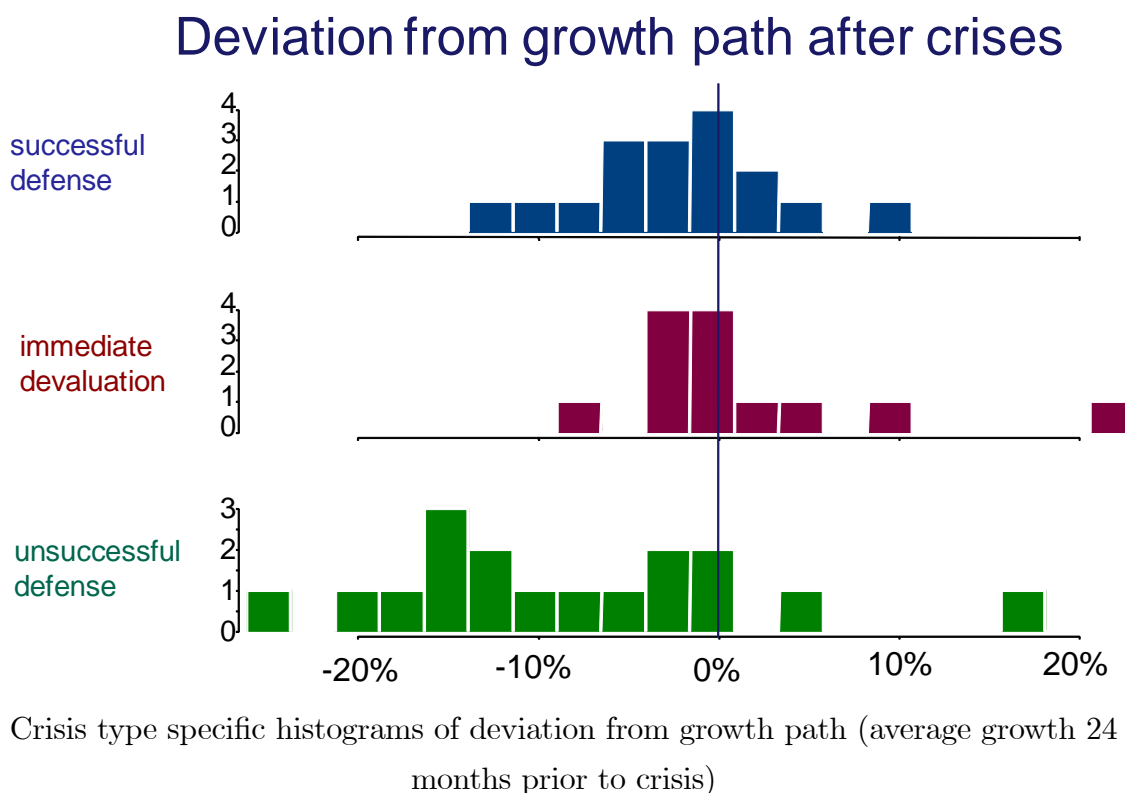


Figure 3.1 indicates how real growth after a currency crisis differs depending on the reaction of the central bank. An unsuccessful attempt to defend the currency is typically followed by a strong decline in growth, which reaches its trough about 12 months after the attack. Three years after the attack real GDP is still lower than in the case of the other two crisis scenarios. If the defense is successful, growth slows down for roughly 6 months, but after slightly more than 12 months catches is even higher than in the case of an immediate devaluation. It is also interesting to note that the development of real GDP before the crisis is very similar for the three subsamples indicating that it is indeed the difference in central bank behavior and not the state of the economy that is responsible for the difference in real GDP development. The estimates based on the two crisis definitions common in the literature, i.e. devaluation and EMPI, blend the different post-crises growth patterns, and subsequently fail to identify the strong recession after an unsuccessful defense of the exchange rate peg.

The difference between our three crisis scenarios is even more pronounced in the case of inflation (figure ??). While average inflation rate decreases after a successful defense, it increases by a factor of 0.2 after an immediate devaluation and 0.5 after

an unsuccessful defense. In contrast to real GDP there seem to exist differences in pre-crisis inflation between the three subsamples. Again, the estimates based on devaluation and EMPI, blend the different post-crisis inflation patterns, and cannot account for the different inflation patterns depending on central bank policy.

The deviations from growth path after a speculative attack also differ for the three types of currency figure (see figure 3.1). Average deviation from trend growth is slightly positive in the case of an immediate devaluation (+0.7%), negative (-2.7%) in case of a successful defense, and strongly negative in case of an unsuccessful defense (-9.2%), while there is no significant difference in pre-crisis performance (+4.9%, +4.9%, and +4.0%). Using a broad sample of developing countries and emerging markets Gupta et al. (2007) also find that the economic consequences of currency crises are quite heterogeneous – 40% of their sample experienced an increase in growth after a currency crisis, while 60% faced a recession. In their analysis they find some evidence that these differences are related to factor such as pre-crisis capital inflow and pre-crisis capital controls. However, they do not control for differences in central bank behavior and do not analyze the inflation differentials. In particular they do not relate this evidence to systematic differences in central bank behavior.

Based on these stylized facts the decision to defend a currency regime involves considerable risks. If the defense fails, the devaluation is only delayed, while the consequences of the attack in terms of real growth and inflation are much more severe than after an immediate abandonment of the currency peg.

To better understand the implications of central bank policy during a speculative attack we also analyze the development of various economic variables separately for the three different crises scenarios. In particular, table 3 yields the results of a Wilcoxon test comparing all pairs of subsamples, including the no crisis sample.¹² As is typical for economic data sets, most of our data is not normally distributed. Some variables show significant skewness and/or leptokurtosis. We therefore require a location test, which is not sensitive to these findings. The Wilcoxon test has a breakdown point of 50%, i.e. it is highly robust and yields unbiased results if the share of outliers in the data does not exceed 50%. Further, it does not require assumptions on the type of the error distribution. However, this advantage comes at the price that the analysis treats each variable separately and ignores correlations and interdependencies between variables.

¹²We apply a three year window to the data, i.e. all data 36 months prior or post a currency crises is not contained in the no crisis subsample.

	no crisis - successful defense	no crisis - immediate devaluation	no crisis - unsuccessful defense	successful defense -immediate devaluation	successful defense -unsuccessful defense	immediate devaluation - unsuccessful defense
real growth ($t_{12} - t_{-1}$)	1,00	0,91	1,00	0,16	0,99	1,00
CPI inflation (t_{12})	0,00	0,00	0,00	0,24	0,15	0,46
log REER ($t_{12} - t_{-1}$)	0,55	0,71	1,00	0,54	1,00	1,00
government deficit / GDP (t_{12})	0,98	0,99	0,96	0,74	0,49	0,29
CPI inflation ($t_{12} - t_{-1}$)	0,13	0,00	0,00	0,09	0,00	0,01
reserves ($t_{12} - t_{-1}$)	0,99	0,07	0,97	0,04	0,66	0,97
FDI / GDP (t_{12})	0,91	1,00	0,98	0,90	0,72	0,22
Exports / GDP($t_{12} - t_{-1}$)	0,76	0,02	0,00	0,06	0,00	0,19
Imports / GDP($t_{12} - t_{-1}$)	1,00	0,01	0,63	0,00	0,06	0,96

Table 3: P-values of one sided Wilcoxon test. Each column compares economic indicators of two subsamples, 12 months after a currency crises and throughout the no crises periods, respectively. Low values indicate significantly lower median in the first group. High values indicate significantly higher median in the first group.

Table 3 presents the results of the Wilcoxon test. In each row we compare for different crises types either the level (indicated by t_{12}) of an economic variable 12 months after the crisis event or the change relative to the pre-crisis level ($t_{12} - t_{-1}$) for the different types of currency crises. Each column compares the various indicators for two given subsamples, e.g. no crisis vs. successful defense in the first column. The test applies a one sided null hypothesis, such that low p-values indicate significantly lower median and high values indicate significantly higher median in the first subsample, respectively.

In the first row of table 3 results for the average change of the growth rate right before the crisis, t_{-1} , and twelve months after the crisis, t_{12} , are examined. In the no crises sample this change in real growth is close to zero, as it nearly averages out over the entire sample. The first result, 1.00, indicates that on the 1% level the change of real growth in no crisis situations – i.e. zero – is higher than the change of real growth after successful defenses. Thus on the 1% level, the real growth rate declines for successful defenses (column one) as well as unsuccessful defenses interventions (column three). In addition this decline in real growth is significantly stronger for an unsuccessful defense than in the case of the other crises scenarios (first row, columns five and six). The second row implies that on the 1% level, inflation is higher after an speculative attack (columns one to three), independently of the central banks reaction. However, the change of inflation (row five) depends on the type of crisis scenario, i.e. inflation increases (on the 1% level) after a devaluation (columns two and three), in particularly in the case of an unsuccessful defense (column five and six). In contrast, it does not change significantly after a successful defense (column one). Real devaluations (row three) only occur after an unsuccessful defense. In this case the nominal exchange rate undershoots. Exports profit from a devaluation in both cases, with or without defensive action, while imports decline after a successful defense but increase after an immediate devaluation.

3.2 Prediction

In the next step, we estimate the role of various fundamentals for real growth after a speculative attack. Due to the relatively small sample, we use a pooled regression without fixed effects. The regression equation is given

$$g_j = \alpha + \sum_i \beta_i X_{ij} + \varepsilon_j,$$

where g_j is the growth rate 12 months after crisis event j , X_{ij} is the i th control variable and ε_j an error term. Control variables are denoted in levels 12 months before the crisis (indicated by t_{-12}) or in changes within the year prior to the crises (indicated growth rate of), where positive values indicate a decline prior to the crisis. We take the control variables from Gupta et al. (2007) and Frankel and Rose (1996) as far as monthly data are available. Secondly, we limit the number of control variables to prevent overfitting, as due to the differentiated crises definition each crises sample has less crises events. The first regression also includes dummies for the different crisis scenarios. Table 4 presents the results.

In our first regression (table 4, column one) we combine all types of currency crises, i.e. the case of the standard EMPI regression. We find only the change in money and the dummy for unsuccessful defense to be (negatively) significant, i.e. real growth is the lower the more the monetary aggregate increased prior to the crisis and it is significantly lower in case of an unsuccessful defense. If we combine "all devaluations", i.e. the Frankel-Rose definition of an currency crises, we find again that a change of money is significant. In addition more open economies on average have lower growth after a devaluation as have countries with a lower pre-crisis real growth. Comparing the estimation results of the three types of currency crises further indicates the profound economic differences between these scenarios. All variables are significant in one of the three regressions, but none of the variables is significant in any two of these estimations.

The decision of a central bank to defend its current regime is risky. If the defense fails, the country faces more severe consequences than after any of the other scenarios. This risk is especially high, if fundamentals are bad (declining FDI and growth rates), since under these conditions the consequences of a failure of the defense are more severe. In addition, we find that open countries grow significantly stronger after an immediate devaluation. Also countries which have revalued in real terms prior to the crises profit more from abstaining from defensive measures. The revaluation typically decreases competitiveness of the export economy and thus reduces growth, while the nominal (and subsequently real) devaluation reverses this effect without bearing additional costs of defensive measures.

We now perform a Wilcoxon test comparing the groups "successful defense" and "unsuccessful defense" using economic indicators 6 months prior to the crises events. With all caveats necessary, we interpret the results as a conditional likelihood for

	all crises	all devaluations	successful defense	immediate devaluation	unsuccessful defense
log M1 ($t_{-1} - t_{-12}$)	-0.12 (-2.5)	-0.16 (-6.28)	-0.16 (-2.5)	0.00 (-0.03)	0.03 (1.6)
log REER ($t_{-1} - t_{-12}$)	0.07 (0.49)	0.01 (0.07)	-0.06 (-0.29)	0.11 (3.1)	-0.18 (-1.7)
log (reserves minus gold) ($t_{-1} - t_{-12}$)	0.03 (0.70)	0.05 (1.67)	0.00 (-0.03)	0.01 (0.33)	-0.36 (-7.7)
FDI / GDP (t_{-12})	0.35 (0.43)	-1.04 (-1.98)	0.78 (0.95)	0.72 (-1.26)	6.34 (14.8)
TRADE / GDP (t_{-12})	-0.03 (-0.71)	-0.05 (-2.64)	-0.05 (-1.7)	0.10 (2.8)	-0.02 (-1.4)
real growth ($t_{-1} - t_{-3}$)	-0.73 (-0.89)	-2.09 (-3.78)	-0.25 (-0.18)	1.12 (1.6)	6.69 (10.5)
Intercept		4.04 (2.44)	4.44 (1.3)	-5.75 (-4.2)	-17.70 (-13.0)
dummy successful defense	0.12 (0.01)				
dummy immediate devaluation	0.34 (1.1)				
dummy unsuccessful defense	-1.35 (-2.8)				
r.squared	0.25	0.35	0.26	0.24	0.84

Table 4: Regression results; t-values in brackets; bold values indicate significance on the 5% level.

one of the scenarios given the value of tested variable.¹³ We find that a defense is more likely to succeed, if

1. growth rates do not decline (p-value 0.05),
2. increase in domestic credit is low (or negative) (p-value 0.004),
3. no or low real devaluation occurs (p.value 0.03),
4. interest rates are declining or rising slowly (p-value 0.03),
5. government debt is low (p-value 0.04), and
6. the ratio of short term debt is low (p-value 0.03).

In other words, if the country struggles for six months with structural problems (low growth, high debt, and capital flight (indicated by increasing interest rates)), it is unlikely to be able to successfully defend the regime. However, this analysis must be treated with care as there are a number of caveats. Firstly, in this step we do not address the endogeneity problem nor interdependencies between the variables. Secondly, the interpretation is very indirect. Finally, the location of the variables is always relative to the two analyzed groups of crises countries and not relative to the entire sample.

4 Conclusion

While the recent global game literature has made great improvements in understanding the role of investors in speculative attacks, the role of central banks as key players and the dynamics of financial crises are not well understood and have so far not been adequately analyzed. We overcome these shortfalls by explicitly modeling (A) the strategic options of market participants and policy makers and (B) the dynamics of financial crises. In case of an attack, the central bank basically faces three alternatives. If it chooses to defend its currency, the defense can be successful or not. Each of these outcomes yields entirely different economic consequences.

¹³The result of a Wilcoxon test can – on intuitive grounds – be interpreted as a conditional likelihood for one of the scenarios given the value of tested variable. If e.g. the test result implies that the median of group 1 is lower than that of group 2, we may conclude, that given a low value of the variable an event is more likely to belong to group 1.

In the empirical results we find that the most significant predictor for the broad range of crises effects on growth, inflation and trade is central bank behavior, i.e. immediate devaluation, successful defense of unsuccessful defense. Secondly, using a two-stage panel regression, we identify crisis relevant sets of economic indicators. Thus, currency crises are not homogeneous events. They differ with respect to their history and economic consequences. As a consequence the decision of the central bank to take defensive measures in order to maintain the current regime involves considerable risk. If the defense fails, the devaluation is only delayed. In addition the consequences of the attack in terms of lower growth and higher inflation are much more severe than after a successful defense or the immediate abandonment of the currency peg.

We also relate our findings to the empirical results found in the literature based on the two standard crisis definitions, namely a significant devaluation and a rise of an exchange market pressure index. Both crises indicators mix different crises types, which should be treated separately according to our model, and therefore cannot differentiate the type specific implications of these crisis types. Throughout the analyses our results are highly sensitive to the crisis types, i.e. the results from estimations and tests differ for different crisis types. Indicators, which are significant for one type are insignificant in the others, and vice versa. Our results thus offer one line of explanation for the well known poor performance of early warning systems and the heterogenous results in the empirical currency crisis literature.

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5 Appendix

5.1 Appendix 1

$$\begin{aligned} \mathbb{E}\left(I_{A>B}|\tilde{A}\right) &= \mathbb{E}\left(I_{\tilde{A}-\xi_{CB}>B}|\tilde{A}\right) = \mathbb{E}\left(I_{-\xi_{CB}>B-\tilde{A}}|\tilde{A}\right) \\ &= \mathbb{E}\left(I_{\xi_{CB}<\tilde{A}-B}|\tilde{A}\right) = \begin{cases} \frac{1}{2} \exp\left(\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B \geq \tilde{A} \\ 1 - \frac{1}{2} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B < \tilde{A} \end{cases} \\ \mathbb{E}C = \mathbb{E}(RI_{A>B} + \phi B) &= \begin{cases} \phi B + \frac{1}{2}R \exp\left(\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B \geq \tilde{A} \\ \phi B + R\left(1 - \frac{1}{2} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right)\right) & \text{if } B < \tilde{A} \end{cases} \end{aligned}$$

We see that this function has extrema if and only if $\phi < \frac{R}{2\sigma}$.

5.2 Appendix 2

First order condition

$$\begin{aligned}
\frac{d\mathbb{E}C}{dB} &= \frac{d}{dB} \begin{cases} \phi B + \frac{1}{2}R \exp\left(\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B \geq \tilde{A} \\ \phi B + R \left(1 - \frac{1}{2} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right)\right) & \text{if } B < \tilde{A} \end{cases} \\
&= \begin{cases} \phi + \frac{d}{dB} \left(\frac{1}{2} \exp\left(\frac{\tilde{A}-B}{\sigma}\right) R\right) & \text{if } B \geq \tilde{A} \\ \phi - \frac{d}{dB} \left(\frac{1}{2} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right) R\right) & \text{if } B < \tilde{A} \end{cases} \\
&= \begin{cases} \phi - \frac{R}{2\sigma} \exp\left(\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B \geq \tilde{A} \\ \phi - \frac{R}{2\sigma} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B < \tilde{A} \end{cases} \stackrel{!}{=} 0 \\
\Rightarrow B &= \begin{cases} \tilde{A} + \sigma \ln\left(\frac{R}{2\sigma\phi}\right) > \tilde{A} & \text{if } B \geq \tilde{A} \\ \tilde{A} - \sigma \ln\left(\frac{R}{2\sigma\phi}\right) & \text{if } B < \tilde{A} \end{cases}
\end{aligned}$$

$$\begin{aligned}
\frac{d^2K}{dB^2} &= \frac{d}{dB} \begin{cases} \phi - \frac{R}{2\sigma} \exp\left(\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B \geq \tilde{A} \\ \phi - \frac{R}{2\sigma} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B < \tilde{A} \end{cases} \\
&= \begin{cases} \frac{R}{2\sigma^2} \exp\left(\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B \geq \tilde{A} \\ -\frac{R}{2\sigma^2} \exp\left(-\frac{\tilde{A}-B}{\sigma}\right) & \text{if } B < \tilde{A} \end{cases} = \begin{cases} > 0 & \text{if } B \geq \tilde{A} \\ < 0 & \text{if } B < \tilde{A} \end{cases} \\
\Rightarrow &\begin{cases} \text{Minimum} & \text{if } B \geq \tilde{A} \\ \text{Maximum} & \text{if } B < \tilde{A} \end{cases}
\end{aligned}$$

For $B < \tilde{A}$ expected costs increase in B . As $B \geq 0$ we get $B_{opt} = 0$ for $B < \tilde{A}$.

To find the optimal strategy we first calculate $\mathbb{E}_A(C(\cdot) | \tilde{A})$ for $B_{opt} = 0$ and $B_{opt} = \tilde{A} + \sigma \ln\left(\frac{R}{2\sigma\phi}\right)$

$$\begin{aligned}
\mathbb{E}_A\left(C\left(\tilde{A} + \sigma \ln\left(\frac{R}{2\sigma\phi}\right)\right) | \tilde{A}\right) &= \phi B + \frac{1}{2}R \exp\left(\frac{\tilde{A}-B}{\sigma}\right) \\
&= \phi\left(\tilde{A} - \sigma \ln\left(\frac{2\sigma\phi}{R}\right)\right) + \frac{1}{2}R \exp\left(\frac{\tilde{A} - \left(\tilde{A} - \sigma \ln\left(\frac{2\sigma\phi}{R}\right)\right)}{\sigma}\right) \\
&= \phi\left(\tilde{A} + \sigma - \sigma \ln\frac{2}{R}\sigma\phi\right) \\
\mathbb{E}_A(C(0) | \tilde{A}) &= R
\end{aligned}$$

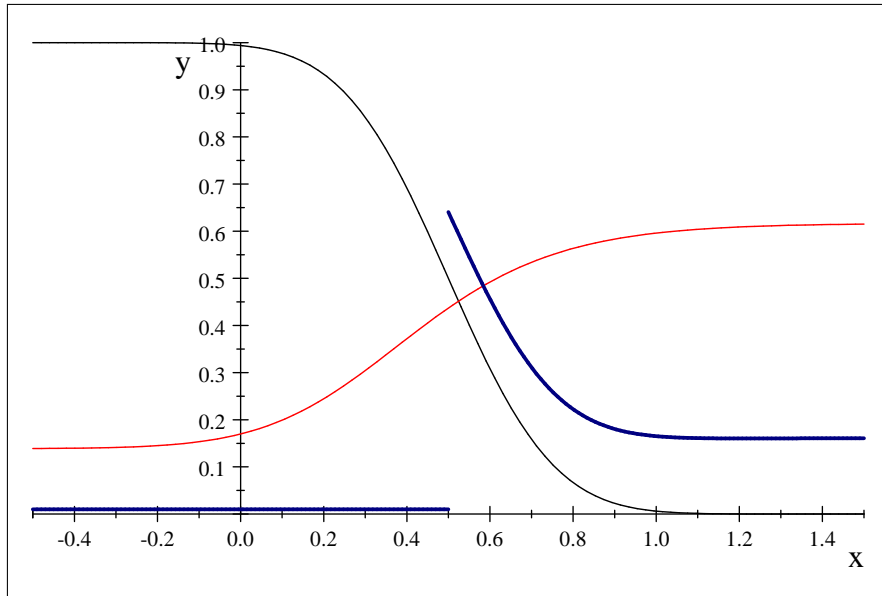
and now compare the two options

$$\begin{aligned} \mathbb{E}_A \left(C \left(\tilde{A} + \sigma \ln \left(\frac{R}{2\sigma\phi} \right) \right) \middle| \tilde{A} \right) &< \mathbb{E}_A \left(C(0) \middle| \tilde{A} \right) \\ \phi \left(\tilde{A} + \sigma - \sigma \ln \frac{2\sigma\phi}{R} \right) &< R \\ \tilde{A} &< \frac{R}{\phi} - \sigma - \sigma \ln \frac{R}{2\sigma\phi}. \end{aligned}$$

We find that the expected costs of taking optimal defense measures are lower than the costs of not defending the current regime if and only if the estimated strength of the attack \tilde{A} is below a threshold $\frac{R}{\phi} - \sigma + \sigma \ln \frac{2}{R}\sigma\phi$. We therefor have

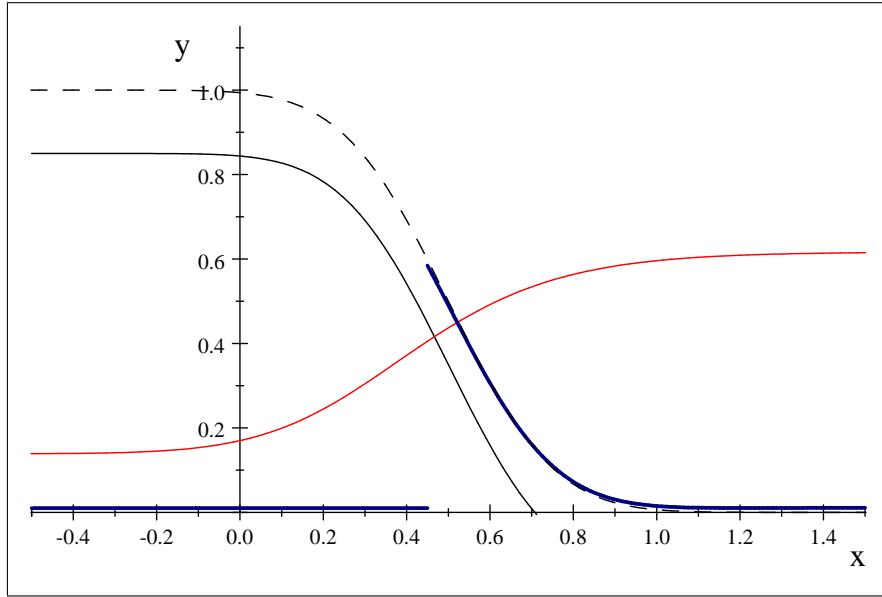
$$B_{opt} = \begin{cases} \tilde{A} + \sigma \ln \left(\frac{R(\theta)}{2\sigma\phi(\theta)} \right) & \text{if } \tilde{A} < \frac{R(\theta)}{\phi(\theta)} - \sigma \ln \frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma \\ 0 & \text{else} \end{cases}.$$

5.3 Appendix 3: An example: θ_0 and $\hat{\theta}$



$\xi_{CB} = 0$: θ_0 is the intersection of $A(\theta)$ (black) and $\frac{R(\theta)}{\phi(\theta)} - \sigma \ln \frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma$ (red).

Further B_{opt} is blue and $\hat{\theta}$ is the intersection of the black (strength of the attack) and the blue line. $\hat{\theta}(\xi_{CB} = 0) = \theta_0$.



$\xi_{CB} = -0.15$: θ_0 is the intersection of $A(\theta) + \xi_{CB}$ (solid black) and $\frac{R(\theta)}{\phi(\theta)} - \sigma \ln \frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma$ (red). Further B_{opt} is blue and $\hat{\theta}$ is the intersection of the dashed black (real strength of the attack) and the blue line.

5.4 Appendix 4

$$1. B_{opt} = G(x^* - \theta) + \xi_{CB} + \sigma \ln \left(\frac{R(\theta)}{2\sigma\phi(\theta)} \right) \Rightarrow R \uparrow \Rightarrow B_{opt} \uparrow$$

$$\theta_0(\xi_{CB}) = \liminf \left\{ \theta : \underbrace{G(x^* - \theta) + \xi_{CB}}_{:=LS} \leq \underbrace{\frac{R(\theta)}{\phi(\theta)} - \sigma \ln \frac{R(\theta)}{2\sigma\phi(\theta)} - \sigma}_{:=RS} \right\}$$

$$\left. \begin{array}{l} R \uparrow \Rightarrow RS \uparrow \\ R \uparrow \Rightarrow x^* \downarrow \Rightarrow LS \downarrow \end{array} \right\} \Rightarrow \theta_0 \downarrow$$

$$2. \text{ analogously: } \phi \uparrow \Rightarrow B_{opt} \downarrow$$

$$\left. \begin{array}{l} \phi \uparrow \Rightarrow RS \downarrow \\ \phi \uparrow \Rightarrow x^* \uparrow \Rightarrow LS \uparrow \end{array} \right\} \Rightarrow \theta_0 \uparrow$$

5.5 Appendix 5: Data

Raw Data Sources

JS: Joint BIS-IMF-OECD-World Bank statistics

WMM: World Market Monitor

IFS: Datastream IFS

JPM: JP Morgan

Data has been checked for outliers and data errors.

Variable	Definition	Source
NEREP	nom. exchange rate end of period	IFS
CPI	consumer price index	IFS
RESMG	reserves minus gold	IFS - JS
DISCRATE	discount rate	IFS
MMRATE	money market rate	IFS
DRATE	deposit rate	IFS
LRATE	lending rate	IFS
DOMC	domestic credit	IFS
DOMCPS	domestic credit to private sector	IFS
M1	monetary aggregate	IFS
GOVDEF	government deficit	IFS
REER	real effective exchange rate	WMM - JPM
GDPN	nominal gdp	WMM
GDPR	real gdp	WMM
CA	current account	WMM
TLIABLOC	local currency denominated debt	JS
longUS	long term us interest rates	IFS
FDI	foreign direct investments	IFS
DEBT	total debt	JS
RESMG	international reserve assets (excluding gold)	JS
LIAB1Y	liabilites to banks - due within a year	JS
EX	exports f.o.b	IFS
IM	imports c.i.f.	IFS