Loss of Confidence and Currency Crises [1]

by

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Abstract Loss of confidence is interpreted as an increase in the ambiguity experienced by investors who maximize Choquet Expected Utility. Currency crises are modelled to resemble bankruns. Using countries having fragile financial systems, a model of twin crises is obtained.

An *exogenous* interim loss of confidence may trigger a crisis, even when the 'fundamentals' remain unchanged. Not recognizing ambiguity has a similar effect. Investors 'overreact' to bad news, as it leads to an *endogenous* loss of confidence.

The stylized facts of the South-East Asian crisis fit the model, and it conforms well to the basic structure of the EU-accession countries in the run-up to their adoption of the Euro.

Transparency, competence, and political stability, offer some protection against currency crises by increasing the level of confidence. The best protection, however, is provided by a stable financial system, as this enables share prices to absorb the impact of a loss of confidence.

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1. Introduction

What causes currency crises? Clearly, there are some intrinsic problems in the economies affected, but it is striking that their outbreak often fails to be related to newly emergent information on fundamentals. Starting with the seminal paper by Krugman (1979, [25]), the

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literature on currency crises set out to address this problem. In the paper at hand, we argue that loss of confidence, interpreted as an increase in ambiguity, plays a role.

Traditional microeconomics is not well equipped to model this loss of confidence. It only allows for changes in probability assessments based on new information. But this is not what has been suggested as the cause of some recent currency crises as, e.g., the South-East Asian crisis. The 'loss of confidence' is due to a growing feeling of unease with the probability assessment, rather than to a change in this assessment itself. It relates to a change in investors' *perceptions*, not to a change in underlying parameters that might shift the *actual (subjective) probabilities*. Including the concept of ambiguity is necessary as conventional approaches do not provide a satisfactory explanation of this kind of crises.

The fundamental difference between risk and ambiguity was already recognized by Keynes (1909/21, [23]) and Knight (1921, [24]). With his famous thought experiment, Ellsberg (1961, [14]) showed that the subjective expected utility approach of Savage (1954, [32]) does not capture this distinction adequately.

Two decades ago, Schmeidler (1982/89, [33]) provided a decision-theoretic foundation for modelling ambiguity.[3] Within this framework, Eichberger and Kelsey (1998, [11]) focus on a special class of beliefs, called E(llsberg)-capacities. These beliefs are a combination of an additive probability assessment and a level of confidence in it. Not only are E-capacities suitable for analysing the effects of a loss of confidence, they also are relatively easy to work with.[4]

The analogy between currency crises and bankruns has been noticed in Obstfeld (1986, [28]) and more recently in Obstfeld (1996, [29]), bankruns and currency crises both being examples of coordination games that may have multiple equilibria. We follow this approach and extend

[3] In contemporary terminology, *uncertainty* is subdivided in (calculable) *risk* and (uncalculable) *ambiguity*. The latter is some times referred to as *Knightian uncertainty*.

[4] Apart from capacities, two alternative ways to model ambiguity should be mentioned. One is the use of *belief functions* in the tradition of Dempster (1967, [8]) and Shafer (1976, [35]). The other possibility is the use of *multiple priors*, which leads to the maxmin expected utility model, as axiomatized in Gilboa and Schmeidler (1989, [18]). E-capacities are compatible with each of these approaches.

it by including the stability of the banking sector in the model. By allowing fragile financial systems in the countries under consideration, a micro-based model of twin crises is obtained.[5] [6]

As this paper focuses on the *causes* of a currency crisis, rather than on the *timing* of its occurrence, attention is restricted to a three period model. A group of countries with identical economies compete for foreign portfolio investments by choosing their individual exchange rate policies, which specify both exchange rate targets and levels of currency reserves. The reserves are financed by issuing bonds denominated in local currency, thus sterilizing part of the foreign portfolio investments. The remaining inflow is invested in illiquid assets, claims on which are traded as shares on the local stock market.

In the first period, each country announces its exchange rate targets and its fractional currency reserves. Foreign investors decide where to invest their capital. In the next period, investors observe a public signal about the prospective asset returns and privately learn their preference for liquidity. Each investor decides whether to withdraw his capital. These decisions determine the local share prices.

The local banking sector has a portfolio of collateralised debt denominated in local currency. The value of the collateral is determined by the local share price. If the share price falls below a given threshold, the value of the collateral falls short of the level of outstanding debt. This causes the banking sector to fall below its capital adequacy requirements and possibly to enter into technical bankruptcy, which poses an acute threat to the stability of the local financial system. The monetary authority wants to prevent the breakdown of the financial system.

When currency reserves cover the total capital outflow, the exchange rate target is met. Otherwise, meeting the target requires a reduced money supply. The reduction in money supply leads to increased local interest rates and forces investments in the illiquid assets into premature

[5]Kaminsky and Reinhart (1999, [21]), use the term *twin crisis* for the combined occurrence of a banking crisis and a currency crises.

[6]More recently, Bauer et.al. (2003, [4]) consider a model which incorporates currency crises and default on foreign debt. Bleaney et.al. (2004, [5]) analyse a model that links currency crises with bankruns.

liquidation. Monetary authorities choose their initial exchange rate policy under competitive pressures from the other central banks in the region.

The failure to recognize the presence of ambiguity causes the monetary authorities to follow an inappropriate reserve policy, as they underestimate the potential threat to the financial system when the prospects of the economy deteriorate. Investors seem to 'overreact', due to an *endogenous* loss of confidence. This (falsely) perceived 'panic reaction' of the investors may trigger a currency crisis. An *exogenous* loss of confidence, which may be the result of political instability, has similar effects.

To prevent currency crises from occurring, local monetary authorities should strengthen their banking sectors. In a stable financial system, a fall in share prices can absorb the effects of an endogenous as well as an unexpected exogenous loss of confidence.[7] The exchange rate attains its target value in either case. The stabilisation of the financial system may involve both time and resources. During the time it takes to stabilize the financial system, policies should be pursued that increase the confidence of investors through the promotion of transparency, competence and political stability.[8] [9]

The model of Morris and Shin (1998, [27]) can be interpreted as implicitly modelling ambiguity as a lack of common knowledge. In an economy that is ripe for a crisis, a speculative attack may be triggered when the fundamentals cease to be common knowledge to investors. Thus, even if the fundamentals have not changed and each investor is aware of this fact, his 'no longer knowing that the others know that he knows that...' is sufficient to make a speculative attack the unique equilibrium. More recently, Bauer (2004, [3]) has shown that the presence of ambiguity may lead to uniqueness in currency crisis models.

[7]For a recent example, one may consider developments in the days after the arrest of Mr. Khodorkovsky, the chairman of Yukos, the Russian oil giant.

[8]Alternatively, the monetary authorities could announce exchange rate targets that undervalue their currencies to safeguard against fickle behaviour of foreign investors. For countries like China, which do not face significant competition for foreign investment, a permanent undervaluation may provide excellent protection against currency crises. Competition for foreign portfolio investments makes this strategy, which goes against the perceived interest of the investors, self defeating in our context.

[9]The focus on institutions and confidence firmly places our model in the category of *fourth generation models of currency crises* in the terminology of the survey article of Breuer (2005, [6]).

In contrast, the driving force behind the result in this paper is a form of dynamic inconsistency. It occurs as a natural consequence of updating beliefs under ambiguity, which leads to an increase in the (relative) level of ambiguity and therefore to a decrease in the level of confidence. Investors tend to act more cautiously after receiving bad news, then they initially intended to.[10] Eichberger and Kelsey (2004, [12]) argue that dynamic inconsistency in updating ambiguous beliefs is inevitable.

The paper is organized as follows. In Section 2 the model is introduced. The equilibrium reserve policies are outlined in Section 3. In Section 4 the consequences of not recognizing ambiguity are analysed. Some stylized facts of the South-East Asian crisis are provided in Section 5: they accord with the logic of the model, which supports the IMF policy, except for its demands for fiscal and monetary austerity. Section 6 indicates that the basic structure of the model also applies to countries in Central and Eastern Europe in the run-up to their joining the Euro. Section 7 contains concluding remarks. Some technical material is gathered in the two Appendices.

2. The Model

2.1. The Economy. Consider a three period world economy containing a region of identical countries, each of which is represented by its own monetary authority. As the expectation of stable exchange rates tends to promote trade and thus welfare, the monetary authority of each country commits itself to exchange rate targets. Apart from the effects on trade, this policy has consequences for foreign portfolio investment. The latter is at the focus of the analysis.

Suppose there are many identical investors from the rest of the world, represented by the interval $[0, 1]$. Each investor owns one unit of Euros, (part of) which can be invested in the local asset of one of the countries in Period 0. Alternatively, (part of) it can be invested in

[10] For the updating of beliefs under ambiguity, we refer to Dempster (1967, [8]), Shafer (1976, [35]), Jaffay (1992, [20]), and Gilboa and Schmeidler (1993, [19]).

a bond denominated in local currency. For simplicity, we assume the bond has a zero rate of return. The investment in the local asset pays out in local currency and either has a high or a low return in Period 2, provided it is not liquidated prematurely. The payouts of the bond and the asset, which apply for each country in the region, are summarized in the following table.

payout in local currency	Period 0	Period 1	Period 2
Bond	-1	1	0
Asset liquidated	-1	α_1	0
Asset successful	-1	0	α_h
Asset failure	-1	0	α_ℓ

where $0 \leq \alpha_\ell < \alpha_1 < 1 < \alpha_h$. Ad interim, in Period 1, investments in the asset can be traded as shares on the local stock market.

Investment in the local asset generates output that may be sold on the world market. Such investment generates an inflow of Euros for their monetary authority, which we assume equals the payoff in local currency at the initial exchange rate, independent of the actual exchange rate in Period 1 and Period 2.[11] Local bonds pay out in local currency in Period 1. As the proceeds cannot be reinvested in the local economy, they generate an interim outflow of foreign currency. The effective payout to foreign investors, denominated in Euros, depends both on the value of the claims in local currency and the exchange rate. At exchange rate r, claims y in local currency yield $x = r \cdot y$ units of Euros. We assume that the initial exchange rate is 1.

Each monetary authority decides on the exchange rate targets r_1 for Period 1 and r_2 for Period 2. Furthermore, it determines what fraction of its initial capital inflow is to be held as currency reserves. For each unit of Euros held as reserve, it issues a bond that pays out one unit of local currency in Period 1. The remainder flows into the stock market and is invested in the local asset. Under such circumstances, the flexibility of share prices is a substitute for a flexible exchange rate. The fragility of the local banking sector, however, complicates the matter.

[11]This may occur when the local asset produces output for an international market where prices are quoted in Euros.

We assume that unintended effects on local money supply are sterilized by issuing long term local bonds to domestic investors. These bonds will mature beyond the time horizon we consider and are not explicitly modelled.

The banking sector in each country is endowed with a portfolio of collateralised loans denominated in local currency with a total nominal value of v, whereas the value of the collateral is c. A fall in the interim share price may reduce the value of the collateral below that of the outstanding debt.[12] This leads to the technical bankruptcy of the banking sector and threatens the stability of the local financial system. The local monetary authority can only allow a limited fall in share prices without risking the breakdown of the financial system. Bearing this in mind, in each period the monetary authority determines the actual exchange. We use $\frac{c-v}{c}$, the fraction of collateral in excess of debt, to indicated the **soundness** of the local banking system.

Through its choice of the actual exchange rate, the monetary authority has the possibility to make 'hold up profits' on foreign investors: after foreign capital is invested in Period 0 at an exchange rate of one, the monetary authority may be tempted to devalue in Periods 1 and 2. Thus, it repays investors fewer Euros than it otherwise would have, which increases its profit. Foreign investors would be less willing to invest in a country that is suspected of applying such practices. Therefore, monetary authorities may want to establish a reputation for abiding by the exchange rate targets they announce.

Each monetary authority is assumed to have established its credibility in the past and is committed to retaining it in the future. This credibility can be secured in two ways, firstly, by realizing the announced exchange rate, or, secondly, when the target proves impossible to reach, by implementing the toughest monetary policy available before allowing a devaluation. Faced with the choice between preventing a currency crisis and securing the survival of its financial system, the monetary authority will choose the latter.

A restrictive ad interim monetary policy forces some assets into premature liquidation. Therefore, we may identify the restrictiveness of the monetary policy with the fraction of assets liquidated: the toughest monetary policy leads to the liquidation of all assets. Per unit of

[12] For instance, because banks have lent to stock market speculators. Alternatively, they may have provided credit to firms that have pledged some of their shares as collateral.

initial investment it, leaves foreign investors with claims of α_1 units of local currency and the monetary authority with α_1 units of Euros.

Ad interim, in Period 1, the economy receives a public signal $\sigma \in \{b, g\}$ about the economy's prospects, which applies for the region as a whole. When the bad signal b is received, the probability of a high asset return in Period 2 is low. When the signal is good, g, this probability equals one. The joint probability distribution of signals and asset payouts is summarized in the following table:

asset state (σ, ϱ)	signal	return	probability
(b, h)	b	α_h	π_{bh}
(b, ℓ)	b	α_ℓ	$\pi_{b\ell}$
(g, h)	g	α_h	π_{gh}
(g, ℓ)	g	α_ℓ	0

where $\varrho \in \{h, \ell\}$ and $\pi_{bh}, \pi_{b\ell}, \pi_{gh} > 0$.

For analytical convenience, we assume all investments in the local asset have the same return. Either all investments are successful, or they all fail.[13] The probability of success equals $\pi_h := \pi_{bh} + \pi_{gh}$, whereas the probability of failure is $\pi_\ell := \pi_{b\ell}$. With a conditional probability of $\pi_h^b := \frac{\pi_{bh}}{\pi_b}$ the assets are successful after the bad signal is received. Similarly, we have $\pi_h^g = 1$.

In Period 1, each investor learns his preference for liquidity. This liquidity preference is private information and is described by his type $t \in \{H, L\}$. Type H investors obtain a relatively high utility from Euros in Period 1. The corresponding utility of L-type investors is relatively low.[14] The fractions of H-types and L-types are denoted by π_H and π_L respectively, with $0 < \pi_H < 1$. They equal the ex-ante probability that an investor will have a high or a low liquidity preference. These probabilities are independent of the asset state (σ, ϱ). For the probability distribution π over $\{H, L\} \times \{b, g\} \times \{h, \ell\}$ we have $\Pr\{(t, \sigma, \varrho)\} = \pi_t \cdot \pi_{\sigma\varrho}$. We denote $S := \{H, L\} \times \{b, g\} \times \{h, \ell\}$.

[13] Thus, we effectively focus on 'systemic' or 'undiversifiable' risk.

[14] One may be tempted to consider H-types as 'speculators' and L-types as 'long-term investors'. It is true that the different types behave this way in Period 1. The catch, however, is that the investors themselves do not know their type in Period 0.

2.2. Beliefs. The investors (potentially) face ambiguity with respect to the joint distribution of signals and investment returns. This ambiguity is modelled by E-capacities as axiomatised in Eichberger and Kelsey (1998, [11]), who also provide an extensive motivation for using E-capacities.

The **E-capacity** $(\pi, \{E_H, E_L\}, \gamma)$, which describes the ex-ante beliefs of the investors, is characterized by three components:

- the probability assessment π,
- the (finest) partition E of the state-space S in unambiguous events, $\{E_H, E_L\}$, with

$$\begin{array}{ll} E_H := & \{(H,b,h),(H,b,\ell),(H,g,h),(H,g,\ell)\} \\ E_L := & \{(L,b,h),(L,b,\ell),(L,g,h),(L,g,\ell)\} \end{array}$$

  and

- a level of confidence in the probability assessment, $\gamma \in [0,1]$.

The probabilities of the unambiguous events E_H and E_L are unambiguously known. So each investor has full confidence in the probabilities that concern his type. Effectively, there is restricted confidence only in (combinations of) strict sub events of E_H and E_L.

The risk attitude of an investor of type $t \in \{H, L\}$ is described by his von Neumann-Morgenstern utility index $u : \mathbb{R}^2_+ \times \{H, L\} \to \mathbb{R}$. We assume

$$u(x_1, x_2; t) := \beta_t \cdot x_1 + x_2,$$

with $\beta_H > \beta_L > 1$. Thus, the investors are risk-neutral. The utility a type t investor derives from the state contingent consumption $(x_1(s), x_2(s))_{s\in S}$ is defined below as his Choquet expected utility with respect to u and the relevant beliefs.

For consumption $(x_1(s), x_2(s))_{s\in S}$ and beliefs (π, E, γ) with $E := \{E_H, E_L\}$, we denote the minimal expected utility on an unambiguous event $E_t \subseteq S$ by

$$M_t(x) := \min_{s\in E_t} u(x(s)).$$

The **Choquet expected utility** of $(x_1(s), x_2(s))_{s\in S}$ for the E-capacity (π, E, γ) equals

$$\mathbb{CE}_s\{u(x(s))\} := \gamma \cdot \mathbb{E}_s\{u(x(s))\} + (1-\gamma) \cdot \mathbb{E}_t\{M_t(x)\},$$

where $\mathbb{E}_s\{u(x(s))\} := \sum_{s\in S} \pi_s \cdot u(x(s))$ and $\mathbb{E}_t\{M_t(x)\} := \sum_{t\in\{H,L\}} \pi_t \cdot M_t(x)$.

As stated above, in Period 1 each investor learns his liquidity preference as represented by his type and observes a signal about prospective asset returns. As in the additive case, he adjusts his beliefs about returns to incorporate this information. For updating additive beliefs Bayes' rule is used. When beliefs are represented by capacities, Gilboa and Schmeidler (1993, [19]) show that Bayes' rule can be generalized in a number of ways. Of those rules, we focus on the Dempster-Shafer rule, which is most widely used.[15]

The Dempster-Shafer update of an E-capacity is once again an E-capacity, the updated probability assessment of which is the Bayesian update of the original one. A formula for updating E-capacities by the Dempster-Shafer rule is provided in Eichberger and Kelsey (1998, [11]).

Suppose the beliefs of the investors are represented by (π, E, γ) as above and the signal σ is received. The Dempster-Shafer rule now yields the updated beliefs $(\pi^\sigma, E^\sigma, \gamma^\sigma)$ with:

	$\sigma = b$	$\sigma = g$
π^σ_h	$\frac{\pi_{bh}}{\pi_b}$	1
γ^σ	$\gamma \cdot \frac{\pi_b}{1-\gamma\cdot\pi_g} \leq \gamma$	$\gamma \cdot \frac{\pi_g}{1-\gamma\cdot\pi_b} \leq \gamma$
E^σ_t	$\{(t,b,h),(t,b,\ell)\}$	$\{(t,g,h),(t,g,\ell)\}$

where the inequalities are strict for $0 < \gamma < 1$.

Given $\sigma = g$ and in spite of $\pi^g_h = 1$, investors are not certain that the asset pays out α_h in Period 2. This is due to the remaining ambiguity within the unambiguous component E^σ_t. No sub event of E^σ_t is unambiguously ruled out from occurring.

When an investor learns $\sigma = b$, the assessed probability of an unfavourable result increases from $\pi_\ell := \pi_{b\ell}$ to $\pi^b_\ell := \frac{\pi_{b\ell}}{\pi_b}$. The bad signal also decreases his confidence in his updated assessment π^b, as does a good signal with respect to the confidence in π^g.

[15] As is shown in Spanjers (1999, [36], Sect. 8.6) for the above beliefs (π, E, γ), the Dempster-Shafer rule and its closest competitor, Full Bayesian Updating, result in the same updated E-capacity.

In the remainder of the paper we make the following assumptions:

- $\alpha_\ell = 0$: When assets fail, their payout is zero.
- $\beta_H > \alpha_h > \beta_L$: When the assets are successful, their payout is sufficiently high to be of interest to the L-types, but sufficiently low not to be desirable for H-types when compared with holding Euros in Period 0.

3. Reserve Policies

In this section we determine the equilibrium reserve policies of the monetary authorities as carried out by their central banks. At the outset, there are no foreign investments in the local economy. Its central bank neither has nor needs any currency reserves. The role of currency reserves follows solely from the interplay of foreign investment in Period 0 and the exchange rate targets. A **reserve policy** is represented by the associated exchange rate targets r_1 and r_2 for the Periods 1 and 2, and a fractional currency reserve ratio μ.

3.1. The Representative Central Bank. Monetary authorities choose reserve policies that maximize their profits from the inflow of foreign investment, while avoiding to lose their reputation for not making 'hold up profits'.[16] Ex-ante the countries' economies are identical, as are the foreign investors. The reserve policies that result from competition between these identical monetary authorities can be obtained as the result of a single decision problem.[17] In this decision problem a representative central bank maximizes the ex-ante Choquet expected utility of a representative investor under suitable constraints. These constraints are:

- feasibility constraints, which are identical to those of the local central banks due to the

[16] Alternatively, one could assume that monetary authorities try to maximize the inflow of foreign investment, while avoiding losses on their foreign exchange reserves. In the context of our analysis both assumptions lead to the same equilibrium behaviour, as in Rothschild and Stiglitz (1976, [31]).

[17] This is adapts the idea of competition between insurance companies modelled in Rothschild and Stiglitz (1976, [31]) to our setting, in which investors are identical in Period 0. The approach has been used in the context of a competitive banking sector in Alan and Gale (1998, [1]) and has been elaborated on in Alan and Gale (2004, [2]). See also Spanjers (1999, [36]).

linearity of the investment technologies,

- a stability constraint that ensures the local financial system does not break down and
- a condition of 'withdrawal equilibrium' regarding the outflow of foreign currency.[18]

In the model under consideration, the stock market essentially transfers local bonds from type L investors to H-types in Period 1 in exchange for shares in the illiquid asset.[19]

Let $\xi \geq 0$ denote the maximal fraction of local bonds that can be held by L-types at the end of Period 1 without threatening financial stability. As share prices at which L-types have an incentive to buy bonds will not occur, this maximal amount can not exceed $\pi_L \cdot \mu$. We assume ξ is related to the soundness of the local banking sector as

$$\xi = \pi_L \cdot \frac{c - v}{c}.$$

For high values of $\xi \in [0, \pi_L]$ the financial system is **stable**, for low values it is **fragile**. At the exchange rate target r_1, the local currency paid out by $\xi \cdot \mu$ bonds buys $r_1 \cdot \xi \cdot \mu$ Euros.

The equilibrium share price in Period 1 may fail to be unique. This is due to the linearity of the preferences of investors for immediate consumption and for shares.[20] It is assumed that the central bank acts in the ex-ante interest of the investors and implements the highest equilibrium price.[21]

[18] The possibility that in Period 1 an inflow of Euros could take place to partially offset the outflow is disregarded. It would distort the results of competition between central banks in a similar manner as competition between mutual funds does in Eichberger and Spanjers (1997/2003, [13]). The distortion arises when investors can be sure to be able to carry out arbitrage between the countries in Period 1. In the contex of emerging economies this fails to be assured, due to the possibilities of default on bonds and treasury bills, temporary capital controls, and suspention of trade in shares and/or the local currency. Such restrictions are not uncommon. Indeed, they caused the breakdown of LTCM in the Russian crisis in 1998.

[19] Suppose that at the beginning of Period 1 each investor holds the same amounts of shares and bonds. Consider the share price for which H-types sell all their shares in exchange for all bond held by L-types. When the share price declines by a small amount, H-types may still sell their shares, but L-types pay less for them. They therefore end up holding some bonds in addition to the shares. Similarly, when the initial share price increases by a small amount, H-types will still buy all bonds, but will hold some shares as well.

[20] The possible non-uniqueness follows directly by consultation of the appropriate Edgeworth-Box.

[21] Thus, for given reserves μ, the representative central bank minimizes the actual redistribution of bonds from H-types to L-types in the withdrawal equilibrium in Period 1. This keeps the ex-ante utility loss from transferring reserves away from investors with the high marginal utility of immediate consumption as small as possible.

Investors correctly anticipate the effective payouts in Euros, x_1 and x_2, as functions of the signal σ, the exchange rate targets r_1 and r_2, the fractional withdrawal ϖ in Period 1 and the success or failure of the assets. Each individual investor is negligible, so he takes the withdrawal behaviour of the others as given.

Since $\beta_H > \beta_L > 1$, it is optimal to have the currency reserves depleted in Period 1. Taking this into account, the optimization problem of the representative central bank, given the beliefs (π, E, γ) of the investors, is:

$$\begin{array}{lllll} \max\limits_{r_1, r_2, \mu, \varpi, \lambda} & \mathbb{CE}\{u(x)\} & & & \\ \text{such that} & \text{for each } \sigma \in \{b, g\}: & & & \\ & \varpi := \varpi(\sigma; \mu, r_1, r_2) & \in & \varpi^*(\sigma; \mu, r_1, r_2) & & \text{(E)} \\ & \varpi \cdot x_1(\varpi; \cdot) & = & \mu + \alpha_1 \cdot \lambda \cdot (1 - \mu) & & (\text{F}_1) \\ & (1 - \varpi) \cdot x_2^h(\varpi; \cdot) & = & \alpha_h \cdot (1 - \lambda) \cdot (1 - \mu) & & (\text{F}_{2h}) \\ & (1 - \varpi) \cdot x_2^\ell(\varpi; \cdot) & = & 0 & & (\text{F}_{2\ell}) \\ & (\varpi - \pi_H) \cdot x_1(\varpi; \cdot) & \leq & r_1 \cdot \xi \cdot \mu + \alpha_1 \cdot \lambda \cdot (1 - \mu) & \text{for } \lambda < 1 & \text{(S)}, \end{array}$$

where $\varpi^*(\sigma; \mu, r_1, r_2)$ is the set of withdrawal equilibria for signal σ, given the reserve policy μ and the exchange rate targets r_1 and r_2, and λ denotes the fraction of assets liquidated.[22]

Condition (E) states that the withdrawals in Period 1 are compatible with a withdrawal equilibrium. (F_1) is the feasibility constraint for Period 1. The feasibility constraints for Period 2 when assets are successful and when assets fail, are denoted by (F_{2h}) and $(\text{F}_{2\ell})$ respectively. Finally, (S) is the condition of financial stability in the absence of a currency crisis.

In general, the currency reserves of the central bank depend on which of the withdrawal equilibria in Period 1 is anticipated to occur. In the above formulation of the optimization problem, it is assumed that after a signal is received, the 'best' withdrawal equilibrium is obtained. This implies that we rule out currency crises that are the consequence of coordination problems only. Thus, we focus on **fundamental currency crises**. Following the terminology of Freixas and Rochet (1997, [17]) for bankruns, a crisis is 'fundamental' when it is caused by beliefs concerning the asset returns, as opposed to beliefs about the withdrawal behaviour of

[22] *Withdrawal equilibrium* in this setting is defined similar to that in the context of bankruns. See also Spanjers (1999, Chapter 5). The withdrawal equilibrium is analysed below.

the other investors.

3.2. Equilibrium. In analysing equilibrium, we start by looking at the effect that competition between local central banks has on the exchange rate targets they set. After finding that the result greatly simplifies our further analysis, we turn to the withdrawal equilibrium and the equilibrium fractional reserve holdings.

Earlier, we assumed that in each period the inflow of Euros generated by the local asset equals its payouts in local currency. A local central bank with an exchange rate target r_1 less than one does not return the entire inflow of Euros in Period 1 to foreign investors. Rather, it keeps some of the Euros obtained in Period 1 as reserves to carry over to Period 2. This 'undervaluation' of the exchange rate target can be helpful, as it generates a surplus of Euros that protects the local currency from unexpectedly high capital outflows in Period 1.

The surplus, however, reduces the ex-ante utility of the foreign investors. It could either be paid out in Period 1 to a utility of at least β_L, or be invested in local assets, with a Choquet expected payout which exceeds that of Euros carried over to Period 2.

Foreign investors in a country that offers an exchange rate target $r_1 < 1$ will find another country that offers a preferred exchange rate policy with an exchange rate target $\widehat{r}_1$ between r_1 and 1. The investors will reconsider and invest in the latter country, making it better off as well, as it increases its profits from foreign investment. As a result no country that offers an exchange rate target $r_1 < 1$ will attract foreign investors.[23]

This is summarized in the following Property.

Property 1. *We may assume without loss of generality that in equilibrium* $r_1 = r_2 = 1$.

[23]It should be noted that an exchange rate target $r_1 > 1$ is not feasible. For $r_1 = 1$, the target $r_2 > 1$ is not feasible either. For $r_1 = 1$ and $r_2 < 1$, some of the Euros remain at the local central bank and are not returned to investors. In this case another country can improve its position by offering $r_2 = 1$.

The nature of competition between central banks leads to reserve policies μ that maximize the ex-ante utility of the representative investor. The ex-ante utility of H-types from wealth invested in successful assets equals that of L-types. But their utility from consuming the same initial wealth as Euros in Period 1 is even higher. So maximizing ex-ante utility amounts to transferring wealth from L-types to H-types.

Due to the linear structure of preferences, this problem results in corner solutions. In particular, the limits of the transfers are determined by the incentive compatibility constraints of L-types. We proceed by looking at these incentive constraints in more detail. In doing so, we denote

$$\widetilde{\alpha}^{\sigma} := \mathbb{CE}\{\alpha_{\varrho}|\sigma\} = \gamma^{\sigma} \cdot \pi_h^{\sigma} \cdot \alpha_h.$$

Consider the situation after signal σ occurs, given fractional withdrawals $\varpi = \pi_H$. The incentive constraint that indicates that at the end of Period 1 all reserves are held by H-types, is denoted by (IC_L^{σ}). For a given reserve policy μ the constraint reads

$$\widetilde{\alpha}^{\sigma} \cdot \frac{1-\mu}{\pi_L} \geq \beta_L \cdot \frac{\mu}{\pi_H}.$$

It holds with equality for

$$\mu_{\sigma}(\gamma) := \frac{\pi_H \cdot \widetilde{\alpha}^{\sigma}}{\pi_L \cdot \beta_L + \pi_H \cdot \widetilde{\alpha}^{\sigma}}.$$

If this constraint is violated, this does not necessarily mean that a currency crises is inevitable after obtaining signal σ. But due to the fragility of the financial system, the central bank can only allow for a limited fall in share prices. Therefore, the relevant incentive compatibility constraint $(\mathrm{IC}_L^{\sigma\xi})$ considers the effective payouts after their maximal decline. When this constraint is violated a currency crisis occurs.

Consider the reserve policy μ and the stability parameter ξ. The incentive constraint of L-types after signal σ and redistribution $\xi \cdot \mu$ through share prices reads

$$\beta_L \cdot \frac{\xi \cdot \mu}{\pi_L} + \widetilde{\alpha}^{\sigma} \cdot \frac{1-\mu}{\pi_L} \geq \beta_L \cdot \frac{(1-\xi) \cdot \mu}{\pi_H}.$$

It is referred to as ($\text{IC}_L^{\sigma\xi}$) and holds with equality for

$$\mu_{\sigma\xi}(\gamma) = \frac{\pi_H \cdot \widetilde{\alpha}^\sigma}{(\pi_L - \xi) \cdot \beta_L + \pi_H \cdot \widetilde{\alpha}^\sigma}.$$

Clearly, if both $\widetilde{\alpha}^\sigma > 0$ and $\xi > 0$, it follows for each level of confidence $\gamma > 0$ and each signal σ that

$$\mu_\sigma(\gamma) < \mu_{\sigma\xi}(\gamma).$$

For the equilibrium exchange rate policy the representative central bank either chooses one of the above mentioned currency reserves or $\mu^*(\gamma) = 1$, which implements a currency board.[24]

Theorem 2. [25] *In equilibrium we have currency reserves* $\mu^*(\gamma) \in \{\mu_b(\gamma), \mu_{b\xi}(\gamma), \mu_g(\gamma), \mu_{g\xi}(\gamma), 1\}$.

It should be noted that for given exchange rate targets *lower* currency reserves make a currency crises *less* likely. The reason for this is that it is not *fractional reserve holdings* that offer protection against currency crises, but the *inflow in Euros that is not returned to the foreign investors* in Period 1. As is shown in Property 1, due to competition between the local central banks, the entire inflow of Euros is instantly returned to the foreign investors.

[24]To interpret equilibria that do not involve a currency board, suppose the investors receive signal σ after their wealth is invested in a country with fractional reserves μ. Three situations may occur for $\varpi = \pi_H$.

Firstly, the incentive constraint (IC_L^σ) and the incentive constraint for H-types (IC_H^σ), which reads

$$\beta_H \cdot \frac{\mu}{\pi_H} \geq \widetilde{\alpha}^\sigma \cdot \frac{1-\mu}{\pi_L},$$

may both hold. The H-types withdraw their capital in Period 1 and the L-types leave theirs in the country. The H-types end up holding all reserves.

Secondly, the incentive constraint (IC_L^σ) may be violated. To establish incentive compatibility the effective payout x_1 must be reduced relative to x_2. In the case ($\text{IC}_L^{\sigma\xi}$) is also violated, such change in payouts is not feasible under fixed exchange rates. Any scope for redistribution from H-types to L-types has already been taken into account in the latter incentive constraint. Therefore, L-types withdraw in Period 1 and the central bank implements a monetary policy that leads to the liquidation of all assets. A currency crisis is the only withdrawal equilibrium.

If (IC_L^σ) is violated but ($\text{IC}_L^{\sigma\xi}$) holds, a currency crisis is prevented. The redistribution from H-types to L-types through a decline in share prices inefficiently leaves L-types with some liquidity at the end of Period 1, but it prevents a currency crisis.

Finally, the incentive constraint (IC_H^σ) may be violated. In this case, the equilibrium share price increases up to the point that the constraint binds. This leaves some H-types holding shares in Period 1.

[25]The proof of Theorem 2 involves a significant amount of rather tedious, though not overly complicated, calculations. It closely follows the proof in Spanjers (1999, [36], Proposition 5.12) in the context of bankruns. An outline of the proof is provided in Appendix II.

4. Failing to Recognize Ambiguity

What happens when the monetary authorities fail to recognize the presence of ambiguity? This question is answered for two guises in which this failure may occur. Firstly, they may (falsely) believe that investors are fully confident about their probability assessments. The consequences of such a belief resemble those of an exogenous loss of confidence. Secondly, monetary authorities may interpret the weights the investors ex-ante assign to the different states of nature as a subjective probability estimate. It should be noted that these weights change when alternatives are considered that obtain their lowest payouts in different states.

To focus on the consequences of the failure to recognize ambiguity, the behaviour of the investors, which is based on their actual beliefs, must be constrained from 'correcting' the mistaken beliefs of the monetary authorities in the perfect foresight equilibrium.[26] Therefore, we make the ad hoc assumption that the information policy of the central bank convinces each individual investor that all other investors share the monetary authority's beliefs about asset states.[27] Since each individual investor is negligible, only the beliefs of other investors matter.

Suppose the monetary authority considers the uncertain probability assessment to be certain, i.e., it falsely believes $\gamma = 1$. It therefore chooses reserves $\mu^*(1)$. The actual interim incentive constraint of L-types, however, is the one implied by γ. Therefore, L-types demand a higher ambiguity premium than the monetary authority implicitly offers in its exchange rate policy. If the currency reserves equal $\mu_{b\xi}(1)$, the signal b causes a currency crisis. For reserves $\mu_b(1)$ a currency crises may or may not occur after a bad signal, depending on the fragility of the financial system. After the signal g a currency crises may or may not arise. For reserves $\mu_g(1)$ a currency crisis is imminent after either signal if the financial system is sufficiently fragile.

[26] As is indicated in McAfee (2004, [26]), many large firms fail to recognize the importance of confidence, which he refers to as 'trust'. In this light, the possibility that monetary authorities may fail to recognize the full impact of the absence of full confidence seems more than plausible.

[27] A policy environment which, as in the case of the monetary authorities in this section, considers the expected utility paradigm as the only sensible way to represent uncertainty would encourage this state of mind to be present. Investors whose beliefs cannot be represented by an additive subjective probability distribution would consider themselves to be unsophisticated exceptions, even when they are not.

A second way in which the monetary authority may fail to recognize ambiguity is by interpreting the specific ex-ante weights the investors assign to the different states of nature as their subjective probability distribution $\widehat{\pi} := (\widehat{\pi}^H, \widehat{\pi}^L)$. This distribution is derived in Appendix I.

The E-capacity (π, E, γ), representing the actual beliefs, is updated using the Dempster-Shafer rule,[28] whereas $\widehat{\pi}$ is updated by Bayes' rule. We obtain the following weights for the asset states when considering the equilibrium withdrawal behaviour of L-types:

	(b,h)	(b,ℓ)	(g,h)	(g,ℓ)
Dempster-Shafer weight	$\frac{\gamma\cdot\pi_{bh}}{1-\gamma\cdot\pi_g}$	$\frac{1-\gamma\cdot\pi_{bh}}{1-\gamma\cdot\pi_g}$	$\frac{\gamma\cdot\pi_g}{1-\gamma\cdot\pi_b}$	$\frac{1-\gamma}{1-\gamma\cdot\pi_b}$
Bayes' weight	$\frac{\pi_{bh}}{\pi_b}$	$\frac{\pi_{b\ell}}{\pi_b}$	$\frac{\gamma\cdot\pi_g}{1-\gamma\cdot\pi_b}$	$\frac{1-\gamma}{1-\gamma\cdot\pi_b}$

As the difference in weights shows, the dynamics of the actual beliefs after a bad signal fail to be reproduced by additive probabilities and Bayesian updating.

The fractional currency reserve ratio for which (IC_L^g) binds for the subjective probability distribution $\widehat{\pi}$ is denoted by $\mu_g(\widehat{\pi}, 1)$. When the representative central bank chooses this reserve policy, the failure to recognize the presence of ambiguity does not influence the withdrawal equilibrium, since $\mu_g(\widehat{\pi}, 1) = \mu_g(\gamma)$ and $\mu_{g\xi}(\widehat{\pi}, 1) = \mu_{g\xi}(\gamma)$. Any fundamental crisis that the central bank may anticipate after the bad signal also occurs when the Dempster-Shafer rule is applied, although after a bad signal a currency crisis may occur where none is expected. After a good signal, the updated probabilities equal the weights assigned by the updated E-capacity. The incentive compatibility constraint of type-L investors holds.

For currency reserves $\mu_{b\xi}(\widehat{\pi}, 1)$ the misjudgment of the monetary authorities has serious consequences, as it may have for reserves $\mu_b(\widehat{\pi}, 1)$. When a bad signal is received and currency reserves are $\mu_{b\xi}(\widehat{\pi}, 1)$, the incentive constraint for L-types just holds for the updated probability $\widehat{\pi}_L^b$ after the maximal fall in share prices. But the investors assign weights according to Dempster-Shafer updated E-capacity. They put a weight on (b, ℓ) which exceeds the probability assigned by the monetary authority. Therefore, the incentive constraint of L-types is violated and a currency crisis occurs.

[28] See Section 2.2.

The central bank may interpret this crisis for reserve holdings $\mu_{b\xi}(\widehat{\pi}, 1)$ as caused by an 'irrational overreaction' of the L-type investors who 'lose their nerves'. After a bad signal is received, the falsely perceived '*panic reaction*' of the investors in fact is a *fundamental currency crisis.*

5. The South-East Asian Crisis

Having analysed our model of currency crises in the presence of ambiguity, we now confront it with the stylised facts of the South-East Asian Crisis.[29] This crisis affected a number of more or less similar economies in the same geographical region. It provides an example where monetary authorities of similar countries used exchange rate policies to compete for foreign investments.

In the light of our model, two distinct phases of the South-East Asian crisis can be recognized. The first phase was characterized by an *exogenous* loss of confidence. It has its roots in the clumsy and at times incompetent reactions to the crisis of the Thai Baht. The second phase was characterized by an *endogenous* loss of confidence. The latter was caused by bad news concerning the fundamentals of the economies in the region.

The initial 'speculative attack' on the Baht may well have been caused by a worsening of the prospects for Thai assets. In terms of the model, the incentive constraint of some patient investors was violated. Either a more rapid decline in stock prices or giving in to the international pressure to devalue might have solved the problem at an early stage.

The Thai government, however, failed to link the attack to fundamental problems. Its stubborn reaction led to a loss of confidence in its economic competence, inducing a further outflow of capital. After depleting its currency reserves in trying to defend its exchange rate peg, it was forced to let the Baht float. As the mutual stand-by treaties with its neighbours failed to stop the fall, confidence in its neighbours also declined, as did their stock markets and currencies.

[29] For an excellent paper on the South-East Asian Crisis in a broader perspective (disguised as a book review) see Williamson (2004, [38]).

The reaction of the region's governments to the devaluations merely increased doubts about their economic competence. The economic policy of the governments in the region and the Malaysian prime minister in particular during the following two months or so, can best be described as follows[30]

> So illiterate is some of the bluster coming from top policy makers, and so discomforting some of their actions, that investors' confidence has been badly battered...

As the investors lost their confidence in the policy makers, shares and currencies lost their value.

After the crisis had calmed down by October, bad signals about the economic prospects of South Korea (and to a lesser extent Japan) hit the market. Updating based on this adverse information led to a further loss of confidence. The increase in ambiguity induced a stronger reaction than the change in the probability assessment about fundamentals seemed to justify. The internal political situation in Korea prevented a swift and prudent reaction and added to the sense of incompetence.[31] It led to a further loss of confidence and a corresponding outflow of capital.

Thus, in our opinion, the story of the South-East Asian crisis fits our model. In particular, the perceived 'over reactions', often interpreted as 'speculative attacks', seem to be adequately modelled by incorporating ambiguity.

6. Policy Prescriptions

The logic of the model suggests the following policy prescriptions.

[30] *The Economist*, September 6th, 1997, 'Too late for a gentle landing'.

[31] With a presidential election comming up in a few weeks' time, the temptation in South Korea to take firm action and restore confidence was at a minimum. In the beginning of December, it negotiated the, up until than, largest bail out ever with the IMF. Even this rescue failed to restore confidence, mainly because of a failing resolve by the Korean government to deal with the crisis and presidential candidates who seemingly had no clue what to do. The incumbent president was severely damaged and the country was in effect leaderless.

When a crisis is imminent —as possibly indicated by the combination of a sharp fall in share prices in a country with a fragile financial system and an increased outflow of capital— it is likely to be prevented by an independently approved devaluation: if the monetary authority is pressured to devalue by, say, the IMF, it may retain its credibility. At the same time, the regulatory policy should be careful not to harm the long term prospects of the local economy.

The anticipation of this regulatory policy by monetary authorities does not reduce its effectiveness. On the contrary, a credible commitment to the policy leads to second best efficiency, provided there are no unexpected changes in the level of confidence. The reason is similar to that in the corresponding model of bankruns.[32]

At times, the regulatory policy may lead to an increase in the number of potential currency crises. But this is not the consequence of a moral hazard problem. Rather, the policy removes the need for excessive caution by the monetary authorities, which is due to the fragility of their financial systems. A commitment to the regulatory policy may increase the number of currency crises to its second-best efficient level.[33]

Furthermore, measures should be taken to enhance the confidence in the economies involved. An increased transparency regarding the financial position of companies and banks might do a lot of good. It could be obtained, for instance, by disentangling industrial conglomerates, liberalizing financial markets and increasing foreign (confidence enhancing!) takeovers. By contrast, a restrictive monetary policy only damages the prospects of the investments even further.

To prevent currency crises from becoming imminent, measures to strengthen the local financial sectors should have the highest priority. A stable financial system enables share prices to perform their task of absorbing the shocks caused by changes in the fortunes of investments

[32]See Spanjers (1999, [36], Section 5.6.3).

[33]In the context of bankruns, this argument builds on Allen and Gale (1998, [1]) and more recently, Allen and Gale (2004, [2]). It more closely follows Spanjers (1999, [37], Chapter 5).

This argument was made in technical detail in a previous version of the paper, but is left out here to improve the focus of the present version. It will form the basis of a separate paper.

and the preferences of their owners.

Accordingly, as far as the logic of the model is concerned, the IMF handled the crisis quite well. By providing bail out packages, it prevented large scale bankruptcies of companies and banks under distress. Furthermore, its support may have stopped the fundamental crisis from turning into a panic after the inevitable devaluation of the currencies involved. The demands for liberalization of financial markets and the lifting of restrictions on foreign ownership increased transparency and may, after a period of transition, have helped to increase confidence. The 'all purpose' recipe of a restrictive monetary and fiscal policy was, however, counter-productive. But perhaps these requirements, which are the most painful for the governments involved, serve as a warning to others that the political price of a bail-out is high. It may convince them to implement confidence enhancing measures and stabilize their financial systems before the next round of bad news hits.

7. Central and Eastern European Countries

Even though the conclusions of the model are in line with the stylized facts of the South-East Asian crisis, its significance surpasses that of providing an explanation for one (albeit important) currency crisis of the past. Its conclusions also apply to other regions where similar economies have fixed exchange rates and may be prone to a loss of confidence. A region that immediately comes to mind is Central and Eastern Europe.

Most countries in this region presently have some kind of more or less flexible exchange rate regime, but it seems probable that this will change in the not-to-distant future.[34] Some of those countries aspire adopting the Euro and contemplate strategies to complete the process by 2009-2010.[35] The rules for joining require, amongst others, that the local currency has a

[34] Of the relevant Central and Eastern European countries, only Bulgaria, Estonia, Lithuania and Hungary have *de jure* stabilized their exchange rate against the Euro. *De facto*, however, the same holds for the Czech Republic, Latvia, the Slovak Republic and Slovenia, leaving Poland and Romania as the only countries with *de facto* flexible exchange rates. See Schnabl (2004, [34]).

[35] See, e.g. CNB (2003, [7]) regarding the Czech Republic. The Convergence Report 2004 of the European Commission (2004, [16]) indicates, however, that the countries still have a long way to go.

fixed exchange rate target against the Euro for a period of at least two years, during which the exchange rate must remain within a 2.25% band around this target.[36] [37]

Assuming that a number of these economies make an effort to adopt the Euro at approximately the same time, as seems likely, there will be an number of similar economies competing for foreign investments through use of their exchange rate policies. These economies are likely to remain subject to ambiguous beliefs from investors. Thus, a situation arises which satisfies the basic assumptions of our model.

The logic of the model not only indicates that tailoring the reserve policy to preventing a currency crisis may fail if the presence of ambiguity is not taken into account; even adjusting currency reserves to allow for an *endogenous* loss of confidence may fail to secure the exchange rate target. The countries in question remain prone to an *exogenous* loss of confidence, e.g. spilling over from political turmoil in neighbouring countries.

The model also suggests a remedy to a loss of confidence, be it endogenous or exogenous. This remedy is to increase the stability of the banking sector, as well as other parts of the economy and society that are hard hit by a large fall in share prices. This would allow the effects of any loss of confidence to be absorbed by share prices, rather than, ultimately, by the exchange rate.

8. Concluding Remarks

The (qualitative) results derived for an *exogenous* loss of confidence may also be obtained for risk averse agents in the absence of ambiguity. As Spanjers (1999, [36], Conjecture 8.1) suggests, qualitative results that depend on a risk premium can be replicated (after suitable adaptations of the model) by using an ambiguity premium, and vice versa. This by no means disqualifies the results. On the contrary, it raises the question whether, at times, premia for ambiguity are mistakenly interpreted as risk premia.

[36] See the Convergence Report 2000 (2000, [15], Annex D.4, p. 70).

[37] This view is not undisputed: see e.g. Egert et.al. (2005, [9]) and Orlowski (2005, [30]).

Such misinterpretations are far from harmless, since they may suggest that policy measures are useless, which are, in fact, effective. Policy makers can do little to reduce risk or to change risk attitudes, so they may not be able to effectively change risk premia successfully. But they may well be able to reduce the premia for ambiguity by increasing transparency and predictability. Confusing the premia for ambiguity with risk premia may grossly underestimate the gains of such 'prudent' policy making.[38] [39] The 'terror premium' on oil prices illustrates this point.

The dynamic inconsistency that leads to an *endogenous* loss of confidence cannot be replicated by assuming risk aversion. Decision makers with ambiguous beliefs who ex-ante plan a course of action contingent on interim information may deviate from these contingent plans once the information is actually obtained. This drives the main results of Section 4, where the monetary authorities fail to recognize the presence of ambiguity.

In the context of our model, ambiguity can easily be detected once it is known what to look for. It should not be accepted at face value that, ex-ante, investors superstitiously perceive a correlation between their liquidity preference and asset returns. Rather, one should compare the weights assigned to the asset states by the same type of investor, for actions that obtain their worst utility level in different states. When these weights change with the action of the investor, there is a strong indication that he faces ambiguity about asset returns.[40]

The stylized facts of the currency crisis which best fits the assumptions of the model, the South-East Asian crisis, are in line with the conclusions. For the countries in Central and Eastern Europe that intend to adopt the Euro, the model indicates that a stable financial sector may be the best guarantee for achieving this goal.

[38] See also Spanjers (2004, [37]).

[39] It should be noted that sometimes an *increase* in ambiguity may be beneficial. In particular, it reduces the incentives for free riding in the provision of public goods, as analysed in Eichberger and Kelsey (1995/2002, [10]). Ambiguity may also be used constructively, e.g. in devising an institutional framework that implements the provision of efficient effort levels in partnerships, as in Kelsey and Spanjers (1997/2004, [22]).

[40] That is, one should compare the weights of the asset states for actions that fail to be co-monotonic. See, e.g. Schmeidler (1982/89, [33]).

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Appendix I

In this Appendix we determine the subjective probability distribution which the monetary authorities may wrongly assume to represent the beliefs of investors. The weights that investors ex-ante assign to the different states, given their optimal actions, are calculated. This is done by focusing attention initially on the currency reserves $\mu_b(\widehat{\pi}, 1)$ and $\mu_g(\widehat{\pi}, 1)$. The resulting weights are mutually consistent, so they are not 'obviously' wrong.

Consider a monetary authority that chooses reserve holdings $\mu_g(\widehat{\pi}, 1)$ in an economy with a fragile banking system. It anticipates H-type investors to withdraw in Period 1. L-types withdraw in Period 2, unless a bad signal is obtained and a fundamental currency crisis occurs. Given their optimal withdrawal behaviour, the effective payouts for H-types and the weights of the associated states are:[41]

	(H, b, h)	(H, b, ℓ)	(H, g, h)	(H, g, ℓ)
Period 1	$\mu + \alpha_1 \cdot (1 - \mu)$		$\frac{\mu}{\pi_H}$	
Period 2	0			
vNM-utility	$\beta_H \cdot [\mu + \alpha_1 \cdot (1 - \mu)]$		$\beta_H \cdot \frac{\mu}{\pi_H}$	
Weight	$\pi_H \cdot (1 - \gamma \cdot \pi_g)$		$\pi_H \cdot \gamma \cdot \pi_g$	

The number in a cell that combines states indicates the weight assigned to the event that consists of these states. Thus, the weight to the event $\{(H, b, h), (H, b, \ell)\}$ equals $\pi_H \cdot (1 - \gamma \cdot \pi_g)$. Regarding L-types the following table results:

	(L, b, h)	(L, b, ℓ)	(L, g, h)	(L, g, ℓ)
Period 1	$\mu + \alpha_1 \cdot (1 - \mu)$		0	
Period 2	0		$\alpha_h \cdot \frac{1-\mu}{\pi_L}$	0
vNM-utility	$\beta_L \cdot [\mu + \alpha_1 \cdot (1 - \mu)]$		$\alpha_h \cdot \frac{1-\mu}{\pi_L}$	0
Weights	$\pi_L \cdot \gamma \cdot \pi_{bh}$	$\pi_L \cdot \gamma \cdot \pi_{b\ell}$	$\pi_L \cdot \gamma \cdot \pi_{gh}$	$\pi_L \cdot (1 - \gamma)$

When the weights in the tables are interpreted as subjective probabilities, the investor acts as if the conditional probabilities of the asset states vary with his type. In particular, under $t = H$ the event $\{(t, b, h), (t, b, \ell)\}$ obtains a relative weight of $1 - \gamma \cdot \pi_g$, whereas the corresponding weight conditional on $t = L$ equals $\gamma \cdot (1 - \pi_g)$. These beliefs suggest that investors perceive a (non-existing) correlation between their own type and the occurrence of certain states.

[41] It should be noted, that the weights of the states may change when a different action is considered.

Next consider the currency reserves $\mu_b(\widehat{\pi},1)$. After receiving a good signal, the incentive constraint for L-types does not bind for $\varpi = \pi_H$. Since the central bank implements the highest asset price compatible with equilibrium, after a good signal H-types obtain some of the asset returns in Period 2, in addition to the currency reserves in Period 1.

Given their optimal withdrawal behaviour, the effective payouts for H-types and the weights for the corresponding states are:

	(H,b,h)	(H,b,ℓ)	(H,g,ℓ)	(H,g,h)
Period 1	$\frac{\mu}{\pi_H}$			
Period 2	0			>0
vNM-utility	$\beta_H \cdot \frac{\mu}{\pi_H}$			$> \beta_H \cdot \frac{\mu}{\pi_H}$
Weight	$\pi_H \cdot (1-\gamma\cdot\pi_{gh})$			$\pi_H\cdot\gamma\cdot\pi_{gh}$

For L-types, we obtain:

	(L,b,h)	(L,g,h)	$\{(L,b,\ell),(L,g,\ell)\}$
Period 1	0		
Period 2	$\alpha_h \cdot \frac{1-\mu}{\pi_L}$	$>0;\ < \alpha_h \cdot \frac{1-\mu}{\pi_L}$	0
vNM-utility	$\alpha_h \cdot \frac{1-\mu}{\pi_L}$	$>0;\ < \alpha_h \cdot \frac{1-\mu}{\pi_L}$	0
Weight	$\pi_L\cdot\gamma\cdot\pi_{bh}$	$\pi_L\cdot\gamma\cdot\pi_{gh}$	$\pi_L\cdot(1-\gamma\cdot\pi_h)$

Combining these four tables, and remembering that $\pi_g = \pi_{gh}$, the following additive weights result:

	(t,b,h)	(t,b,ℓ)	(t,g,h)	(t,g,ℓ)
$t=H$	$\pi_H\cdot(1-\gamma\cdot\pi_g)$		$\pi_H\cdot\gamma\cdot\pi_{gh}$	0
$t=L$	$\pi_L\cdot\gamma\cdot\pi_{bh}$	$\pi_L\cdot\gamma\cdot\pi_{b\ell}$	$\pi_L\cdot\gamma\cdot\pi_{gh}$	$\pi_L\cdot(1-\gamma)$

These weights are maintained if the financial system is sufficiently stable to ensure that after a bad signal no currency crisis occurs. They are also obtained for the reserve holdings $\mu_{b\xi}(\widehat{\pi},1)$ and $\mu_{g\xi}(\widehat{\pi},1)$, and consistent with the weights for $\mu=1$. The reason is that the 'worst case' for H-types occurs in an event containing the state (H,b,ℓ), whereas the 'worst case' for L-types occurs in an event containing the state (L,g,ℓ).

Appendix II

This sketch of the proof of Theorem 2 is organized as to which of the incentive compatibility constraints hold for $\varpi = \pi_H$, i.e., when H-types withdraw in Period 1 and L-types wait for Period 2. For each of these cases, the optimal reserves $\mu \in [0,1]$ are determined. First we distinguish between the case in which whenever ($\mathrm{IC}_L^{b\xi}$) holds, so does (IC_L^{g}), and the case in which this implication fails to hold.

(i) $\mu_{b\xi}(\gamma) \leq \mu_g(\gamma)$. This refers to the case in which (IC_L^{g}) holds whenever ($\mathrm{IC}_L^{b\xi}$) does.

(ia) ($\mathrm{IC}_L^{g\xi}$) *is violated.* In this case, any assets will be liquidated at a loss, irrespective of the signal received. The representative central bank would be better off by choosing reserve $\mu = 1$.

(ib) ($\mathrm{IC}_L^{g\xi}$) *holds, but* (IC_L^{g}) *is violated.* By assumption of case *(i)* constraint (IC_L^{g}) being violated implies that ($\mathrm{IC}_L^{b\xi}$) is violated too.

If the cost of liquidation, the probability of a bad signal and the fraction of L-types are sufficiently low, the representative central bank would prefer to have its currency reserves to equal $\mu_g(\gamma)$. Otherwise, if the cost of liquidation, the probability of a bad signal and the fraction of L-types are sufficiently high, the central bank would prefer to hold only currency reserves.

(ic) (IC_L^{g}) *holds but* ($\mathrm{IC}_L^{b\xi}$) *is violated.* In this situation, after a good signal H-types hold some assets, after a bad signal a currency crisis occurs. The representative central bank would rather increase its currency reserves to $\mu_g(\gamma)$. After a good signal, the payout of Euros to H-types would increase, after a bad signal the loss of liquidation would be reduced.

(id) ($\mathrm{IC}_L^{b\xi}$) *holds but* (IC_L^{b}) *is violated.* After a bad signal, a currency crisis is prevented, but some L-types inefficiently end up holding Euros in Period 1. If the bad signal is sufficiently likely and the fraction of L-types is sufficiently high, a decrease in reserves causes an increase in efficiency after a bad signal, which outweighs the losses due to a lower payout to H-types after a good signal. If a good signal is sufficiently likely and the fraction of L-types is sufficiently low,

the gains of a higher payout of Euros to H-types after a good signal outweighs the decreased efficiency after a bad signal.

(ie) (IC$_L^b$) *holds.* After both signals, H-types end up holding some assets. Reserves should be increased to $\mu_b(\gamma)$.

(ii) $\mu_{b\xi}(\gamma) > \mu_g(\gamma)$. In this case (IC$_L^{b\xi}$) holds whenever (IC$_L^g$) holds.

(iia) (IC$_L^{g\xi}$) *is violated.* See case *(ia)*.

(iib) (IC$_L^{g\xi}$) *is holds but* (IC$_L^{b\xi}$) *is violated.* If the probability of a bad signal, the cost of liquidation and the fraction of L-types are sufficiently high, ex-ante utility can be increased by reducing currency reserves to $\mu_{b\xi}(\gamma)$. If the probability of a bad signal, the cost of liquidation and the fraction of L-types are sufficiently low, the central bank would benefit from increasing currency reserves to $\mu_{g\xi}(\gamma)$.

(iic) (IC$_L^{b\xi}$) *holds but* (IC$_L^g$) *is violated.* Here a reduction in currency reserves reduces the ad-interim inefficiency that occurs both after a good and a bad signal.

(iid) (IC$_L^g$) *holds but* (IC$_L^b$) *is violated.* If the bad signal is sufficiently unlikely and the fraction of H-types is sufficiently high, the currency reserves should be increased to $\mu_g(\gamma)$. Otherwise the representative central bank could improve by reducing the reserves to $\mu_b(\gamma)$.

(iie) (IC$_L^b$) *holds.* See case *(ie)*.

■