Speculative Attacks: Panic or Arbitrage¹

Allan Bødskov Andersen
Department of Finance
The Aarhus School of Business
Fuglesangs Allé 4
DK-8210 Aarhus V.
Denmark

Phone: +45 8948 6656

Fax: +45 8615 1943

E-mail: aan@hha.dk

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Abstract

This paper formulates a second generation currency crises model, which is consistent with many facts regarding the structural economies in Southeast asia. Emphasis is laid on the propagation mechanism from a financial crisis to a currency crisis. Micro-foundation, endogenous labour supply, and nominal wage rigidity are key features of our model. It has the same closed form solution as previous second generation models. We then formulate a statistical test, which tests the null-hypothesis of an ‘arbitrage’ crisis against a ‘panic’ crisis alternative, without needing any measure of fundamentals. The test amounts to a test for whether there are discrete jumps in a measure of a devaluation probability. Thus, the test requires as input only a time series of devaluation probabilities, and these are estimated for five Asian countries using a probit-Markov model. The results show big inter-country differences in the characterization of the recent crisis in terms of credibility and the role of fundamentals.

JEL Classification: C52, F31, F33, F41

1 Introduction

In recent years the recurrence of speculative attacks on currency pegs and target zones has received much attention from economists working with open economy macroeconomics. Disregarding questions concerning the desirability of a fixed exchange rate regime, the main question to ask from an economic policy point of view is whether speculative attacks can be prevented by taking appropriate measures (usually a strengthening of “fundamentals”), and whether the appropriate measures are worthwhile. Evaluating the potential good of strengthening fundamental economic variables requires an understanding of the nature of speculative attacks — do they take the form of “panic” or are they rational reactions to fundamental economic conditions in a country or region?

Much economic theory has shown how fundamentals can be the driving force behind speculative attacks. The so-called first generation of models of speculative attacks stressed how internal inconsistencies in economic policies can lead to speculative attacks. Krugman (1979) is an oft-cited contribution to this literature, which demonstrated that speculators attack a fixed exchange rate regime before foreign reserves run out by “natural causes”. This happens because an arbitrage opportunity arises at the point of exhaustion of a country’s foreign reserves, and the elimination of this arbitrage opportunity leads speculators to attack the currency prior to the exhaustion of foreign reserves.

There are two main problems with this theory. One relates to the mechanical nature of the monetary authority’s actions and the other relates to the predictability of the speculative attack. The first problem concerns the model assumptions: if a government has chosen to implement the fixed exchange rate regime in the first place, why does it not defend the regime instead of letting speculators force its abandonment? The assumption of passivity on the part of economic policy authorities can hardly be attributed to lack of access to international capital markets, as expressed e.g. in Obstfeld (1994):

“For industrial European countries with access to world capital markets, reserve adequacy *per se* is far less of a concern than it was in the early 1970s; this factor no longer deserves the primacy assigned it in Krugman’s analysis.”

The second generation of models of speculative attacks addresses this problem: the objectives of the monetary authority are spelled out explicitly, and the benefits from defending a currency regime are weighted against the costs. Only when the benefits from maintaining a currency regime exceed the costs will the monetary authority defend a currency, and speculators try to determine whether a given monetary authority has high or low costs of defending a given regime. If costs are deemed too high, then speculators

attack the currency regime. For a model containing this mechanism, see e.g. Obstfeld (1994).

The second problem is more of an empirical nature: papers like e.g. Eichengreen and Wyplosz (1993), which reviews the onset of the EMS crisis finds little evidence of deteriorating fundamentals in some of the EMS countries which were forced to devalue in 1992. In particular, Sweden and Ireland did not show the expected signs of forward exchange rates falling outside the currency bands. Great Britain and Italy (and later the rest of the EMS-countries) abandoned their semi-fixed exchange rates far before their international reserves were exhausted, and none of them were precluded from international financial markets. These and other findings have given strength to the presumption that speculative attacks may be a self-fulfilling event coming purely out of speculators' expectations of future policy changes. Self-fulfilling expectations were first introduced by Obstfeld (1986) in a first generation model, but they can arise in both types of models above as demonstrated by e.g. Obstfeld (1996), strengthening the hypothesis of self-fulfilling attacks. There is thus a solid theoretical foundation for asserting that speculative attacks may take the form of panic.

The recent crisis in Asia presents new challenges for economists seeking the forcing mechanisms behind the incident. Indeed, the Asian "case" has fostered a very interesting debate among researchers as to how we should approach the analysis of the crisis. In particular, the absence of the "Usual Suspects", i.e. productivity slowdown, deterioration of international reserves, rising domestic interest rates etc., has led Radelet and Sachs (1998) to argue, that the crisis was by and large caused by the rapid shifting moods of speculants, and hence, the crisis could have been avoided or at least did not have to be as severe as it revealed itself to be. On the other hand, Krugman (1998), Corsetti, Pesenti and Roubini (1999) have argued, that the crisis was indeed justified by fundamentals, when these are interpreted in an appropriate broad sense.¹ While the debate may go on for a long time to come, the answer is ultimately empirical, and this paper contributes to resolving the question.

A problem for the "panic" versus "arbitrage" debate is that empirical studies so far have not succeeded in formally testing the hypothesis of "panic". So far the most ambitious attempt at formally testing whether the collapse of a currency-peg was the result of self-fulfilling speculation is Jeanne (1997),² but this study formally tests whether panic could

¹However, in Krugman (1999) he seems to have changed his mind, now favouring an explanation based on self-fulfilling expectations.

²Recently, Masson (1999) investigates the possibility of multiple equilibria in the Asian countries using an approach closely related to Jeanne (1997).

be the cause of collapse. Upon having reached this conclusion, Jeanne observes:

“As the jumps in the estimated regime-shift probability show, self-fulfilling animal spirits allow the model to capture the well-identified episodes of acute speculation which took place in 1992 and 1993.”

This paper goes one step further and tests whether the actual regime-shift probability jumps. Jumps in the regime-shift probability is the defining characteristic of the self-fulfilling speculation hypothesis, hence testing the hypothesis of jumps amounts to a formal test of this hypothesis. In this paper, in order for a currency crisis to qualify as being characterized as “panic”, we shall make the identifying assumption, that not only do fundamentals support multiple equilibria, but also that the economy actually visits one or more of them during the unfolding of a crisis.

We base our empirical test on the theoretical model outlined in the next section. The model is designed to be consistent with prevalent macroeconomic conditions in Southeast Asian economies prior to the collapse, as well as it allows for multiple equilibria as in e.g. Jeanne (1997). It has been stressed by e.g. Krugman (1998) and Corsetti, Pesenti and Roubini (1998a) that the growth strategies followed by many countries in the region encouraged excessive corporate borrowing to finance low-yield projects. Specifically, the government seems to have played an important role in fostering structural weaknesses in the corporate sector. Explanations of negative government influence range from lax banking regulation and implicit “bailout” guarantees to political favouritism. We build our model around this structural weakness of the corporate sector.³ The government has two ways of meeting an output target: first, it can offer a bailout on failed projects, thereby ensuring investors a high rate of return. This results in overinvestment and thereby higher output. Second, the government can devalue — or leave the currency peg — and thus increase output. We follow Corsetti et al. (1999) in assuming that there is a limit to the extent to which foreign creditors will finance increasing corporate debt, and hence that at some point the government may be forced to devalue in order to meet its output target. From this point on, the analysis is that of a standard second generation currency crisis model. We thus model the deterioration of fundamentals in the “bailout” regime as in a standard first generation currency crisis model, but when fundamentals have deteriorated sufficiently, there is scope for self-fulfilling speculation. Using this approach our model is consistent with many pre-crisis facts, like for instance

³The empirical relevance of Moral Hazard in financial intermediaries in the Asian countries has been provided by Sarno and Taylor (1999). They build a test upon the observation that the presence of Moral Hazard causes asset-price bubbles. The evidence is indeed affirmative.

the generally good state of public finances, low unemployment and high (but decreasing) growth rates.

We present a fairly detailed exposition of the model, though our motivation is mainly empirical. We do this because we can show in an instructive way how the recent micro-founded model of the Asian crisis presented by Corsetti et al. (1999)⁴ can be modified and extended to a second generation framework, in which a currency crisis is not expected to follow a financial crisis with certainty. Rather, a currency crisis follows as an optimal policy reaction from a government facing a financial crisis. This offers a framework in which we can identify and extract testable implications for the two main views on the Asian crisis described above. We must stress, however, that the empirical test by no means is restricted to follow from the very special model presented here; as we will see, a very large class of models indeed yield exactly the same empirical implications.⁵ Our model shares many properties with the CPR-model, consequently, we will focus on the issues where our model deviates from theirs.

The paper is outlined as follows. Section 2 presents a crisis model which encompasses the possibility of multiple equilibria, while still being consistent with several important pre-crisis facts in many of the Asian countries infected with unstable currencies. Section 3 motivates our empirical approach, and presents the testing strategy. In section 4 the data is described, and results are presented. Section 5 concludes.

2 The Model

We analyze a small open economy in which the firms are specialized in the production of one internationally traded good. The firms produce output by means of two types of factor inputs, labour and capital. The consumption good can be converted into the investment good (capital) at zero costs, and we furthermore abstract from installation costs. The firms operate under perfect competition, i.e. they face a perfectly elastic demand curve for goods. Individuals own the firms, supply labour, and rent capital to the firms. Following Blanchard and Kiyotaki (1987) and Obstfeld and Rogoff (1995), we assume that individuals have a degree of monopoly power in an otherwise non-segmented labour market.

⁴For notational ease, we will henceforth refer to Corsetti et al. (1999) as the “CPR-model”.

⁵The empirical implications from our model is in fact identical to the conditions derived in Jeanne (1997), who also stresses the generality of his result.

2.0.1 The firms

Assume there is a continuum of individuals, indexed by j , $j \in [0, 1]$. Each individual supplies labour of type j according to a labour supply schedule to be described shortly. Let $l_t(j)$ denote the supply of labour of type j at time t . The representative firm produces the consumption good according to the production function

$$Y_t = \tilde{A}_t K_t^\alpha L_t^{1-\alpha} \quad 0 < \alpha < 1, \quad (1)$$

where K_t denotes the capital stock at time t . The representative firm employs labour according to the CES specification

$$L_t = \left[\int_0^1 l_t(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}, \quad (2)$$

where L_t denotes the (aggregate) level of labour input in the firm. θ is the wage elasticity of demand for labour that worker j faces, and is furthermore the elasticity of substitution between each type of labour in the production function. The assumption that the prevailing market conditions on the labour market is well characterized by monopolistic competition, implies that θ is strictly greater than one.

$\tilde{A}_t$ is a stochastic, identical independent distributed technology shock. Specifically, we follow the CPR-model in defining

$$\tilde{A}_t = \begin{cases} A + \sigma & \text{with probability } \frac{1}{2} \\ A - \sigma & \text{with probability } \frac{1}{2}. \end{cases}$$

Thus, A is the unconditional expectation of $\tilde{A}$.

As for the timing of variables, we assume that investments at date t determines the capital level at date $t + 1$. Furthermore, we assume that capital depreciates fully each period, such that (denoting investments by I)

$$I_t = K_{t+1}. \quad (3)$$

Again, this assumption ensures analytical tractability, and can be relaxed along the lines presented in Bénassy (1995).

The firm now solves the following profit maximization problem

$$\max_{l_t(j), K_t} E_t \Pi = P_t Y_t - \int_0^1 w_t(j) l_t(j) dj - P_t \rho_t K_t, \quad (4)$$

subject to (2) and (1). P_t denotes the price level at t , ρ_t is the real rental rate of capital, and $w_t(j)$ is the nominal wage for a unit of type j labour input. The first order conditions are

$$\frac{w_t(j)}{P_t} = (1 - \alpha) A K_t^\alpha l_t(j)^{-\frac{1}{\theta}} L_t^{\frac{1}{\theta} - \alpha}, \quad (5)$$

$$\rho_t = \alpha A K_t^{\alpha-1} L_t^{1-\alpha}. \quad (6)$$

Since the firms behave competitively, the factors of production are paid their expected marginal products in equilibrium.

The assumption of monopolistic competition in the labour market is the single most important deviation we make from the CPR-model, which assumes a constant, exogenous supply of labour. Later, we will see that this will make it possible for the government to boost output by a devaluation, if nominal wages are rigid in the short run. In the CPR-framework, a devaluation (if it occurs) follows from an inconsistent monetary policy in classic Krugman (1979)-style.

2.0.2 The individuals

Individuals have access to international financial markets. Furthermore, since individuals have a degree of monopoly power, they take the firm's demand for labour (5) into account when solving their optimization problem. We further assume that individuals are risk neutral. Agents are infinitely lived and derive utility from consumption, real balances, and leisure. Their rate of time preference is equal to the world real interest rate. At date t , the representative household j maximizes the following infinite horizon expected utility function

$$E_t \sum_{s=t}^{\infty} \frac{1}{(1+r)^{s-t}} \left[C_t(j) + \chi \log \left(\frac{M_t(j)}{P_t} \right) - \frac{\kappa}{2} l_t(j)^2 \right], \quad (7)$$

subject to an intertemporal flow budget constraint, expressed in nominal terms as

$$P_t B_{t+1}(j) + M_t(j) = P_t(1+r)B_t(j) + M_{t-1}(j) + w_t(j)l_t(j) + P_t \rho_t K_t - P_t C_t(j) - P_t I_t - P_t T_t^{to}(j), \quad (8)$$

where $M_t(j)$ is type j 's holdings of real balances at the end of period t , $B_t(j)$ is j 's net position of a real bond in the beginning of period t ,⁶ and the real bond is the only internationally traded asset. It has a face value of one, and pays the owner one plus the world real interest rate next period. $T_t^{to}(j)$ is the net total tax (benefit) paid (received) in period t by individual j . Total taxes are decomposed into a lump-sum part denoted $T_t(j)$ and a distortionary part $\tau_t(j)$, which is dependent on the amount of labour input

⁶This dating convention obeys the notation suggested by Obstfeld and Rogoff (1996), and is important since we let individuals derive utility from real balances. The 'end-of-period-real-balances' approach adopted here ensures (absent any nominal rigidities) that money is neutral *per se*. However, it implies that individuals do not derive utility of real balances within the period they enjoy the transaction services they provide. See Rankin (1994) for further discussion.

as well as on the capital stock.⁷ The exact properties of $\tau_t(j)$ are defined below.

The households maximize (7) subject to (5) and (8).⁸ Allowing for expected future distortionary taxes on capital and labour, the first order conditions are

$$\frac{M_t(j)}{P_t} = \chi \frac{1 + i_{t+1}}{i_{t+1}}, \quad (9)$$

$$l_t(j)^{1+\frac{1}{\theta}} = \frac{1}{\kappa} \left(1 - \frac{1}{\theta}\right) (1 - \alpha) A K_t^\alpha L_t^{\frac{1}{\theta}-\alpha} - \frac{1}{\kappa} E_t \frac{\partial \sum_{s=0}^{\infty} \tau_{t+s}/(1+r)^s}{\partial l_t(j)}, \quad (10)$$

$$\rho_{t+1} - E_t \frac{\partial \sum_{s=0}^{\infty} \tau_{t+s}/(1+r)^s}{\partial K_{t+1}} = 1 + r. \quad (11)$$

(9) is the demand for real balances. It has been made dependent on i , the nominal interest rate, by applying the uncovered interest parity and the purchasing power parity, respectively,

$$1 + i_{t+1} = (1 + r) E_t \left(\frac{S_{t+1}}{S_t} \right), \quad (12)$$

$$P_t = S_t P_t^*, \quad (13)$$

where S_t denotes the nominal exchange rate defined as the amount of the home currency needed to buy one unit of the foreign currency, and P_t^* denotes the foreign price level. Henceforth, we will make the usual normalization, $P_t^* \equiv 1$.

(10) is the supply of labour. By using the expression for the real product wage (5), it can be re-formulated as

$$l_t(j) = \frac{1}{\kappa} \left(1 - \frac{1}{\theta}\right) \frac{w_t(j)}{P_t} - \frac{1}{\kappa} E_t \frac{\partial \sum_{s=0}^{\infty} \tau_{t+s}/(1+r)^s}{\partial l_t(j)}, \quad (14)$$

which reveals (abstracting from the tax distortion) that the supply of labour is inefficiently low, due to individuals' monopoly power. As the degree of monopoly power decreases (i.e. as θ tends to infinity) the supply of labour tends to the efficient level, which would be the outcome under perfect competition. It also implies that the labour supply locus fails to reflect directly the marginal disutility of labour. Hence, workers are over-compensated in equilibrium. This implies that the amount of labour in equilibrium is determined by

⁷With this setup, we avoid making the assumption of a segmented – and indeed a very heterogenous – labour market, as in the CPR-model.

⁸The constrained maximization problem can be transformed to an unconstrained maximization problem in the following way. Divide (8) by P_t and substitute (5) into the resulting expression. Isolate $C_t(j)$, and insert this into the object function. The first order conditions follow by taking derivatives with respect to $M_t(j)$, $l_t(j)$ and I_t , taking aggregate labour supply L_t as given. Asset accumulation is determined residually.

the labour demand in the short run, in case the nominal wage is rigid.⁹ This fact is very important in determining the short run properties of the model.

Lastly, (11) is the standard arbitrage condition. Households invest in capital exactly to the point where the expected marginal payoff equals the payoff on the foreign asset.

2.0.3 The Government

At this point, it suffices to stress the redistributive role of the government. Denoting T_t^{to} and M_t aggregate taxes and money supply, respectively, we assume that the government finances T_t^{to} purely out of seignorage, such that

$$T_t^{to} + \frac{M_t - M_{t-1}}{P_t} = 0. \quad (15)$$

We shall later be more specific about the goals the government might pursue, indeed, this will play an important role in determining the crisis propagation.

2.1 Dynamics of the Pre-crisis Regime: The Role of Moral Hazard

As is common in the literature originating from Obstfeld and Rogoff (1995), we will limit ourselves to the analysis of an equilibrium, in which all the households are symmetric. Hence, individuals supply equal amounts of labour, demand the same wage, face identical tax schedules etc. Therefore we can drop the argument j everywhere, and identify individual variables with aggregates.¹⁰

2.1.1 The bailout Scheme

We follow the CPR-model in assuming that the government insures the individuals' firms against adverse technology shocks. In particular, individuals expect that in case of a favorable shock to technology ($\tilde{A} = A + \sigma$), the government will do nothing, and in case of an adverse shock ($\tilde{A} = A - \sigma$), the government bails out domestic firms, and thereby guarantees a return on investment which is equal to the world real interest rate. For analytical convenience, we will also assume that the government guarantees the individuals the wage which prevails under the good state of nature. This assumption has no influence on any of the subsequent qualitative results.

⁹These properties of the labour market are discussed in greater detail in Obstfeld and Rogoff (1996).

¹⁰Note that $l_t(j) = L_t$ for all j in symmetric equilibrium.

This bailout scheme can be consistent with the government's budget constraint only if the present value of the transfers to the individuals equals the present value of future net taxes. Specifically, assume that from a time t_0 to some t_{max} , the government's solvency constraint reads

$$E_{t_0} \sum_{s=t_0+1}^{\infty} \left(\frac{1}{1+r} \right)^{s-t_0} (-T_s^{to}) = E_{t_0} \left[\sum_{s=t_0+1}^{t_{max}} \left(\frac{1}{1+r} \right)^{s-t_0} \phi_s^K K_s + \sum_{s=t_0+1}^{t_{max}} \left(\frac{1}{1+r} \right)^{s-t_0} \phi_s^l L_s \right], \quad (16)$$

where ϕ^K denotes the bailout transfer per unit of capital, and ϕ^l denotes the bailout transfer per unit of supplied labour. $\phi^K = \phi^l = 0$ in the good state, and we assume that

$$\phi_t^K = 2\sigma\alpha K_t^{\alpha-1} L_t^{1-\alpha}, \quad (17)$$

$$\phi_t^l = 2\sigma(1-\alpha) \left(1 - \frac{1}{\theta} \right) K_t^\alpha L_t^{-\alpha} \quad (18)$$

in the bad state. Also, $-\phi_{t+1}^K = E_t \frac{\partial \sum_{s=0}^{\infty} \tau_{t+s}/(1+r)^s}{\partial K_{t+1}}$, and $-\phi_{t+1}^l = E_t \frac{\partial \sum_{s=0}^{\infty} \tau_{t+s}/(1+r)^s}{\partial L_{t+1}}$. Now, from (6) and (11) the capital stock is determined by the equilibrium condition

$$1+r = \alpha(A+\sigma)K_t^{\alpha-1}L_t^{1-\alpha}, \quad (19)$$

i.e. as if there was no uncertainty about the technology always being in the good state. Similar arguments allow us to write the first order condition (14) under the bailout scheme as

$$L_t = \frac{1}{\kappa}(A+\sigma) \left(1 - \frac{1}{\theta} \right) (1-\alpha)K_t^\alpha L_t^{-\alpha} \quad (20)$$

in the symmetric equilibrium.

Consistent with the evidence from Asia, note that the implicit bailout guarantee does not necessarily strain the current fiscal balance. In particular, the government can let $T_t^{to} = 0$ before t_{max} . However, the individuals will be able to finance their losses by borrowing in the international financial markets against future bailout transfers from the government. Of course, the bailout scheme will put considerable strains on *future* fiscal balance. Before t_{max} , however, the result is excessive external debt.

To see this, we need to solve for the level of capital and labour input in the pre-crisis steady state. Conditions (5), (6), (11), and (14) constitute four equations in four unknowns: ρ_t , $\frac{W_t}{P_t}$, K_t , and L_t . Solving the system for the case without bailout gives the following natural capital stock and employment level

$$\bar{K} = \left[\frac{\alpha \left[\frac{1}{\kappa}(1-\alpha) \left(1 - \frac{1}{\theta} \right) \right]^{\frac{1-\alpha}{1+\alpha}} A^{\frac{2}{1+\alpha}}}{1+r} \right]^{\frac{1+\alpha}{1-\alpha}}, \quad (21)$$

$$\bar{L} = \left[\frac{\alpha^\alpha \left[\frac{1}{\kappa} (1 - \alpha) \left(1 - \frac{1}{\theta} \right) \right]^{\frac{1-\alpha^2}{1+\alpha}} A}{(1+r)^\alpha} \right]^{\frac{1}{1-\alpha}}. \quad (22)$$

Under the bailout scheme, similar calculations yield

$$\hat{K} = \left[\frac{\alpha \left[\frac{1}{\kappa} (1 - \alpha) \left(1 - \frac{1}{\theta} \right) \right]^{\frac{1-\alpha}{1+\alpha}} (A + \sigma)^{\frac{2}{1+\alpha}}}{1+r} \right]^{\frac{1+\alpha}{1-\alpha}}, \quad (23)$$

$$\hat{L} = \left[\frac{\alpha^\alpha \left[\frac{1}{\kappa} (1 - \alpha) \left(1 - \frac{1}{\theta} \right) \right]^{\frac{1-\alpha^2}{1+\alpha}} (A + \sigma)}{(1+r)^\alpha} \right]^{\frac{1}{1-\alpha}}. \quad (24)$$

Hence, $\hat{K} > \bar{K}$ and $\hat{L} > \bar{L}$, where a “ $\hat{}$ ” refers to the bailout, and a “ $\bar{}$ ” refers to the absence of bailout, respectively. From the production function, it is directly verified that $\hat{Y} > \bar{Y}$. Thus, we can conclude from these results, that the input of labour as well as the capital stock is higher under the bailout scheme, than what would have been the case without the scheme. Note that the “bar”-levels do not correspond to the efficient outcomes. The distortion inherent from the monopolistic competition in the market for labour are still present in $\bar{K}$, $\bar{L}$, and $\bar{Y}$.

With these results, the argument for the country running an excessive external debt (relative to the case of no bailout) is parallel to those presented in the CPR-model, to which we refer for the details. Basically, the result follows from the fact that the privileged are able to borrow in the international financial markets against future bailout revenue. Hence, in periods with favorable shock to technology, there will be no borrowing, and in periods with a negative shock, the individuals will borrow in order to finance their losses. Creditors are willing to lend to the individuals, since they anticipate that current private and corporate debt will be translated into future public liabilities. This differs grossly from the situation with no bailout scheme. In this situation, a loss will be considered as bad luck, and there will be no excessive borrowing on average. However, the government cannot credibly deny the existence of a bailout policy, and hence $\bar{K}$ and $\bar{L}$ cannot be a part of a time-consistent equilibrium.

2.2 Financial crisis and crisis Propagation

The situation described above is not sustainable. Assume that at some point t_{max} , external debt reaches a critical level, and creditors seize to expand credit any further, if

the government fails to demonstrate their willingness to initiate the bailout transfers.¹¹ Hence, t_{max} is the time at which the country enters a financial crisis, and the government starts to bail out individual and corporate debt. Now, assume that as a condition to roll over existing debt, and as a condition for still having access to international financial markets, the government is forced to leave its bail out scheme (think of this as being a requirement from the IMF). Hence, after t_{max} , we maintain the assumption that the capital stock, the input of labour, and production fall to their natural levels, $\bar{K}$, $\bar{H}$, and $\bar{Y}$.

2.2.1 Government Incentives

In order to explain why the financial crisis propagates into a currency crisis, we need to be more specific about the government's preferences at this point.

Recall that there are two sources of imperfections in this economy. One stemming from the households having monopolistic power in the labour market, and one stemming from the excessive investments/borrowing due to the bailout scheme. Suppose that the government cares about the inefficiently low production level $\bar{Y}$, and hence sets a production goal $Y^* > \bar{Y}$. At the same time, the government dislikes inflation (which is equal to a depreciation, since purchasing power parity holds). We summarize this in assuming that the government minimizes a loss function given by

$$\mathcal{L}_t = (y_t - y^*)^2 + \mu_t \iota(\Delta s_t), \quad (25)$$

where s denotes the log of the nominal exchange rate, lower case y 's denote the log of the upper case Y 's, and $\iota(\cdot)$ is an indicator function, which equals one in case of devaluation, and zero otherwise. The escape clause term μ_t has been given numerous interpretations. Especially in the literature concerned with EMS crises in 1992-3, it has been interpreted as being a political cost the government faces in case of devaluation (i.e. loss of reputation). In terms of the Asian crises, it may more naturally reflect the direct cost encountered when the real domestic burden of foreign debt is increased upon a devaluation, and/or higher ex-post interest rates.

¹¹Similarly, the CPR-model postulates the existence of a "show me the money" condition, which is introduced through a critical level for the debt-to-reserves ratio. While we could have adopted a similar setup here, such a very specific constraint seems unnecessary narrow in nature. The CPR-model further assumes that creditors refuse to roll over any existing debt, despite the fact that creditors' expectations about the existence of a bailout scheme is validated. This exclusion from borrowing in the international financial markets produce an expectation of future monetization of public debt, which in turn leads to deterioration of foreign reserves as the government tries to maintain its currency peg. Hence, such a setup corresponds to a classical first generation model of currency crisis.

Now, if $Y^* = \hat{Y}$ it is obvious that the government is able to minimize its loss function ($\mathcal{L} = 0$) by implementing the bailout scheme described above, in combination with a exchange rate peg.¹²

2.3 Post-Financial crisis Dynamics

The absence of a credible bailout scheme after t_{max} , creates a *credibility distortion* of size $y^* - \bar{y} > 0$ for the government, and creates an incentive for the government to create surprise inflation.¹³ In order to generate this result, we need to make two key assumptions: First, the nominal wage for workers are rigid in the short run, and second, they fix the nominal wage based on an expectation about future inflation. Furthermore, recall that the stock of capital is constant in the short run, since it takes one period to install new capital.

Now, what is the government's incentive to devalue? Suppose it does, then the real product wage will fall, since the nominal wage is fixed. Therefore the demand for labour will increase. Recall that because of the monopoly power, workers set a wage above their marginal disutility of labour. Thus, *ex post* it will always be optimal for individuals to supply an extra amount of labour, should the demand increase due to falling real product wage. Therefore, in the short run, the input of labour is demand determined, such that condition (10) does not bind.

In order to illustrate the basic point, we assume the following is true in the short run in the post-financial crisis period. The representative firm's demand for labour is based on their expectation about the technology shock $\tilde{A}$. The individuals fix the nominal wage at $\bar{W}$, say, based on their time t expectation about future inflation, P_t^e . Absent any devaluation the production level $\bar{Y}_t$ (slightly abusing notation) is given by (1) and (5) as

$$\bar{Y}_t = (1 - \alpha)^{\frac{1-\alpha}{\alpha}} A^{\frac{1}{\alpha}} \bar{K} \bar{W}^{\frac{1-\alpha}{-\alpha}} P_t^e^{\frac{1-\alpha}{\alpha}} \equiv \Phi P_t^e^{\frac{1-\alpha}{\alpha}}, \quad (26)$$

where $\Phi = (1 - \alpha)^{\frac{1-\alpha}{\alpha}} A^{\frac{1}{\alpha}} \bar{K} \bar{W}^{\frac{1-\alpha}{-\alpha}}$ is constant. *Actual* output Y_t is determined by the

¹²In the second generation currency crises literature originating from Obstfeld (1994), the present quadratic loss function is a popular choice. However, output in the loss function is often motivated by its close correlation with employment, in models that build upon Phillips curve assumptions. Here, while the output goal is reached by making further distortions in the economy, it is still consistent with a story building on unemployment, since $\hat{L} > \bar{L}$. Furthermore, this result carries through even if $\phi^l = 0$ in all (both) states of nature.

¹³As is common in the literature, we assume that the government (or the monetary authorities) controls the exchange rate, and hence the price level, directly.

actual inflation,

$$Y_t = \Phi P_t^{\frac{1-\alpha}{\alpha}}. \quad (27)$$

Taking natural logs and subtracting the two preceding equations, we reach

$$y_t = \bar{y}_t + \frac{1-\alpha}{\alpha}(p_t - p_t^e) = \bar{y}_t + \frac{1-\alpha}{\alpha}(s_t - s_t^e). \quad (28)$$

This confirms the intuition above: The government can boost production in the short run by choosing a price level greater than the expected price level, thereby creating an incentive to devalue. Any public announcements about (absence from) future devaluations from the government thus suffer from the time inconsistency problem addressed by Barro and Gordon (1983).

This suggests the following propagation mechanism: Given the government is forced to leave its bailout policy, it gives them an incentive to devalue which was not present before the financial crisis. The model is now in a form, in which we can use the general framework suggested by Jeanne (1997), to carry out the empirical analysis.

2.4 Discussion

As in the CPR-model, the model presented in this section is consistent with several of the pre-crisis facts in many Asian countries. First, the fiscal balances were generally in a good state before the crises. In the model, it is shown that it is by no means necessary for a country vulnerable to speculative attacks to run large budget deficits. It is the net present value of future public liabilities stemming from the combination of 'bad' corporate debt and the bailout policy, which hampers the country's shield against speculative attacks. Second, the countries were running low, but increasing external deficits in the period before the crises. In the model, the external deficit is higher, the longer the sequence of bad technology shocks. Third, low unemployment and generally high growth rates are explained by the bailout policy pursued by the government. Consistent with the evidence from Asia, growth slowdown and high unemployment were not manifested before well into the crisis, when the government was forced to leave its bailout policy.

All these properties are shared with the CPR-model. However, our setup allows for the fact, that the Asian countries continued to have access to the international financial markets after the crisis began, though admittedly on very different terms and conditions. In the CPR-model, it is assumed that the government is forced to monetize the abrupt increase in public deficit on the onset of the crisis, which is equivalent to conducting monetary policy which is inconsistent with a currency peg, given limited international reserves. Here, the government stays with the currency peg, as long as it finds it optimal

to do so. Indeed, the ‘fundamentals’ may be in such a bad state, that the currency crisis essentially is unavoidable, but this is only one of a range of alternatives this framework allows for.

We shall henceforth identify a situation in which the currency crisis were unavoidable as ‘arbitrage’, since equilibrium in this case is determined by ruling out an arbitrage opportunity at the point, where the government runs out of international reserves. ‘Panic’ is used to describe a situation, in which a currency crisis arises when it did not have to, merely because of suddenly abrupt shifts in the speculators’ expectations about the sustainability of the currency peg. As we will see shortly, since expectations of a devaluation increase the government’s costs to defend the peg, devaluation expectations may be self-fulfilling, adding to the claim that the crisis were more severe than necessary. The next sections test ‘arbitrage’ against the ‘panic’ alternative.

3 Empirical implementation

We start by showing how the model can be brought to a form in which the framework of Jeanne (1997) is applicable, and thereby demonstrating the possibility of multiple equilibria explicitly. This will require a number of simplifying assumptions.

3.1 Definitions and maintained assumptions

First, we define an equilibrium as a sequence of speculators’ beliefs and policy determined currency levels, in which the beliefs are optimal given the government behaviour, and government behaviour is optimal given beliefs (i.e. a Nash equilibrium). Assume that individuals form their expectation about the future currency level rationally, such that

$$E_t(s_{t+1}) = s_t^e. \quad (29)$$

Then, assuming that $y_t = \bar{y}_t$ initially, use (28) to deduce that

$$y_{t+1} = y_t + \frac{1-\alpha}{\alpha}[s_{t+1} - E_t(s_{t+1})] = y_t + \beta[s_{t+1} - E_t(s_{t+1})], \quad (30)$$

where $\beta \equiv \frac{1-\alpha}{\alpha}$. If the government leaves the currency peg, assume that the government will devalue with an amount Δs . Then by denoting the individuals time t assesment about the possibility of a devaluation at time $t + 1$ by π_t , we have

$$E_t(s_{t+1}) = \pi_t \Delta s, \quad (31)$$

where we have normalized the initial currency level to zero, without loss of generality. In the following we will also normalize the (log of) output target y^* to zero. We are now in a position to evaluate the governments' temptation to devalue. If the government devalues, production is given by

$$y_t^d = y_{t-1} + \beta(1 - \pi_{t-1})\Delta s, \quad (32)$$

whereas if it does not,

$$y_t^p = y_{t-1} - \beta\pi_{t-1}\Delta s. \quad (33)$$

The benefit, H , from the peg is found from evaluation of the governments' loss-function under the two alternatives

$$H_t = \mathcal{L}_t^d - \mathcal{L}_t^p = \mu_t + (\beta\Delta s)^2 + 2\beta\Delta s y_{t-1} - 2(\beta\Delta s)^2 \pi_{t-1}, \quad (34)$$

where $\mathcal{L}_t^d$ and $\mathcal{L}_t^p$ is the value of the loss function contingent on a devaluation and staying with the peg, respectively.¹⁴ Now, Proposition 1 in Jeanne (1997) proves that when the system can be rewritten in the form (34), then the possibility of multiple equilibria depends on the model's parameters, and from the properties of the distribution function of the innovation in the 'fundamentals' variable

$$\psi_t = \mu_t + (\beta\Delta s)^2 + 2\beta\Delta s y_{t-1}, \quad (35)$$

where the innovation term is given by $u_t = \psi_t - \psi_{t-1}$. For a given level of fundamentals there may be a unique equilibrium (i.e. a 1 : 1 -mapping between ψ_t and π_{t-1}). However, for certain parameter values and contingent on the properties of the distribution function for u_t , there may exist more than one level of π_{t-1} compatible with a given level of the fundamentals. This situation is illustrated in figure 1. If fundamentals are in the interval $[\psi^{**}, \infty[$, then there is a unique (low) level of the devaluation probability, such that the currency peg survives unless a very negative value of the innovation in the fundamentals is realized. Similarly, if fundamentals belong to $] - \infty, \psi^*]$, then there is a unique (high) level of the devaluation probability. Hence, the currency peg is abandoned unless a very favourable shock to fundamentals occurs. However, there may exist a middle range of the fundamentals, $[\psi^*, \psi^{**}]$, in which there is multiple 'sunspot'-equilibria (in the figure two or three).

¹⁴The self-fulfilling aspect of the model is easily understandable from this expression: a higher level of the individuals' assesment of the possibility of a devaluation at time t (i.e. higher π_{t-1}) reduces the benefit from the peg, and may make H_t drop to below zero, thus making a devaluation inevitable, and validating speculators beliefs about a vulnerable peg *ex post*.

How does this fit into the ‘panic’ vs. ‘arbitrage’ story? In the following we will identify a crisis arising from arbitrage, if the level of fundamentals is in the range in which the associated level of devaluation probability is unique and high, i.e. to the left of ψ^* . Here, in some sense the crisis is ‘justified’ by fundamentals. Panic arises in the situation with multiple equilibria,¹⁵ in which it is possible that the government finds it optimal to abandon the currency peg, only because speculators coordinate an equilibrium with a high devaluation probability. The fixed exchange rate regime could indeed have survived, had the speculators coordinated a low probability equilibrium. Hence, for certain fundamental values, the rapid shifting moods of speculators (hence the term ‘panic’) can indeed force the abandonment of a currency peg, thus giving support to the view that a crisis is more severe than it has to be.

3.2 Testing strategy

It should now be clear that discrete jumps in the devaluation probability are the defining aspect of a panic crisis.¹⁶ The test we employ utilizes this simple fact in a fairly sophisticated way.

Our strategy will be to test whether there are discrete jumps in an estimated time series of devaluation probabilities. Under our assumptions, we need no measure of a fundamentals variable. This is a big advantage, since we estimate the devaluation probabilities from financial market data, which are available at a much higher frequency than macroeconomic data (daily observations as opposed to quarterly or yearly). This is important, since a high frequency will improve the power of the test. However, a frequency tending to infinity is not required in order to obtain consistency.

The immediate problem with our characteristic of a panic is that any measure of a devaluation probability is not observed in continuous time. So the natural question is now how we can distinguish discrete jumps in a time series of discretely observed devaluation

¹⁵For identification purposes, we require that the economy actually visits at least two of those equilibria before and during the crisis, in order to qualify as panic.

¹⁶Throughout, we will maintain the identifying assumption that there can be no discrete jumps in the fundamentals, so that any discrete jump in the devaluation probability stems from a jump from one equilibrium to another. While this seems reasonable *prima facie*, the validity of this assumption remains an open question. However, in an interesting study, Kaminsky and Schmukler (1999) investigate the correlation between news and rumors and volatility of financial markets in nine Asian countries during the crisis. They find support for the view, that investors’ over-reaction to bad news and herding behavior played an important role in explaining market volatility. This may be taken as casual evidence for the validity of our definition of ‘panic’.

probabilities, which by nature will appear as a sequence of discrete changes. Aït-Sahalia (1997) has derived a restriction, which can be used to test the null of the evolution of a time series being well described by a Markov diffusion process, against the alternative of a general Markov process, which allows for jumping sample paths (henceforth called the diffusion test). The continuity of the sample paths is the defining characteristic of a Markov diffusion process, and we will take the general Markov alternative as a maintained assumption. Performing this test is equivalent, under our assumptions, to test the null of an arbitrage crisis against the panic alternative.

3.3 Estimation of the devaluation probabilities

We estimate the devaluation probabilities using a general probit-Markov model.¹⁷ It is a simple and efficient way to extract devaluation probabilities from financial market data. Its theoretical underpinning is the UIP, which is expected to hold in an arbitrage free world with risk-neutral agents, and perfect capital mobility.

The UIP can be expressed as

$$\log(1 + i_t) - \log(1 + i_t^*) \equiv \delta_t = E_t(\Delta s_{t+1}), \quad (36)$$

where i_t denotes the domestic interest rate between time t and $t + 1$, and i_t^* is its foreign (US) counterpart. δ denotes the interest rate differential, and $\Delta s_{t+1} = s_{t+1} - s_t$. Define two states $S^\dagger$, $S^\dagger \in \{0, 1\}$, where

$$S^\dagger = \begin{cases} 0 & \text{if } \Delta s_t = 0 \\ 1 & \text{if } \Delta s_t \neq 0 \end{cases}.$$

This allows us to rewrite (36) as

$$\delta_t = \pi_t E_t(\Delta s_{t+1} | S^\dagger = 1) + (1 - \pi_t) E_t(\Delta s_{t+1} | S^\dagger = 0) = \pi_t E_t(\Delta s_{t+1} | S^\dagger = 1), \quad (37)$$

since $E_t(\Delta s_{t+1} | S^\dagger = 0) = 0$ by definition. For the empirical implementation and consistent with the Markov assumption, we assume that the expected change in the log of the exchange rate conditional on a change is well described by a first order autoregressive process,

$$E_t(\Delta s_{t+1} | S^\dagger = 1) = \rho_0 + \rho_1 \Delta s_t. \quad (38)$$

Next, we model the devaluation probability according to the probit model,

$$\pi_t = \int_{-\infty}^{\gamma' z_t} \frac{1}{2\pi} e^{-t^2/2} dt \equiv \Phi(\gamma' z_t), \quad (39)$$

¹⁷This model has previously been used by Mizrach (1995) with data from EMS countries.

where $\Phi(\cdot)$ is the normal cumulative distribution function, γ is a $(n \times 1)$ parameter vector, and z_t is a $(n \times 1)$ vector of explanatory variables. Hence, we can write (37) as

$$\delta_t = \Phi(\gamma' z_t)(\rho_0 + \rho_1 \Delta s_t). \quad (40)$$

This is our final model to be estimated (with an error term added). The estimated devaluation probability at time t can then be extracted as $\Phi(\gamma' z_t)$.

For the interest differential, we use three-month interest rates. Due to the importance of the data being of high frequency (daily observations), we are fairly restricted in our choice of explanatory variables, z_t . We choose to use only one, namely a simple proxy for the home term structure behaviour. Often, speculative attacks are associated with a steep inversion of the term structure,¹⁸ and we capture this by specifying $z_t = [1 \quad z_{1t}]'$ (i.e. $n = 2$), where z_{1t} equals the difference between home overnight interest rate and the home three-month rate. The model is estimated by non-linear least squares (NLS), which is robust to departures from normality in terms of consistency. This minimization problem was solved numerically, using the BFGS algorithm.

The estimated devaluation probabilities $\Phi(\gamma' z_t)$ then serve as our time series which is used in the actual test, and they are treated as if they were directly observed.

3.4 The diffusion test

The details of the diffusion test developed by Aït-Sahalia (1997) are presented in Appendix A. The test is based on an inequality constraint of a functional of the implied transition densities for the assumed devaluation probability diffusion processes.¹⁹ These diffusion processes are valid for every sampling interval, and in particular, the consistency of the test does not require that the sampling interval tends to zero. The inequality constraint is similarly valid for every sampling interval, and consistency is ensured by letting

¹⁸We believe that there are at least two main sources to this observation. First, risk-neutral investors bid up the home short term interest rate, as they obtain short term loans in order to speculate against the currency, and as they must do in order to satisfy the UIP arbitrage constraint. Risk-averse investors furthermore require a higher risk premium facing a potential rise in exchange rate volatility. Second, the very shortest interest rates are often manipulated by the monetary authorities, in order to penalize speculation and thereby hampering the profitability of speculation. Similar arguments are presented in, amongst others, Mizrach (1995) regarding the former argument, and McCallum (1994) regarding the latter.

¹⁹There is a large literature on diffusion processes, see Karlin and Taylor (1981) for an extensive treatment. In economics, the most extensive use of continuous-time econometric models has been in the finance literature on term structure modeling and option pricing. See Campell, Lo and MacKinlay (1997) for a recent overview.

the sample size tending to infinity. Using nonparametric estimates of the densities, the test checks this necessary and sufficient characterization of a diffusion as a Markov process with continuous sample paths.

First, we introduce some notation. Let $p(y|x)$ denote the transition density for the diffusion for devaluation probabilities, given a fixed sampling interval Δ . It measures the probability that the devaluation probability at time t is equal to y conditional on being equal to x at time $t - 1$, i.e.

$$p(\pi_t = y | \pi_{t-1} = x) \equiv p(y|x). \quad (41)$$

Let $p(y, x)$ denote the corresponding joint density, and $p(x)$ the marginal density. The inequality restriction can be formulated in the following hypothesis (see Appendix A).

$$\begin{cases} H_0 : p(y|x)p(\tilde{y}|\tilde{x}) > p(y|\tilde{x})p(\tilde{y}|x) & \text{for all } x < \tilde{x}, y < \tilde{y} \\ H_1 : p(y|x)p(\tilde{y}|\tilde{x}) \leq p(y|\tilde{x})p(\tilde{y}|x) & \text{for some } x < \tilde{x}, y < \tilde{y} \end{cases}. \quad (42)$$

Recall that H_0 corresponds to the arbitrage alternative, and H_1 the panic alternative. We then consider the following test statistic D ,

$$D = \int_0^1 \int_0^1 \int_{0, y < \tilde{y}}^1 \int_{0, x < \tilde{x}}^1 \max[-\lambda(y, \tilde{y}|x, \tilde{x}), 0] p(y, x) p(\tilde{y}, \tilde{x}) dx dy d\tilde{x} d\tilde{y}, \quad (43)$$

where

$$\lambda(y, \tilde{y}|x, \tilde{x}) = p(y|x)p(\tilde{y}|\tilde{x}) - p(y|\tilde{x})p(\tilde{y}|x). \quad (44)$$

The estimate of D , $\hat{D}$, is formed by replacing the densities in (43) by their nonparametric estimates. The integration limits are 0 and 1 since the supports for the integrands are themselves probabilities. In the nonparametric estimation problem we employ an endpoint correction procedure (see Wand and Jones (1995) and Müller (1991)), in order to obtain consistency of the Kernel estimator at the discontinuities of the probability densities at 0 and 1. Having obtained estimates of $p(y, x)$ and $p(x)$, by Bayes' rule we have

$$\hat{p}(y|x) = \frac{\hat{p}(y, x)}{\hat{p}(x)}. \quad (45)$$

The nonparametric estimation procedure is described in Appendix B.

3.5 Critical values for the diffusion tests

There is yet no available asymptotic probability distribution of the test statistic $\hat{D}$. Furthermore, asymptotics for statistics involving nonparametric estimates are typically derived under mixing conditions. This means that the asymptotic distribution is likely to

be a bad approximation in finite samples, when the data is highly dependent (as data on interest rates typically are).

We therefore calculate critical values of $\hat{D}$ by Monte Carlo experiments, in order to evaluate the significance of the test statistics. In doing this, we need to calculate $\hat{D}$ under the null-hypothesis. This is done using the following procedure (performed separately for each country). First, we specify a diffusion model which satisfies the null, i.e. a model with continuous sample paths. Next, we estimate the parameters of this model using the time series of devaluation probabilities. Finally, using these estimated parameters and the actual sample size, N sample paths for the process under the null is simulated and the $\hat{D}$ -statistic is calculated for each sample path. These N values are then sorted and used to extract the significance level for the test statistic calculated from the actual data. For instance, a 95% critical value is the $.95 \times N$ 'th number of the sorted test statistics.

With this procedure, the idea is to estimate the critical values from sample paths which at the same time satisfy the null and are as close as possible to our observed devaluation probabilities.

As our diffusion model under the null, we use the specification suggested by Chan, Karolyi, Longstaff and Sanders (1992),²⁰

$$dx_t = (\nu + \omega x_t)dt + \sigma x_t^\varphi dZ, \quad (46)$$

where $(\nu, \omega, \sigma, \varphi)$ are the parameters to be estimated, and dZ denotes the innovation in a standard Brownian motion. This specification was chosen for the following reasons. First, if ω is negative the process is mean-reverting, which is desirable since we are modeling a devaluation probability. Second, the volatility of the process is allowed to be dependent on the level of the devaluation probability; a property which seems to be inherent in the data. Finally, the parameters are rather easily estimated by the Generalized Method of Moments, see Hansen (1982).

4 Data and results

All data come from the BIS. We have data for five Asian countries, Indonesia, South-Korea, Malaysia, Taiwan and Thailand. These are treated as the 'home' country. As reference foreign country, we use the US. Common for these Asian countries is, that they all experienced (and still experience) a heavy financial and currency crisis, starting in the fall 1997. Prior to the crisis, all the countries more or less conducted a unilateral

²⁰This specification is often referred to as the 'CKLS-model' in the finance literature.

exchange rate peg against the US dollar.

Our exchange rate data is the daily spot exchange rate, defined in units of the local currency per US dollar. The very short term interest rates are the daily overnight rates announced by the local central banks. For Indonesia, Malaysia and Thailand, the three-month rates are the deposit rates, for Korea we use three-month CD's, and for Taiwan the money market rate. For the US, we use the three-month Treasury bond rate. The differences in the definitions of these rates are by no means unimportant, but the rates were chosen subject to availability.

4.1 Results

The results from the estimation of the probit-Markov models and the diffusion tests are presented in table 1, and the estimated devaluation probabilities with the corresponding changes in the exchange rates are plotted in figures 2-6. As typical examples of the kernel estimates, the estimates of $p(x)$, $p(y|x)$ and $p(y, x)$ for Indonesia are plotted in figures 7-9.

γ_0 and γ_1 are both strongly significant in all cases, and γ_1 has the expected positive sign (such that a steeper inversion of the term structure is associated with an increase in the devaluation probability.) A devaluation is, *ceteris paribus*, associated with a decrease in the interest differential in Indonesia, Korea, and Taiwan, while it is the opposite with Malaysia and Thailand. The former observation is compatible with a 'releasing the pressure' explanation, and the latter observation can be rationalized as a 'negative sign of credibility'. ρ_1 is also very significant for all countries. Since this is a non-linear model, we should not put too much emphasis on the high R^2 -figures, but rather treat them as a tentative sign of a reasonable fit.

The plots of the devaluation probabilities reveal that while all the countries in this sample suffered from the crisis in terms of increasing exchange rate volatility, they deviated significantly from each other in terms of credibility. Most pronounced is the situation in Indonesia, in which the devaluation probability rose approximately a half percentage point at the onset of the crisis,²¹ and remained high until the end of 1998. This is consistent with the exchange rate behaviour, indeed Indonesia experienced the most dramatic change in exchange rate volatility. Similarly, Korea and Malaysia suffered from increasing devaluation probabilities, but they dropped faster than in the Indonesian case. It seems that the crises in Taiwan and Korea came less as a surprise for the financial markets, as the devaluation probability exhibits no or very little change in pattern during the crisis

²¹As the probit-Markov model is very parsimonious, it would be naïve to interpret the probability levels too strongly. Rather, it is the changes in the devaluation probability that matters.

period.²²

The critical values for the diffusion test were calculated as described above, with $N = 100$.²³

At conventional significance levels, we reject the hypothesis of ‘arbitrage’ for Indonesia and South-Korea, and marginally so for Thailand (see Table 1). We cannot reject ‘arbitrage’ for Malaysia and Taiwan. Thus, self-fulfilling expectations seemed to play an important role in Indonesia and South-Korea.

In this paper, we have not treated the issue of contagion. However, in an interesting paper, Masson (1999) develops a model of contagion through trade-effects, which allows for multiple equilibria. Hence, a crisis in a country can be triggered by a negative shock propagating through trade-links with other crisis countries.²⁴ In his empirical analysis, he then checks whether the fundamentals were in the region where multiple equilibria are possible, and, amongst the Asian countries, finds this to be the case only for Indonesia. In this paper, we are with the diffusion test able to say a little more. Not only were the fundamentals in a region where multiple equilibria are possible, but the economy also visited at least two of those equilibria during the crisis.

Our results for Malaysia, Taiwan and Thailand also agrees with the findings of Masson (1999). In his analysis, however, South-Korea is (perhaps surprisingly) judged immune to crises stemming from multiple equilibria.

At a more fundamental level, the diffusion test can be viewed as a general way to judge whether an economy vulnerable to sun-spot equilibria actually visits more than one equilibrium. To the author’s knowledge, no such test has previously been described in the literature.

4.2 Conclusion

We have developed a variant of the CPR-model, which allows for a richer range of policy reactions in the aftermath of a financial crisis, while still being consistent with several of the pre-crisis facts in the Asian countries. The most important deviations from the CPR-model are the assumption of homogenous individuals, endogenous labour supply, and absence of any assumptions which effectively excludes the home country from the international financial markets when facing a financial crisis following from an inefficient

²²We may take this as evidence of a ‘Peso-problem’.

²³This apparently low number of Monte Carlo replications was chosen due to the computational burden of calculating the test statistic. The estimated parameters from the CKLS-models are available from the author upon request.

²⁴Glick and Rose (1999) also stress the importance of the trade-link in contagion.

bailout policy. We then identified a necessary and sufficient condition on the transition probabilities for an estimated time series of devaluation probabilities, which allows us to distinguish a ‘panic’ situation from an ‘arbitrage’ situation in a statistical rigorous way. The analysis shows that there are important inter-country differences in terms of credibility. In particular, the currency crises seemed to come less as a surprise in Taiwan and Korea.

Furthermore, the diffusion tests provide evidence for the view that the crises in Indonesia and South-Korea had an element of ‘panic’ in them. In Malaysia and Taiwan, the evidence support the ‘arbitrage’ view. Thailand remains a borderline case.

There are numerous important aspects of the crises, which have not been taken into account in this analysis. First, the (popular) issue of contagion has been ignored. Second, the important distinction between corporate and personal debt plays no crucial role in our analysis. Third, there are some evidence that liquidity-issues played an important role in Asia, and our model pay little attention to the fact that while none of the Asian countries were completely excluded from international financial markets, it is evident that the loans obtained in the post-crisis period have been on fundamentally different terms compared to the pre-crisis period.²⁵ Fourth, while our model can explain the propagation mechanism between a financial crisis and a currency crisis, it does not go all the way in explaining a complete breakdown, of which Indonesia is the clearest example.

For the empirical analysis, we could consider whether the results from the diffusion test is robust to other measures of devaluation probabilities, and the power properties of the diffusion test should be investigated. All these issues are left for future research.

²⁵Chang and Velasco (1998) consider the liquidity explanation in some detail.

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Appendix A. The diffusion test

We refer to Aït-Sahalia (1997) for details of regularity conditions. Consider two independent processes for the devaluation probability, π_t and $\tilde{\pi}_t$, with the common transition probability density p . Suppose that $\pi_t = x$ and $\tilde{\pi}_t = \tilde{x}$ with $x < \tilde{x}$. Continuity of the sample paths requires that on any future date $t + \Delta$, x cannot be higher than $\tilde{x}$ without their sample paths having crossed at least once between time t and $t + \Delta$. We denote the value of x at time $t + \Delta$ y , and correspondingly for $\tilde{x}$. Also, we consider two mutually exclusive sets Y and $\tilde{Y}$, such that if $y \in Y$ and $\tilde{y} \in \tilde{Y}$ then $y < \tilde{y}$. Thus, the probability that $y \in Y$ and $\tilde{y} \in \tilde{Y}$ without their sample paths having crossed between t and $t + \Delta$, can be written as

$$\begin{aligned} & Pr(y \in Y, \tilde{y} \in \tilde{Y}, \text{no crossing} | x, \tilde{x}) \\ &= Pr(y \in Y, \tilde{y} \in \tilde{Y} | x, \tilde{x}) \\ & - Pr(y \in Y, \tilde{y} \in \tilde{Y}, \text{at least one cross} | x, \tilde{x}). \end{aligned} \tag{47}$$

Next, assume that the sample paths cross once between t and $t + \Delta$. Then by the reflection principle of Markov processes, we can from that point on no longer distinguish the two processes. Thus we can interchange them, such that the last term in (47) becomes

$$\begin{aligned} & Pr(y \in Y, \tilde{y} \in \tilde{Y}, \text{at least one cross} | x, \tilde{x}) \\ &= Pr(\tilde{y} \in Y, y \in \tilde{Y}, \text{at least one cross} | x, \tilde{x}) \\ &= Pr(\tilde{y} \in Y, y \in \tilde{Y} | x, \tilde{x}). \end{aligned} \tag{48}$$

In words: The crossing event is redundant. By independence of π_t and $\tilde{\pi}_t$,

$$\begin{aligned} & Pr(y \in Y, \tilde{y} \in \tilde{Y} | x, \tilde{x}) = P(Y|x)P(\tilde{Y}|\tilde{x}) \\ & Pr(\tilde{y} \in Y, y \in \tilde{Y} | x, \tilde{x}) = P(Y|\tilde{x})P(\tilde{Y}|x), \end{aligned} \tag{49}$$

where P is the cumulative distribution function of the two processes. Finally, the probability that $y \in Y$ and $\tilde{y} \in \tilde{Y}$ without their sample paths crossing is

$$P(Y|x)P(\tilde{Y}|\tilde{x}) - P(Y|\tilde{x})P(\tilde{Y}|x) > 0, \tag{50}$$

where the expression is positive because the probability of any possible event is positive. Hence, if the transition density p is continuous, the restriction in H_0 in (42) follows directly.

The intuition is fairly straightforward. Given our assumptions, and given $x < \tilde{x}$, the probability that the processes stay in the same order is greater than the probability of reversing order. If this is not true, the process allows for jumps. The idea behind the test statistic in (43) is to ‘add up’ the number of incidents, where the process seems to

have jumped. Those incidents are weighted with the common joint distribution of the processes, such that an apparent jump is penalized more heavily, the higher the likelihood that the processes are in that neighbourhood.

Appendix B. Kernel estimation of transition densities.

The literature on kernel density estimation and nonparametric regression is very large, and we will not attempt to review the literature here. Useful references include Wand and Jones (1995) and Silverman (1986).

The nonparametric kernel estimate of the unconditional (marginal) density $p(x)$ at any point x , is given by

$$\hat{p}(x) = \frac{1}{Th_u} \sum_{i=1}^T K\left(\frac{x - \pi_i}{h_u}\right), \quad (51)$$

where K is the kernel function, T is the sample size, and h_u is the bandwidth. The kernel density estimate is a smooth histogram of the devaluation probabilities. Kernel estimates are generally consistent, but biased, and the choice of the bandwidth value h_u represents a ‘classic’ trade-off between the biasedness of the estimator on the one hand, and the variance of the estimator on the other. Conversely, the choice of kernel function is less important in that respect.

For the estimations in this paper, the bandwidths were chosen according to the ‘over-smoothed’ bandwidth selection procedure described in Wand and Jones (1995). This amounts to calculating an upper bound for an asymptotically mean integrated standard error (h^{AMISE}) optimal bandwidth choice, and then successively lowering the bandwidth value until a reasonable estimate is reached, based on visual inspections of plots of the estimated density functions. This procedure was chosen for its simplicity, but more advanced and computationally intensive bandwidth selection routines are available. The upper bound for h^{AMISE} is given by

$$\left[\frac{243 \int_{-\infty}^{\infty} K(x)^2 dx}{35 \int_{-\infty}^{\infty} x^2 K(x) dx} \right]^{\frac{1}{5}} s, \quad (52)$$

where s is the sample standard deviation.

The Epanechnikov kernel function was used in all estimations because of its optimality properties and the fact that the support of this kernel is finite, $[-1,1]$, which makes the boundary correction reasonably simple. An overview of boundary kernels and their usefulness is offered by Müller (1991). We need to make boundary corrections in our case, because the density of the devaluation probabilities is known to have discontinuities at zero and one (since they are probabilities!)

To estimate the joint density of y and x , we use the kernel estimator

$$\hat{p}(y, x) = \frac{1}{Th_j^2} \sum_{i=1}^{T-1} K\left(\frac{x - \pi_i}{h_j}\right) K\left(\frac{y - \pi_{i+1}}{h_j}\right). \quad (53)$$

The kernel estimate for the conditional density is then by Bayes' rule

$$\hat{p}(y|x) = \frac{\hat{p}(y, x)}{\hat{p}(x)}. \quad (54)$$

Table 1: Results.

Country	T	γ_0	γ_1	ρ_1	R^2	$\hat{D}$
Indonesia	853	-62.052 (.28449)	.034168 (.000036902)	-.00079655 (7.8353×10^{-6})	.796	.36899 $p < .01$
Korea	875	-239.66 (0.17157)	.017276 (3.2996×10^{-6})	-.00024255 (2.70056×10^{-6})	.885	.50089 $.02 < p < .03$
Malaysia	1067	-181.74 (.21247)	.0035872 (6.2605×10^{-7})	.00055609 (7.6818×10^{-7})	.590	.38201 $.71 < p < .72$
Taiwan	1366	369.81 (.28363)	.0035851 (5.71327×10^{-7})	-.00033616 (7.6351×10^{-7})	.790	.46365 $.67 < p < .68$
Thailand	848	128.24 (.21009)	.015067 (4.7704×10^{-6})	.0010325 (1.1422×10^{-5})	.781	.38310 $.11 < p < .12$

Notes: The numbers in brackets are the Newey-West heteroskedastic and autocorrelation consistent standard errors, calculated with a lag truncation factor equal to 10. ρ_0 were in all cases restricted to zero, due to identification problems. All calculations were performed in GAUSS.

Figure 1: Fundamentals and devaluation probability

Figure 2: Indonesia

Figure 3: Korea

Figure 4: Malaysia

Figure 5: Taiwan

Figure 6: Thailand

Figure 7: Indonesia

Figure 8: Indonesia

Figure 9: Indonesia