Are Currency Crises Unpredictable?

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Abstract

I consider a dynamic capital stock adjustment of a less developed country in a catching-up endogenous growth model. I show that there exists a possibility of reversals or switching between steady state paths that lead to ‘good’ and ‘bad’ equilibria. Such possibility exists even in a model where short-term capital flows and their reversals are assumed to be infeasible; i.e. when all international investment is assumed to be sunk and cannot be repatriated. Shifts of expectations can then lead to switching of the steady state to which the economy is approaching. I interpret this finding as a reminder that expectation driven currency crises need not be a direct result of increased volume of volatile short-term international capital flows in recent decades. I empirically illustrate the existence of unexplainable currency crises by estimating a probit model augmented for the possibility of ‘sunspot’ crises. The results suggest that allowing for the existence of unexpected crises leads to an improved inference on the mechanism of the crises that can be predicted.

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1. Introduction

The conventional wisdom in international economics is that indeed speculative capital brings the danger of expectation reversals resulting in capital account crises irrespective of fundamentals. See, for example, Obstfeld (1994), Calvo (1998b) or Calvo and Mendoza (1997). Nevertheless, direct capital inflows are often regarded as ’safe’ in this respect, due to the country specificity of such investments and the general impossibility of sudden reversals caused by expectation changes. However, capital flows need not be reversed in order to inflict damage to an open economy. Sudden stops of capital inflows for a country that faces an international borrowing constraint have to result in damaging adjustment in domestic absorption. Therefore, a sudden decrease in capital inflows should also be considered current account crises, see the discussion in Calvo (1998a).

In this paper I develop a model of technological catching-up of a less developed economy where no negative outflows of capital are possible by construction but in which an exogenous outside shock (expectations reversal) has a real impact on the economy. The model builds on work done by Krugman (1991) and Matsuyama (1991) in the context of labor flows in a two-sector model of economic development. In a standard endogenous growth theory, the pool of new technologies
that a country faces would generate "technological catching-up", i.e. a process of
adjustment where such country acquires these new technologies. A usual simpli-
fication is to treat technology level as equivalent to the per capita capital level
of the country. Catching-up is then a process of capital accumulation via either
domestic savings or international capital transfers.

My model captures the mechanism that governs flows of long-term investments
or foreign direct investment (FDI). Although different from short-term capital, I
show that the flow of FDI can be very similar in its behavior and similar exogenous
and endogenous conditions can induce its reversal. In particular, inflow of long-
term capital depends on expectations about future returns. When expectations
change, there might be a sudden discrete jump in its volume or it can even dry
up completely. Although these changes are unlikely to produce sudden balance-
of-payments crises, their effect can be exacerbated by the reaction of short-term
capital.

Given this conclusion, I then turn to the empirical evidence to assess whether
unexpected or unexplainable currency crises do indeed occur. Although there are
many theoretical models in the literature implying different sets of preconditions
that are capable of generating financial crises and panics, the empirical treatments
of financial crises ignore this and, instead, focus either on testing one model at a
time, or attempt an a-theoretical construction of 'stylized facts' about financial crises and/or construct early warning indicators (Kaminsky, Lizondo and Reinhart, 1998). This approach fails to address the challenge that over a period of time, there might be different crisis mechanisms at work that generated the crises that we observed in the data. The empirical literature has evolved from cross country studies at a point in time (Sachs, Tornell and Velasco, 1996) and pooled panel estimation of probit models (Frankel and Rose, 1996) to applications of random effects logit models (Esquivel and Larrain, 1998) and Markov switching models that endogenize the definition of a crisis either with a fixed transition probability matrix (Jeanne and Masson, 2000) or with the transition matrix estimated by a pooled logit model (Peria, 2000).

However, the literature has continued to assume that there is a single 'type' of crises and I argue that this is potentially a serious shortcoming. As a remedy, I propose a framework in which different theoretical models can be tested simultaneously. I derive the exact maximum likelihood estimator of a dependent binary variable model with several crisis-generating mechanisms. This estimator is equivalent to the composite warning indicator in Kaminsky, Lizondo and Reinhart (1998) but instead of having to use computationally very demanding grid search methods, the approach here is based on maximizing a well-specified
likelihood function. I discuss some evidence that suggests that allowing for such possibility leads to an improved inference on the mechanism of the crises that can be predicted.

In the next section I will present the theoretical model and show that unexpected crises can occur even if one only considers FDI flows. Section three will discuss the empirical evidence and section four will conclude.

2. Theoretical Model

My model assumes a standard constant returns to scale production function with labor augmenting technological change. The room for productivity increases in the developing country is assumed to be limited by the technology available in world, and that the limiting factor is the level of per capita capital at the world technological frontier. Furthermore, the marginal increases in technology level are assumed to depend negatively on the difference between domestic technology and the world technology frontier. This assumption is known as the Gerchenkron hypothesis. The Gerchenkron hypothesis implies that the rate of technological progress is proportional to the difference between the per capita capital stock in the developing country and the country at the technological frontier. When the limiting level of per head capital (the level at the technological frontier) is reached,
the level of technology in the developing country is maximized.

I assume that all firms in the economy are identical, i.e. facing the same production function. However, the effect of capital accumulation on the level of technology is assumed to be a positive externality and, therefore, the firms do not take it into account in their decision-making. The rest of the world is assumed to be large enough so that any capital flows from or into the developing country or any capital accumulation abroad do not influence its constant rate of return on capital. The important implication is that the rate of return on capital in the developing country is at first increasing in the level of capital stock. It reaches a maximum at a level lower than at the world technology frontier and is then decreasing with the capital stock. Such relationship is the main reason why multiple equilibria exist in the model.

Suppose that investors compare returns on capital in the two parts of the world at each instant of time. Then the resulting arbitrage ensures that the returns on capital are equalized and given the relationship between capital stock and its rate of return, there are two possible solutions (steady states). The adjustment is instantaneous and the final level of capital in the developing country is fully determined by arbitrary expectations.

I consider two assumptions that create more plausible dynamics of the capital
adjustment. First, I introduce costs of capital movement. In this case, the capital transfer becomes an investment decision. It also naturally brings a role for expectations. Costs of capital movements force the agents to care not only about current returns on capital but also about future returns. For example, we could observe capital inflows even when the return on capital in the developing country is initially lower than in the rest of the world but if sufficient amount of amount of capital is accumulated the return is higher.

Second, I show that the resulting dynamics in the model with costs of capital movement is the same as in a model where international investment is assumed to be sunk. When capital investments are sunk, there is no possibility to withdraw the principal, the only part that can be repatriated are profits on the investment. The decision whether to invest in the developing country is then based on comparing the total discounted sum of all expected profits with the profits that could be obtained abroad. The decision is very simple: if the difference is positive, than investors decide to invest in the developing country. For simplicity I assume that there is an exogenous stream of savings the agents allocate between the two parts of the world. Endogenizing the savings would only affect the speed of transition but, since investment decisions are irreversible, the topology of capital dynamics would be qualitatively the same.
The model has three steady state solutions, provided that the relationship between return on capital and the capital stock is as described above. The steady states with highest and lowest level of capital are stable (I refer to these as the ‘good’ and ‘bad’ equilibria) while the intermediate steady state is unstable. Suppose the economy starts with some initial level of capital. Expectations then determine the total discounted return from investing in the developing country. If agents are rational, the initial expected sum of discounted profits has to be consistent with the subsequent path the economy takes off. If the initial level of capital is below a critical level, then there is no path to the ‘good’ equilibrium. Nobody then invests in the country and the capital stock does not change. If the economy starts with higher capital stock, there are two possibilities. Either the agents are optimistic, expect to achieve the good equilibrium in the end. Positive expected returns from investing in the developing country then induce all agents to invest their savings in the developing country. On the other hand, if the agents are pessimistic, there is no inflow of capital in the developing country. If the developing country starts with a very high level of capital stock, then there is only one steady state path leading to the good equilibria.
2.1. The Model

The structure of the model and the conclusions rely on a specific form of technological change. Formally, if $Y$ is output of some composite good, $K$, $L$ and $T$ are the capital, labor and the technology level respectively, then one can write a constant returns to scale production function with labor augmenting technology as:

$$Y_t = F(K_t, L_t \cdot T_t) = f(k_t, T_t)$$  \hspace{1cm} (2.1)

where

$$T_t \sim \frac{K_t}{L_t} = k_t$$  \hspace{1cm} (2.2)

The room for productivity increases in the developing country is limited by the technology available in the world. Furthermore, the marginal increases in technology level is assumed to depend negatively on the difference between domestic technology and the 'world technology frontier'. Hence we have that

$$\frac{\partial T_t}{\partial k_t} \sim k^* - k_t$$  \hspace{1cm} (2.3)

where $k^*$ is the limiting level of per head capital in the rest of the world which when reached maximizes the level of technology in the developing country. This
is what will be in this context called a 'successful transition'. Integrating this condition leads to a more specific family of functions from which we can choose conveniently that:

\[ T_t = k_t(2k^* - k_t) \]  \hspace{1cm} (2.4)

for \(0 \leq k_t \leq k^*\).

Suppose that all firms in the developing country are identical, i.e. facing a production function described by (2.1) and (2.2). However, the effect of capital accumulation on the level of technology is assumed to be a positive externality and, therefore, the firms do not take it into account in their decision-making. With perfect competition, the instantaneous returns to capital in the economy would, therefore, be:

\[ r_t = \frac{\partial f}{\partial k_t} \bigg|_{T=\text{const}} \]  \hspace{1cm} (2.5)

The rest of the world is assumed to be large enough so that any capital flows from or into the developing country or any capital accumulation abroad do not influence its constant rate of return \(r^*\) on capital.

Suppose that the production function is a Cobb-Douglass type with decreasing
returns to scale to capital and constant returns to technology:

\[ Y_t = (k_t)^\alpha T_t \]  \hspace{1cm} (2.6)

Then (2.5) can be written as:

\[ r_t = \alpha \cdot (k_t)^{\alpha-1}[2k^*k_t - (k_t)^2] \]  \hspace{1cm} (2.7)

The relationship between \( k_t \) and \( r_t \) of this kind is drawn in figure 1. For the results in this paper, I will only need to assume that rate of return on capital in the developing country depends on the total level of capital in the same manner, i.e. \( r_t \) is lower for small values of \( k_t \), then it is higher and as \( k_t \) approaches \( k^* \), \( r_t \) approaches \( r^* \) (as in figure 1). However, I need not know the exact functional form.

2.2. Static Approach

Suppose that investors compare returns on capital in the two parts of the world at each instant of time. Then the resulting arbitrage ensures that \( r_t = r^* \) and the only possible capital levels of the developing country are \( k^* \), \( k \) or 0 (the boundary level). The adjustment is instantaneous and the final level of capital in the developing
country is fully determined by the initial $k_0$ (history). If $k < k_0 < k^*$ then $r^* < r_0$ and, therefore, capital will flow in the developing country and the economy will end up with $k^*$ (successful transition). However, if $0 < k_0 < k$ then $r_0 < r^*$ and there will be outflow of capital from the developing economy and the economy will end up with no capital at all. Even if we assumed that outflow of capital from the developing country is impossible, this case would still be a ‘development trap’ - the economy would be stuck with its initial level of capital.

Therefore, the length and end-result of a transition are decided at the beginning of the process and are fully determined by historical incidence (the initial per head capital level). More disturbing is the fact that the transition is only quasi-dynamic process. If capital moves costlessly across countries, the adjustment is instantaneous. The next section will try to remedy these deficiencies.

2.3. Dynamic Approach

First obvious remedy is to introduce costs of capital movement. In this case, the capital transfer becomes an investment decision. It also naturally brings a role for expectations. Costs of capital movements force the agents to care not only about current returns on capital but also about future returns. If we start off with a situation where return on capital in the developing country is initially
lower than in the rest of the world but if sufficient amount of amount of capital is accumulated the return is higher, there is a potential for multiple equilibria and self-fulfilling outcomes. However, this approach could be criticized for being rather ad hoc. Below, I will discuss more intuitively appealing alternative. The resulting dynamics is very similar to the case of the ad hoc costs of capital movement which is worked out in an appendix.

Let us assume that once the capital is invested, there is no possibility to withdraw the principal, the only part that can be repatriated in a short term are profits on the investment \( r_t \). Of course, in the long-run the principal is also recovered but we assume here that the investment is sunk for some period of time which we assume to be sufficiently long so that we can treat it as infinity.\(^1\) If the capital investments are irreversible, then the decision whether to invest in the developing country at time \( t \) is based on comparing the total discounted sum of all expected profits with the profits that could be obtained abroad:

\[
R_t = \int_t^\infty (r_s - r^*) \cdot e^{-\theta(s-t)} ds \tag{2.8}
\]

The decision is very simple: if \( R_t \) is positive, than investors decide to invest in

\(^1\)Alternatively, one could argue that when recovering the principal, the sale price of the asset again depends on discounted sum of future profits.
the developing country. Suppose that there is an exogenous stream of savings $s_t$ (per capita) the agents have and allocate between the two parts of the world. We are interested in the determination of the end-result of transition. Endogenizing the savings would only affect the speed of transition but, since investment decisions are irreversible, the topology of capital dynamics would be qualitatively the same.

Given these assumptions, the capital in the developing country change according to:

$$\frac{dk_t}{dt} = Z(R_t) \cdot s_t \quad (2.9)$$

where

$$Z(R_t) = \begin{cases} 1 & \text{if } R_t > 0 \\ 0 & \text{otherwise} \end{cases} \quad (2.10)$$

Equations (2.8) and (2.9) together with the initial conditions describe the behavior of the system. However, the initial $R_0$ has to be consistent with the equilibrium path the economy will take off. If this was not the case, the agents would not be rational.
Differentiating (2.8) with respect to time yields:

\[
\frac{dR_t}{dt} = -r_t + r^* \tag{2.11}
\]

Now, (2.9) and (2.11) is a system of differential equations for \( R_t \) and \( k_t \). The \( \frac{dR_t}{dt} = 0 \) locus is from (2.11) given by

\[
0 = r_t - r^* \tag{2.12}
\]

This equation has two solutions for \( k_t \), provided that the relationship between \( r_t \) and \( k_t \) is as in figure 1. Therefore, the locus is composed from two lines: \( k_t = k \) and \( k_t = k^* \). For \( k_t \) smaller than \( k \), \( \frac{dR_t}{dt} \) is positive while for \( k_t \) between \( k \) and \( k^* \), it is negative.

Since we have postulated the time derivative of capital by (2.9), the \( \frac{dk_t}{dt} = 0 \) locus is not a line but the whole half-plane \( R_t \leq 0 \). This is due to the investment irreversibility assumption. Also, \( \frac{dk_t}{dt} \) is positive for strictly positive \( R_t \).

There are several steady states. Obviously \((k_t, R_t) = (k^*, 0)\) is a steady state but also all points \((k, 0)\) where \( k < k^* \) are steady states. It can be easily verified that there is a unique path leading to the \((k^*, 0)\) steady state which starts at a
point \((k^c, 0)\) where \(k^c < k\) is a critical level of capital determined endogenously by the system.

The economy starts with some initial level of capital \(k_0\). Then expectations determine the total discounted return \(R_0\) from investing in the developing country. If agents are rational, this initial \(R_0\) has to be consistent with the subsequent path the economy takes off. If the initial level of capital is below \(k^c\) then there is no path to the ‘good’ equilibrium and agents have to set the initial \(R_0\) equal to zero. Nobody then invests in the developing country and the capital stock does not change.

If the economy starts with \(k^c \leq k_0 < k^*\), there are two possibilities. Either the agents are optimistic, expect to achieve the good equilibrium, and set the initial \(R_0\) so that it puts them on the unique path leading there. Positive expected returns from investing in the developing country induce everyone invest their savings in the developing country resulting in a successful transition. On the other hand, if the agents are pessimistic, setting initial \(R_0\) to zero, there is no inflow of capital in the developing country.

To determine the critical level \(k^c\), we can exploit the fact that on the successful path all savings are invested in the developing country. In addition, the path starts
at a point \((k^c, 0)\). From the definition of \(R_t\) we obtain:

\[
0 = \int_0^\infty (r_t - r^*) e^{-\theta t} dt
\]  

(2.13)

where the path for \(r_t\) is given by the, now exogenous, path of \(k_t\). The only variable in this equation is the initial level of capital, \(k_0 = k^c\). Solving this condition gives \(k^c\) as a function of the path of savings \(s_t\), the world interest rate \(r^*\) and the discount factor \(\theta\). Note that as \(\theta \to \infty\) then \(k^c \to k\) and the dynamics is equivalent to the results from the static approach of the above section.

Negative outside shocks, in this context represented for example by increase in \(r^*\), increase both critical levels of capital; \(k^c\) and \(k\), shifting the indeterminate region to the right. Even if the economy was on the stable 'good' equilibrium path before such shock, there is a possibility that after the shock the only possible equilibrium is stagnation. By the same reasoning, the shock could send an economy from the region with unique 'good' equilibrium to an intermediate region where expectations of investors will decide the outcome for the developing country.
3. Empirical Illustration

The situation where the observable binary variable is a combination of several latent binary variables is likely in cases where there are, for example, competing theoretical explanations (models) of the endogenous variable. If these models are not exclusive, i.e. they can be in operation on the same economic agent at the same time, the resulting observable (binary) variable is a logical OR composition of the underlying binary variables associated with each model. An example are models of currency crises - there are several competing models in the literature and each of them produces a currency crisis under some realization of disturbances. These models can operate on the same agent – a country can have a crisis due to inconsistent government policies and five years later there can be a crisis due to a liquidity squeeze on international investors. Alternatively, these two channels can operate at the same time.

The assumption that makes this model not estimable by standard techniques is that the two different latent variables that drive the dependent binary variable do not offset each other. This assumption is violated in a variety of settings and in these it is legitimate to use the standard single model technique such as logit or probit estimation. In that case, the two models imply a single latent
variable (addition of the two latent variables) that drives the dependent binary variable. However, if the two forces do not counteract each other, the resulting maximum likelihood function is slightly more complicated and standard probit or logit estimation should not be applied.

In the context of currency crises, some competing theoretical explanations do not offset each other – if the government is running inconsistent policies that would result in the crisis in the next period, the crisis will take place regardless of the absence of liquidity squeeze on international investors. That is, the low probability of crisis implied by model two does not alleviate the high probability of crisis implied by model one. To make sure that the complete separation of the two models hold, one also has to verify that the opposite is true, i.e. government policies and liquidity squeeze on investors although unable to generate crisis separately, would generate one if compounded.

3.1. Binary Variables Models

Binary variables are variables that take on only two discrete values. They are often used in a various areas of econometric inquiry, ranging from microeconomics (consumer decision to buy or not to buy for example a house) to macroeconomics or international finance (currency attack occurs or does not occur). There is a
standard procedure to estimate a single binary variable using a continuous valued explanatory variables – probit or tobit estimation techniques.

In this paper we will show that some applications of probit or tobit estimation are in fact estimating a composite binary variable instead of a single binary variable. Composite binary variable is a variable that is a product of logical operation involving several binary variables. I will derive the maximum likelihood estimation in this case and apply the procedure to the problem of predicting currency crises.

3.1.1. Basic Setup

Let us assume that there is a single observable binary variable $Y$ and that there is a vector $a$ (continuously) valued explanatory variables. The default value of $Y$ is zero and there are two alternative theoretical models that generate a value of one in $Y$. We define two binary variables $Y_1$ and $Y_2$ corresponding to each model. That is $Y_1$ (or $Y_2$) is equal to one if model one (or two) suggests $Y$ should be one, and it is zero otherwise. Variable $Y$ is then a logical OR operated on these two variables:

$$Y_t = (Y_t^1 \text{ or } Y_t^2) = Y_t^1 + Y_t^2 - Y_t^1 \cdot Y_t^2 \quad (3.1)$$

This is just stating the $Y$ is equal to one if model one or model two predicts
it should be one. The two models are assumed to be the standard binary variable models, i.e.:

\[ Y_{t1} = \begin{cases} 1 & \text{if } X_t \cdot \beta_1 + \varepsilon_{t1} > K_1 \\ 0 & \text{otherwise} \end{cases} \] (3.2)

and

\[ Y_{t2} = \begin{cases} 1 & \text{if } X_t \cdot \beta_2 + \varepsilon_{t2} > K_2 \\ 0 & \text{otherwise} \end{cases} \] (3.3)

where \( K_1 \) and \( K_2 \) are scalars, \( \beta_1 \) and \( \beta_2 \) are the coefficients of the two models and \( X \) is the common vector of explanatory variables.

This is contrasted to the common latent variable specification which is:

\[ Y_t = \begin{cases} 1 & \text{if } X_t \cdot (\beta_1 + \beta_2) + \varepsilon_t > K \\ 0 & \text{otherwise} \end{cases} \] (3.4)
Given the structure (1)-(3), the probability of $Y_i = 1$ is then:

$$Pr(Y_i = 1) = Pr(X_i^t \cdot \beta_i + \varepsilon_i > K_i) = Pr(\varepsilon_i > K_i - X_i^t \cdot \beta_i) = F_i(X_i^t \cdot \beta_i - K_i)$$

(3.5)

and also

$$Pr(Y_i = 0) = 1 - Pr(Y_i = 1) = 1 - F_i(X_i^t \cdot \beta_i - K_i)$$

(3.6)

where $F_i(.)$ is the cumulative probability distribution function of the disturbance $\varepsilon_i$. Taking into account the definition of $Y$, the probability that $Y = 0$ is then:

$$Pr(Y_t = 0) = Pr(Y_t^1 = 0) \cdot Pr(Y_t^2 = 0) = (1 - F_1) \cdot (1 - F_2)$$

(3.7)

and hence

$$Pr(Y_t = 1) = 1 - (1 - F_1) \cdot (1 - F_2) = F_1 + F_2 - F_1 \cdot F_2$$

(3.8)

Under the assumption that $K_1$ and $K_2$ are 0, the likelihood function for $Y$ is
as follows:

\[
L = \prod_{T_o} [1 - F_1(X_t \cdot \beta_1)] \cdot [1 - F_2(X_t \cdot \beta_2)] \cdot \\
\prod_{T_1} [F_1(X_t \cdot \beta_1) + F_2(X_t \cdot \beta_2) - F_1(X_t \cdot \beta_1) \cdot F_2(X_t \cdot \beta_2)]
\]  

(3.9)

where \( T_1 = \{ t | Y_t = 0 \} \) and \( T_2 = \{ t | Y_t = 1 \} \).

Maximum likelihood estimators maximize \( L \) with respect to \( \beta_1 \) and \( \beta_2 \) and the variance-covariance matrix parameters of \((\varepsilon^1, \varepsilon^2)\) which are reflected in the functional form for \( F_1 \) and \( F_2 \). As in the standard probit or tobit application, the full set of parameters is not identified and we can only estimate \( \frac{\beta_i}{\text{var}(\varepsilon)} \).

3.1.2. Compounding Models

Here we want to allow for the possibility that the two different forces (latent variables) can compound in causing the observable variable to become 1 but, however, they do not counteract each other. That is if model one predicts the dependent variable to be one, it is going to be one regardless of the realization of error terms and explanatory variables in model two. Such situation is more likely to arise in the context of currency crises prediction.

The construction of the likelihood function is analogous to the case discussed
above. For the sake of brevity it will not be covered here, however, a note on this
topic is available on request from the author.

3.1.3. Other issues

The baseline model above was a composition of two binary variables. The exten-
sion to a composition of \( n \) binary variables is straightforward. Furthermore, the
models are nested, i.e. the \( n \) binary variable model contains all the \( n - p \) binary
variable models as special cases – setting the \( \beta_n, \beta_{n-1}, \ldots, \beta_{n-p+1} \) equal to each
other. Hence, if we set an upper limit on \( n \), we could test and find an optimal
\( n \). This could be then used in situations where we are uncertain about how many
different models are actually generating our data.

Furthermore, notice that the model (3.4) is nested in the model (3.1)-(3.3). If
model (3.4) is the true data generating process, it would be replicated by (3.1)-
(3.3) with \( \beta_1 = \beta_2 \) and with the covariance between \( \varepsilon^1 \) and \( \varepsilon^2 \) being an identity
matrix. If one were to maximize the likelihood function (3.9) on data generated
by (3.4), the parameters \( \beta_1 \) and \( \beta_2 \) would not be identified. Furthermore, if (3.9)
is formulated with an iid assumption on \( \varepsilon^1 \) and \( \varepsilon^2 \), the obtained estimators could
still be either consistent or unbiased and one could test the restriction of \( \beta_1 = \beta_2 \).
The maximum likelihood implied by model (3.1)-(3.3) with $\beta_1 = \beta_2$ is:

$$L = \prod_{T_0} [1 - F(X_t \cdot \beta)]^2 \cdot \prod_{T_1} [2 \cdot F(X_t \cdot \beta) - F(X_t \cdot \beta)^2]$$

(3.10)

$$= L_{true} \cdot \prod_{T_0} [1 - F(X_t \cdot \beta)] \cdot \prod_{T_1} [2 - F(X_t \cdot \beta)]$$

$$= (L_{true})^2 \cdot \prod_{T_1} \left[ \frac{2}{F(X_t \cdot \beta)} - 1 \right]$$

$$= (L_{true})^2 \cdot Bias$$

(3.11)

with $L_{true}$ defined as the correct maximum likelihood function in this case:

$$L_{true} = \prod_{T_0} [1 - F(X_t \cdot \beta)] \cdot \prod_{T_1} [F(X_t \cdot \beta)]$$

(3.12)

3.2. Empirical Results

Let me first present results obtained with the standard estimation techniques (e.g. single latent variable probit estimation). I have taken the data compiled by Kaminsky, Lizondo and Reinhart (1998)\(^2\) and estimated a probit model with dependent variable being the indicator whether a currency crises has occurred and the explanatory variables being lagged changes in GDP, exchange rate, stock prices, import and export prices, and inflation (see Kaminsky et al. for variable

\(^2\)Downloadable from C. Reinhart’s web page at http:\\www.bsos.umd.edu\econ\faculty

The individual parameter estimates are not significant for the conclusion that I draw from this exercise. Intuitively, the probit estimation looks for regularities in the behavior of the explanatory variables prior to an occurrence of a currency crises. However, if there are several possible patterns of behavior of the explanatory variables that precede the crises, one would expect the prediction of the crises will be difficult. On the other hand, under the same circumstances, prediction of 'tranquil' periods will still be relatively more efficient.

Table 1 reports the predictions of the probit model compared with the actual occurrences of crises for the estimations carried out on the Kaminsky et al. sample, as well as results from Frankel and Rose (1996).\(^3\) The predictions were classified according to the 50 percent probability rule, e.g. if the probit estimated likelihood function indicates that there is more than a 50 percent probability of an occurrence of a crises, we say that the model is predicting a crises. In general the prediction threshold depends on the loss function. That is if the losses from not predicting a crises when one does occur are higher than losses associated with having too many false alarms, then the threshold should be lowered. However, the

\(^3\)Frankel and Rose use annual data.
general pattern indicated in Table 1 still holds; the probit model is much better at predicting tranquil periods than the crises. It is difficult to judge how much of the failure to predict crises periods is due the fact that the panel is unbalanced. However, I would still conclude that improved inference can be made by allowing for unexpected (hence unpredictable in an out-of sample context) as well predictable crises.

**Table 1, Pooled Probit Estimates**

<table>
<thead>
<tr>
<th>Kaminsky et al. data</th>
<th>crises does occur</th>
<th>no crises occurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>model predicts a crises</td>
<td>5</td>
<td>0</td>
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<th>Frankel and Rose (1996)</th>
<th>crises does occur</th>
<th>no crises occurs</th>
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<td>6</td>
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**4. Conclusion**

In this paper I have presented a simple model of FDI or long-term investment flows. The conclusions drawn from the model are that long-term investment flows
are potentially governed by the same volatile patterns as short-term capital flows. Specifically, expectation changes about future conditions affect the current flows and, therefore, discrete jump and ‘sudden stops’ with damaging consequences for the economy are possible. The purpose of the model is to alert the policy makers to this possibility. The policy discussions often implicitly assume that short-term capital flows are responsible for the balance-of-payments crises in recent decades. This leads to an emphasis on putting restrictions in place that affect the compositions of capital flows that developing countries receive. The argument in this paper makes such efforts futile in preventing ‘sudden stops’ of capital inflows.

The model also points out the possibility of crises that are purely expectations driven. In an applied work, if we do not have data on all the events on which agents can coordinate their expectations, we must take into account the possibility that some of the events in our sample are not predictable with the explanatory variables at hand. I propose modified probit and tobit estimators that do allow for such possibility.

5. References


6. Appendix

We are interested in the decision of an agent who has to allocate his/her funds between the developing country and the rest of the world. To make our life easy we separate the saving decision by assuming that there is an exogenous stream of savings in both parts of the world and we consider a representative ‘investment fund’ that allocates these savings. The fund can invest in a capital in either part of the world, it can also move capital already committed in one country but it faces costs $\phi(.)$ of moving capital from or into the developing country. The objective of
the fund is to maximize return on its investment that is to maximize:

\[
\int_0^\infty [r_t K_t + r^* K_t^* - \phi(F_t)] e^{-\theta t} dt
\]  
(6.1)

where \( F_t \) is flow of funds into the developing country at time \( t \), subject to the constraints on changes of capital given by the exogenous stream of savings:

\[
\frac{dK_t}{dt} = S_t + F_t 
\]  
(6.2)

and

\[
\frac{dK_t^*}{dt} = S_t^* - F_t 
\]  
(6.3)

This is a familiar intertemporal maximization problem, \( K_t \) and \( K_t^* \) are the state variables, and \( F_t \) is the choice variable. The Hamiltonian of the problem is:

\[
H_t = (r_t K_t + r^* K_t^* - \phi)e^{-\theta t} + \lambda(S_t + F_t) + \mu(S_t^* - F_t)
\]  
(6.4)

Differentiating \( H_t \) with respect to \( F_t, K_t \) and \( K_t^* \) yields the first order condi-
\[ 0 = -\phi(F_t) e^{-\theta t} + \lambda + \mu \quad (6.5) \]

\[ \frac{d\lambda}{dt} = r_t e^{-\theta t} \quad (6.6) \]

\[ \frac{d\mu}{dt} = r^* e^{-\theta t} \quad (6.7) \]

Differentiating (6.5) with respect to time and substituting from (6.6) and (6.7) eliminates the multipliers and the resulting Euler equation is:

\[ \theta \phi'(\cdot) - \phi''(\cdot) \frac{dF_t}{dt} - r_t + r^* = 0 \quad (6.8) \]

Equation (6.8) together with the budget constraints (6.2) and (6.3) gives a system of differential equations for \( K_t \), \( K_t^* \) and \( F_t \). Notice that \( K^* \) does not enter equation (6.8) and, therefore, we can first solve (6.2) together with (6.8) and then determine the path of \( K_t^* \) from equation (6.3).

Assuming for simplicity that \( S_t = S_t^* = 0 \), the \( \frac{dF_t}{dt} = 0 \) and \( \frac{dK_t}{dt} = 0 \) loci are given by:

\[ \theta \phi'(\cdot) = r_t - r^* \quad (6.9) \]
where we assumed $\phi''(.) \neq 0$, and

$$F_t = 0 \quad \text{(6.10)}$$

The resulting phase diagram is drawn in figure 3. There are three steady states, in the $(F_t, K_t)$ space: $(0, K^*)$ which is stable, $(0, K)$ which is unstable and $(0, 0)$ which is stable. There is also a unique equilibrium path leading to each of the stable steady states. These two paths could overlap (depending on exact specification of the adjustment costs function) in a region around $K$. Hence the results are substantially the same as in the model with irreversible capital investments.