A Fuzzy Characterization of Uncertainty in Financial Crises

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1. Introduction

The modern literature on currency crises began with Krugman´s (1979) canonical model, further refined by Flood and Garber (1984). These papers inaugurated the era of the so-called first generation models of crises. They present speculative attacks arising as the result of the rational behavior of agents with perfect foresight. The balance of payments problem that triggers to ensuing currency crisis is due to the existence of a budget deficit financed by an expansion of domestic credit. The monetization of the public deficit leads to a downfall in international reserves which are intended to defend a fixed exchange rate. At certain point – the earliest moment at which the attack could be successful – the exhaustion of reserves force the government to abandon the peg. That is: *economic fundamentals drive the crisis*.

Despite the criticisms about the mechanical way in which the government policy is represented in those first-generation models, they were fairly accepted until they failed to address the issues behind the crises of the second half of the nineties. It became the high time for what Obstfeld (1984, 1986) had called second-generation models, which allowed the existence of speculative attacks even with government policies consistent with keeping an exchange rate peg. Still, these models leaved flow disequilibria – like public budget deficits o current account deficits – out of the picture. They focused instead on stock disequilibria – typically the short run public debt *vis-à-vis* the financial system liquidity –. Besides, those models allowed multiple equilibria, and kept a key role for self-fulfilling prophecies in financial markets with imperfect and asymmetric information. Another significant difference between both types of models in that in the second-generation ones the timing of a crisis is arbitrary, allowing one to arise in a country whose fixed exchange rate might otherwise have survived indefinitely (Krugman 1999).

While the literature was starting to develop and to discuss second-generation models, the crisis in Asian erupted. During 1997 several of those economies faced sharp devaluations which lead to an interruption in their successful models of development. In those countries, the exchange market crisis was clearly accompanied by a crisis in the financial sector. After those experiences, the idea of joint financial and currency crises, became more central. Twin crises (Kaminsky y Reinhart, 1999) became the usual target of *third-generation* models. Although which several features similar with second-generation models, third –generation ones bring back fundamentals as triggers of crises.

Along the lines followed by the third-generation models, we present a model that does not focus on fundamentals as the main cause of a crisis but without claiming that fundamentals do no matter. On the contrary, speculative attacks will be seen as fully justified by weak fundamentals. On the other hand, a country with sound and very strong fundamentals in not a vulnerable target for such attacks. The interest here is oriented to a range of fundamentals in which a crisis could happen but not necessarily.

The rest of the paper is organized al follows. Section 2 discusses the nature of a crisis in a bank-based financial system, arising from uncertainty on exchange rate. Section 3 presents a fuzzy model of financial herding. Finally, section 4 analyzes liquidity constraints faced by financial sector in developing countries.

2. The Nature of Financial Crises triggered by Uncertainty on the Exchange Rate

Financial intermediation in developing economies is almost always bank-dominated. That is, the bulk of capital inflows are channeled through the domestic banking system. The concern about the linkages and interactions among these domestic financial institutions and foreign investors arises from the fact that they played a crucial role in most of the key financial events in the developing world during the last three decades.

While most of the flows intermediated through the domestic banking system are, typically, short run ones, the direct foreign investment is not channeled by the national banks. As the former depend on portfolio decisions, the effects of them on the banking system depend critically on the factors that affect those decisions. Moreover, the characteristics and impact produced by those factors are different, depending on the policy regime adopted and the general macroeconomic environment.

The instability of bank deposits has been studied in the literature, and “contagion” runs have been the main factor identified in banking crises. The process is as follows: uncertainty about the soundness of the banking sector generates a preference for liquidity. Then, the “first-come, first-served” process whereby deposits are paid-off to depositors starts a run (Diamond –Dybvig, 1983).

Thinking along the same lines, our interest here is instead focused on banking crises not stemming from withdrawals due to mistrust in the reliability of banks, but either from of a change in the conditions of international financial markets or the fear of agents about a possible devaluation. In the former case,

agents reduce their demands for deposits increasing their demand of monetary base using it as a liquidity hedge; in the latter one, people flee from both bank deposits *and* the monetary base increasing their demand for assets abroad. Note that in this case the pressure is exerted not only on deposits but also on the international reserves of the central bank.

Whatever the reason for withdraws, banks face the so-called *liquidity risk*, that is the inability to obtain funding to satisfy current obligations. The balance sheets of banks show the very nature of this problem. On the liabilities side, depositors try to get their deposits - which are liquid - while on the other side long-term and illiquid assets - bank loans- are held. As the liquidity of bank assets, like that of any other financial instrument, is given by the time needed to sell it obtaining the total value without incurring in excessive transactions cost, the nature of the end-users/intermediaries debt contract determines the illiquidity of loans, due to the credit process. Thus, a maturity mismatch may arise.

For an agent that brings capital from abroad and demands domestic currency-denominated deposits, a non anticipated change in the nominal exchange rate implies a systemic risk which is not diversifiable. The withdrawal of deposits and the demand of assets abroad is the only way to avoid that risk. Although facing the risk of bank default, agents will also withdraw deposits. Alternatively, either hoarding domestic currency or making direct investments in the country may be the preferred alternatives if no change of relative prices is expected. The case of unexpected changes in the exchange rate cannot be handled appropriately in the framework of objective probability theory. The uncertainty here is quite different from risk, as was already set out by Knight.

Pure uncertainty arises because some changes that could happen in the economic environment do not obey a stable probability distribution. Hence, it is not possible to know the future making inferences from past data. This applies also to events that change the economic environment in ways that cannot be anticipated or to events with no diversifiable risk.

Without appropriate tools for making decisions under uncertainty these phenomena may well be ignored if the mentioned events are perceived as unlikely and information costly. However, an alternative is to use a model where those events are represented by parameters that depend on the degree of uncertainty, indicating the risk premia of assets. Those parameters must focus on the *relevant* uncertainty of the agent. Hence, uncertainty about the interest rate matters if the substitution between short run assets and long run assets is the privileged relationship. On the contrary, if uncertainty about price level matters most, emphasis should be focused on the substitution between financial assets and

fixed capital. Notice that, from a perspective of capital movements, the uncertainty represented by that parameter will be focused on the stability of the exchange rule, and then the relevant substitution is between domestic currency denominated assets and assets abroad.

An increasing uncertainty triggers a loss of confidence that leads to a liquidity crisis in the financial system. Literature on default risk in the financial system of developed countries highlights the impact on the confidence of agents provoked by events like those discussed above, namely those to which objective probabilities cannot be attached (significant changes in policy regime, financial crises in other markets and/or other countries, etc.). It must be pointed out, however, that similar questions can be raised concerning the behavior of capital flows.

Taking into account that an unanticipated devaluation is a very important source of uncertainty, several economies have developed the so-called "dollarized fraction" into their domestic banking systems: Banks can take dollar-denominated deposits, and make dollar-denominated loans. Given that, agents can substitute domestic issued assets denominated in "pesos" for domestic issued dollar-denominated assets. In this way, they can hedge their assets against capital losses arising from an unanticipated devaluation. However, if the uncertainty keeps increasing, agents will try to substitute assets issued domestically (whatever the currency in which they are denominated) for assets issued abroad. In other words, they try to replace a domestic debtor for an international one.

Given all this discussion our goal in this paper is manifold. In the first place we will introduce a characterization of uncertainty in terms of the risk premium. We identify this percentage with a real number μ. The definition of μ arises from the difference between the returns of different types of assets weighted up by the degree in which they can be deemed as being low risk ones.

3. A Fuzzy Model of Financial Hedging

Consider three assets, 1, 2 and 3, where 1 represents three assets. The proportions in which a certain amount of wealth **w** is invested in each one constitute a vector $x = (x_1, x_2, x_3)$. That is, $x_1 + x_2 + x_3 = 1$.

The composition of this portfolio depends on the context in which the investment decision is made. If we denote the state of the world (which summarizes all the relevant parameters taken into account by the decision maker) as θ, we denote by $\rho_i(\theta)$ the degree in which asset i may be deemed as *highly risky*. This degree is not a probabilistic measures but a fuzzy membership function. Then, $0 \leq \rho_i(\theta) \leq 1$, and

if $\rho_i(\theta) = 1$ the asset is said of high risk, while if $\rho_i(\theta) = 0$ it is considered risk-less.

At a given state of the world θ the returns of the assets are (nominally) described by a vector $r(\theta) = (r_1(\theta), r_2(\theta), r_3(\theta))$. The goal of a rational decision maker will be to find $x = (x_1, x_2, x_3)$ such that she maximizes the returns of her portfolio, minimizing the associated high risks. The objective of the investor can be described by means of the following function:

$$F(\theta) = r(\theta) \cdot x^{1-\rho(\theta)}$$

where $x^{1-\rho(\theta)} = ((1-\rho_1(\theta)) \ln x_1, (1-\rho_2(\theta)) \ln x_2, (1-\rho_3(\theta)) \ln x_3)$.

Then, we have the following result:

Proposition 1: *For each asset i the optimal proportion invested is* $x_i^*(\theta) = \{(1-\rho_i(\theta))\, r_i(\theta)\}/R(\theta)$ *where* $R(\theta) = \sum_{j=1}^{3} (1-\rho_j(\theta))\, r_j(\theta)$

Proof: *Immediate from the maximization of* $F(\theta)$ *subject to* $x_1 + x_2 + x_3 = 1$. □

A new situation θ' will be associated to $r(\theta')$ and corresponding high risk values $\rho(\theta') = (\rho_1(\theta'),\rho_2(\theta'),\rho_3(\theta'))$. We assume that r is positively correlated to increases of ρ, i.e. that

$$\text{if } \rho_i(\theta') - \rho_i(\theta) \geq 0 \text{ then } r_i(\theta') - r_i(\theta) \geq 0$$

We say that a transition from θ to θ' is *uncertainty-increasing* for asset i if:

$$r_i(\theta') - r_i(\theta) \leq r_i(\theta')\rho_i(\theta') - r_i(\theta)\rho_i(\theta)$$

Then, we have the following result:

Proposition 2: *If the transition from* θ *to* θ' *is uncertainty-increasing for asset* i, *then the optimal proportion verifies* $x_i^*(\theta') \leq x_i^*(\theta)$ *if* $R(\theta') \leq R(\theta)$.

Proof: *Trivial.* □

While this result yields a sufficient condition for decreasing shares, a necessary condition obtains if we consider the transition to be *relative uncertainty-increasing* for asset i:

$$\{(1- \rho_i(\theta')) r_i(\theta')\} / \{(1- \rho_i(\theta)) r_i(\theta)\} \leq R(\theta') / R(\theta)$$

That is, if the new returns of the asset weighted up by its degree of non-high-risky nature improve less than the corresponding returns for the entire portfolio.

Proposition 3: *If the transition from* θ *to* θ' *is relative uncertainty-increasing for asset* i, *then the optimal proportion verifies* $x_i^*(\theta') \leq x_i^*(\theta)$.

Conditions to apply this result follow from considering the *low risk premium* of an asset i over an asset j at a state of the world θ:

$$\mu_{ij}(\theta) = (1-\rho_j(\theta))r_j(\theta) / (1- \rho_i(\theta))r_i(\theta)$$

This index measures proportion of the return of j (weighted up by its associated low risk degree) over that of i. We have that:

Lemma 1: *The transition from* θ *to* θ' *is relative uncertainty-increasing for asset* i *if* :

$$\mu_{ij}(\theta) \leq \mu_{ij}(\theta') \text{ and } \mu_{ik}(\theta) \leq \mu_{ik}(\theta')$$

for $j \neq k \neq i$,.

Proof: *By the definition of low risk premium,* $\mu_{ij}(\theta) \leq \mu_{ij}(\theta')$ *and* $\mu_{ik}(\theta) \leq \mu_{ik}(\theta')$, *indicate, without loss of generality, that*

$$(1-\rho_j(\theta))r_j(\theta) / (1- \rho_i(\theta))r_i(\theta) \leq (1-\rho_j(\theta'))r_j(\theta') / (1- \rho_i(\theta'))r_i(\theta')$$

and

$$(1-\rho_k(\theta))r_k(\theta) / (1- \rho_i(\theta))r_i(\theta) \leq (1-\rho_k(\theta'))r_k(\theta') / (1- \rho_i(\theta'))r_i(\theta')$$

adding up these two inequalities plus 1 = 1 *we obtain:*

$$(1-\rho_j(\theta))r_j(\theta) / (1- \rho_i(\theta))r_i(\theta) + (1-\rho_k(\theta))r_k(\theta) / (1- \rho_i(\theta))r_i(\theta) + 1 \leq$$

$$\leq (1-\rho_j(\theta'))r_j(\theta') / (1- \rho_i(\theta'))r_i(\theta') + (1-\rho_k(\theta'))r_k(\theta') / (1- \rho_i(\theta'))r_i(\theta') + 1$$

notice that the left hand of this inequality is

$$R(\theta) / \{(1- \rho_i(\theta)) r_i(\theta)\}$$

while the second hand is:

$$R(\theta') / \{(1- \rho_i(\theta')) r_i(\theta')\}.$$

Therefore:

$$\{(1- \rho_i(\theta')) r_i(\theta')\} / \{(1- \rho_i(\theta)) r_i(\theta)\} \leq R(\theta') / R(\theta)$$

i.e. the transition is relative uncertainty-increasing for asset i. □

4. Fractional-reserve Banks and Liquidity Constraints

The assets owned by banks are long-term and illiquid, except for the small liquid proportion held to meet the normal demand for withdrawals. Their liabilities, in turn, are liquid, or at least more liquid than their assets. It is a very well-known rule of safe financial management that the values of short-run assets must be higher than the value of short-run liabilities in order to avoid liquidity problems. Nevertheless, this can not be true for *all* agents nor for the system as a whole. Since one agent's financial asset is another's liability, there must be some agents for whom the value of their short-term liabilities exceeds that of their short-term assets.

That disparity is the justification for the existence of a banking system: its role is to hold a greater amount of short term liabilities than of short term assets. In a sense, the liquidity is created out of a paradox: under normal conditions, the public perceives the banks as the most liquid agents, when in fact they are highly exposed to liquidity shocks. However, if any event provokes a change in the public perception, it may be followed by a higher proportion of withdrawals. As there is not a secondary market of bank loans, banks become illiquid. When fractional-reserve banks in developed countries face a liquidity problem, they are likely to get emergency funds from a domestic lender-of-last-resort and/or from de world capital market as long as they are solvent. As is pointed out below, this is a possibility not available in emerging economies.

However, if deposits issued domestically but dollar-denominated are allowed, based on the idea that agents trust their domestic debtor but only provided that the debt is issued in foreign currency, it is possible to avoid a crisis, as soon as portfolio substitution goes from deposits in domestic currency to deposits in dollar-denominated domestically issued deposits. A gradual asset substitution avoids the collapse and leads a non traumatic dollarization of the banking system.

Even though a complete full dollarization process make the devaluation expectations less relevant, there is a risk remaining, namely *country risk*. This is a systemic risk that agents can not diversify, and it could be avoided by holding a portfolio without domestic assets. A sudden change in agents'

preferences that leads to a higher demand for assets issued in the rest of the world, implies a capital outflow with effects over domestic monetary aggregates that can end in a collapse of the banking system.

As was mentioned above, when a bank system in a mature economy faces liquidity problems there are some mechanisms that allow stopping any attempt of bank run. The problem in developing countries arises from the fact that when agents (both residents and no residents) flight from domestic deposits – whatever the currency they are denominated – they also flight from all other domestic assets included public ones. Then, all domestic agents, included the government, face liquidity constraints. Therefore, the public sector cannot act as a lender-of-last-resort. Furthermore, as international investors flight from the country too, banks being run over by depositors are unable to get funds in the world capital markets. The crisis cannot be stopped at that point.

This is in fact a story that can be told in terms of our fuzzy model of uncertainty. That is, we can discuss the changes in portfolios among three kinds of assets: 1, pesos in the domestic banking system; 2, dollars in domestic banks; and 3, dollars abroad. For simplicity, we assume that $r_3 = \mathbf{r}$ as well as $\rho_3 = 0$ for all three states of the world we will consider, θ, θ' and θ''.

In state θ, the agents invest their wealth in the proportions $x^*(\theta) = (x_1^*(\theta), x_2^*(\theta), x_3^*(\theta))$. Then, a transition to θ' ensues, associated with the possibility that banks will not repay the peso-nominated deposits, due to the flight of capitals, that constitute the source of the short term resources of banks. That is, $\rho_1(\theta) \leq \rho_1(\theta')$. By our characterization it follows that $r_1(\theta) \leq r_1(\theta')$. Since the domestic banks face difficulties, it will happen also that $\rho_2(\theta) \leq \rho_2(\theta')$ and consequently $r_2(\theta) \leq r_2(\theta')$. If $\mu_{12}(\theta) \leq \mu_{12}(\theta')$ *and* $\mu_{13}(\theta) \leq \mu_{13}(\theta')$, we know that the proportion $x_1^*(\theta')$ will decrease in $x^*(\theta')$, while $x_2^*(\theta')$ and $x_3^*(\theta')$ will increase. On the other hand, we have that $R(\theta') \leq R(\theta)$ since, otherwise, it would mean that asset 3 will become relative risk increasing. In fact, this is consistent with our argument: the only change in the overall return (weighted up by the risk of its components) of the portfolio ensues from an increase of uncertainty and not from higher returns to inversion. In consequence, at state θ', the deposits in dollars will increase, both in the domestic banks and abroad, at the expense of peso deposits.

If a new state θ'' obtains, in which the systemic risk of devaluation increases, banks face both the possibility of not being able to repay their peso and dollar denominated deposits. Therefore, both assets 1 and 2 increase their relative uncertainty, which amounts to a new $x^*(\theta'')$ in which $x_3^*(\theta'')$ increases

at the expense of the shares invested in 1 and 2 (again with $R(\theta'') \leq R(\theta')$).

The extreme cases arise when $\rho_1(\theta') = 1$, and therefore $x_1^*(\theta') = 0$. That is, if peso denominated deposits are considered highly risky, only dollar deposits will be made. On the other hand, when $\rho_1(\theta'') = 1 = \rho_2(\theta'')$, only $x_3^*(\theta'') > 0$, i.e. all deposits will be transferred abroad.

This in fact, can be seen as a stylized description of the transitions undergone by the Argentinean economy from 1991 to 2001. θ can be seen as the situation at the beginning of the period, when a convertibility regime was implemented and the financial system was liberalized. Those policies allowed investors to diversify their portfolios with the three types of assets. In 1994/1995 the Mexican crisis induced a flight of capitals from the emerging markets, including Argentina. Although the exchange rate was preserved, it became clear that holding assets in pesos was risky. Therefore, massive transfers to dollar denominated deposits were made by the investors, both in the country and abroad.

Finally, with the collapse of the exchange rate approaching in 2000/2001, investors saw that the government would not be able to act as a lender of last resort, and therefore banks would not be able to repay nor dollar nor pesos deposits. Therefore, a massive flight of capitals started, which ended up forcing the collapse of the convertibility system.

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