EVERY BANK RUN NEED NOT CAUSE A CURRENCY CRISIS. MODELS OF TWIN CRISIS WITH IMPERFECT INFORMATION

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
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By

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ABSTRACT

In the 1970’s, the “twin crisis” pattern emerged: currency crises often followed
bank runs. Many observers developed deterministic twin crisis models: every bank
run causes a currency crisis. These models contrast with the historical record: even
if several banks fail, the currency peg may survive. A satisfactory theory of such
phenomena allows the twin crises to occur endogenously. This dissertation consists
of two endogenous twin crisis models and an empirical examination of these models.

The first chapter, Anatomy of a Twin Crisis, models twin crisis in a one-bank set-
ting with risk-averse domestic depositors and risk-neutral foreign depositors. Some
domestic depositors (“impatient”) require immediate liquidity. Other depositors de-
mand immediate liquidity when fearing bank failure. Depositors use imperfectly
correlated sunspot variables when deciding to run. Domestic depositors observe one
sunspot variable; foreigners observe another. A net foreign reserve drain may cause a
currency crisis. Foreign depositors contribute to this drain through currency conver-
sions; domestic depositors exacerbate the drain by running, forcing a bank bailout.
When foreign and domestic depositors run on the bank, currency crisis results; a run
by foreign or domestic depositors alone need not provoke a crisis.

The second chapter, When Bad Things Happen to Good Banks, emphasizes sys-
temic aspects of twin crises. This model features multiple ex-ante identical banks and
depositors who observe sunspots specific to their bank and country of residence. After
calibrating to Turkish data, the model computes “systemic risk” - the probability that sufficient banks fail, causing a currency crisis. Systemic risk may be fundamental or self-fulfilling. As the fraction of impatient depositors increases, the banks’ emphasis shifts from serving depositors to providing consumption insurance. Also, almost all systemic risk is self-fulfilling. The model predicts that increasing interbank deposits encourages banks to consider systemic impacts of their actions.

The third chapter, Diamond-Dybvig Theory Passes a Simple Test, examines withdrawal decisions by domestic and foreign investors in detail. When depositors “run,” they choose short-maturity deposits over long-maturity ones. If many depositors run, banks face “liquidity shocks.” This chapter demonstrates a relationship between liquidity shocks faced by banks and interest rates offered by banks cognizant of the possibility of runs.
Dedicated to my parents.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Dedication</td>
<td>iv</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>v</td>
</tr>
<tr>
<td>Vita</td>
<td>vi</td>
</tr>
<tr>
<td>List of Tables</td>
<td>x</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xii</td>
</tr>
<tr>
<td>Chapters:</td>
<td></td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. ANATOMY OF A TWIN CRISIS</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>6</td>
</tr>
<tr>
<td>2.2 The model</td>
<td>9</td>
</tr>
<tr>
<td>2.2.1 People and institutions</td>
<td>9</td>
</tr>
<tr>
<td>2.2.2 Assets, Currencies and Goods</td>
<td>10</td>
</tr>
<tr>
<td>2.2.3 A sunspot vector and its distribution</td>
<td>11</td>
</tr>
<tr>
<td>2.3 The game</td>
<td>13</td>
</tr>
<tr>
<td>2.3.1 Timing of the model</td>
<td>13</td>
</tr>
<tr>
<td>2.3.2 The contract and related variables</td>
<td>14</td>
</tr>
<tr>
<td>2.3.3 Rules of the game</td>
<td>15</td>
</tr>
<tr>
<td>2.4 Equilibrium</td>
<td>17</td>
</tr>
<tr>
<td>2.4.1 Classes of Contract</td>
<td>17</td>
</tr>
<tr>
<td>2.4.2 Equilibrium of the Post-deposit Subgame</td>
<td>18</td>
</tr>
</tbody>
</table>

vii
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Twin Crises by Region</td>
<td>1</td>
</tr>
<tr>
<td>2.1 Agents’ Strategies by Type</td>
<td>18</td>
</tr>
<tr>
<td>2.2 Parameters used in the calibration</td>
<td>28</td>
</tr>
<tr>
<td>2.3 Optimal contracts – low values of $\lambda$</td>
<td>29</td>
</tr>
<tr>
<td>2.4 Optimal contracts – medium values of $\lambda$</td>
<td>29</td>
</tr>
<tr>
<td>2.5 Optimal contracts – high values of $\lambda$</td>
<td>30</td>
</tr>
<tr>
<td>3.1 Possible States for Each Bank</td>
<td>53</td>
</tr>
<tr>
<td>3.2 Strategy Descriptions</td>
<td>55</td>
</tr>
<tr>
<td>3.3 Calibrated Parameter Values</td>
<td>62</td>
</tr>
<tr>
<td>3.4 Sample Results</td>
<td>65</td>
</tr>
<tr>
<td>4.1 Kolmogorov-Smirnov Test Results</td>
<td>81</td>
</tr>
<tr>
<td>4.2 Shocks and their Relationship to Recessions</td>
<td>85</td>
</tr>
<tr>
<td>A.1 Latin Symbols Used (A-E)</td>
<td>100</td>
</tr>
<tr>
<td>A.2 Latin Symbols Used (F-Q)</td>
<td>101</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.1 Theoretical Relationship between ( \lambda ) and ( c_I )</td>
<td>117</td>
</tr>
<tr>
<td>B.2 Regression Graph: Chile</td>
<td>118</td>
</tr>
<tr>
<td>B.3 Regression Graph: Colombia</td>
<td>118</td>
</tr>
<tr>
<td>B.4 Regression Graph: Mexico</td>
<td>119</td>
</tr>
<tr>
<td>B.5 Regression Graph: Switzerland</td>
<td>119</td>
</tr>
<tr>
<td>B.6 Regression Graph: Turkey</td>
<td>119</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

Between 1976 and 2002, 38 countries experienced at least one period of twin crisis,\(^1\) that is, a period when a currency crisis followed a banking crisis.\(^2\) Twin crises occurred in developing and developed regions of the world. Table 1 shows the distribution of these 38 countries by region.

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of Crises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>7</td>
</tr>
<tr>
<td>Asia</td>
<td>8</td>
</tr>
<tr>
<td>Europe</td>
<td>9</td>
</tr>
<tr>
<td>Latin America</td>
<td>10</td>
</tr>
<tr>
<td>Middle East</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1.1: Twin Crises by Region

A twin crisis typically leads to a fall in Gross Domestic Product (GDP). Zimbabwe experienced a relatively mild twin crisis in 1997; its GDP fell by 3.5%.\(^3\) Korea, C.\(^2\) These figures and Table 1.1 are based on Glick and Hutchison (1999).\(^3\) All calculations in this chapter are the author’s based on data from Datastream. Declines in GDP are stated relative to a linear trend.

\(^1\) Kaminsky and Reinhart (1999) coined the term “twin crisis.”
\(^2\) These figures and Table 1.1 are based on Glick and Hutchison (1999).
\(^3\) All calculations in this chapter are the author’s based on data from Datastream. Declines in GDP are stated relative to a linear trend.
Indonesia and Thailand also suffered crises in 1997, but the GDP of each of these countries fell by more than 13%.

The reasons for studying twin crises are therefore several. First, this is a worldwide phenomenon, affecting many countries directly and almost all countries through trade linkages. Understanding how and why these crises occur aids both governments and firms. Second, these crises are pernicious economic events; studying them may suggest ways to prevent them. Third, “[m]uch as the study of disease is one of the most effective ways to learn about human biology, the study of financial crises provides one of the most revealing perspectives on the functioning of monetary economies.” (Eichengreen and Portes, 1987, p. 10).

Although the specific reasons for crisis in each country have differed, there is a common pattern. A country liberalizes its financial system, removing interest rate restrictions, reducing or eliminating reserve requirements and allowing foreign competition in the banking sector. This country typically maintains a fixed exchange rate, either as a vestige of the previous regime, or as a new policy designed to achieve macroeconomic stability. The combination of a fixed exchange rate and a liberalized banking sector proved extremely volatile. Depositors lose confidence in banks and demand their money in a series of bank runs. Central banks bail out the banks; this policy drains reserves away from the potential defense of the currency peg. Speculators pounce, demanding the conversion of the fixed currencies into American dollars, thus triggering a currency crisis.

The existing theoretical literature models this pattern well. Velasco (1987) published the first mathematical model. Chang and Velasco (2000a, 2000b, 2001) wrote three articles examining the mechanics of the crisis. An unasked question in these
papers is whether the pattern, once begun, need come to fruition. Does every bank run lead to a currency crisis?

The central argument of this dissertation is that twin crises do not follow automatically from the first sign of trouble in the financial sector. In some circumstances bank runs lead to currency crises and in some circumstances they do not. This argument is not new; Kaminsky and Reinhart (1999) and Glick and Hutchison (1999) both noted this point, while showing that a banking crises makes a currency crisis more likely. The theoretical models of twin crisis in this thesis are thus non-deterministic.

The dissertation consists of four chapters and a technical appendix. In Chapter Two, I present a simple non-deterministic model of twin crisis, based loosely on Diamond and Dybvig’s (1983) model of bank runs and Chang and Velasco’s (2000a) model. This model focuses on the interactions between domestic and foreign depositors in the banking system. In most real-world crises, both domestic and foreign residents participate in the banking system and foreign currency markets. Their goals differ, their information differs and, insofar as the financial systems may have different rules for locals and foreigners, their abilities to respond differ. While other authors have noted the participation and interaction of foreign and domestic residents in financial markets, this insight had never been incorporated in a twin crisis model. In particular, the model of Chapter Two uses sunspot variables to differentiate between the information of foreigners and locals. While each group observes a different

\[\text{\textsuperscript{4}}\text{Indeed, some processes for liberalizing financial systems do not lead to financial crises. Glick and Hutchison (1999) list five countries that liberalized their financial systems and experienced no crises. The question of how to liberalize one's financial system effectively is outside the scope of this dissertation.}\]

\[\text{\textsuperscript{5}}\text{See Brennan and Cao (1997).}\]

\[\text{\textsuperscript{6}}\text{These are mathematical devices used to model extrinsic randomness. See Shell (1977), Cass and Shell (1983), among others.}\]
sunspot variable, the two sunspots are imperfectly correlated. This allows locals to make inferences about the foreign sunspot and vice-versa. Potentially, this imperfect informational structure can affect incentives for bank runs.

Chapter Three presents an extended version of the model of Chapter Two. Diamond and Dybvig’s (1983) model contains only one bank; for the purposes of explaining why depositors may rationally run, one bank suffices. During twin crises, a single bank failure may cause a cascade of solvent banks to fail. This contagion effect is well-documented in the literature.\footnote{See, among others, Aharony and Swary (1996), Dasgupta (2001), Gay and Timme (1991), and Schoenmaker (1996).} The model of Chapter Three has multiple banks and multiple sunspots. In this model, the sunspot one sees depends not only on one’s country of residence but also on the bank in which one has deposited. While this complicates the solution of the model, vis-à-vis the simpler model in Chapter Two, it also allows further investigation of why some banking crises lead to currency crises and some do not. The answer is simple – some banking crises are severe and some are not. By allowing for contagion, this model identifies systems likely to have severe banking crises.

Chapter Four examines the bank withdrawal decision in greater detail. One possible motivation for withdrawing money from the bank is the receipt of a random shock to desired consumption. From the banks’ perspective, shocks to the desired consumption of their depositors are a single liquidity shock. The model of Chapter Three shows a theoretical relationship between the magnitude of the liquidity shock at a given time and the interest rate paid at that time. Chapter Four presents an econometric investigation of this relationship. I use data from developing and developed countries. Deploying modern regression techniques, I confirm the theoretical
relationship found in Chapter Three. Details of these regressions, as well as descriptions of the real-world events that could have motivated the withdrawals, form the bulk of Chapter Four.
CHAPTER 2

ANATOMY OF A TWIN CRISIS

2.1 Introduction

Many papers examine banking crises and currency crises separately. Those who study twin crises\(^8\) bring together unanswered questions from two related but distinct literatures. Interactions between banking and currency problems are complex; this paper contributes to the theoretical literature on twin crises.

This chapter innovates in its modeling of domestic and foreign investors. Both domestic and foreign residents may deposit in the bank and participate in the foreign currency markets. When foreign and domestic agents play a bank-run game, they each receive “sunspot”\(^9\) signals common to other agents from their country. The domestic sunspot and the foreign sunspot are imperfectly correlated. Imperfect correlation between the sunspots changes the set of potential equilibria of the bank-run game.\(^10\)

In addition, some equilibria lead to a currency crisis and some do not. A non-deterministic explanation of how a bank run causes a currency crisis has been absent

\(^8\)Kaminsky and Reinhart (1999, p. 473) define a twin crisis as “[t]he interactions between banking and currency problems ....”

\(^9\)Shell (1977) and Cass and Shell (1983) pioneer the mathematical treatment of sunspot variables.

\(^{10}\)See Diamond and Dybvig’s (1983, p. 404) classic paper on bank runs, from which this chapter draws extensively: “A bank run in our model is caused by a shift in expectations, which could depend on almost anything, consistent with the apparently irrational observed behavior of people running on banks.”
from the theoretical literature until now. Such an explanation is necessary; Kaminsky and Reinhart (1999) and Glick and Hutchison (1999) show that a banking crisis makes a currency crisis more likely, but not a certainty.

I use the model to answer several questions. How does the interplay between foreign investors and domestic residents change the character, likelihood or timing of a twin crisis? Can foreign investors, acting on their own, cause a twin crisis even when domestic investors do not withdraw their bank deposits? Can domestic investors, acting on their own, precipitate a twin crisis, when foreign investors maintain a high level of confidence in the economy and do not liquidate their investments? If foreign investors and domestic investors withdrew their funds from the banking system simultaneously, would the combined actions of both groups of investors exacerbate the effects of a twin crisis or make the occurrence of a twin crisis more likely? Should theorists focus on shifts in investor expectations to explain how the crisis occurs? How much overlap is there between the expectations of domestic and foreign investors?

To put these questions into bold relief, a review of recent Turkish financial history is useful. In January 2000, Turkey adopted a fixed exchange rate path, trying to control inflation.\(^\text{11}\) In September, the Turkish government created new banking regulations. By December, ten Turkish banks had failed and fallen under government supervision. As the year 2001 began, investors noted the diminished capacity of the Turkish government to maintain the fixed exchange rate; confidence in the peg dropped precipitously. On February 19th, foreigners withdrew $5 billion from Turkish

\(^{11}\)Central Bank of the Republic of Turkey governor Gazi Erçel explained the fixed exchange rate to foreign investors in London. “It will be noted that while we are making [a] strong commitment to a pre-announced exchange rate path, we are simultaneously announcing our exit strategy, which should allay concerns about the difficulty of making a smooth exit from such systems.” (Erçel, 2000, p. 6)
investments, an amount exceeding one-fourth of the foreign exchange reserves of the central bank. Three days later, the government floated the Turkish Lira (TL). (The Economist, 2000a, 2000b, 2001)

These events show strong linkages between banking sector problems and a currency crisis. They also suggest that a focus on central bank reserves is appropriate. Accordingly, reserves play a critical role in my model.

To consider the model in context, I review the literature that precedes it. Until recently, currency-crisis theorists belonged to one of two schools. First-generation modelers believe that “bad” macroeconomic fundamentals cause currency crises. Second generation modelers believe that random shifts in expectations cause currency crises.\(^{12}\) Krugman (1999) and others present models including the financial sector, referred to collectively as third generation models.\(^{13}\)


\(^{12}\)The first papers in the first and second generation literatures are Krugman (1979) and Obstfeld (1986) respectively.

\(^{13}\)For a review of the first and second generation models, see Jeanne (2000). For a review of early third generation models, see Marion (1999).

\(^{14}\)Economists knew of the linkages between banking crisis and currency crisis in the 1930’s. For examples relating to the Austrian credit crisis, see Bradford (1933), Dulles (1932) and Long (1931). Ellis (1939) wrote a particularly poignant economic analysis. Velasco (1987) wrote the first mathematical model, using the Diamond-Dybvig framework.
I borrow from the third-generation papers by Chang and Velasco, relaxing some of their assumptions. This allows me to avoid the deterministic link between the two crises present in their work. Unlike previous work in this field, a banking crisis can fail to lead to a currency crisis in this model.

The remainder of Chapter Two has the following structure. Section 2 explains the basics of the model and section 3 details the timing of the game. In section 4, I define and characterize some equilibria. Section 5 explains the parameterization of the model. In section 6, I present a numerical solution of the model. Section 7 contains my concluding thoughts and ideas for extension. Proofs are reserved to Appendix B.

2.2 The model

2.2.1 People and institutions

The model follows the Diamond-Dybvig tradition of bank-run models. A small-open endowment-economy lasts for three periods – 0, 1 and 2. There are three types of agents – domestic impatient, domestic patient, and foreign – as well as two institutions – a bank and a government. This section describes these actors; the next section enumerates the choices they face.

A unit-measure continuum of domestic agents consists of patient and impatient agents. All domestic agents are risk-averse, but their utility depends on when they consume, not on who they are. Agents consuming $c_I$ in period 1 receive utility $g(c_I)$. Patient agents holding real money balances $m$ in period 1 and consuming $c_P$ in period
2 receive utility $g(A[c_P, m])$. A known fraction $\lambda$ of domestic agents are impatient; domestic agents learn if they are patient costlessly in period 1. There is also a unit-measure continuum of foreign agents; foreign agents are risk neutral. Foreign agents earn $\rho_1$ per dollar deposited and held until period 1; deposits held until period 2 earn $\rho_2$.\footnote{I assume the relationship $\rho_2 \geq \rho_1$. This assumption means the yield curve for deposits by foreigners is upward sloping.}

A single bank exists for risk-sharing purposes. Agents deposit at the bank, hoping to earn a high return. The bank’s objective function is expected domestic utility.\footnote{Were the two functions not identical, another bank could emerge, pay higher returns and capture all of the first bank’s business.} The bank invests depositors’ resources in two assets described below.

The government is both fiscal and monetary authority. To accumulate foreign exchange reserves, the government sets a reserve requirement on domestic deposits, $(1 - \eta)$, and a tax rate for domestic withdrawals, $\tau$.\footnote{Although reserve requirements on domestic deposits do not usually generate foreign exchange reserves, they do in this model. Domestic deposits come from their dollar-denominated endowment. Thus, domestic agents essentially deposit dollars at the bank in period 0. Reserve requirements on these deposits generate foreign exchange reserves. Since domestic agents also withdraw dollars, a withdrawal tax acts similarly.} While there is no explicit deposit insurance in this model, the government may bail out the bank in some states of the world.

\section*{2.2.2 Assets, Currencies and Goods}

This model has two assets. An investment of one unit in the “world” asset yields one unit whenever the investment is liquidated. An investment of one unit in the
“productive” asset yields $R_2$ units if liquidated in period 2 but only $R_1$ units if liq-
uidated in period 1. The values of $R_1$ and $R_2$ are fixed and known; they obey the
relation $0 < R_1 < 1 < R_2$.\footnote{The condition $R_1 < 1$ is necessary so that the productive asset does not dominate the world asset. Cooper and Ross (1998) note that if $R_1$ is not sufficiently small, the bank can meet its liquidity needs by liquidating the productive asset.} Let $\gamma_b$ be the share of deposits the bank invests in the
productive asset.

There are two currencies in this model; the home currency is the lira and the
other currency is the dollar. Initially the government fixes the exchange rate at unity.
There is a single good, usable both as an input to production and for consumption.
This good always costs one dollar. The bank invests in the two assets in period 0 and
liquidates these investments in periods 1 or 2 for dollars.\footnote{This is a highly dollarized economy.}

### 2.2.3 A sunspot vector and its distribution

One may critique the Chang and Velasco (2000a, 2000b, 2001) papers for not
the Mexican financial crisis with a foreign and a domestic sunspot variable. Their two
sunspot variables are statistically independent. I present a dependent specification,
modelling the overlap of information between domestic and foreign agents.\footnote{Brennan and Cao (1997) show that domestic investors have an informational advantage when
investing in the stock market. But they also show that some information is common to domestic and foreign investors. In this paper, foreign and domestic investors learn different information, but the information of domestic agents is not per se superior to that of foreign agents.}

A simple story explains the dependent specification. Suppose foreign agents and
domestic agents read a newspaper article to learn the state of the economy and
its banks. Domestic agents and foreign agents both read “between the lines” of
the article, but they do so differently. The “common” aspect of the sunspot vector,
which requires that the specification be dependent, is the newspaper article itself. The “semi-private” (i.e., common to one group of agents but not to the other) aspect of the sunspot vector is each group’s interpretation of the article. Semi-private information requires the correlation between the sunspots to be imperfect.

Denote the domestic and foreign sunspot variables by $s_d$ and $s_f$ respectively. Domestic agents only observe $s_d$, whereas foreign agents only observe $s_f$. I describe the joint distribution of $s_d$ and $s_f$ below.\footnote{Here is a process to generate $(s_d, s_f)$. Nature draws $s_d$ first, taking on the value 1 with probability $\pi_1$. Nature draws $s_f$ after $s_d$ (but recall that foreigners do not observe $s_d$). The variable $s_f$ takes on the value 1 with probability $\pi_2$ if $s_d$ has taken on the value 1. On the other hand, if $s_d$ has taken on the value 0, $s_f$ takes on the value 1 with probability $\pi_3$. Both variables have conditional Bernoulli distributions, where the Bernoulli parameter for the unconditional distribution of $s_f$ depends on the realization of $s_d$.}

\[
\begin{align*}
\Pr(s_d=0, s_f=0) &= (1 - \pi_1) (1 - \pi_3) \\
\Pr(s_d=0, s_f=1) &= (1 - \pi_1) \pi_3 \\
\Pr(s_d=1, s_f=0) &= \pi_1 (1 - \pi_2) \\
\Pr(s_d=1, s_f=1) &= \pi_1 \pi_2
\end{align*}
\]

$\pi_1$, $\pi_2$, $\pi_3$ are in the open unit interval and $\pi_2 > \pi_3$. The triple $(\pi_1, \pi_2, \pi_3)$ describes the distribution of $(s_d, s_f)$ completely. Kaminsky and Reinhart (1999) and Glick and Hutchison (1999) estimate parameters similar to $\pi_1, \pi_2$ and $\pi_3$.

The sunspot vector can act as a coordinating mechanism among agents. In particular, in subgames with multiple equilibria, the sunspot vector determines which equilibrium is selected.
2.3 The game

2.3.1 Timing of the model

Here is a summary of how the model unfolds over time.

Period 0:

1. Domestic agents receive an endowment, $e_d$. Foreigners arrive with investment funds, $e_f$.

2. The government announces the tax rate, $\tau$, and the required reserve rate, $1-\eta$.

3. The bank announces the contract, $C(c_i,c_p,\gamma_b,\rho_1,\rho_2)$.

4. Foreign and domestic agents deposit at the bank.

5. The bank sends required reserves to the central bank. The bank invests the rest in the two assets according to the contract.

Period 1:

1. Domestic agents learn their type - patient or impatient.

2. Nature draws $s_d$ and $s_f$, revealing them to domestic and foreign agents respectively.

3. The bank opens for business. Agents of various types arrive in random order. Agents claiming to be impatient receive $(1 - \tau)c_f$ dollars, if available. Agents claiming to be patient receive $m$ liras. If foreign agents arrive, they receive $\rho_1 e_f$ liras.\footnote{I assume foreign and domestic agents are distinguishable.} The bank withholds taxes from domestic withdrawals.
4. If the bank serves all customers in queue, go to item 5. The bank liquidates assets to serve domestic agents. The government may bail out the bank.

5. Foreigners holding liras trade them for dollars at the central bank.

Period 2:

1. Any remaining investment in the productive asset matures.

2. The bank pays \((1 - \tau) c_P\) dollars to domestic agents who claimed to be patient in period 1, if available. The bank remits \(\tau c_P\) dollars to the government as taxes. The bank also pays \(\rho_2 e_f\) liras to any remaining foreign agents. If the bank has dollars left over, it pays them to the government.\(^{24}\)

3. Foreign agents holding liras trade them for dollars at the central bank.

4. The economy ends.

\subsection*{2.3.2 The contract and related variables}

The bank’s decisions in period 0 are critical. In period 0, the bank offers a contract \(C(c_I, c_P, \gamma_0, \rho_1, \rho_2) \in \mathbb{R}_+^6\) to which agents respond. Determining which is the optimal contract is the subject of the equilibrium section. Notice that I preclude suspension of convertibility, since payments to domestic agents are not contingent on the history of withdrawals. That is, the bank must continue paying \(c_I\) to domestic agents until it runs out of dollars and has liquidated all assets.

\(^{24}\)The lira payments \(\rho_1\) and \(\rho_2\) affect the bank in different ways. The bank receives liras for \(\rho_1\) payments from the central bank. The bank may make \(\rho_1\) as high as it chooses, without affecting its budget constraint. On the other hand, the bank is required to plan to have one dollar on hand for every lira it offers to pay foreign agents in period 2. That is, a higher promised value of \(\rho_2\) affects the bank’s budget constraint directly by limiting payments the bank can make to patient and impatient agents.
Liras received by domestic agents in period 1 provide liquidity services and then “disappear.” Since these liras are amorphous, the model does not determine their quantity uniquely. I assume real money balances are proportional to GDP, namely \( m = \kappa [\lambda c_I + (1 - \lambda) c_P].^{25}\)

### 2.3.3 Rules of the game

In period 0, if agents deposit at the bank, the bank splits the deposits between the two assets. If agents do not deposit, domestic agents can divide their endowment between the two assets. Foreigners may not invest directly in the productive asset.

In period 1, agents arrive at the bank. The bank can always accommodate the demands of foreigners, since foreigners receive liras when withdrawing from the bank. The central bank prints liras costlessly, equating supply and demand. Domestic agents claiming to be patient present no problems for the bank either since the bank also pays them liras. The bank can only obtain dollars by liquidating assets. As domestic agents claiming to be impatient arrive, the bank liquidates some assets and pays each agent \((1 - \tau) c_I\), remitting \(\tau c_I\) to the central bank as taxes.\(^{26}\)

The rules of the game include the bank’s liquidation policy. Let \(a_d\) be the measure of domestic agents that claim to be impatient and let \(a_f\) be the measure of foreign agents that arrive in period 1. First, note that the bank is indifferent to the value of \(a_f\). The bank pays foreign agents in liras; it need not liquidate any assets to pay

---

\(^{25}\)Chang and Velasco (2000a) determine real money balances by imposing a satiation level of money demand.

\(^{26}\)Because of the return structure of the two assets, the bank does not liquidate any of the productive asset until it is forced to do so by the presence of domestic agents claiming to be impatient.
foreigners. Let \( L(a_d) \) be the amount of the productive asset the bank will liquidate in period 1 if \( a_d \) agents claim to be impatient. Then

\[
L(a_d) = \max \left[ \min \left( \gamma_b \eta \epsilon_d + \epsilon_f, \frac{a_d \epsilon_f - (1 - \gamma_b) \frac{\eta \epsilon_d + \epsilon_f}{R_1}}{0} \right), 0 \right]
\] (2.1)

Liquidation is bounded below by 0 and above by total investment: \( \gamma_b \eta \epsilon_d + \epsilon_f \). The fractional term in \( L(a_d) \) represents the amount liquidated to pay \( a_d \) agents \( c_f \). The bank may liquidate all its assets while additional domestic agents remain in queue claiming to be impatient. Whether this will trigger a bank bailout depends on the behaviour of foreign agents. Foreign agents know that a bailout reduces the dollar value of the liras they receive from the bank. The government bails out the bank only if no foreigners are present at the bank in period 1. The bailout consists of a rebate of all taxes collected in period 1. After a bailout occurs, the bank distributes \((1 - \tau) c_f\) to each agent until its resources are once again exhausted.  

After collecting liras at the bank, foreigners proceed to the central bank. If dollars in the reserve vault exceed the liras in circulation, each lira can be exchanged for one dollar. If not, the central bank pays foreigners proportionally, effectively devaluing the lira.  

In period 2, domestic agents that claimed to be patient return to the bank. If the bank has unliquidated assets, these assets mature; the bank uses the dollars

\footnote{That the bank does not need to liquidate assets to serve foreign agents comes from the central bank’s supplying liras indelically to the bank.}

\footnote{By arriving in period 1, foreign agents “pay a monitoring cost,” since their expected return is lower in period 1 than in period 2. So monitored, the government cannot bail out the bank.}

\footnote{Both the Latin American financial crises of the 1980’s and the East Asian financial crises of the 1990’s ended with government bailouts. Although Mundaca (2000) models an optimal bailout, I use an ad-hoc bailout because it is more similar to the one typically implemented by central banks.}
from maturing investments to pay domestic agents claiming to be patient \((1 - \tau) c_p\), remitting \(\tau c_p\) to the government as taxes.\(^{30}\)

After all assets have matured and the bank has paid all domestic agents claiming to be patient, the bank sends any remaining dollars to the central bank. This guarantees that bank profits cannot exceed zero. Finally, if foreign agents have liras, they convert them to dollars at the central bank. The payment procedure is the same as the one used in period 1.

2.4 Equilibrium

2.4.1 Classes of Contract

Diamond and Dybvig (1983, p. 409) show that whether or not the post-deposit subgame has a run equilibrium depends on the contract the bank has offered. The bank can offer a contract which prevents runs, or a contract which allows runs.\(^{31}\) A non-naive bank should understand the possibility of a crisis; it should act to prevent it in some circumstances and not do so in others. In a model related to the one presented here, Peck and Shell (2001) show that the optimal contract may come from either the No-Run Class or from the Run Class. Since these classes are disjoint, the bank can compute the optimal contract from each one separately and then compare the optima in expected-utility terms. The bank then chooses the “best of the best.”

\(^{30}\)If the bank cannot serve every domestic agent claiming to be patient, it will serve as many agents as possible, but will not change the amount each agent receives. Even if the bank cannot serve everyone in period 2, the government will not bail out the bank in period 2. These considerations are irrelevant in equilibrium.

\(^{31}\)A contract is said to prevent runs if the set of equilibria of the subgame played after the announcement of that contract does not include a run equilibrium. A contract that does not prevent runs is said to allow runs.
2.4.2 Equilibrium of the Post-deposit Subgame

The subgame consists of a move by Nature, “choosing” the realization of the sunspot vector, followed by choices by the three types of agents. Two simplifications can sharpen our focus. First, I restrict our attention to type-symmetric equilibria, that is, equilibria, in which all agents of the same type act identically. Second, I note that impatient agents always rationally claim to be impatient. I can express an equilibrium as a strategy for patient agents and a strategy for foreign agents such that no-one wishes to deviate. More formally, let

\[ \sigma_d : s_d \rightarrow \{ \text{CI,CP} \}, \text{ and let } \sigma_f : s_f \rightarrow \{ A1, A2 \}, \text{ where} \]

CI means claim to be impatient; CP means claim to be patient;
A1 means arrive in period 1; A2 means arrive in period 2.

Each type of agent has four possible strategy functions; these functions are listed in Table 2.1 below.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>(s_d=0)</th>
<th>(s_d=1)</th>
<th>Strategy</th>
<th>(s_f=0)</th>
<th>(s_f=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{d,1})</td>
<td>CP</td>
<td>CI</td>
<td>(\sigma_{f,1})</td>
<td>A2</td>
<td>A1</td>
</tr>
<tr>
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<td>CI</td>
<td>CI</td>
<td>(\sigma_{f,2})</td>
<td>A2</td>
<td>A2</td>
</tr>
<tr>
<td>(\sigma_{d,3})</td>
<td>CP</td>
<td>CP</td>
<td>(\sigma_{f,3})</td>
<td>A1</td>
<td>A1</td>
</tr>
<tr>
<td>(\sigma_{d,4})</td>
<td>CI</td>
<td>CP</td>
<td>(\sigma_{f,4})</td>
<td>A2</td>
<td>A1</td>
</tr>
</tbody>
</table>

Table 2.1: Agents’ Strategies by Type

Let \(\Sigma_d = \{ \sigma_{d,1}, \sigma_{d,2}, \sigma_{d,3}, \sigma_{d,4} \}\) and \(\Sigma_f = \{ \sigma_{f,1}, \sigma_{f,2}, \sigma_{f,3}, \sigma_{f,4} \}\) be the strategy sets for domestic and foreign agents with typical elements \(\sigma_d\) and \(\sigma_f\) respectively. Each individual agent has an expected payoff function, \(E_d U_d\) for domestic agents and \(E_d U_f\) for foreign agents, which depends on the strategy played by all other agents of the
same country, the strategy played by all agents of the other country, the strategy played by that individual agent and the contract offered by the bank.

Definition 1 A pair of strategies \((\sigma_d, \sigma_f)\) is a type-symmetric Nash equilibrium of the post-deposit subgame if 2 conditions hold:

1. For all patient agents in \([0, 1 - \lambda]\) and for all \(\bar{\sigma}_d \in \Sigma_d\), \(E_s U_d(\sigma_d, \sigma_f, \bar{\sigma}_d, \cdot) = E_s U_d(\sigma_d, \sigma_f, \bar{\sigma}_d, \cdot)^{32}\)

2. For all foreign agents in \([0, 1]\) and for all \(\bar{\sigma}_f \in \Sigma_f\), \(E_s U_f(\sigma_d, \sigma_f, \bar{\sigma}_f, \cdot) = E_s U_f(\sigma_d, \sigma_f, \bar{\sigma}_f, \cdot)\)

Note that the Nash equilibrium of the subgame takes Nature’s move into account; agents may co-ordinate on the realization of the sunspot vector. Aumann (1974) notes that there is a 1-1 correspondence between the Nash equilibria of the game where Nature is included as a player and the correlated equilibria of the game which Nature does not play. The equilibria found here differ from those of the bank-run literature because of the informational structure. Neither is all information public; nor is all information private. The correlation between \(s_d\) and \(s_f\) is imperfect; imperfect correlation leads to a rich array of equilibria.

2.4.3 Equilibrium of the Subgame: No-Run Class

The No-Run Class consists of the set of all contracts such that, given the realization of the sunspot vector and the contract announced, the post-deposit subgame does not have an equilibrium which includes a bank run by domestic agents. For contracts

\(^{32}\)The first argument of \(E_s U_d\) and \(E_s U_f\) is the strategy played by the mass of domestic agents. The second argument is the strategy played by the mass of foreign agents. The third argument is the strategy played by one particular agent, domestic or foreign. This may differ from the strategy played by the mass of agents of the same type. Finally, the suppressed arguments in \(E_s U_d\) and \(E_s U_f\) stand for the contract vector \((c_1, c_p, \gamma_b, \rho_1, \rho_2)\).
in this class, domestic bank runs are suboptimal by construction. The bank does not consider foreign utility when designing the contract except insofar as is necessary to ensure foreign deposits. Despite this fact, foreigners do not run here either.

**Theorem 1** If the contract is of the No-Run Class, foreigners always optimally arrive in period 2.

**Proof.** See Appendix B. ■

The unique equilibrium of the subgame is \((\sigma_{d,3}, \sigma_{f,2})\). Note that sunspots do not matter for this equilibrium. Players make the same choices, regardless of what Nature does beforehand. Since domestic agents ignore sunspots when faced with a contract in this class, foreign agents are also better off selecting a pure strategy.

### 2.4.4 Equilibrium of the Subgame: Run Class

The No-Run Class consists of the set of all contracts such that, given the realization of the sunspot vector and the contract announced, the post-deposit subgame has an equilibrium which includes a bank run by domestic agents. I show in Theorem 2 below that, for some values of the parameters, one Nash equilibrium of this subgame is \((\sigma_{d,1}, \sigma_{f,1})\).

**Theorem 2** For some parameter values, the Run Class is non-empty.

**Proof.** See Appendix B. ■

Note that for this equilibrium, sunspots matter.\(^{33}\) In some situations, it is better to run on the bank; in some situations it is better not to run. This is the classical case of Diamond and Dybvig (1983).

\(^{33}\)The equilibrium derived in the previous section is also an equilibrium for subgames played after announcing a contract of the Run Class.
2.4.5 Game Equilibrium: Assumptions and Conditions

Following the announcement of a contract of the No-Run Class, the subgame has a unique equilibrium. Following the announcement of a contract of the Run Class, there are at least two type-symmetric equilibria – one for which sunspots matter and one for which sunspots do not matter. I assume that agents choose the equilibrium characterized in the previous subsection. Relaxing this assumption complicates the bank’s objective function greatly.

I assume that agents have the choice to deposit all of their endowment in the bank or not to deposit at all. Depositing at the bank must be individually rational. Agents must receive a higher expected return by depositing than in autarchy. Consider the deposit decision for foreigners. Since foreigners may not invest in the productive asset except through the bank, their net autarchic return is 0. They receive \( e_f \) when their investment of \( e_f \) matures. Since foreigners are risk-neutral, they deposit so long as the gross expected return equals I. Domestic agents can split their endowment between the two assets. Let \( \gamma_{aut} \) be the fraction of a typical domestic agent’s endowment invested in the productive asset. The autarchic return is

\[
r_{aut}(\gamma_{aut}) = \lambda g (e_d [R_1 \gamma_{aut} + 1 - \gamma_{aut}]) + (1 - \lambda) g (e_d [R_2 \gamma_{aut} + 1 - \gamma_{aut}]).
\]

There is a unique \( \gamma^*_{aut} \in [0, 1] \) which maximizes this expression. Thus, the return to domestic

---

34Peck and Shell (2001) also make this assumption. If one wanted to complicate the game greatly, one could remove this assumption and replace it with a contract-dependent equilibrium selection mechanism.

35I prove that \( \gamma^*_{aut} \) is unique in Appendix B. The existence of \( \gamma^*_{aut} \) follows from the compactness of \([0, 1] \) and the continuity of \( r_{aut} \) in \( \gamma_{aut} \). Note that the value of \( \gamma^*_{aut} \) depends on \( \lambda \) as well as the curvature parameters of the utility function.
agents not depositing at the bank is \( r_{a_{aut}} (\gamma_{a_{aut}}^*) \). Any contract must satisfy two conditions: expected domestic utility equals \( r_{a_{aut}} (\gamma_{a_{aut}}^*) \) and expected foreign utility equals \( 1 \).

### 2.4.6 Aggregation of the Equilibrium

The bank is concerned less with the action of its depositors individually than with their actions collectively. I aggregate domestic and foreign actions as the pair \((a_d, a_f)\).

**Definition 2** A domestic bank run occurs when \( a_d = 1 \)

**Definition 3** A bank run by foreigners occurs when \( a_f = 1 \).

**Definition 4** A currency crisis occurs when the demands for dollars exceed the supply of dollars in the central bank’s reserves.

In some equilibria, the pair \((a_d, a_f)\) depends on the state (the realization of the sunspot). There are four possible states.

\[
(s_d, s_f) = (1, 0) \ [\text{state 1}]; \\
(s_d, s_f) = (1, 1) \ [\text{state 2}]; \\
(s_d, s_f) = (0, 0) \ [\text{state 3}]; \\
(s_d, s_f) = (0, 1) \ [\text{state 4}];
\]

### 2.4.7 Equilibrium of the Game: No-Run Class

The bank chooses the best contract from the No-Run Class. The bank’s problem can be written as follows:

\[
\max_{C \in \mathbb{R}^2_+} \lambda g((1 - \tau) c_I) + (1 - \lambda) g(A [(1 - \tau) c_P, m]), \text{ s.t.} \quad \tag{2.2}
\]

\(^{36}\)That the foreign individual rationality condition holds with equality follows from the fact that the bank maximizes expected domestic utility but is indifferent to foreign utility.
\[
\lambda c_I = (1 - \gamma_b) (\eta e_d + e_f) \tag{2.3}
\]

\[
[1 - \gamma_b + R_1 \gamma_b] (\eta e_d + e_f) > c_I \tag{2.4}
\]

\[
A (c_P, m) > c_I \tag{2.5}
\]

\[
\lambda g ((1 - \tau) c_I) + (1 - \lambda) g (A [(1 - \tau) c_P, m]) \geq r_{aut} (\gamma_{aut}) \tag{2.6}
\]

\[
\lambda c_I + (1 - \lambda) c_P + I = [1 - \gamma_b + R_2 \gamma_b] (\eta e_d + e_f) \tag{2.7}
\]

Some explanation of the above equations is necessary. The maximand, (2.2), represents expected domestic utility. The bank calculates expected domestic utility differently for contracts of the No-Run Class than it does for contracts of the Run Class. If the contract is of the No-Run Class, the only uncertainty remaining in the game is idiosyncratic. The bank knows that exactly \(\lambda\) domestic agents claim to be impatient and receive \(g((1 - \tau)c_I)\) and exactly \((1 - \lambda)\) domestic agents claim to be patient and receive \(g(A [(1 - \tau)c_P, m])\).

Since the bank is certain there are no runs, it invests exactly \(\lambda c_I\) in the world asset. Investing less requires costly early liquidation of the productive asset. Investing more is inefficient since the bank can earn higher returns by using the information that runs
will not occur. Equation (2.3) specifies this restriction on investment. Inequalities (2.4) and (2.5) define the No-Run Class. Inequality (2.4) guarantees that patient agents receive at least $c_I$ regardless of what they claim. Inequality (2.5) ensures that patient agents receive payment strictly greater than $c_I$ if they claim to be patient. Inequality (2.6) is the individual rationality constraint for domestic agents; if (6) is satisfied, domestic agents will deposit their resources with the bank. There is no individual rationality constraint for foreigners, since foreign individual rationality is satisfied with any pair $(\rho_1, \rho_2) = (\rho_1, 1)$, where $\rho_1 < 1$. The maximum profit the bank can make is zero. Equation (7) is the zero profit constraint.

**Theorem 3** Inequalities (2.4), (2.5) and Equation (2.7) are necessary and sufficient for a contract to be of the No-Run Class.

**Proof.** See Appendix B. 

2.4.8 Equilibrium of the Game: Run Class

The bank selects the best contract from the Run Class. The problem can be written as follows:

\[
\max_{C \in \mathbb{R}^4} \sum_{s=1}^{4} \Pr_s U_{d,s} (\sigma_{d,1}, \sigma_{f,1}) \text{, s.t.} \\
\lambda c_I \leq (1 - \gamma_b) (\eta_{d} + e_{f}) \\
\sum_{s=1}^{4} \Pr_s U_{d,s} (\sigma_{d,1}, \sigma_{f,1}) \geq r_{aut} (\gamma_{aut}^*)
\] (2.8)

\[
\lambda c_I \leq (1 - \gamma_b) (\eta_{d} + e_{f}) \\
\sum_{s=1}^{4} \Pr_s U_{d,s} (\sigma_{d,1}, \sigma_{f,1}) \geq r_{aut} (\gamma_{aut}^*)
\] (2.9)

24
\[
\sum_{s=1}^{4} \Pr_s U_{f,s}(\sigma_{d,1}, \sigma_{f,1}) = e_f \tag{2.11}
\]

\[
A(c_P, m) \geq c_I \tag{2.12}
\]

\[
[1 - \gamma_b + R_1 \gamma_b] (\eta e_d + e_f) \leq c_I \tag{2.13}
\]

\[
\lambda c_I + (1 - \lambda) c_P + \rho_2 e_f = [1 - \gamma_b + R_2 \gamma_b] (\eta e_d + e_f) \tag{2.14}
\]

In the above maximization problem, \(U_{d,s}\) is expected domestic utility of state \(s\), \(U_{f,s}\) is expected foreign utility of state \(s\) and \(\Pr_s\) is probability of state \(s\). These probabilities come from the distribution of the sunspot vector, as noted by Aumann (1987). Note that expected utility depends upon the Nash equilibrium. The details of \(U_{d,s}\) and \(U_{f,s}\) are in Appendix B.

Inequality (2.9) guarantees that if there is no bank run, the bank need not liquidate the productive asset. It is the analogue of (2.3). This constraint does not necessarily bind, since the bank may choose to have additional resources on hand. Inequality (2.10) and equation (2.11) are the individual rationality constraints; so long as they are met, foreign and domestic agents deposit, eschewing autarchy. Inequalities (2.12) and (2.13) are the conditions for a contract to be of the Run Class. Equation (2.14) is the zero profit constraint.

**Theorem 4** Inequalities (2.12) and (2.13) and equation (2.14) are sufficient for contracts to be of the Run Class.
Proof. See Appendix B. ■

2.5 Calibration

The complexity of the model does not admit-closed form solutions. Calibrating the model thus has two purposes. First, it allows me to describe the solution and to show its existence. Second, it allows me to analyze policy. In this chapter, I calibrate the model to Turkish data; I evaluate the Turkish fixed-exchange rate policy explicitly in the following sections.

2.5.1 Utility functions

Based on Holman’s (1998) empirical results, I use a Cobb-Douglass form for the money-in-the-utility (MIU) function.\(^{37}\) In particular, let

\[
A[c_p, m] = c_p^\beta m^{1-\beta}, \quad 0 < \beta < 1
\]  

(2.15)

I set \(\beta = 0.98\), following Holman. A high value of \(\beta\) implies that liquidity services from holding domestic currency are not valuable, something common to countries with weak banking systems. For the overall utility function, I choose the following “hybrid.”\(^{38}\)

\[
g(c_I) = -\frac{1}{\alpha} \exp[-\alpha c_I] + \frac{1}{\alpha} + \zeta c_I, \quad \alpha > 0, \quad \zeta > 0
\]  

(2.16)

\(^{37}\)For more on MIU functions, see Feenstra (1986) and Brock (1974).

\(^{38}\)This function has the same properties as a CARA utility function for small values of \(c_I\); it also possesses the properties of a linear utility function. The coefficient of absolute risk aversion for the function \(g\) is \(\frac{\alpha}{1+\alpha \alpha c_I + \zeta}\). It ranges from \(\frac{\alpha}{1+\alpha \alpha c_I + \zeta}\) when \(c_I = 0\) to 0, as \(c_I\) approaches \(\infty\). The \(g\) function is positive, increasing, concave, bounded below but not bounded below for all non-negative values of \(c_I\).
From the estimates of Antle (1987) and Wolf and Pohlman (1983), I calibrate $a$ to values ranging from 3.5 to 5. I thus check the solution for sensitivity to the parameter $\alpha$.\footnote{The papers by Antle and Wolf and Pohlman estimate the parameter $\alpha$ in a CARA function.} The parameter $\zeta$ is atheoretical; computational considerations dictated that I set it to $10^{-10}$.

2.5.2 Other parameters

I take estimates of $\pi_1$, $\pi_2$, and $\pi_3$ from Kaminsky and Reinhart (1999). They estimate the unconditional probability of a bank run ($\pi_1 = 0.1$), the probability of a currency crisis conditional on a bank run ($\pi_2 = 0.46$) and the probability of a currency crisis conditional on no bank run ($\pi_3 = 0.29$). Their data set contains more than 50 developing countries, including Turkey. For the rest of the parameters, I use Turkish data directly. For example, I set $\tau$ to 0.145 to match the average tax/GDP ratio for Turkey from 1987-2000. I fix $R_2$ at 1.7 to accord with the annualized dollar-based return from the Istanbul Stock Exchange Composite Index from 1986-1999. Allen and Gale (2000) suggest that $R_1$ should be fairly small, so that banks do not liquidate the productive asset to meet predictable liquidity needs; on this basis, I set $R_1 = 0.3$. Because there is evidence that inverse monetary velocity is non-stationary,\footnote{For a non-stationary time-series, no long-run expected value exists. Accordingly, the average over a particular sample is a meaningless statistic.} I fix $\kappa = 0.16$ to match the value of inverse M1 velocity in Turkey in the last quarter before the fixed exchange rate. The ratio of foreign deposits to total deposits in Turkey exceeded 50% in 1995; to capture this feature, I set $e_d = e_f = 10$.\footnote{The foreign deposit ratio is $\frac{e_f}{e_f + e_d}$.}
Finally, since the equilibrium could be potentially sensitive to my choice of \( \lambda \), I choose several values ranging from 0.25 to 0.85. Table 2.2 summarizes the parameterization used in the empirical model.\(^{42}\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value(s)</th>
<th>Parameter</th>
<th>Value(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e_d )</td>
<td>10</td>
<td>( \beta )</td>
<td>0.98</td>
</tr>
<tr>
<td>( e_f )</td>
<td>10</td>
<td>( \lambda )</td>
<td>0.25 to 0.85, step 0.05</td>
</tr>
<tr>
<td>( R_1 )</td>
<td>0.3</td>
<td>( \eta )</td>
<td>0.94</td>
</tr>
<tr>
<td>( R_2 )</td>
<td>1.7</td>
<td>( \tau )</td>
<td>0.145</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>3.5 to 5, step 0.5</td>
<td>( \pi_1 )</td>
<td>0.1</td>
</tr>
<tr>
<td>( \zeta )</td>
<td>( 10^{-10} )</td>
<td>( \pi_2 )</td>
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</tr>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

Table 2.2: Parameters used in the calibration

### 2.6 Results and Discussion

Tables 2.3-2.5 show results for low, medium and high values of \( \lambda \). In Tables 2.3 and 2.5, the low and high range respectively, the optimal contract comes from the No-Run Class. That is, the bank offers a contract that prevents runs. In the medium range (Table 2.4), the optimal contract comes from the Run Class. Here the bank tolerates a small probability of runs to give higher expected utility to impatient and patient agents.

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\(^{42}\)In the table, “step” denotes the size of the increment in an arithmetic sequence with given start and finish.
<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$\lambda$</th>
<th>$c_I$</th>
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Table 2.3: Optimal contracts – low values of $\lambda$

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<thead>
<tr>
<th>$\lambda$</th>
<th>$c_I$</th>
<th>$c_P$</th>
<th>$\rho_1$</th>
<th>$\rho_2$</th>
<th>$\gamma_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>10.3</td>
<td>15.1</td>
<td>0.06</td>
<td>1.53</td>
<td>0.67</td>
</tr>
<tr>
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<td>15.1</td>
<td>0.03</td>
<td>1.54</td>
<td>0.67</td>
</tr>
<tr>
<td>0.50</td>
<td>10.3</td>
<td>16.1</td>
<td>0.07</td>
<td>1.53</td>
<td>0.67</td>
</tr>
<tr>
<td>0.52</td>
<td>10.3</td>
<td>16.1</td>
<td>0.04</td>
<td>1.54</td>
<td>0.67</td>
</tr>
<tr>
<td>0.55</td>
<td>10.3</td>
<td>17.1</td>
<td>0.10</td>
<td>1.51</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Table 2.4: Optimal contracts – medium values of $\lambda$
\[
\begin{array}{|c|c|c|c|c|}
\hline
\alpha & \lambda & c_I & c_P & \gamma_b \\
\hline
3.5 & 0.75 & 6.7 & 57.75 & 0.74 \\
4 & 0.75 & 5.9 & 61.83 & 0.77 \\
4.5 & 0.75 & 5.2 & 65.4 & 0.8 \\
5 & 0.75 & 4.7 & 67.95 & 0.82 \\
3.5 & 0.8 & 6.7 & 69.34 & 0.72 \\
4 & 0.8 & 5.9 & 74.78 & 0.76 \\
4.5 & 0.8 & 5.2 & 79.54 & 0.79 \\
5 & 0.8 & 4.7 & 82.94 & 0.81 \\
3.5 & 0.85 & 6.7 & 88.66 & 0.71 \\
4 & 0.85 & 5.9 & 96.36 & 0.74 \\
4.5 & 0.85 & 5.2 & 103.1 & 0.77 \\
5 & 0.85 & 4.7 & 107.9 & 0.79 \\
\hline
\end{array}
\]

Table 2.5: Optimal contracts – high values of \( \lambda \)

For contracts of the No-Run Class, consumption given to agents claiming to be impatient depends negatively on the curvature of the utility function, that is on the degree of risk aversion.\textsuperscript{43} Dollars come from liquidated bank assets. As domestic agents become more risk averse, the bank must pay more to agents claiming to be patient, to induce them to report their types accurately. Foreign consumption is defined by \( \rho_1 \) and \( \rho_2 \). For contracts of the No-Run Class, \( \rho_2 \equiv 1 \) and \( \rho_1 \) is an arbitrary value between 0 and 1.

The relationship between consumption and investment explains how the bank’s investment choices depend on \( \lambda \) and \( \alpha \). Investment in the productive asset increases with risk aversion. Without bank runs as a complicating factor, the bank holds

\textsuperscript{43}The coefficient of absolute risk aversion is \( \text{ARA}(\alpha) = \frac{\alpha e^{-\alpha \zeta} (e^{\lambda_a} - 1)}{e^{-\alpha \zeta} + \zeta} \). After some rearranging, \( \text{ARA}'(\alpha) = \frac{\zeta e^{-\alpha \zeta} (e^{\lambda_a} - 1) - e^{-2\alpha \zeta} \zeta}{(e^{-\alpha \zeta} + \zeta)^2} \). If \( \alpha < 1 \), \( \text{ARA}'(\alpha) < 0 \) for any value of \( \zeta \). Given that \( \zeta = 10^{-10} \), the negative term dominates the positive term for any reasonable value of \( c_I \). With relative risk aversion defined as a negative number, a fall in \( \text{ARA}(\alpha) \) implies increasing risk aversion. Thus, an increase in \( \alpha \) also increases absolute risk aversion.
investments to maturity. The bank pays agents claiming to be patient from the maturing productive asset. Investment in the productive asset falls with the proportion of impatient, since dollars available for investment are fixed. As the proportion of impatient agents increases, more investment dollars have to be diverted to the world asset to prevent unnecessary liquidations of the productive asset. These relationships hold throughout the No-Run Class.

For the parameter values presented in Table 2.4, twin crises occur with positive probability. If \( \lambda \) is in this range, a twin crisis occurs whenever both domestic and foreign agents run on the bank. If there is a bank run by foreigners but no run by domestic agents, there will not be a twin crisis. If there is a run by domestic agents but not by foreigners, there may be a twin crisis, depending on the other parameters of the model.

Let us now focus further on the possibility of runs leading to currency crises, as displayed in Table 2.4. Payment to agents claiming to be impatient (\( c_I \)) does not vary with either the curvature parameter \( a \) or the impatience parameter \( \lambda \). Furthermore, it is significantly larger than the amounts offered to agents claiming to be impatient in contracts of the No-Run Class. Extra compensation to agents claiming to be impatient makes the bank vulnerable to runs; the bank is willing to tolerate this risk since it raises expected domestic utility. Payments to agents who claim to be patient are much lower in contracts of the Run Class than they are in contracts of the No-Run Class. These payments generally increase with \( \lambda \), much as they do in contracts of the No-Run Class.

Foreign consumption is based on \( \rho_2 \), significantly greater than unity, and \( \rho_1 \), close to zero. Paying foreigners no liras in period 1 disciplines them not to arrive in period
1; small positive values of $\rho_1$ also serve this purpose. This lowers the $\rho_2$ that needs to be paid to satisfy the foreign individual rationality constraint. Since higher values of $\rho_2$ leave the bank with less resources to pay domestic agents, the bank chooses $\rho_1 > 0$ to maximize expected domestic utility. The parameters $\rho_1$ and $\rho_2$ do not vary monotonically in $\lambda$. This fact defies easy explanation.

The bank keeps a precautionary reserve against the possibility that some patient agents claim to be impatient for the range of $\lambda$ in Table 2.4. As a result, $\lambda c_f < (1 - \gamma_h) (\eta e_d + e_f)$, making the value of $\gamma_h$ unaffected by $\lambda$. This involves a sacrifice by agents receiving payments in period 2 but the sacrifice ensures that twin crises are relatively rare events.

That the bank maintains a precautionary reserve explains why $c_f$ does not change with $\lambda$. Clearly, $c_f$ is bounded between $[1 - \gamma_h + R_1 \gamma_h] (\eta e_d + e_f)$ and $A (c_P, m)$. Since the upper bound is increasing in $\lambda$ and the lower bound is unchanging in $\lambda$, there is no need to offer more to impatient agents in the face of their increasing presence in the economy. Since $c_f$ is unchanging, this allows $c_P$ to increase with $\lambda$. The bank’s obligation to patient agents (in state 3) is $(1 - \lambda) c_P$ not $c_P$. For the parameter values presented in Table 2.4, $(1 - \lambda) c_P$ decreases with $\lambda$. As the measure of patient agents decreases, the bank rewards them more handsomely for their patience; nevertheless, total payments to patient agents decrease, since the payment per patient agent rises more slowly than the proportion of patient agents falls.

In this model, the values of all parameters are known; I conjecture here about the effects of parameter uncertainty. There are two types of uncertainty – uncertainty about $\lambda$ (which affects the Class from which the optimal contract is chosen as well as some of its values) and uncertainty about $a$ (which affects only the parameters
of the optimal contract. Uncertainty about these parameters could lead the bank to offer a contract which violates individual rationality, allows runs when they should be prevented, prevents runs when they should be allowed, increases the probability of a currency crisis or combines any of these errors. Because the variables of the optimal contract vary discontinuously at the $\lambda$-boundary of the Run Class, parameter uncertainty can cause devastating consequences. While the origins of the Turkish crisis are probably not parameter uncertainty, if the Turkish Central Bank had estimated $\lambda$ incorrectly by 0.05, that error could have magnified the effects of the crisis greatly.

There are two other results that bear mentioning. First, for any contract that leads to a twin crisis with positive probability, there is a positive probability of a domestic bank run alone (although these probabilities are not equal). Furthermore, if a twin crisis occurs, a domestic bank run must have occurred. A bank run by foreigners need not lead to a currency crisis. This emerges from two assumptions: first, that foreign agents are paid liras, whereas domestic agents are paid dollars, and second, that agents make simultaneous decisions.

2.7 Conclusion

This chapter presents a model of a twin crisis, in which fragilities in the banking sector can spill over into a currency crisis. Banks typically mismatch the maturities of their assets and liabilities. In the model, the productive asset matures in two periods, despite the fact that the bank’s demand deposit liabilities are due after one period. This feature exists in stable banking systems. What is unusual is the lack of

\(^{44}\)For the contracts of the Run Class presented in Table 2.4, the probability of a twin crisis ranges between 30\% and 40\%. 

33
confidence that depositors may display in the banking system. The combination of the mismatch in maturities and the lack of confidence leads to an explosive crisis.

In the model presented in this chapter, a sunspot variable causes people to change their expectations. But Demirgüç-Kunt and Dentraigache (1997, p. 5) considered a large sample of countries and concluded that “crises do not appear to be solely driven by self-fulfilling expectations as in Diamond and Dybvig (1983).” One possible extension to the model would allow the probabilities $\pi_1$, $\pi_2$ and $\pi_3$ to evolve over time due to “real” events in the model. In particular, consider an extension to an infinite horizon of periods, where each collection of three periods is a realization like the present model.\textsuperscript{45} One could derive a definition of economic growth and let the probabilities depend on economic growth.

This extension requires several decisions about the model in an infinite horizon. One possibility is that the state variables are independently distributed across time (even if that distribution is evolving over time). Another possibility is that the state variables $(s_d,s_f)$ evolve over time according to a stationary Markov process. These questions require separate research.

Alternatively, the model could be extended by adding more banks to the system. One bank failure might be weatherable, but many bank failures might lead to a currency crisis. The implications for Turkey are profound; understanding how a critical number of bank failures leads to a currency crisis may affect the bailout or recapitalization policy.

There are fixed exchange rate regimes today; how vulnerable are they? Could this model answer that question? This model could examine a country with a fixed exchange rate.

\textsuperscript{45}This idea borrows from Temzelides (1997).
exchange rate, a relatively open financial system with weak controls, high implicit deposit insurance and high rates of foreign deposits. This also needs a separate model.
CHAPTER 3

WHEN BAD THINGS HAPPEN TO GOOD BANKS

3.1 Introduction

In the 1970’s, many developing countries partially liberalized their financial systems by removing restrictions on deposit interest rates, reducing or eliminating reserve requirements and allowing foreign competition in the banking sector. Many of these countries kept one vestige of the previous regime – a fixed exchange rate. The combination of a fixed exchange rate with a liberalized banking sector proved particularly lethal to the financial system. By the early 1980’s, many of these countries experienced pervasive bank runs. In an attempt to stem the tide, central banks offered to bail out the banks experiencing runs, thereby weakening their foreign currency reserve position. Speculators pounced on the weakened currencies, forcing the abandonment of fixed exchange rates. Kaminsky and Reinhart (1999) termed this phenomenon a twin crisis, since it begins with a crisis in the banking sector and ends with a currency crisis.

This chapter presents a theoretical model of twin crisis; the model allows the examination of the actions of foreign and domestic depositors in an economy with a fragile banking system and a fixed exchange rate. N ex-ante identical banks offer a contract to their depositors based on when they arrive and on their country of
residence. This contract includes some payments in domestic currency and some in foreign currency. Domestic agents are of two types – impatient and patient. Impatient agents have an immediate need for liquidity; they withdraw from their bank as soon as they discover this need. Patient agents may defer withdrawing for one period in the hope of collecting a higher return or may pool themselves with the impatient agents. Foreign agents have the same choices as patient agents, but unlike the risk-averse patient agents, foreign agents are risk-neutral. After depositing, domestic agents learn whether they are patient or impatient. Patient agents and foreign agents then play a post-deposit subgame. The actions of patient and foreign agents at any one bank determine whether that bank fails. The failures of banks in the system determine whether the currency peg survives, since bank failures cause the central bank to lose reserves.

Each depositor observes a “sunspot variable” particular both to his bank and to his country of residence. Nature reveals a two-dimensional sunspot vector for each of the n banks but each depositor observes exactly one of the 2n sunspots. The sunspot vectors are statistically dependent, allowing for the possibility of interbank “contagion.” Since I model an unsophisticated banking system, banks may not trade contingent claims on each other’s deposits. I make the following standard modeling assumptions. Nature assigns depositors randomly to banks. The proportion of domestic depositors at any bank with immediate liquidity needs (“impatient”) is constant across banks and known to all. I also assume that there is an equal number of domestic and foreign depositors at each bank.\footnote{The fact that the number of domestic and foreign depositors are equal matches the empirical distribution of depositors in Turkey. See section 2.6 for more on calibration.}
In the remainder of this section, I further motivate the study of this problem and review some of the previous literature. Sections 2 and 3 set out the formal model. Section 4 explains the statistical setup for the sunspot variables. Section 5 defines a Nash equilibrium of the banking game. In section 6, I present the results of the numerical model, which is calibrated to Turkish data. Section 7 concludes. Proofs are reserved to Appendix B.

Early models of twin crises47 were deterministic; in these models, every bank run leads to a currency crisis. There are two problems with such models. First, they obscure the difference between a bank run and a bank panic.48 Second, deterministic twin crises models approximate reality poorly. Two episodes in which several banks collapsed but the currency peg survived are the Overend’s crisis of 186649 and the French-Arab crisis of 1988-90.50 By contrast, Sundararajan and Baliño (1991, pp. 39-50) detail examples of six developing countries which experienced only partial banking collapses but severe currency crises.51

The Turkish twin crisis of 2001 follows the Sundararajan and Baliño pattern. In January 2000, Central Bank Governor Gazi Erçel adopted a fixed exchange rate path for the lira in an attempt to control inflation. Depositors lost faith both in Turkish banks and in the lira. Thirteen months later, the severity of the foreign exchange


48Bhattacharya and Thakor (1993, p. 26) make a related point: “A bank run relates to an individual bank; a panic is a simultaneous run on many banks. A model of banking panics must explicitly address the contagion effects of runs. Neither Diamond-Dybvig nor Chari-Jagannathan model panics.”

49For more on the Overend’s crisis, see Batchelor (1986), Clapham (1944) and the Economist magazine, (May and June, 1866)


51The assets of failing banks ranged from 19% to 51% of banking system assets.
reserve drain forced the Central Bank to float the lira. During this period, the deposit insurance fund seized control of 10 banks and closed 8 other banks. Fifteen months after the beginning of the float, the 10 banks administered by the deposit insurance fund had also ceased operations. (TBB Website) This chapter argues that the Turkish crisis was not preordained.

The challenge for any model of twin crisis is to explain why some banks fail and others do not; further, such a model must determine the threshold where banking sector problems become sufficiently severe as to threaten the currency. A model of twin crisis must attempt to quantify “systemic risk.” What was the extent of systemic risk in Turkey in January 2000? Did the fixed exchange rate path augment systemic risk in Turkey? I constructed my model to answer this question, among others.

My work belongs to the literature on systemic risk.\(^{52}\) Davis (1995) defines systemic risk as

> a disturbance in financial markets which entails unanticipated changes in prices and quantities in credit or asset markets, which lead to a danger of failure of financial firms and which in turn threatens to spread so as to disrupt the payments mechanism and capacity of the financial system to allocate capital.\(^{53}\)

The question “[w]hat was the extent of systemic risk?” emerges from a “macro” perspective on the financial system. This question ignores the components of the system and their interactions. As a complement to the framework of systemic risk, Masson (1999) devised a taxonomy of interactions between components of a system. This taxonomy allows the researcher to ask “micro” questions about the relative

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\(^{52}\)For a review of the systemic risk literature, see Davis (1995) and De Bandt and Hartmann (2000).

\(^{53}\)This is similar to Minsky’s (1962, p. 251) definition of financial crisis. Kaufman’s (1995, p. 47) definition of systemic risk is somewhat broader.
importance of these effects. In Masson’s terminology, “monsoonal effects” refers to the situation where an exogenous factor affects the system. “Spillover effects” connotes the situation where the fundamentals in one part of the system affect the fundamentals in another part of the system. “Contagion effects” describes the situation where beliefs about one part of the system affect beliefs about another part. I assess the relevance of these three effects for the economy of my model and relate my model to Masson’s taxonomy.

My work also belongs to the vast literature that follows Diamond and Dybvig’s classic (1983) paper on bank runs. In that literature, uncertainty and incomplete information play a significant role. Some of these papers model multiple banks. Models with multiple banks allow the opportunity to study bank-systemic issues and their interaction with a currency peg. But the Diamond-Dybvig multiple bank literature is disappointing on several counts. First, many of the papers fail to consider explicitly the sequential service constraint (a notable exception is Smith, 1991). This failure means that contracts between the banks and their depositors may not be implementable. Second, most of these papers focus on banks trading contingent claims as a way to prevent crisis. The preeminent paper of this type is Allen and Gale (2000). In papers where banks trade contingent claims, it is impossible to examine the dynamics of the crisis since crises do not occur. Furthermore, establishing interbank markets where none exist may be difficult in practice; interbank markets

---


55 Diamond and Dybvig (1983, p. 408) explained that “a sequential service constraint ... specifies that a bank’s payoff to any [person] can depend only on the agent’s place in line and not on future information about [people] behind him in line.” For more on the sequential service constraint, see Wallace’s (1988) classic paper.
may prevent banking crises in financially developed countries but another mechanism may be needed for countries with less-well-developed financial markets. Third, none of these papers consider the effects of multiple bank failures on the currency. That is, there are no models of twin crises with multiple banks.

Finally, I draw on a paper by González-Hermosillo (1996) outside the Diamond-Dybvig framework which emphasizes the probability of systemic risk. This emphasis is unique among models of banking crisis. González-Hermosillo bases her model on two geometric Brownian motions – one to represent exogenous liquidity demands and one to represent the exogenous return of “the market.” From these Brownian motions, she derives each bank’s optimal portfolio and level of capitalization. In so doing, she considers both endogenously chosen deposit insurance and the costs of insolvency. The probability of insolvency for each bank depends both on the exogenous Brownian motions and on choice variables for the bank. The probability of systemic risk is the joint probability of a critical number of failures. I adopt this operational definition of systemic risk here.

3.2 The Model

3.2.1 Assets, currencies and goods

There are two assets in which agents and banks may invest. The “world” asset is a storage technology. One unit invested in period 0 returns one unit in period 1 or one unit in period 2 (but not both). The “productive” asset yields $R_1$ units in period 1 or $R_2$ units in period 2 (but not both) per unit invested in period 0. Where $0 < R_1 < 1 < R_2$, the world asset dominates the productive asset if assets are liquidated in period 1, but not if assets are liquidated in period 2.
The lira and the dollar are the two currencies of the model. A fixed exchange rate of unity initially prevails between them. The government can print liras but not dollars, since dollars are foreign currency. The government incurs a liability of one dollar for every lira it prints. The consumption good always costs one dollar. This economy is highly dollarized, since agents receive their endowments in dollars and frequently make bank withdrawals in dollars.

3.2.2 Decision-makers and their decisions

A small, open economy lasts for three periods, denoted 0, 1 and 2. There are five types of decision-makers in the model economy – domestic impatient agents, domestic patient agents, foreign agents, banks and the government. Nature assigns each agent to a bank.\textsuperscript{56} I index the domestic agents at each bank along a continuum of unit measure, where the measures of impatient and patient agents are $\lambda$ and $1-\lambda$ respectively.\textsuperscript{57} I also index the foreign agents at each bank along a separate continuum of unit measure.\textsuperscript{58}

In period 0, agents decide whether to deposit their resources at their bank or to receive the autarchic return. If agents deposit, they choose when to withdraw a pre-specified amount – period 1 or period 2. Each bank determines the sizes of the withdrawals available to depositors – the “deposit contract.” The government sets the economic environment – fixing tax rates, required reserve rates, and deciding when to bail-out failing banks.

\textsuperscript{56}That is, an agent will deposit at the bank “suggested” by Nature if he or she is indifferent between so doing and depositing at another bank.

\textsuperscript{57}As usual in models in the Diamond and Dybvig (1983) tradition, agents do not discover their type until period 1. The nationality of each agent is public information.

\textsuperscript{58}In the aggregate, the measures of domestic impatient, domestic patient and foreign agents are $n\lambda$, $n(1-\lambda)$, and $n$ respectively.
3.2.3 Objective functions and notation

Impatient agents only value consumption in period 1. Patient agents value consumption in period 2 and the holding of liras during period 1.59 If patient agents pretend to be impatient, they forego the holding of liras in period 1 and consume in period 1. When patient agents claim to be impatient, they receive utility as if they were a impatient agents. While domestic agents are risk-averse, foreign agents are risk neutral.60

Let \( c_I(j) \) denote consumption offered to an impatient depositor of bank \( j \), \( j = 1 \ldots n \).61 Analogously, let \( c_P(j) \) and \( m(j) \) represent respectively consumption and liras offered to a patient agent of bank \( j \). The utility function for impatient agents is:62

\[
g(c_I(j)) = -\frac{1}{\alpha} \exp[-ac_I(j)] + \frac{1}{\alpha} + \zeta c_I(j), \quad \alpha > 0, \quad \zeta > 0
\] (3.1)

The utility function for patient agents is:63

\[
g(A|y(j), m(j)) = g\left(c_P(j)\beta m(j)^{1-\beta}\right), \quad 0 < \beta < 1
\] (3.2)

Let \( \rho_1(j) \) and \( \rho_2(j) \) denote the gross lira return for foreigners withdrawing in periods 1 and 2 respectively. Finally, let \( \gamma_b(j) \) be the share of the \( j^{th} \) bank’s deposits that it invests in the productive asset.64

59 This assumption reflects the transactions motive for holding money.

60 It is a standard assumption in models of this type that depositors be risk-averse. I assume that foreign investors are risk-neutral over the fraction of their total assets they invest in this economy because that fraction is likely to be a small one.

61 I drop the dependence on \( j \) in the equilibrium section since I assume that all banks offer the same contract. This assumption does not emerge as a result of this model, since I do not allow agents to choose the bank at which they deposit, but would emerge in a more complicated model with potential depositor mobility. See De Bandt (1995), for example.

62 This utility function is positive, increasing, concave, bounded below but not bounded above. See Chapter Two for discussion of the risk-aversion properties of this function.

63 I discuss in detail in Chapter Two the reasons for the choice of this function as well.
Banks maximize the expected utility of their domestic depositors, subject to constraints including feasibility, individual rationality and incentive compatibility. Diamond and Dybvig (1983) noted that contracts which provide liquidity services have a run equilibrium. If a bank believed that agents will run with probability p, it should use this information to design its contract. Furthermore, the bank might choose not to accept the risk of a bank run and offer a contract to prevent bank runs. Having the option to offer a contract which prevents runs complicates the bank’s objective function.

I do not model the government’s objective function. I consider the government’s taxation and reserve requirement behaviour as given from data. This modeling strategy does not permit the determination of optimal government behaviour. But it suggests conclusions about the consequences of “rule-of-thumb” government behaviour. While I do not find the optimal tax or reserve rate, I evaluate the tax or reserve rates used by the Turkish government.

3.2.4 A collection of sunspot variables

In order to take seriously the possibility that its depositors might run, a bank needs to assess the beliefs of its depositors. To make this task tractable, I introduce a collection of sunspot variables. A sunspot variable reveals information unrelated to the fundamentals of the economy; agents may use this information to assist in decision-making and possibly in equilibrium selection. Duffy and Fisher (2002, p. 4) note that “the semantics of the language of sunspots matters; if it is not immediately

\footnote{If banks did not maximize expected utility of their depositors, Bertrand competition among banks would drive the non-maximizing banks out of business. See de Bandt (1995) for an elaboration of this point.}
clear to all individuals how a sunspot variable realization is to be interpreted, then that sunspot variable is unlikely to play any role in coordinating expectations.” [italics in original]

In Chapter Two, I compare the sunspot variables with interpretations of a newspaper article which announced some change in circumstances unrelated to fundamentals.

“On February 19, 2001, the day before the [debt] auction, Turkish Prime Minister Bulent Ecevit stormed out of a key meeting of top political and military leaders stating a ‘dispute’ had arisen between himself and the country’s president. He further emphasized that ‘of course, this is a serious political crisis’ without elaborating the future of the government or the economic program.” (Gençay and Selçuk, 2001, p. 3)

A resident of Turkey and a foreigner might interpret this report differently. These differing interpretations explain why there must be at least two sunspot variables – one for domestic agents and one for foreign agents. The fact that there are two interpretations of the news report does not justify why agents observe bank-specific sunspot variables. Bank specific sunspot variables can be justified by additional sunspot-style announcements: “bank j could be vulnerable to a run,” or “bank i is sound.”⁶⁵

Let s(i,j) be the sunspot variable observed by an agent of type i, depositing at bank j, where i = d, f (domestic or foreign), and j = 1 … n. I discuss the correlation between different sunspot variables below.

⁶⁵It is important to remember that the announcements must be irrelevant to the fundamentals. Given that all banks offer the same contract, all banks will be both sound and vulnerable to a run (simultaneously). But the combination of Ecevit’s declaration with an announcement that one equilibrium seems more likely than another could be sufficient (in a Duffy and Fisher sense) to induce changes in behaviour.
3.3 The game

3.3.1 Timing of the model

Here is a summary of how the model unfolds over time.

Period 0:

1. Domestic agents receive an endowment, $e_d$. Foreigners arrive with resources for investment, $e_f$.

2. The government announces the tax rate, $\tau$, and the required reserve rate, $1-\eta$.

3. Each bank announces the contract, $C(c_f(j), c_F(j), \gamma_b(j), \rho_1(j), \rho_2(j))$, it will offer conditional on foreign and domestic deposits and on government policies announced in item 2.

4. Foreign and domestic agents deposit at their banks.

5. Banks deposit required reserves at the central bank. Banks invest the rest of their deposits in the productive asset and the world asset according to the contracts offered in item 3.

Period 1:

1. Domestic agents learn their type — patient or impatient.

2. Nature draws the sunspot variables $\{s(d, j)\}_{j=1}^n$ and $\{s(f, j)\}_{j=1}^n$, revealing them to domestic and foreign agents respectively.

I state all amounts in this subsection in per-capita terms.
3. Banks open for business. Agents of various types arrive in random order. Banks liquidate their holdings of the world asset. Agents claiming to be impatient receive, net of taxes, \((1 - \tau)c_I(j)\) dollars, if available. Agents claiming to be patient receive \(m(j)\) liras. If any foreign agents arrive, they receive \(\rho_1(j)e_f\) liras. Banks withhold taxes from domestic withdrawals.

4. If every bank serves all its depositors in queue, go to item 5. Some banks may have to liquidate productive assets in order to serve as many domestic agents as possible. The government may bail out some banks at this stage.

5. Foreigners trade liras for dollars at the central bank.\(^{67}\)

Period 2:

1. Any remaining investment in the productive asset matures.

2. Banks pay \((1 - \tau)c_P(j)\) dollars to any domestic agent who claimed to be patient in period 1, if available. Banks remit \(\tau c_P(j)\) dollars to the government as taxes. Banks also pay \(\rho_2(j)e_f\) liras to any remaining foreign agents.\(^{68}\) If any bank has dollars left over at this point, it remits them to the government.\(^{69}\)

3. Foreign agents holding liras trade them for dollars at the central bank. If the quantity of liras in circulation exceeds the dollar reserves of the central bank, a currency crisis occurs.

4. The economy ends.

\(^{67}\)For a discussion of the foreign exchange timing, see Chapter Two.

\(^{68}\)See Chapter Two for a discussion of the roles of \(\rho_1\) and \(\rho_2\) in the bank's decision as well as the relationship between \(\rho_1\) and \(\rho_2\).

\(^{69}\)That is, the government is the residual claimant of each bank. This assumption can be partially justified by the fact that the government may bail out banks if they experience runs.
3.3.2 The contract and related variables

In period 0, each bank offers a contract \( C(c_l (j), c_P (j), \gamma_b (j), \rho_1 (j), \rho_2 (j)) \in \mathcal{R}_+ \) to which agents respond. Determining which is the optimal contract is the subject of the equilibrium section. The quantity of money is not uniquely determined.\(^70\) Liras received by domestic agents in period 1 (if any), provide liquidity services and then “disappear.” Since these liras are amorphous, the model does not determine their quantity uniquely. I propose that liras paid to domestic agents at each bank be proportional to dollar payments to domestic agents, namely \( m(j) = \kappa [\lambda c_l (j) + (1 - \lambda) c_P (j)] \).\(^71\) In equilibrium, every bank offers the same quantity of liras to patient agents, \( m(j) = m \forall j \); lira balances are proportional to “GDP” with constant of proportionality \( \kappa \). The variable \( \kappa \) is “Cambridge \( k \),” the constant money multiplier advocated by Keynes and his students. Note that \( \kappa \) is constant across banks.

3.3.3 The rules of the game

In period 0, banks invest their deposits according to the contract. If agents do not deposit resources at their bank, domestic agents can divide their endowment between the two assets. Foreigners, by contrast, may not invest directly in the productive asset.

In period 1, all domestic and possibly some foreign agents arrive at their banks. Banks can always accommodate the demands of foreigners, if any, since foreigners may

\(^70\)The contract determines uniquely the quantity of liras paid to foreign agents but not that paid to domestic agents.

\(^71\)Chang and Velasco (2000a) also face the problem of an indeterminate quantity of money. They solve this problem by imposing a satiation level of money demand.
withdraw only in liras. Agents claiming to be patient present no problems for banks either; banks pay them in liras which the central bank creates. By contrast, banks obtain dollars only by liquidating assets. As domestic agents claiming to be impatient arrive, banks liquidate some assets and pay each agent \((1 - \tau) c_I (j)\), remitting \(\tau c_I\) to the central bank as taxes.\(^7\) Notice that I preclude suspension of convertibility, since the payment to domestic agents does not depend on the history of withdrawals. That is, the \(j^{th}\) bank must pay \((1 - \tau) c_I (j)\) to domestic agents until it runs out of dollars and has liquidated all assets.\(^8\)

Banks must determine the amount of the productive asset that they will liquidate in period 1. I assume that the bank pays foreign agents in liras. This assumption corresponds to reality; people investing in a foreign country usually invest in assets denominated in the currency of that country. When the assets mature, or when they sell the assets, they have to convert the foreign currency back to their own currency. An immediate result of the assumption that the banks pay foreigners in liras is that the banks need not liquidate any assets to pay foreigners. On the other hand, the \(j^{th}\) bank may have to liquidate some of the productive asset to pay domestic agents. Let \(a_d (j)\) be the measure of domestic agents that claim to be impatient at the \(j^{th}\) bank. Let \(a_f (j)\) be the measure of foreign agents that arrive in period 1 at the \(j^{th}\) bank. Then \(L(a_d (j))\) is the amount of the productive asset the \(j^{th}\) bank will liquidate in period 1 if \(a_d (j)\) agents claim to be impatient. From its liquidation of the world

\(^7\)Because of the return structure of the two assets, no bank liquidates any of the productive asset until it has liquidated its entire holdings of the world asset.

\(^8\)This is a stronger form of the sequential service constraint than the ones proposed by Diamond and Dybvig (1983) and Wallace (1988). Not only does this assumption improve the tractability of the numerical model, it allows the comparison of contracts for different parameter values (see the results section and Chapter Four).
asset, the \(j^{th}\) bank received \((1 - \gamma_{b} (j)) [\eta e_d + e_f]\). If this amount does not suffice to pay agents claiming to be impatient, the \(j^{th}\) bank will liquidate a portion of the productive asset. The amount liquidated will be \(\frac{a_d(j)c_l(j)-(1-\gamma_{b} (j)) [\eta e_d + e_f]}{R_1}\). Finally, the \(j^{th}\) bank cannot liquidate more of the productive asset than its original investment, \(\gamma_{b} (j) [\eta e_d + e_f]\). Thus,\(^7^4\)

\[
L (a_d (j)) = \min \left( \gamma_{b} (j) [\eta e_d + e_f], \frac{a_d(j)c_l(j)-(1-\gamma_{b} (j)) [\eta e_d + e_f]}{R_1} \right)
\]  

(3.3)

Some banks may liquidate all their assets but additional domestic agents remain in their queues claiming to be impatient. Whether this confluence of events will trigger a bank bailout depends on the behavior of foreign agents. I assume that the government bails out banks only if no foreigners are present at those banks in period 1.\(^7^5\) The government never bails out a bank by giving more than it needs to give all its agents \(c_l (j)\). Since a bank needing a bailout can obtain \((1 - \gamma_{b} (j)) (\eta e_d + e_f)\) by liquidating all its assets, the typical bank bailout will be of size \(a_d (j)c_l (j) - (1 - \gamma_{b} (j)) (\eta e_d + e_f)\). I assume the government will not bail out the bank with an amount greater than the government collected in taxes from depositors of that bank, \(\tau c_l (j)\). The bailout function is thus:

\[
B (a_d (j)) = \min [a_d (j) c_l (j) - (1 - \gamma_{b} (j)) (\eta e_d + e_f), \tau c_l (j)]
\]  

(3.4)

\(^7^4\)In equilibrium, \(L(\cdot)\) takes only two values: 0 or \(\gamma_{b} (j) (\eta e_d + e_f)\).

\(^7^5\)The assumption that the government only bails out banks with no foreigners present can be motivated by reference to monitoring and moral hazard. If foreigners arrive in period 1, they are effectively monitoring the bank and the government. The bailout reduces the dollar value of the limos foreigners receive; their presence prevents the government from bailng out the bank to help its domestic depositors. Note that if a foreigner arrives at his bank in period 1, his return is \(\rho_1 (j)\), not \(\rho_2 (j)\). One may interpret \(\rho_2 (j) - \rho_1 (j)\) as a monitoring cost. The “free-rider problem” ensures that no foreigner pays this monitoring cost unless all foreigners do so.

50
After a bailout has occurred, the bailed-out banks distribute \((1 - \tau) c_I (j)\) to each
domestic agent in queue, until the banks’ resources are once again exhausted.\(^{76}\)

Foreigners proceed to the central bank after visiting their banks. The central bank
compares liras in circulation with dollars in its reserve vault. If the latter quantity
exceeds the former one, foreigners exchange each lira for one dollar. If the former
exceeds the latter, the exchange rate becomes the ratio of the latter to the former.
In that case, the central bank exchanges liras for dollars at the new exchange rate.\(^{77}\)
Since investors have forced this depreciation, I call this event a currency crisis.

In period 2, domestic agents that claimed to be patient return to their banks. The
banks may have liquidated all of their assets in period 1; if so, there is nothing with
which to pay returning domestic agents. If any bank has assets left over in period 2,
these assets mature and yield dollars. Those banks use the dollars to pay domestic
agents claiming to be patient \((1 - \tau) c_P (j)\), remitting \(\tau c_P (j)\) to the government as
taxes. If some banks cannot serve every domestic agent claiming to be patient, they
will not change the amount each agent receives. Even if some banks cannot serve
everyone in period 2, the government will not bail them out. In equilibrium, however,
a bailout in period 2 is never necessary.

After all assets have matured and banks have paid all agents claiming to be patient,
some dollars may remain in the bank vaults. If so, banks remit those dollars to the

\(^{76}\)This bailout policy is public information. I ignore here issues of central bank credibility.

\(^{77}\)Note that that this scheme for paying foreigners does not violate a sequential service constraint
for currency exchange. I show below (see Theorem 6) that foreigners always arrive in period 2 in
equilibrium. By the beginning of period 2, the government knows exactly how many dollars it will
have at the end of period 2. The central bank can begin proportional payments as soon as the first
foreigner arrives at its doors.
central bank. This guarantees that no bank makes profits.\textsuperscript{78} Finally, if foreign agents have collected liras, they convert them to dollars at the central bank. The procedure for determining the exchange rate remains the same as the one used in period 1.

3.4 The Sunspot Variables and Contagion

Statistically independent sunspots allow the identification of monsoon and spillover effects, but not of contagion effects. I model the sunspots as Bernoulli random variables. This choice allows for a tractable form of statistical dependence – a first-order Markov chain.

Here is the notation, based on Helgert (1970).

Pr(s(d,0) = 1) = p.\textsuperscript{79}
Pr(s(d,j) = 1|s(d,j-1) = 0) = p_0.
Pr(s(d,j) = 1|s(d,j-1) = 1) = p_1.
Pr(s(f,j) = 1|s(d,j) = 1) = \pi_2.
Pr(s(f,j) = 1|s(d,j) = 0) = \pi_3, where \pi_2 > \pi_3.

p = (p, p_0, p_1, \pi_2, \pi_3)

Nature uses this algorithm to determine the value of the sunspot variables.

1. Determine s(d,0), using the fact that Pr(s(d,0) = 1) = p.
2. Draw s(d,j), using the Markov transition probabilities (p_0, p_1).
3. Draw s(f,j) using the conditional probabilities (\pi_2, \pi_3).

For each bank j, j = 1 ... n, there are four possibilities.

\textsuperscript{78}This aspect of the model ensures that liras paid to foreigners in period 2 are backed by dollars, whereas liras paid to anyone in period 1 need not be.

\textsuperscript{79}There is no 0\textsuperscript{th} bank. But Nature performs an initial draw of the random variable before beginning the Markov chain; this is analogous to selecting a conditional distribution.
The aggregate state indicates what has occurred in the banking system. Let \( n_h \) represent the number of occurrences of state \( h, h = 1 \ldots 4 \) and let \( \mathbf{n} \equiv (n_1, n_2, n_3, n_4) \). The \( n_h \) must obey \( 0 \leq n_h \leq n \) and \( \sum n_h = n \). I call the distribution of the \( n_h \) Augmented-Helgert (AH). The AH(\( \mathbf{n}; \mathbf{p} \)) distribution is the product of three distributions. Two of these are independent Binomial distributions. The third is the Helgert distribution of the sum of Bernoulli variables distributed according to a Markov chain. Since there is no simple closed-form expression for \( \text{Helg}(\cdot) \), expectations over AH(\( \mathbf{n}; \mathbf{p} \)) need to be taken numerically.

Let Bin\( (z; z_1, z_2) \) denote the probability that the realization of a binomially-distributed random variable is \( z \), assuming \( z_1 \) draws and a per-draw probability of \( z_2 \). Let Helg\( (z; z_1, z_2, z_3, z_4) \) denote the probability that the realization of a Helgert-distributed random variable is \( z \), assuming \( z_1 \) draws, initial probability \( z_2 \), and transition probabilities \( z_3 \) and \( z_4 \). Then

\[
AH(\mathbf{n}; \mathbf{p}) = \text{Bin}(n_1; n_1 + n_2, 1 - \pi_2) \cdot \\
\text{Bin} (n_3; n_3 + n_4, 1 - \pi_3) \cdot \text{Helg} (n_1 + n_2; n, p, p_0, p_1).
\]

\( ^{80} \text{Gabriel (1959) presents a formula for this probability distribution using triple summations. Pedler (1971) express this distribution using Laplace transforms, Bessel functions and Dirac Delta functions. Bhat and Lal (1988) write this distribution as an Augmented Markov chain. None of these expressions combine conveniently with the Binomial distribution in the AH distribution.} \)

\( ^{81} \text{There is no standard name for the Helgert distribution in the statistical literature. I use that name because Helgert’s (1970) paper was the first to derive a simple recursion for the probability mass function of this distribution. I present details of this recursion in Appendix B.} \)
3.5 Equilibrium

After explaining the rules of the game, I am now ready to derive an equilibrium. I solve the game by backward induction, deriving first the equilibrium of the post-deposit subgame and then the equilibrium of the entire game, assuming subgame perfection.

3.5.1 Classes of Contract

Diamond and Dybvig (1983, p. 409) showed that whether or not the post-deposit subgame has a run equilibrium depends on the contract the bank offers. Any bank can offer a contract which prevents runs or a contract which allows runs.\(^8^2\) Refer to contracts which prevent runs as contracts of the No-Run class and to contracts which allow runs as contracts of the Run class.\(^8^3\) A non-naive bank should understand the possibility of a crisis; it should act to prevent it in some circumstances and not do so in others.\(^8^4\)

3.5.2 Equilibrium of the Subgame

The post-deposit subgame consists of Nature’s “selecting” the realization of the sunspot vectors, followed by the choices of the two types of agents.\(^8^5\) A strategy indicates how an agent responds to the sunspot variable he sees. I consider only

---

\(^8^2\)A contract is said to prevent runs if the set of equilibria of the subgame played after the announcement of that contract does not include a run equilibrium. A contract that does not prevent runs is said to allow runs.

\(^8^3\)I ignore here contracts for which the post-deposit subgame has no equilibrium, that is, for which agents would not rationally deposit their resources at the bank.

\(^8^4\)I am primarily interested in equilibria of the Run class, since those contracts can lead to a twin crisis. I describe the equilibrium of the subgame and of the game for contracts of the No-Run Class in Chapter Two.

\(^8^5\)Only patient and foreign agents play this subgame. Impatient agents always report their type honestly.

54
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<th>s(f,j)=0</th>
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<td>CI</td>
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<td>CP</td>
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<tr>
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<td>CP</td>
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<td>A2</td>
<td>A1</td>
</tr>
</tbody>
</table>

Table 3.2: Strategy Descriptions

type-symmetric pure strategies.\textsuperscript{86} A domestic strategy may be written formally as σ\textsubscript{d} : s(d,j) \rightarrow \{CI, CP\}, where CI means claim to be impatient and CP means claim to be patient. A foreign strategy may be written σ\textsubscript{f} : s(f,j) \rightarrow \{A1, A2\}, where A1 means arrive in period 1; A2 means arrive in period 2. Each type of agent has four possible strategies.

Let Σ\textsubscript{d} = \{σ\textsubscript{d,1}, σ\textsubscript{d,2}, σ\textsubscript{d,3}, σ\textsubscript{d,4}\} and Σ\textsubscript{f} = \{σ\textsubscript{f,1}, σ\textsubscript{f,2}, σ\textsubscript{f,3}, σ\textsubscript{f,4}\} be the strategy sets for domestic and foreign agents with typical elements σ\textsubscript{d} and σ\textsubscript{f} respectively. Each individual agent has an expected payoff function, E\textsubscript{s}U\textsubscript{d} for domestic agents and E\textsubscript{AHH}U\textsubscript{f} for foreign agents, which depends on the strategy played by all other agents of the same nationality, the strategy played by all agents of the opposite nationality, the strategy played by that individual agent and the contract offered by the bank.

Definition 5 A pair of strategies (σ\textsubscript{d}, σ\textsubscript{f}) is a type-symmetric Nash equilibrium of the post-deposit subgame if 2 conditions hold:

\textsuperscript{86}By type-symmetric strategies, I mean that each type of agent plays a strategy that may differ across banks only insofar as do the realizations of the sunspot vectors. This is not an arbitrary restriction, since all banks are ex-ante identical and that individual agents do not have enough information to distinguish among them when selecting a strategy.
1. For all patient agents in \([0, 1 - \lambda]\) and for all \(\tilde{\sigma}_d \in \Sigma_d\), \(E_d U_d(\sigma_d, \sigma_f, \tilde{\sigma}_d, \cdot) \geq E_d U_d(\sigma_d, \sigma_f, \tilde{\sigma}_d, \cdot)^{87}\).

2. For all foreign agents in \([0, 1]\) and for all \(\tilde{\sigma}_f \in \Sigma_f\), \(E AH U_f(\sigma_d, \sigma_f, \tilde{\sigma}_f, \cdot) \geq E AH U_f(\sigma_d, \sigma_f, \tilde{\sigma}_f, \cdot)\).

Even though it is possible to compute \(E_d U_d\) and \(E_f U_f\) for each of the 16 strategy pairs and all the possible deviations from them, I focus on a particular equilibrium, namely \((\sigma_{d1}, \sigma_{f2})\). The utility calculations are in Appendix B. It is possible to reduce these utility comparisons to three simple conditions, as explained in the following two theorems.

**Theorem 5** If three regularity conditions hold, domestic depositors will rationally follow the sunspot signals, running only when they see a bad signal at their bank, \(s(d, j) = 1\). Formally, if \(A(c_p, m) > c_l, (1 - \gamma_b + R_1\gamma_b)(\eta e_d + e_f) \leq c_l, \) and \(\lambda c_f + (1 - \lambda) c_p + \rho_2 e_f = (1 + R_2\gamma_b - \gamma_b)(\eta e_d + e_f)\) a domestic depositor at bank \(j\) will run on his bank only when \(s(d, j) = 1\).

**Proof.** The proof is nearly identical to that for Theorem 2 and omitted for brevity. Note that the third condition guarantees that all patient agents can be served in period 2 at banks that did not experience runs in period 1. \(\blacksquare\)

**Theorem 6** If the domestic agents are known to be running on their banks according to the sunspot signals and \(\rho_1\) is 0 (or, by continuity, a small positive), it is optimal for foreign agents to arrive in period 2.

**Proof.** See Appendix B. \(\blacksquare\)

---

87The first argument of \(E_d U_d\) and \(E AH U_f\) is the strategy played by the mass of domestic agents. The second argument is the strategy played by the mass of foreign agents. The third argument is the strategy played by one particular agent, domestic or foreign. This may differ from the strategy played by the mass of agents of the same type. Finally, the suppressed arguments in \(E_d U_d\) and \(E AH U_f\) stand for the contract vector \((c_l, c_p, \gamma_b, \rho_1, \rho_2)\).
3.5.3 Aggregation of the equilibrium at the bank level

The banks pay less attention to the actions of their depositors individually than to the cumulative effect of their actions. Refer to \((a_d(j), a_f(j))\) as the bank-level strategy aggregator.

**Definition 6** A domestic bank run occurs at the \(j^\text{th}\) bank when \(a_d(j) = 1\)

**Definition 7** A bank run by foreigners occurs at the \(j^\text{th}\) bank when \(a_f(j) = 1\).

**Definition 8** A currency crisis occurs when the central bank is forced to devalue the lira, because the demand for dollars exceeds the supply of dollars in its reserves.

By Theorems 5 and 6 above, for some parameter values, a Nash equilibrium of the subgame is \((\sigma_{d1}, \sigma_{f2})\); the bank-level Nash strategy aggregator corresponding to this Nash equilibrium is:

- \((1, 0)\), when \(s(d, j) = 1\) and \(s(f, j) = 0\) [state 1]
- \((1, 0)\), when \(s(d, j) = 1\) and \(s(f, j) = 1\) [state 2]
- \((\lambda, 0)\), when \(s(d, j) = 0\) and \(s(f, j) = 0\) [state 3]
- \((\lambda, 0)\), when \(s(d, j) = 0\) and \(s(f, j) = 1\) [state 4]

The aggregate state is a random vector \((n_1, 0, n - n_1, 0)\) distributed according to a conditional \(AH(n; p)\) distribution. Note that for this equilibrium, sunspots matter, although only for domestic agents.\(^{88}\) In some situations, domestic agents receive higher expected utility by running on the bank; in other situations they receive higher expected utility by not running.

\(^{88}\)There is another equilibrium of the subgame — one in which patient agents honestly report their type regardless of the sunspots. As is common in the sunspots literature, I assume that if an equilibrium exists where sunspots matter, that equilibrium is selected.
3.5.4 Equilibrium of the Game: Individual Rationality

I assume foreigners may not invest in the productive asset except through a bank; thus their per-dollar gross autarchic return is 1. Since foreigners are risk-neutral, they will deposit at a bank so long as the expected return to depositing at the bank equals 1. Domestic agents can split their endowment between the two assets in any way they choose. Let $\gamma_{aut}$ be the fraction of a typical domestic agent’s endowment invested in the productive asset. In autarchy, domestic agents earn $r_{aut} (\gamma_{aut}) = \lambda g (\epsilon_d [R_1 \gamma_{aut} + 1 - \gamma_{aut}]) + (1 - \lambda) g (\epsilon_d [R_2 \gamma_{aut} + 1 - \gamma_{aut}])$. There is a unique $\gamma_{aut}^* \in [0, 1]$ which maximizes this expression.\textsuperscript{89} In equilibrium, expected per-capita domestic utility must meet or exceed $r_{aut} (\gamma_{aut}^*)$ and expected per-capita foreign utility must equal $e_f$.\textsuperscript{90}

3.5.5 Equilibrium of the Game

To solve the game, the banks maximize utility of their domestic depositors. In so doing, they must not only take into account the behaviour of agents during the post-deposit subgame, but also whether agents would rationally deposit at their banks. These considerations require that the banks constrain their maximization with incentive compatibility and individual rationality constraints. In addition, since the banks know that runs occur in the post-deposit subgame with positive probability, they must account for this possibility when computing expected utility. Let $U_d^*$ and $U_f^*$ denote the values of $U_d$ and $U_f$ respectively when the Nash equilibrium $(\sigma_{d,1}, \sigma_{f,2})$ is played during the post-deposit subgame.

\textsuperscript{89}I prove that $\gamma_{aut}^*$ exists and is unique in Appendix B.

\textsuperscript{90}That the foreign individual rationality condition binds follows straightforwardly from the fact that the bank maximizes expected domestic utility but is indifferent to foreign utility.
One may simplify considerably the problem of determining each bank’s optimal contract. I search for a symmetric equilibrium in which each bank offers the same contract. If there are no profitable deviations from the symmetric contract, that contract is a Nash equilibrium of the game.

Suppose n-1 banks offer the contract \( C = (c_l, c_P, \gamma_b, \rho_1, \rho_2) \) and one bank offers the contract \( \hat{C} = (\hat{c}_l, \hat{c}_P, \hat{\gamma}_b, \hat{\rho}_1, \hat{\rho}_2) \). I now show that \( \hat{\rho}_2 = \rho_2 \) in equilibrium. If \( \hat{\rho}_2 < \rho_2 \), then foreign depositors receive fewer liras from the deviating bank than from any other bank. The rules for currency conversion of the model imply that the dollar value of the liras received from the deviating bank is also smaller than the analogous value for other banks. If \( \hat{\rho}_2 < \rho_2 \), foreigners do not deposit at the deviating bank. Since \( \rho_2 \leq R_2 \), the presence of foreign deposits at any bank increases expected domestic utility. Accordingly, \( \mathbb{E}_s U^*_d \left( \hat{C} \right) < \mathbb{E}_s U^*_d \left( C \right) \). On the other hand, if \( \hat{\rho}_2 > \rho_2 \), domestic depositors at the deviating bank lose utility because foreigners collect some payments otherwise paid to domestic agents. Once again, \( \mathbb{E}_s U^*_d \left( \hat{C} \right) < \mathbb{E}_s U^*_d \left( C \right) \). Since expected utility of domestic agents is smaller at the deviating bank, no bank will deviate with respect to \( \rho_2 \). That is, \( \hat{\rho}_2 = \rho_2 \) in equilibrium.

The rules of the game largely insulate individual banks from one another. Only \( \rho_2 \) links the banks, as explained above. If \( \rho_2 \) is identical across banks, the rest of the contracts are independent of one another. Independence of the contracts holds despite the possibility of bailouts. Since each bank’s bailout consists of a rebate of the taxes paid by its depositors, a bailout of every bank in the system is feasible. Furthermore, if \( \hat{c}_l \) and \( \hat{c}_P \) differ from \( c_l \) and \( c_P \), the size of the potential bailout of the deviating bank will differ from the size of the potential bailouts of other banks, but it will not affect the utility of the domestic depositors at other banks. Thus, one
may consider the decision problem for a representative bank; the contract chosen by the representative bank is chosen optimally by all banks.

Formally, the banks solve this problem:\footnote{91}

\[
\max_{C \in \mathbb{R}_+^n} E_s U^*_d, \text{ s.t.} \quad (3.6)
\]

\[
\lambda c_I = (1 - \gamma_b) (\eta e_d + e_f) \quad (3.7)
\]

\[
E_s U_d \geq r_{aut} (\gamma^{**}_{aut}) \quad (3.8)
\]

\[
E_{AH} U^*_f = ne_f \quad (3.9)
\]

\[
A(c_P, m) \geq c_I \quad (3.10)
\]

\[
\lambda c_I + (1 - \lambda) c_P + \rho e_f = (1 - \gamma_b + R_a \gamma_b)(\eta e_d + e_f) \quad (3.11)
\]

In the above maximization problem, equation (3.7) guarantees that if there is no bank run, the bank need not liquidate any of the productive asset. Inequality (3.8) and equation (3.9) are the individual rationality constraints; they guarantee that foreign and domestic agents will deposit their resources at the bank, eschewing autarchy. Inequality (3.10) is the domestic incentive compatibility constraint. Equation (3.11) is the zero profit constraint for each bank. Note that I do not impose the constraint that the utility-maximizing contract is of the Run class. The solution to 

\footnote{91}I drop dependence on j in the statement of the maximization problem.
this problem can only an equilibrium of the game if the utility-maximizing contract is of the Run class. However, it is not an equilibrium of the game if there is a contract of the No-Run class which offers higher utility than the solution of this problem. It is theoretically possible that such a contract exists because the best contract which prevents runs maximizes a different utility function, i.e., not $E_d U_d^\ast$. The final step in determining that the solution to the maximization problem of this section is indeed the equilibrium of the game thus requires this comparison of expected utilities.

3.6 Calibration and Results

The theoretical model presented above does not admit a closed form solution. In particular, the fact that banks have the possibility of choosing either a contract that allows runs or one that prevents runs introduces a point of non-differentiability into the banks’ objective function. The advantages of calibrating the model are thus two: first, to be able to find the optimal contract, and second, to be able to comment on the effectiveness of Turkish policy.

3.6.1 Calibration of Parameters

Table 3.3 lists the values of the parameters used in the numerical solution of the model. I calibrate the parameters $e_d, e_f, \eta, R_2$, and $\tau$ to match Turkish data. I calibrated the parameters $\alpha, \beta, \zeta$ and $R_1$ using some studies based on other developing and developed countries$^{92}$ since no specific Turkish studies were available. I discuss these values in Chapter Two.

$^{92}$These countries included Argentina, India, Israel and the United States.
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</table>

Table 3.3: Calibrated Parameter Values

I set the value of $n$ to 81; this matches the number of banks in Turkey at the beginning of the fixed exchange-rate period. The parameter $\lambda$ (the fraction of impatient agents) does not have a real-world analogue. I solved the model for $\lambda$ from 0.01 to 0.48.\(^{93}\) It is not immediately obvious how to choose the parameters in $p$. I take $\pi_2$ and $\pi_3$ from Kaminsky and Reinhart’s (1999) seminal article on twin crises. Kaminsky and Reinhart also estimated the unconditional probability of a bank run: $\hat{\pi}_1 = 0.1$. Thus, I match the unconditional moment:

$$E_{AH} \left[ \frac{n_1 + n_2}{n} \right] = 0.1$$ (3.12)

In Turkey, about 20\% of the banks failed during the crisis. One way to interpret this deviation from the Kaminsky and Reinhart estimate is that Nature chose a “bad” distribution. Accordingly, I match the conditional moment:

$$E_{AH} \left[ \frac{n_1 + n_2}{n} \right] s(d, 0) = 1 = 0.2$$ (3.13)

Restrictions (12) and (13) together require $p_0 = 0.01$ and $p_1 \in [0.91, 0.93]$. The “initial” parameter $p$ can range between 0.01 and 0.13.

\(^{93}\)Values of $\lambda$ greater than 0.48 gave rise to contracts of the No-Run class.
3.6.2 Systemic risk

González-Hermosillo (1996) defines systemic risk as the joint probability of a large number of bank failures. Since this paper focuses on twin crises, I define systemic risk as the joint probability of enough bank failures such that there is a currency crisis. In other words, systemic risk is the probability of a twin crisis.

Solving this model numerically yields a numerical estimate of systemic risk. The magnitude of systemic risk varies with $\lambda$, $p$, $p_0$, and $p_1$. Decision-makers in the model economy know these four parameters; analysts of the Turkish banking system do not. Varying $\lambda$ and $p$ as discussed in the previous section yields estimates of systemic risk between 7.5% and 14.9%.

These values compare favourably with other studies of systemic risk. Mizrach (1996) notes that the risk of devaluing the French franc averaged 14.72% in the 5 days prior to the realignment on 12 January, 1987. The franc and Turkish lira were both fixed within target zones. Glick and Hutchison’s (1999) study of 90 countries computed systemic risk of 20% (on average) for the period 1975-1997. This study included countries that used classic exchange-rate pegs as well as more target zones.

The computation of the magnitude of systemic risk also yields the threshold number of banks to fail, $n^*$. Both $p$ and $\lambda$ affect $n^*$, which ranges between 21 and 25 banks. For fixed $p$, $n^*$ is a “step” function of $\lambda$, since $n^*$ must be an integer. The values of $n^*$ are reasonable. In Turkey, 18 banks closed and several other banks were recapitalized (an option not present in my model). This aspect of the model corresponds closely to Turkish experience.
3.6.3 Monsoons, spillovers and contagion

The model presented in this paper allows no scope for monsoonal effects, since there is no fundamental uncertainty and small scope for spillovers, since foreigners’ preferences are the only fundamental linkages between banks. Each bank is a separate entity, caring only about the welfare of its domestic depositors. Consider a version of the model where the domestic sunspot variables were statistically independent of one another. The possibility of bailouts link the banking sector and the currency. But the magnitude of systemic risk is very small, between $10^{-6}$ and $10^{-4}$. In this version of the model, no contagion effects are present, since agents’ beliefs are statistically independent of one another across the components of the financial system (i.e., the banks). I refer to this minuscule probability as spillover risk; it is the risk that bank runs spill over into the currency sector. Contagion effects account for the bulk of systemic risk. As in Masson (1999), contagion is the residual, accounting for systemic risk not otherwise counted in monsoonal effects or spillover effects. Since monsoonal effects are non-existent and spillover effects are insignificant, I call the 7.5-14.9% systemic risk “contagion.”
3.6.4 Optimal contracts

Turkish and foreign data determine 13 of the parameters completely and 3 of the parameters partially. Only the fraction of impatient agents, $\lambda$, is free. From the bank’s perspective, the optimal contract is a function of the 17 parameters of the economy. Table 3.4 displays some sample results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Solution</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda$</td>
<td>0.2</td>
<td>$c_I$</td>
<td>8.13</td>
</tr>
<tr>
<td>$p$</td>
<td>0.01</td>
<td>$c_P$</td>
<td>24.99</td>
</tr>
<tr>
<td>$p_0$</td>
<td>0.01</td>
<td>$\gamma_b$</td>
<td>0.92</td>
</tr>
<tr>
<td>$p_1$</td>
<td>0.92</td>
<td>$\rho_2$</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Table 3.4: Sample Results

I collapse the optimal contract to a scalar function of a single parameter; in what follows, I detail the properties of this function. It is worthwhile noting how the optimal contract can be so collapsed. Although there are many probability triples $(p, p_0, p_1)$, which satisfy restrictions (3.12) and (3.13), these triples serve only to compute expected foreign utility. The expected number of non-failing banks, $E_{AH} [n - n_1 - n_2] \equiv Q$, does not differ across these triples. I use the triple $(0.01, 0.01, 0.92)$. The only parameter that may vary is $\lambda$. Next note that equations (3.7), (3.9) and (3.11) form a linear system in the payments to domestic agents, $c_I$ and $c_P$, the payments to foreign agents $\rho_2$ and in the fraction of their deposits that banks invest in the productive asset, $\gamma_b$. I can express any three of these solution-values in terms of the fourth. Accordingly, I write the optimal contract as $c_I^*(\lambda)$.  

65
The graph of $c^*_f(\lambda)$ (printed in Appendix B), shows that $c^*_f$ is an increasing, continuous, convex function of $\lambda$. Indeed, a quadratic polynomial fits $x^*(\lambda)$ with $R^2$ greater than 0.99. Here is an intuitive explanation of the shape of $c^*_f$. Consider the size of a bank run. Since $\lambda$ is the proportion of impatient agents in the economy, $1-\lambda$ is the proportion of domestic agents who may run on their bank. As $\lambda$ increases, the size of a bank run decreases. The banks can afford to offer more generous terms to impatient agents when the size of a potential run decreases.

A second explanation for the shape of $c^*_f$ comes from examining the role of taxation in the model. An increase in $c_L$ and $\lambda$ increases tax revenue. Tax revenue serves two purposes – bailouts and paying foreigners converting liras to dollars. Thus foreigners are pleased with a simultaneous increase in $c_L$ and $\lambda$. Domestic agents are also pleased. Note that $c^*_f(\lambda)$ satisfies the property that all depositors can receive $(1 - \tau) c_L$ during a run, if payments from bailouts are included. At banks at which a run occurs, domestic depositors receive a higher payment. At banks without runs, domestic depositors receive better insurance against the “risk” of being impatient.

### 3.7 Conclusion

In this chapter, I present a theoretical model of twin crisis with contagion in the banking system. The model explains how shifting public opinion can cause a crisis in an apparently healthy banking system, in turn leading to a currency crisis.

The calibrated model describes the Turkish crisis reasonably accurately. Turkish residents, responding to “sunspot information,” withdrew deposits from some banks.

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94Since the bailout function depends on $a_{dL}$, this does not mean that a bank run ceases to be an equilibrium of the post-deposit subgame for these contracts.
On the heels of these withdrawals, foreign investors liquidated lira-denominated investments, draining central bank reserves. The Turkish government behaved mechanically. It bailed out some banks (using the deposit insurance fund) and paid dollars to foreigners holding liras, maintaining the fixed exchange rate as long as possible.

As measured in the model, Turkish government policy exposed the financial system to systemic risk of about 10%. This is a large risk; policymakers should calculate the expected benefits from the policy succeeding, the expected costs of the policy failing and compare these with the costs and benefits of other policies which expose the financial system to different levels of systemic risk. An assessment of these costs and benefits falls outside the scope of the model.

The model suggests implications for government policy different from those in the rest of the banking literature. Many authors note that banking systems are inherently fragile because they are susceptible to bank runs. Diamond and Dybvig (1983) suggested that the government could suspend convertibility to prevent bank runs. Indeed, one focus of the literature following Diamond and Dybvig has been optimal suspension schemes. But in my model, the government may not suspend convertibility. Anecdotal evidence from the recent crisis in Argentina suggests that suspension of convertibility is not a viable option for policy-makers in the middle of a twin crisis. Although the Argentine government suspended convertibility of deposits to cash in December, 2001, a federal court ruled in September, 2002, that this decree was unconstitutional. (La Nacion, 13 Sept., 2002). The inability of the government to suspend convertibility prompts the government to consider other policy options to reduce the fragility of the system.
In the model, the banking system is fragile because the interests of the banks and the government potentially diverge. Each bank cares only about itself and its depositors, whereas the government probably cares about the welfare of all depositors. That each bank is self-interested is rational; there are no interbank deposits, no interbank loans, nor any other provisions that link the banks’ fundamentals one to another. The policy implication of this model is clear: the government should encourage fundamental linkages between banks in the system. In essence, encouraging fundamental linkages is tantamount to modifying the objective function of the bank to include concerns for all depositors. In that scenario, banks might be motivated to choose a contract that prevents runs because a run at another bank could impair their interbank deposits, for example. In the model, the government delegates the role of intermediating investment to the banking system; the challenge for the government is to do so in such a way as not to threaten the system itself.
CHAPTER 4

DIAMOND-DYBVIG THEORY PASSES A SIMPLE TEST

4.1 Introduction

One of the most desirable features of money is that it provides liquidity services. People frequently keep some portion of their assets in liquid form—either cash or demand deposits. One reason for doing so is the presence of uncertainty in financial markets; liquid assets offer partial protection against random consumption shocks.\(^{95}\)

In Diamond and Dybvig’s (DD) (1983) model of bank runs, consumer-depositors do not hold cash. They deposit money in the bank. Despite the presence of idiosyncratic uncertainty, there is no precautionary demand for cash balances in DD because the demand deposit contract offered by the bank is generous. Banks promise agents depositing one unit in period zero more than one unit in period one if they receive the random consumption shock and even more than that if they do not. In Chapter Three, I present a twin crisis\(^{96}\) model based on DD. In this model, consumer-depositors do not hold cash either. They deposit; they withdraw in the face of liquidity shocks (or if inclined to run on the bank), receiving the one period return.

\(^{95}\)A consumer/depositor experiences consumption shocks. Since the bank has potentially many such depositors, the bank views these shocks as liquidity shocks.

\(^{96}\)Kaminsky and Reinhart (1999) refer to the sequence of a banking crisis followed by a currency crisis as a twin crisis.
The goal of this chapter is to examine the relationship between liquidity shocks and interest rates. By interpreting the model of Chapter Three in a general deposit framework, I test the implications of that model.

The model in Chapter Three implies a relationship between liquidity shocks and interest rates. In periods when a large liquidity shock occurs, the real interest rate on short-maturity deposits is higher than it is in periods with a small liquidity shock. In particular, the model implies that the real interest rate is a convex function of the size of the liquidity shock. To test this hypothesis, I need first to identify periods when a given country experienced a liquidity shock and measure that shock. Then I can examine the relationship between interest rates and shocks during those periods using regression analysis.

The rest of this chapter has the following structure. In section 2, I summarize the theoretical model of Chapter Three and link it to the empirical model. Section 3 discusses the raw data and the data treatment procedures. Section 4 presents and explains the regression model. In section 5, I present the results of the regressions. Section 6 concludes. The Appendix lists the data sources and gives details of some calculations.

4.2 Models

4.2.1 The Theoretical Model

In period 0, banks offer an optimal deposit contract to domestic and foreign residents. The contract depends on the quantity of foreign and domestic deposits as well as on regulations governing required reserves and the taxation of interest payments.
The contract specifies the payments for agents of different types; the payments depend on the agent’s country of residence, whether the agent arrives in period 1 or in period 2, and whether the agent claims to be “impatient.” The banks pay parts of the contract in liras and parts of the contract in dollars, the domestic and foreign currencies respectively. The contract is subject to “sequential service.” Furthermore, in the simple contracts I study, the banks may not decrease payments to agents waiting in line based on the measure of agents already paid. In order to make these payments, the banks invest some deposits in a productive asset and the remainder in a storage technology.

In period 1, some domestic agents learn that they are genuinely impatient and thus need to consume immediately. The measure of these impatient agents is λ. Impatient agents come to their banks and demand c₁ dollars. The rest of the agents in the economy, patient and foreign play a banking game. Patient agents have two choices. They may claim to be impatient and receive c₁. Alternatively, they may claim to be patient, accepting liras in period 1 and retaining the right to return in period 2 for a larger payment in dollars. Foreign agents also have two choices. They may arrive and demand liras in period 1. They may prefer to wait and demand a greater quantity of liras in period 2. In essence, both foreign and domestic agents have the option to run on their banks. Under some conditions, these bank runs may lead to bankruptcies, bank bailouts and currency crises.

For domestic agents playing the banking game, the optimal choice is not obvious; patient agents prefer to claim impatience if other patient agents at their bank are doing the same, but prefer to claim patience otherwise. Nature reveals a collection

\footnote{This means that the banks may not base their payments on future events, such as how many agents claiming to be of each type will arrive.}
of sunspot variables to domestic and foreign agents. Agent see a sunspot variable particular to their bank and country of residence; a pattern of correlation among the sunspot variables allows agents to make inferences about the sunspots they do not see from the sunspot they see. In effect, the sunspots act as equilibrium coordination devices.

The banks solve the game by backward induction. In the first step, they determine the Nash equilibrium of the banking game between domestic and foreign agents. In general, the equilibrium depends on the realization of the sunspot variables. Then the banks find the unique contract which maximizes expected domestic utility (using the probabilities of the sunspots to calculate expected utility). Since the maximization problem is subject to several constraints, one may reduce the problem to a one-dimensional unconstrained maximization. I therefore summarize the contract with the scalar $c_I$.

It is worth noting that neither $c_I$ nor $\lambda$ depend on whether there is a run on a particular bank. If there is no run on a particular bank, exactly $\lambda$ domestic agents claim to be impatient and receive $c_I$ each. If there is a run, all domestic agents claim to be impatient. As many agents as possible receive $c_I$ each; the rest receive 0.

For each value of $\lambda$, there is a different optimal value of $c_I$. The function $c_I^* (\lambda)$, formed by solving the banks' maximization problem for various values of $\lambda$, is increasing and convex. Here is one explanation for why $c_I (\lambda)$ is an increasing function. Banks conscious of the possibility of runs have two competing goals which affect their optimal choice of $c_I$. First, the goal of preventing bank runs suggests that $c_I$ should be as low as possible. The lower is $c_I$, the less desirable it is for patient agents to claim to be impatient. Second, the goal of providing consumption insurance indicates
that $c_I$ should be as high as possible. The higher is $c_I$, the more agents who are genuinely impatient receive. For low values of $\lambda$, very few agents are impatient, so the banks pay low values of $c_I$ to discourage runs. For high values of $\lambda$, many agents are impatient so the banks pay high values of $c_I$ to provide consumption insurance to the impatient.

A second explanation relates to the “size” of a bank run. Since $\lambda$ is the proportion of impatient agents in the economy, $1-\lambda$ is the proportion of domestic agents who may run on their bank. As $\lambda$ increases, the size of a bank run decreases. Smaller bank runs require less premature liquidation of the productive asset. Smaller bank runs thus lead to larger bank assets during a run, since premature liquidation of the productive asset is costly. The banks thus offer more generous terms to impatient agents when the size of a potential run decreases.

The convexity of the function $c_I(\lambda)$ follows from an individual rationality constraint which the banks’ contract must satisfy. Expected utility from depositing must exceed the utility of alternative investment opportunities. Even in autarchy, domestic agents have the opportunity to invest in the productive asset and the storage technology. If they did not deposit in a bank, they would split their endowment between investments in the productive asset and the storage technology in an optimal way, hedging against the risk of being impatient. As $\lambda$ increases, this risk becomes more pronounced. For values of $\lambda$ above a certain threshold, domestic agents would optimally invest their entire endowment in the storage technology. Since the autarchic return grows with $\lambda$, $c_I(\lambda)$ must be convex in order to satisfy the individual rationality constraint.
4.2.2 Connecting the theoretical and empirical models

The model presented in the previous section is static. Data available to test that model, however, is time-series data, which requires that the model be given an explicitly dynamic flavour. Let $\lambda_t$ be a random variable whose realizations correspond to $\lambda$ in the model of Chapter Three. In each period, after $\lambda$ is revealed, a version of the game described in Chapter Three occurs. From the perspective of an econometrician, there are observations on $c_t$ and $\lambda$ for a sequence of periods.

The variable $c_t$ is a real interest rate. The DD model is typically understood in the context of demand deposits. The model of Chapter Three also has a natural interpretation in the framework of time deposits. In period 0, agents purchase a time deposit which matures in period 2. If an agent receives a random consumption shock, he or she liquidates the time deposit at a penalty, converting it to a time deposit that matures in period 1.\footnote{While secondary markets for time deposits have developed recently in the United States, they are not available in most countries. Purchasers of time deposits typically have only two options – liquidation at a loss, or holding the deposit to maturity.} During a bank run, the bank may not have sufficient funds to cover the liquidated two-period time deposits.

Since DD’s model and its successors have always been interpreted in the context of demand deposits,\footnote{An exception is Catalan (2000, p. 22).} some justification of using time deposits in this work may be necessary. Gilkeson, et al. (1999) model agents who may liquidate time deposits early at a penalty in order to reinvest in other time deposits with shorter maturities. Using an American dataset, the authors compute the reinvestment incentive and estimate its impact in the decision to liquidate time deposits. For deposits of long maturity, the reinvestment incentive is a significant determinant in the liquidation decision.
Time deposits are a significant investment vehicle in developing countries (Conlisk, 1970). Many of these countries experience high and variable inflation. Some short-maturity deposits, such as demand deposits or savings deposits, have negative ex-post real returns. Faced with the restricted choice of investing in demand deposits or a storable good whose value would rise roughly with the general inflation rate, depositors rationally choose the storable good. The banking system can function only if there is a maturity for which the ex-ante real rate of return is positive. In Chapter Three, that maturity is two periods; in the real-world datasets I examined, it is one to three months.

It is important to note that short-maturity interest rates are not exactly equivalent to $c_I$ from the theoretical model. In the model, $c_I$ is the effective interest rate paid to depositors who purchase long-maturity deposits and liquidate them early. The short-maturity rate proxies for the rate earned by liquidating long-maturity deposits early; if the expectations hypothesis of the term-structure holds approximately, this is a reasonable proxy.

Finding a real-world variable to stand for $\lambda$ is equally difficult. One may gain insight into the liquidity shocks faced by the banking system by examining depositor behaviour in the theoretical model. Depositors who claim to be impatient in period 1 do two things. First, they shorten the maturity of their deposits from two periods to one period. Second, they request payment in foreign currency rather than domestic currency. One may thus potentially identify a liquidity shock as shifts in the maturity structure of time deposits or shifts in the currency of payment.

100 Demand deposits have an infinitesimal maturity. Since withdrawing savings deposits may require seven days notice, their maturity is slightly longer.

It is important to include as shocks only such dates when there is an identifiable shift in maturity. For example, a negative liquidity shock occurs when the quantity of one-month and three-month deposits increases and the quantity of six-month and one-year deposits decreases. I term the opposite set of changes a positive liquidity shock. I discard periods when the deposits changed in the same direction for all maturities. In this case, depositors expressed greater or less confidence in the banking system as a whole, not in the deposits of particular maturities. These “autarchic” choices do not occur in the equilibrium of the model of Chapter Three. Finally, I reject periods when the quantity of deposits changed in an inconsistent way. For example, I exclude a period where the quantity of one-month and six-month deposits increased, but the quantity of three-month and one-year deposits decreased. In such a period, the withdrawal behaviour of depositors is uninformative about their maturity preferences. In the same vein, I include only dates where there is an identifiable shift in the currency of deposits held at a given maturity.

An ideal but unavailable dataset for testing the theoretical model would be a panel dataset which contains observations on individual depositors’ holdings. It is possible, however, to make general inferences from aggregate data. A decrease in long-maturity deposits which coincides with an increase in short-maturity deposits corresponds to depositors liquidating deposits of one type and buying deposits of the other in the aggregate. Depositors holding time deposits at their maturity have three options: to reinvest in a deposit of the same maturity, to reinvest in a deposit of another maturity, or to consume the principal. If most depositors consume the principal of their deposits, the deposit series should decrease at all maturities.
Similarly, if most depositors invest in deposits with shorter maturities, there should be a decrease in the quantity of long-maturity deposits held and an increase in the quantity of short-maturity deposits held.

4.3 The Data

4.3.1 The Raw Data

The availability of data largely determines the countries I study. For a country to be included, it must report monthly observations on the consumer price index, interest rates, and either deposits (disaggregated by maturity), or monetary aggregates.\textsuperscript{102} The source I use, DataStream, reports macroeconomic data for 77 countries. Only some of these countries meet the data requirements. From the countries that meet the data requirements, I select a sample of countries for each of the following three types: developing countries which experienced a financial crisis in the past 25 years, developed countries which experienced a crisis and developed countries which did not experience a crisis.

I can divide the countries I use into two groups based on the type of data they use. A small group of countries report monthly deposit data disaggregated by maturity: France, Indonesia, Mexico, Switzerland and Turkey. For the rest of the countries in the study, no disaggregated deposit data is available. These countries are Argentina, Bangladesh, Chile, Colombia, New Zealand, Korea, Portugal, Singapore, and Sri Lanka.

\textsuperscript{102}Details on the data used are in Appendix B.
For these countries, I use series constructed from monetary aggregates.\textsuperscript{103} By construction, M1-M0 is demand deposits and M2-M1 is savings and short-maturity time deposits.\textsuperscript{104}

Since I based the empirical model on a twin crisis model, I use crises to divide the sample into three groups. Countries in Group A experienced a twin crisis. Countries in Group B experienced a banking crisis without a currency crisis. Countries in Group C, the control group, experienced no crisis in the sample period. Group A consists of Colombia, Indonesia, Korea, Mexico, Norway, and Turkey. Group B consists of Bangladesh, France, Portugal, Singapore and Sri Lanka. Group C consists of Chile, New Zealand and Switzerland. Argentina defied classification using my taxonomy, since it experienced a banking crisis in 1996-1997 and a twin crisis in 2002. All groups contain both developing and developed countries.

4.3.2 Identification of Liquidity Shock Dates

Since I use deposit data to identify liquidity shocks, I now discuss the time-series properties of the deposit series. These series are non-stationary for two reasons. First, economic theory says that money grows with nominal income. Second, economic theory suggests that people have a desired quantity of real deposits. If they hold these deposits in domestic currency and the domestic currency depreciates over time (either as a discrete currency crisis, or as a persistent trend), the quantity of domestic currency deposits must rise to compensate for the depreciation.

\textsuperscript{103}I am grateful to Julia Thomas for this suggestion.

\textsuperscript{104}M0 is high-powered money. M1 is M0 plus demand deposits. M2 is M1 plus savings and short-maturity time deposits.
To analyze these series, I need to remove the non-stationarities. I convert the series to fractions of total deposits. This conversion removes non-stationarity due to economic growth, assuming people increase their deposits in roughly equal proportions by maturity. Frequently, these series are still non-stationary, reflecting a financial deepening effect. As McKinnon (1973) argued, investors increase their investments in long-maturity instruments as the financial system becomes more stable. Intermediation through long-term investments benefits both lenders and borrowers, offering the former a higher rate of return and offering the latter more stable sources of finance. I deal with this source of non-stationarity by first-differencing. I then fit ARMA \((p,q)\) models to the differenced series. Details are presented in Appendix B. I use the residuals of the ARMA models to construct the liquidity shock indices.

If these residuals are Gaussian, five percent of them should lie outside \(\pm 1.96\) standard deviations from the mean. The distributions of financial data typically have fat tails. For the residuals from the deposit series, more than five percent of the data are in the tails of their distributions. For each series, I identify the dates for which the standardized residuals are greater than 1.96 in absolute value. As mentioned above, I reexamine the deposit series and include as shocks only such dates when there is an identifiable shift in maturity.

I use two other methodologies to identify shock periods. Some countries present deposit data disaggregated not only by maturity but also by currency (domestic or foreign). Using the same procedure as I use for the maturity shocks, I identify the large residuals in the deposit series for each currency. I include only periods where the deposits in the two currencies moved in opposite directions. This reflects a preference for one currency over the other, consistent with Chapter Three. But I
reject periods where deposits in both currencies decreased, as it is an autarchic choice. For countries which reported deposit series disaggregated both by maturity and by currency, I include both types of shocks in the analysis.

When working with the series based on money supply data, I do not divide by total deposits to create a fraction. Since there are only two series which make up total deposits, the correlation between the fractional series is identically -1. Once again, I difference the deposit series and fit ARMA models. I also identify the potential shocks using a 1.96- standard-deviation-cutoff rule. I deploy the same rule as with the non-money-based deposit series; I eliminate the periods where changes moved in the same direction. Unfortunately, there is a 90% correlation (for most countries) between the money supply data at different measures of breadth. In some of these cases, this leaves me with too few data points on which to run regressions and perform statistical inferences.

I perform one final robustness check – Kolmogorov-Smirnov tests. Details are presented in Appendix B. I present here the test results for countries for which I ran regressions; results for other countries are similar and thus omitted for brevity.105

105In Table 4.1, M is the number of shock periods and N is the number of non-shock periods. The critical value, KSCrit, is the 5% value from the Kolmogorov-Smirnov distribution with parameters M and N, calculated as described in Appendix B. The KSStat column is the Kolmogorov-Smirnov statistic. If KSStat > KSCrit, I reject the null hypothesis that the two distributions are equal.
<table>
<thead>
<tr>
<th>Country</th>
<th>Rate</th>
<th>M</th>
<th>N</th>
<th>KSStat</th>
<th>KSCrit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>30-89 days</td>
<td>13</td>
<td>232</td>
<td>0.3031</td>
<td>0.2125</td>
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<tr>
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<tr>
<td>Switzerland</td>
<td>1 year</td>
<td>17</td>
<td>199</td>
<td>0.1747</td>
<td>0.1983</td>
</tr>
<tr>
<td>Turkey</td>
<td>Sight</td>
<td>25</td>
<td>140</td>
<td>0.1186</td>
<td>0.1817</td>
</tr>
<tr>
<td>Turkey</td>
<td>1 month</td>
<td>25</td>
<td>140</td>
<td>0.1029</td>
<td>0.1817</td>
</tr>
<tr>
<td>Turkey</td>
<td>3 months</td>
<td>25</td>
<td>140</td>
<td>0.1371</td>
<td>0.1817</td>
</tr>
<tr>
<td>Turkey</td>
<td>6 months</td>
<td>25</td>
<td>140</td>
<td>0.1645</td>
<td>0.1817</td>
</tr>
<tr>
<td>Turkey</td>
<td>1 year</td>
<td>25</td>
<td>140</td>
<td>0.1886</td>
<td>0.1817</td>
</tr>
</tbody>
</table>

Table 4.1: Kolmogorov-Smirnov Test Results

The method of determining shock periods is original but has several analogues in the econometrics literature. First, the vector autoregression (VAR) literature typically calls the residuals from the autoregressions shocks. While the genesis of this idea is in Sims (1980, p. 21), the technique has been used repeatedly since that time. In fact, the Box-Jenkins methodology is a univariate version of a VAR.

Second, the technique used by Eichengreen, Rose and Wyplosz (1995, hereafter ERW) to determine the timing of currency crises is comparable to the methodology of this chapter. ERW compute an index consisting of percentage changes in interest rates, exchange rates and foreign exchange reserves,
using the inverse of the volatilities of these series as weights. They identify shocks using a cutoff rule based on two standard deviations to the mean, applying the rule to the index.

4.3.3 Construction of the Liquidity Shock Index

I convert the liquidity shocks to an index using a two-step procedure. First, following ERW, I sum the shocks in an identified period, weighting the sum by the standard deviations of the deposit-residual series. This creates a scalar measure of the shock. Second, I map the scalar measure to the interval [0,1]. I compute the empirical distribution functions of the shocks and convert the measured shocks to a uniform [0,1] distribution. This makes the index analogous to λ.\textsuperscript{106}

4.3.4 Construction of Real Interest Rates

I convert nominal interest rates of various maturities to real interest rates by subtracting the inflation rate, measured by the CPI.\textsuperscript{107} There are two reasons to make this transformation. First, even though the model of Chapter Three does not have inflation, agents care about real returns in a model with inflation. Second, some countries that experienced crises also experienced hyperinflations. In those countries, the nominal interest rate is non-stationary, but the real interest rate may be. Augmented Dickey-Fuller tests on the interest rate series confirm that the real interest rates are stationary.\textsuperscript{108} Finally, I transform net real rates to gross rates and divide by 100. I eliminate those periods in which the gross real rate is negative.

\textsuperscript{106}This procedure truncates the effects of large shocks in both the positive and the negative directions. It may lower the fit of the regressions.

\textsuperscript{107}This procedure is consistent with agents’ having perfect foresight vis-à-vis inflation.

\textsuperscript{108}I always reject the null of a unit root at the 10% level, often at the 5% or 1% level.
4.4 The Regressions

4.4.1 The Regression Specification

Let $\lambda$ be the magnitude of the liquidity shock, $x$ be the gross real interest rate, and $\varepsilon$ be an iid error term. Based on the model in Chapter Three, the regression equation is:

$$x_t = \beta_0 + \beta_1 \lambda_t + \beta_2 \lambda_t^2 + \varepsilon_t \quad (4.1)$$

I use ordinary least squares to estimate the regression for each country. I then correct for small sample size and bootstrap the standard errors. Efron (1979, pp. 17-18) shows that least squares estimates corrected using a non-parametric bootstrap are consistent and asymptotically efficient.

Efron’s proof relies on the statistical independence of the error term in the regression. Even though the data used in this chapter are initially time series data, it is reasonable to argue that the $\varepsilon$ are serially independent, as I assume. First, the independent variable, $\lambda$, is the weighted sum of residuals from ARMA models. ARMA modelling removes the serial dependence and correlation between the deposit series of the same country. The weighted sum of several uncorrelated series of white noise is itself white noise. Second, even if the dependent variable, $x$, is serially dependent, the fact that the shock periods are not chronologically adjacent to one another eliminates most of the serial dependence imposed on the $\varepsilon$ by the $x$’s.

109In the empirical model, the variable $x$ takes the place of the variable $c_t$ in the theoretical model.
4.4.2 Other Potential Variables for the Regression

In the model of Chapter Three, $c_I$ depends on all the parameters of the model, not just on $\lambda$. In particular, $c_I$ depends positively on $R_2$, the gross return on the productive asset. In omitting $R_2$ from the regression equation, I implicitly assume that it is constant. In Chapter Three, I calibrated the model using stock returns for $R_2$. This may not be appropriate, since net stock returns can be negative, contradicting the assumption in the theoretical model. Omitting $R_2$ may lead to misspecification bias in the regressions.\textsuperscript{110} How to deal with $R_2$ remains an open question.

4.4.3 Exogeneity of the Regressor

It is well-known,\textsuperscript{111} that the yield curve tends to flatten and slopes downwards in anticipation of recessions, typically maintaining its negative slope throughout the recession period. Indeed, this empirical regularity is often used to predict recessions.\textsuperscript{112} If the slope of the yield curve changes due to an impending recession, investors rationally shift investments from long-term to short-term, in order to maximize returns. In order to argue that random consumption shocks experienced by investors cause shifting investments along the yield curve, it is worth investigating whether the measured liquidity shocks in the deposit series occur around the same time as recessions.

\textsuperscript{110}Adding a variable for the log-differenced stock returns to the regressions worsens the fit of the curve but does not substantially change the coefficient estimates.

\textsuperscript{111}Kessel (1965) investigated this relationship using OLS. Chauvet and Potter (2002) present recent evidence on this relationship using more sophisticated econometric techniques.

\textsuperscript{112}See, for example, Chauvet and Potter (2002).
I begin by dating recessions for six countries in my sample:\textsuperscript{113} Colombia, Indonesia, Mexico, Singapore, Switzerland, and Turkey. I define a recession as two or more consecutive quarters of negative growth. Even though this is not the definition of a recession used by the National Bureau of Economic Research, Acemoglu and Scott (1994, p. 1305) refer to it as “the standard definition of recession.” It was also the definition of recession used by the United States Congress in the Gramm-Rudman-Hollings Law of 1985. (See Zarnowitz and Moore, 1991, p. 257) I then verify which of the shocks occurred during a recession, as displayed in Table 4.2 below.\textsuperscript{114}

<table>
<thead>
<tr>
<th>Country</th>
<th>S</th>
<th>SR</th>
<th>SRN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombia</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Indonesia</td>
<td>12</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mexico</td>
<td>14</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Singapore</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Switzerland</td>
<td>17</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Turkey</td>
<td>28</td>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 4.2: Shocks and their Relationship to Recessions

None of the countries shown here had more than 20% of their shocks during a recession when the yield curve sloped downwards. The shocks which occurred during a recession when the yield curve sloped downwards frequently occurred during a twin crisis, as they did for Indonesia, Mexico, and Turkey. It seems reasonable to use this regression to identify the effects of random consumption shocks.

\textsuperscript{113} Data for some of the other countries was not available at quarterly frequencies. I also did not perform this procedure on data from countries for which I identified too few shock periods to run regressions.

\textsuperscript{114} In Table 4.2, I use the following abbreviations. S stands for shocks, SR for shocks during a recession, and SRN for shocks during a recession when the yield curve had a negative slope.
4.5 Results

For each of the countries for which I run regressions, I divide the shock periods into two categories: ones in which a shock was followed by another shock less than 3 months later, and ones in which a second shock did not occur. I then describe political, economic, social, military and natural events that occurred during these clusters of shock periods. The model of Chapter Three assumes that agents demand liquidity for fundamental and non-fundamental reasons. Agents who are genuinely impatient demand liquidity for fundamental reasons. Patient agents may demand liquidity by running on their bank if they “see a sunspot.”

4.5.1 Chile (1985-2002)

The methodology described above allows the identification of 13 shock periods for Chile Persistent problems occurred in 1985 and 1992.

1985 was a tumultuous year in Chile. In February, Bolivia defaulted on its foreign debt, causing investors to reexamine the external positions of all Latin American countries. Investors noted that the principal threat to the Chilean economy came from persistent drops in the price of copper – the primary Chilean export. (Kristof, 1985) In March, a earthquake measuring 7.4 on the Richter scale hit Santiago and the surrounding region.\textsuperscript{115} This earthquake killed 82 people and injured 2000 others. (Associated Press, 1985)

\textsuperscript{115} Several quantitative models exist for determining the economic effects of an earthquake. Cho, et al. (2001) simulated the effects of a magnitude 7.1 earthquake in the Los Angeles area using a transportation network model. Losses totaled 6.05\% of Gross Regional Product. Selcuk and Yeldan (2001) used a dynamic, general equilibrium model to measure the costs of the magnitude 7.4 earthquake which hit Turkey in 1999. Depending on the policies pursued by the government, the losses range between 1.2\% and 5.8\% of GDP.
The tide of bad news turned in May, when foreign creditors rescheduled Chilean loans, deferring repayment of principal for another six years.\textsuperscript{116} (Reuters, 1985b) In August, the IMF lent Chile $0.85 billion from a fund used to compensate countries for drops in the prices of their chief exports. (Reuters, 1985a) In September, leaders of the major opposition political parties signed an accord detailing their conception for a return to civilian rule. (Chavez, 1985).

For Chile, 1992 was a much better year than 1985. In May, the President of Chile met his American counterpart to discuss free trade between the two countries. (Bradsher, 1992 and Greenhouse, 1992) In June, the first municipal elections since the resignation of General Pinochet registered voter turnout of about 90%. (Nash, 1992) Both of these events signified a strengthening of Chilean democracy – something which typically foreshadows higher economic growth.

For the Chilean case, the only interest rate available during this period is a composite interest rate for time deposits ranging between 30 and 89 days. The regression indicates a statistically significant,\textsuperscript{117} convex relationship between liquidity shocks and interest rates. The estimated relationship is:\textsuperscript{118}

\textsuperscript{116}Morisset (1991) estimated a simultaneous equations model for Argentina. In that country, a 20% debt reduction led to a 1.16% increase in GDP. Using the IMF’s MULTIMOD model, Dooley, et al. (1990) estimated the effect of a 10% debt buyback as an initial increase of 1.7% in the GDP growth rate. While the growth rate eventually returns to its steady state value, the new steady state is higher. Bulow and Rogoff (1989) show that rescheduling is frequently in the debtor country’s interest, since if it does not do, it may lose access to short term trade credits. In a simple model, Krugman (1988) shows that debt rescheduling is always in creditors’ best interests as well.

\textsuperscript{117}Throughout this paper, statistical significance in regressions is tested at the 5% level, using the standard errors corrected by bootstrap and evaluated using Student’s t-distribution with the relevant number of degrees of freedom. In this paper, I report both statistically significant and insignificant results, placing more weight on the former.

\textsuperscript{118}Bootstrap-corrected t-statistics in parentheses.
\[ x = 1.19 - 1.38\lambda + 2.44\lambda^2 \]  \hspace{1cm} \text{(Chile)}

(2.24) \hspace{1cm} (1.86)

DF = 10, \( R^2 = 0.32, R_d^2 = 0.19 \)

### 4.5.2 Colombia (1986-2002)


While I report some Colombian economic or political events which coincide with the shocks, most of the events pertain to the fifty-year long civil war (Ruiz, 2001, p. 4). Sanchez (2001, p. 1) argues that “violence has become the reference point for Colombian politics, society and economy during the second half of the twentieth century.” Even though the civil war lasted for a long time, events which signalled major shifts in the momentum of the war affected the maturity structure of deposits. This assertion need not be contradicted by the fact that the magnitude or concentration of the violence was uncorrelated with the rate of economic growth for two reasons. (Sanchez, 2001, p. 9). First, shocks to the financial system need not be associated with fundamentals such as the rate of economic growth. Second, a correlation between violence and economic growth emerged in post-1998 data.

Despite the civil war, Colombia’s government actively pursued international trade in 1993. In October, Colombia and Venezuela deregulated their financial service sectors as part of their free trade agreement.
This deregulation included allowing some international branching between the two countries. (New York Times, 1993) In December, Colombia and Venezuela concluded a free trade agreement with Mexico. (Associated Press, 1993)

The civil war reintensified in 1994. In January, members of the FARC (Revolutionary Armed Forces of Colombia) guerrilla group killed 35 members of a left-wing political party. It was the “country’s worst massacre in five years.” (Brooke, 1994). But the government signed a peace pact with other rebels in Medellin about a month later. (New York Times, 1994). This typifies the observation by Sanchez (2001, p. 25) that violence is accompanied by a “permanent (indefinite) process of negotiation.”

The process of negotiations continued in subsequent years. In July, 1995, the Colombian government offered to pull troops out of Uribe province, in order to start negotiations with the FARC. (Brooke, 1995). Another move to placate rebels came in December, 1996, when the Colombian government passed a law allowing the seizure of land used for cultivating illegal drugs and redistributing it to peasants. (Schema, 1996). Since the grievances of the FARC are partly economic in nature, the Government hoped this would diminish the violence.

The violence intensified in 1998 after a Colombian-American military agreement. This agreement provided for joint training exercises and military assistance to Colombia from the United States. In December 1999, the military created a special task force to fight guerrillas. The force included US-trained soldiers and used US-made equipment. (Reuters, 1999). The US gave $1.7 billion to Colombia in 2000 to fighting rebels and drug traffickers. (Becker, 2000)

The Colombian dataset provides two interest rates – the demand-deposit rate and the three-month time-deposit rate. Since the regression results were similar for both
rates, I report only the result for the time-deposit regression. This regression indicates a statistically insignificant, convex relationship between liquidity shocks and interest rates. The estimated relationship is:

\[ x = 1.19 - 1.12\lambda + 1.33\lambda^2 \]  
(Colombia)

(1.32)  
(0.75)

DF = 17, R^2 = 0.20, R^2_a = 0.11

4.5.3 Mexico (1993-2002)

My shock identification scheme yields 14 periods for Mexico. Mexico differs from some of the other countries under study since the Mexican dataset begins in August, 1993. In addition, almost every shock identified is part of a grouping of shocks. There were shocks in 1995 (primarily the resolution of Tequila crisis), as well as in 1998, 1999, 2000 and 2001.

Mexican central bank reserves declined throughout 1994, reaching $6 billion in December. At this point, the Mexican government floated the peso.\(^{119}\) (Edwards and Naim, 1997, p. 317).

The spring of 1995 saw the unfolding of both political and economic dramas. In March, former President Salinas began a brief hunger strike to protest his brother’s arrest for murder. This caused the exchange rate to fall further. (Golden, 1995). In the same month, the eighth largest bank in Mexico failed and fell into government hands. (DePalma, 1995d). By April, the International Monetary Fund (IMF) stated that the Tequila effect had been contained. (Edwards and Naim, 1997, p. 319)

\(^{119}\)This currency crisis is frequently called the “Tequila” crisis.
The government bailout of Mexican banks continued through June, 1995, reaching a cost of $5 billion. (DePalma, 1995b). Two important political events occurred in June. In the wake of poor corporate earnings and further declines in the peso’s value, the government, business and labour signed a new pact on the economy, the third in less than a year. (DePalma, 1995c) The three major political parties signed an accord to change election procedures starting in 2000. (DePalma, 1995a). The new procedures led to the first competitive multi-party elections in 2000.

In July 1998, the Mexican government revealed that the true cost of bailing out the banks during the Tequila crisis was $62 billion. (Preston, 1998a). This news was particularly grating since 12 of the 19 major banks had failed despite government assistance. The size of the bailout plan brought a constitutional issue to the fore; debts of the bailout agency are technically debts of the Mexican Government and thus have to be approved by the Mexican Congress. It was only in December that the three parties reached an agreement on how to deal with this debt (Preston, 1998b).

In January 1999, Raúl Salinas, brother of the former President, was convicted of murder and sentenced to 50 years in prison. (Preston, 1999). This ended the four-year-long “soap-opera-like” trial that had consumed Mexican politics. In August 2000, Mexico repaid its debts to the IMF. (Associated Press, 2000).

Liquidity shocks in 2001 were driven by international events as well as domestic ones. In August 2001, the People’s Revolutionary Armed Forces detonated three small bombs outside bank branches in Mexico City. (Thomson, 2001). In September, President Vincente Fox came to Washington for meetings with the President of the United States and the American Congress,
attempting to improve Mexican-American relations. (Sanger, 2001). The terrorist attacks on the World Trade Center of September 11, 2001 probably also created a liquidity shock in Mexico.

The Mexican dataset lists six different interest rates, ranging in maturity from demand deposits to 180 day time deposits. According to the theory in Chapter Three, the relationship between liquidity shocks and interest rates holds for a relatively short-term rate, particularly the shortest maturity for which real interest rates are positive. I perform the regression using all six rates. Since none of the regressions yield statistical significance,\(^\text{120}\) it is difficult to determine the point on the yield curve where the relationship fails to hold. For the four regressions using time deposits, the relationship is estimated to be concave, not convex. For both chequing and savings deposits, the estimated relationship is convex. I present the result for savings deposits (essentially deposits with a maturity of one week).

\[
x = 0.83 - 0.21\lambda + 1.19\lambda^2 \\
\quad (0.21) \\
\quad (0.50)
\]

\[
\text{DF} = 10, R^2 = 0.06, R^2_a = -0.12
\]

### 4.5.4 Switzerland (1984-2002)

For Switzerland I identify 17 periods as shocks. Switzerland is a developed country. It experienced no banking crises or currency crises during the sample period. Its shocks cluster in three years: 1988-9, 1992, and 1998. Before explaining the specific

\(^{120}\text{One possible reason for the lack of statistical significance in the Mexican case is the clustering of the shock periods, which may invalidate the assumption that the residuals are serially uncorrelated.}\)
nature of these shocks, it is worth giving a brief description of the Swiss banking system, since it differs from those of the other countries studied in this paper.

The Swiss banking system began to occupy a prominent place in the financial world because of the “impact of the 1914-1918 war on the monetary and banking systems of Europe. All were wiped out, purely and simply, except one: that of the Swiss.” (Bauer and Blackman, 1998, p. 175). In the postwar period, Switzerland attracted foreign capital, particularly from Germany. The restrictions imposed by the German government on foreign exchange and foreign banking transactions in 1931 hit the Swiss banking system hard. (Bauer and Blackman, 1998, p. 210). “Of the eight major banks of the time, one went bankrupt, another survived only because it received massive help from the federal government and four had to be substantially reorganized.” (Guex, 2000, p. 243) As a result, the Swiss Parliament passed the Banking Law of 1935; article 47 deals with bank secrecy. This article criminalized the revelation of bank secrets. (Kleiner and Schwob, 2002, section 3). “Throughout the twentieth century, the maintenance or even reinforcement of bank secrecy represented a major objective of Swiss authorities.” (Guex, 2000, p. 237). Any attempt to amend the banking law and limit secrecy provisions is a liquidity shock in the meaning of this paper.

121Swiss Banking Law of 1935, Article 47, (author’s translation)

1. Whosoever reveals a secret, which was entrusted to him in his capacity as executive, employee, authorized representative, liquidator, or commissioner of a bank, as observer from the banking commission, or as an executive or employee of a recognized auditing agency, or which he observed in this capacity, or whoever seeks to induce someone to reveal such a professional secret, shall be punished with up to six months imprisonment or a fine up to 50,000 francs.

2. If the culprit is negligent, the punishment is a fine of up to 30,000 francs.

3. The revelation of professional secrets is also punishable after the termination of the official relationship or professional practice.

4. The Federal and Cantonal regulations on the duty to give evidence and on the duty to report to the authorities remain reserved.
During the fifty years that followed, Switzerland solidified and strengthened its position a world banking centre, due in large part to its banking secrecy provisions. One of the first attempts to modify these provisions significantly began in 1988. In December, the Minister of Justice and the Police resigned amid allegations that her husband’s company had laundered money. (New York Times, 1988). Ironically, her resignation stalled the introduction of a new banking law to stiffen penalties for money laundering.

In September 1992, the law on money laundering was finally passed. It lowered the amount of cash deposits that customers may make anonymously and required investment managers to identify their clients to Swiss banks.\textsuperscript{122} (Business Law Brief, 1992). A second economic shock came that year. In November and December, the European Monetary System (EMS) came under heavy fire as Spain and Portugal realigned their currencies and speculators attacked the French franc, hoping to force a realignment for that currency as well. Swiss banks suffered because much of their investments were denominated in the weakening European currencies. (Agence France Presse, 1992)

In 1997, an American government report accused the Swiss government and the Swiss banks of keeping gold and money taken by the Nazis from their victims, without making post-war restitution. (Sanger, 1997). In March, 1998, the Swiss banks began distributing money from a $188 million fund for Nazi victims, describing the fund as humanitarian assistance, not compensation. (Reuters, 1998) Public outcry convinced banks that this fund was insufficient. In response, the three largest Swiss banks agreed to establish a compensation fund between $1 and $3 billion. (Sanger, 1998)

\textsuperscript{122}This provision required amending the Banking Law.
Losses by the two largest banks\textsuperscript{123} revealed in October, 1998, included not only payments to the victims’ fund, but also money lost from loans to Russia before that country’s currency crisis and loans to the Long Term Capital Group, a large American hedge fund. (Andrews, 1998). Consumer prices in Switzerland fell in December, pushing average inflation to zero and sparking fears of bank loan defaults. (Bloomberg News, 1998).

There are five interest rates in the Swiss dataset: one week, one month, three months, six months and one year. Regressions with each of these rates found the relationship between liquidity shocks and interest rates to be convex and statistically insignificant. Since Switzerland never experienced high inflation during the sample period, expected inflation was also low. This means that ex-ante real rates were positive for all maturities. I present regression results for the one week interest rate below.

\[
x = 1.03 - 0.32\lambda + 0.88\lambda^2 \quad \text{(Switzerland)} \tag{1.06} \tag{1.35}
\]

\[
DF = 14, R^2 = 0.14, R^2_a = 0.02
\]

4.5.5 Turkey (1988-2002)

Since Turkey reports deposits both by maturity and by currency, I am able to identify 25 shock periods. The shocks cluster in several years: 1987, 1989, 1993-1996, 2000-1. In Turkey, the majority of the shock periods are associated with political and economic developments.

\textsuperscript{123}In the interim, the Swiss Bank Corporation and UBS merged, so the number of large banks involved in the fund dropped to two.
The year 1987 was a busy one for Turkey’s financial system. The government announced plans to deregulate interest rates in December, 1987. The financial system acquired some sophistication as the government authorized the creation of mutual funds. (Denizer, 2000) The Central Bank of the Republic of Turkey (CBRT) began using open-market operations. (Tukel, 1995 and Kancal, 1995). Full-scale political competition resumed four years after the return to civilian rule. The first competitive elections were announced in May and held in November. (Onis, 1986) Ominously, deficits began to rise again around this time. (Denizer, 2000)

In 1989, the Turkish government liberalized the capital account and allowed the lira to appreciate. Massive inflows resulted. (Denizer, 2000) In addition, the gold market was partially liberalized although it remained regulated. (Tukel, 1995)

The public sector borrowing requirement in Turkey reached 12% in 1993. (Denizer). In April 1993, President Turgut Ozal died. Prime Minister (PM) Suleyman Demirel became President in May; his chosen successor, Tansu Ciller, assumed the office of the PM in July. There had not been a government without Ozal since 1979. (Brown and Mortimer, 1993 and Brown, 1993). The legal reserve requirement on bank deposits reached 46% in 1993 (Financial Times of London, 1993).

Moody’s and Standard and Poor’s downgraded the sovereign rating for Turkey in January, 1994. As a result, there was a balance of payments crisis which necessitated a massive devaluation of the Turkish Lira. (Onis, 1996). To address the crisis, the Ciller government undertook a massive austerity programme. (Riemer, 1998) This led to a recession as well. (Brown, 1994)
In 1996, a customs union with the EU came into existence. (Riemer, 1998) This did not remedy the political problems Turkey faced. Early elections called in December 1995 had not produced a stable outcome. Ciller and Mesut Yılmaz formed a shaky coalition. (Barham, 1996). Investors seemed nervous about this coalition; dollarization of the Turkish economy continued. The Ciller-Yılmaz coalition soon collapsed as well.


In 2001, a public row between the Prime Minister and the President spooked investors and caused a twin crisis. (Economist, March 1, 2001)

There are five interest rates available in the Turkish dataset, with maturities ranging from demand deposits to one year time deposits. The one month deposit shows a statistically significant, convex relationship between the size of liquidity shocks and interest rates. The other maturities of time deposits show a convex relationship which is statistically insignificant. Accordingly, I show the results for the one month deposit.

\[ x = 1.19 - 20.08\lambda + 60.53\lambda^2 \quad \text{(Turkey)} \]

\[ \text{DF} = 25, R^2 = 0.18, R_a^2 = 0.11 \]

97
4.5.6 Other countries

I perform regressions on data from Indonesia, Singapore and Sri Lanka. None of these regressions have more than nine degrees of freedom. As a result, none of the estimates is statistically significant (or close to it) and none of the estimated relationships are convex.

I applied my shock identification procedure to data from Argentina, Bangladesh, France, New Zealand, Norway, South Korea, and Portugal. In none of these cases was I able to identify more than five shock periods. Since my regression estimated three parameters, this amount of data is insufficient to perform the regressions.

4.6 Conclusions

This paper presents evidence of a relationship between liquidity shocks faced by the banking system and the interest rates paid by banks in the system. The relationship holds for several countries, including those which experienced banking and/or currency crises during the period of study and those that did not. In particular, this model holds for three countries in Latin America – Chile, Colombia and Mexico – as well as Switzerland and Turkey.

In the description of the data above, I divided my sample of 15 countries into three groups. The regression model holds for three countries in group A – Colombia, Mexico, and Turkey – and two countries in group C – Chile and Switzerland. The fact that the regression model holds for some countries which experienced twin crises and some which experienced no crisis supports the conclusion of Chapter Three. In that model, the relationship between liquidity shocks and interest rates is independent of the random occurrence of a crisis.
This model does not give strong policy implications if consumption shocks faced by depositors (and by extension liquidity shocks faced by banks) are purely random. I presented a calendar of events for each of the five countries. The events selected are sometimes fundamental to the banking system and sometimes not. But even non-fundamental events can be predicted. There is frequently early evidence of political turmoil; in certain regions of the world, earthquakes are likely. If these events are non-fundamental to the banking system, and if agents treat them as “sunspots,” perhaps the liquidity shocks can be predicted as well, with some error. This could lead to a predictive model of interest rates, something which is properly the subject of further research.
# APPENDIX A

## SYMBOLS USED

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Part of the utility function of the patient</td>
</tr>
<tr>
<td>A1</td>
<td>strategy: arrive in period 1</td>
</tr>
<tr>
<td>A2</td>
<td>strategy: arrive in period 2</td>
</tr>
<tr>
<td>AH</td>
<td>Augmented-Helgert distribution</td>
</tr>
<tr>
<td>(a_d)</td>
<td>Measure of domestic agents claiming to be impatient</td>
</tr>
<tr>
<td>(a_f)</td>
<td>Measure of foreign agents arriving in period 1</td>
</tr>
<tr>
<td>B</td>
<td>Bailout function</td>
</tr>
<tr>
<td>Bin</td>
<td>Binomial distribution</td>
</tr>
<tr>
<td>C</td>
<td>The contract</td>
</tr>
<tr>
<td>CI</td>
<td>strategy: claim to be impatient</td>
</tr>
<tr>
<td>CP</td>
<td>strategy: claim to be patient</td>
</tr>
<tr>
<td>(c_d)</td>
<td>Payment promised to those claiming to be impatient</td>
</tr>
<tr>
<td>(c_p)</td>
<td>Payment promised to those claiming to be patient</td>
</tr>
<tr>
<td>(e_d)</td>
<td>Domestic endowment</td>
</tr>
<tr>
<td>(e_f)</td>
<td>Foreign investment</td>
</tr>
</tbody>
</table>

Table A.1: Latin Symbols Used (A-E)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g$</td>
<td>Part of the domestic utility function</td>
</tr>
<tr>
<td>Helg.</td>
<td>Helgert distribution for sum of Bernoulli-Markov variables</td>
</tr>
<tr>
<td>$L$</td>
<td>Liquidation function</td>
</tr>
<tr>
<td>$m$</td>
<td>Real money holdings</td>
</tr>
<tr>
<td>$n$</td>
<td>Number of banks (Chapter Three)</td>
</tr>
<tr>
<td>$n^*$</td>
<td>Critical number of banks to fail</td>
</tr>
<tr>
<td>$n_1$</td>
<td>Number of banks whose sunspot vector is (1,0)</td>
</tr>
<tr>
<td>$n_2$</td>
<td>Number of banks whose sunspot vector is (1,1)</td>
</tr>
<tr>
<td>$n_3$</td>
<td>Number of banks whose sunspot vector is (0,1)</td>
</tr>
<tr>
<td>$n_4$</td>
<td>Number of banks whose sunspot vector is (0,0)</td>
</tr>
<tr>
<td>$p$</td>
<td>Initial probability for the Markov chain</td>
</tr>
<tr>
<td>$p_0$</td>
<td>Markov transition probability: state 1 to state 0</td>
</tr>
<tr>
<td>$p_1$</td>
<td>Markov transition probability: state 1 to state 1</td>
</tr>
<tr>
<td>PRA</td>
<td>Temporary variable used in Appendix proofs</td>
</tr>
<tr>
<td>PRB</td>
<td>Temporary variable used in Appendix proofs</td>
</tr>
<tr>
<td>$Q$</td>
<td>$E_{AH} [n - n_1 - n_2]$</td>
</tr>
</tbody>
</table>

Table A.2: Latin Symbols Used (F-Q)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>Return on the productive asset by period 1</td>
</tr>
<tr>
<td>$R_2$</td>
<td>Return on the productive asset by period 2</td>
</tr>
<tr>
<td>$r_{aut}$</td>
<td>Autarchic return function</td>
</tr>
<tr>
<td>$s_d$</td>
<td>Domestic sunspot (Chapter Two)</td>
</tr>
<tr>
<td>$s_f$</td>
<td>Domestic sunspot (Chapter Two)</td>
</tr>
<tr>
<td>$s(d,j)$</td>
<td>Domestic sunspot at $j^{th}$ bank (Chapter Three)</td>
</tr>
<tr>
<td>$s(f,j)$</td>
<td>Foreign sunspot at $j^{th}$ bank (Chapter Three)</td>
</tr>
<tr>
<td>$U_d$</td>
<td>Domestic utility (generic)</td>
</tr>
<tr>
<td>$U_{d,k}$</td>
<td>$K^{th}$ temporary calculation for domestic utility</td>
</tr>
<tr>
<td>$U_{d}^*$</td>
<td>Domestic utility when Nash equilibrium strategy is played</td>
</tr>
<tr>
<td>$U_f$</td>
<td>Foreign utility (generic)</td>
</tr>
<tr>
<td>$U_{f,k}$</td>
<td>$K^{th}$ temporary calculation for foreign utility</td>
</tr>
<tr>
<td>$U_{f}^*$</td>
<td>Foreign utility when Nash equilibrium strategy is played</td>
</tr>
<tr>
<td>$x$</td>
<td>Regressand (Chapter Four)</td>
</tr>
</tbody>
</table>

Table A.3: Latin Symbols Used (R-Z)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Curvature parameter from the utility function</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Elasticity of consumption</td>
</tr>
<tr>
<td>$\gamma_{aut}$</td>
<td>Fraction invested in the productive asset in autarchy</td>
</tr>
<tr>
<td>$\gamma^*_{aut}$</td>
<td>Optimal $\gamma_{aut}$</td>
</tr>
<tr>
<td>$\gamma_b$</td>
<td>Fraction invested in the productive asset by the bank</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>Temporary variable used in Appendix proofs</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Reserve requirement</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Temporary variable used in Appendix proofs</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Cambridge k</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Fraction of impatient agents</td>
</tr>
<tr>
<td>$\pi_1$</td>
<td>Probability of $s_d = 1$</td>
</tr>
<tr>
<td>$\pi_2$</td>
<td>Probability of $s_f = 1$ conditional on $s_d = 1$</td>
</tr>
<tr>
<td>$\pi_3$</td>
<td>Probability of $s_f = 1$ conditional on $s_d = 0$</td>
</tr>
</tbody>
</table>

Table A.4: Greek Symbols Used (Alpha-Pi)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_1$</td>
<td>Return to foreign deposits, 1 period</td>
</tr>
<tr>
<td>$\rho_2$</td>
<td>Return to foreign deposits, 2 period</td>
</tr>
<tr>
<td>$\Sigma_{d}$</td>
<td>Domestic strategy set</td>
</tr>
<tr>
<td>$\Sigma_{f}$</td>
<td>Foreign strategy set</td>
</tr>
<tr>
<td>$\sigma_d$</td>
<td>Typical domestic strategy</td>
</tr>
<tr>
<td>$\sigma_f$</td>
<td>Typical foreign strategy</td>
</tr>
<tr>
<td>$\sigma_{d,i}$</td>
<td>Domestic strategy “i”</td>
</tr>
<tr>
<td>$\sigma_{f,i}$</td>
<td>Foreign strategy “i”</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Taxation rate for domestic deposits</td>
</tr>
<tr>
<td>$\chi$</td>
<td>Temporary variable used in Appendix proofs</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Temporary variable used in Appendix proofs</td>
</tr>
</tbody>
</table>

Table A.5: Greek Symbols Used (Rho-Omega)
APPENDIX B

APPENDIX

B.1 Details Omitted from the Main Text

B.1.1 Details of Expected Utility

The Model of Chapter Two

Here are the expected utilities earned by domestic and foreign agents in each of the four states.

\[ U_{d,1} = \left( \min \left[ 1, \frac{[1-\gamma_b + R_1 \gamma_b](\eta e_d + e_f)}{(1-\tau) c_I} \right] \right) g ((1 - \tau) c_I) \]

\[ U_{d,2} = \left( \frac{[1-\gamma_b + R_1 \gamma_b](\eta e_d + e_f)}{c_I} \right) g ((1 - \tau) c_I) \]

\[ U_{d,3} = \lambda g ((1 - \tau) c_I) + (1 - \lambda) g (A [(1 - \tau) c_P, \kappa (1 - \tau) m]) \]

\[ U_{d,4} = U_{d,3} \]

\[ U_{f,1} = \min [\rho_2 I, (1 - \eta) e_d] \]

\[ U_{f,2} = \min [\rho_1 I, (1 - \eta) e_d + \tau [1 - \gamma_b + R_1 \gamma_b] (\eta e_d + e_f)] \]

\[ U_{f,3} = \rho_2 I \]

\[ U_{f,4} = \min [\rho_1 I, (1 - \eta) e_d + \tau \lambda c_I] \]

The Model of Chapter 3

\[ E_s U_d (\sigma_{d,1}, \sigma_{f,2}, \sigma_{d,1}, \cdot) = \pi_1 U_{d,1} + (1 - \pi_1) U_{d,2} \]
\[ E_s U_d (\sigma_{d,1}, \sigma_{f,2}, \sigma_{d,2}, \cdot) = g ((1 - \tau) c_I) \]

\[ E_s U_d (\sigma_{d,1}, \sigma_{f,2}, \sigma_{d,3}, \cdot) = (1 - \pi_1) U_{d,2} \]

\[ E_s U_d (\sigma_{d,1}, \sigma_{f,2}, \sigma_{d,4}, \cdot) = (1 - \pi_1) g ((1 - \tau) c_I) \]

\[ E_{AH} U_f (\sigma_{d,1}, \sigma_{f,2}, \sigma_{f,1}, \cdot) = \left[ 1 - \pi_1 - \pi_3 + \pi_1 \pi_2 + \pi_1 \pi_3 \right] U_{f,1} \]
\[ + \left[ \pi_1 + \pi_3 - \pi_1 \pi_2 - \pi_1 \pi_3 \right] U_{f,2} \]

\[ E_{AH} U_f (\sigma_{d,1}, \sigma_{f,2}, \sigma_{f,2}, \cdot) = U_{f,2} \]

\[ E_{AH} U_f (\sigma_{d,1}, \sigma_{f,2}, \sigma_{f,3}, \cdot) = U_{f,1} \]

\[ E_{AH} U_f (\sigma_{d,1}, \sigma_{f,2}, \sigma_{f,4}, \cdot) = \left[ 1 - \pi_1 - \pi_3 + \pi_1 \pi_2 + \pi_1 \pi_3 \right] U_{f,2} \]
\[ + \left[ \pi_1 + \pi_3 - \pi_1 \pi_2 - \pi_1 \pi_3 \right] U_{f,1} \]

\text{where}

\[ U_{d,1} = \left( \min \left[ 1, \frac{\left[ 1 - \gamma_c + R_1 \gamma_d (\eta e_d + e_f) \right]}{(1 - \tau) c_I} \right] \right) g ((1 - \tau) c_I) \]

\[ U_{d,2} = \lambda g ((1 - \tau) x) + (1 - \lambda) g (A [(1 - \tau) c_P, m]) \]

\[ U_{f,1} = \min \left[ n \rho_{1} e_{f} n (1 - \eta) e_{d} + (n_2 + n_3 + n_4) \tau \lambda c_I \right] \]

\[ U_{f,2} = \min \left[ n \rho_{2} e_{f} n (1 - \eta) e_{d} + (n_3 + n_4) \tau (\lambda c_I + (1 - \lambda) c_{P}) + \rho_{2} e_{f} \right] \]

\text{The expressions for } U_{d,t} \text{ and } U_{f,t} \text{ for } t = 1, 2 \text{ follow from the rules of the game.}

For example, at a bank where a run occurs, every domestic agent demands x. Those whom the bank serves receive utility of \( g((1 - \tau) c_I) \), since \( \tau c_I \) is paid in taxes. The multiplicative term which precedes \( g((1 - \tau) c_I) \) in \( U_{d,1} \) represents the fraction of domestic agents that can be served. The other expressions have similar interpretations.

B.1.2 ARMA Modelling the Deposit Series

The series which emerge from the first-differencing are stationary but potentially persistent. To remove the persistence in these series, I use the classic Box-Jenkins approach, implemented via the computer program PEST (Brockwell and Davis, 1991). PEST selects the order of the autoregressive (AR) model to minimize the Akaike
Information Criterion. It then solves the Yule-Walker equations to get initial estimates. It finally estimates the model via maximum likelihood. After verifying that the residuals do not display persistence, I use PEST again to verify that there is no autoregressive, moving average (ARMA) model, that fits better than the pure AR model identified above. I select a model and save the residuals from each series for further analysis.\textsuperscript{124}

\subsection{Kolmogorov-Smirnov Tests}

The KS test is a non-parametric test; one version seeks to determine if two subsamples come from the same or different distributions. In particular, let \( x \) be some random unserially-correlated variable of interest with a total sample size of \( m + n \). Let \( F \) be the distribution of a sample of size \( m \) and \( G \) be the distribution of a sample of size \( n \). The KS test statistic is based on \( \sup_x \left| \hat{F}(x) - \hat{G}(x) \right| \), where the hats above the variables denote the empirical analogues of the population distribution functions. If the two subsamples are of approximately equal size, an asymptotic distribution is available. See Kim and Jennrich (1970, p. 80) In the case I consider here, the two samples are of very different sizes, since most periods do not correspond to shocks. The asymptotic distribution is not very accurate for this case, so I need to compute the “exact” distribution. It is difficult to compute the exact distribution, since it involves factorials of \( (m+n) \). I compute the distribution but approximate factorials with their Stirling approximation, \( n! \approx \sqrt{2\pi n} \left( \frac{n}{e} \right)^n \). See Brualdi (1999, p. 81) and

\textsuperscript{124}Note that I do not constrain the deposit series to have the same ARMA \((p,q)\) model for every maturity. Persistence in demand deposits frequently occurs at lag 12, indicating shopping patterns associated with a Christmas effect. Persistence in long-maturity deposits seems to reflect the withdrawal penalty. Since there is an interest cost to withdrawing long-maturity deposits early, depositors wait several months before liquidating their deposits, until the interest rate differential between current and potential investments is sufficiently large.
Feller (1967) for more details. It is easy to verify that as \( m \) and \( n \) each approach infinity, the distribution I use also converges to the asymptotic distribution. In samples of the type I consider, where \( m \) is small and \( n \) is large, the distribution I use is more accurate than the asymptotic one.

B.2 Lemmata, Theorems and Proofs

B.2.1 Lemmata

**Lemma 1** \( c_P > c_I \) is a necessary condition for \( A[c_P, m] > c_I \).

**Proof.** Let \( c_P = \theta c_I \). Either \( \theta < 1 \) or \( \theta = 1 \) imply that \( c_I > A[c_P, m] \). Recall that

\[
A[c_P, m] = c_P^\beta m^{1-\beta}, \quad 0 < \beta < 1 \text{ and } m = \kappa [\lambda c_I + (1 - \lambda) c_P], \quad 0 < \lambda < 1 \text{ and } 0 < \kappa < 1. \quad \text{(125)}
\]

By substitution, \( A[c_P, m] = c_I \theta^\beta \kappa^{1-\beta} [\lambda + (1 - \lambda) \theta]^{1-\beta} \). Substitution of \( \theta = 1 \) yields the result. \( \blacksquare \)

**Lemma 2** \( c_P > c_I \) is not sufficient for \( A[c_P, m] > c_I \).

**Proof.** It is easy to find a counterexample. Write \( c_P = c_I (1 + \varepsilon) \). By the same logic and similar substitutions to those in the previous lemma, one may write \( A[c_P, m] = c_I (1 + \varepsilon)^\beta (\kappa + (1 - \lambda) \kappa \varepsilon)^{1-\beta} \). In the simulations, \( \beta = 0.98, \kappa = 0.16 \). Let \( \varepsilon = 0.001 \). Then for \( \lambda = 0.2 \), the counterexample condition is satisfied. \( \blacksquare \)

**Lemma 3** \( \gamma^*_\mathrm{aut} \) is unique.

**Proof.** \( r_{\mathrm{aut}} (\gamma_{\mathrm{aut}}) = \lambda g (e_d |R_1 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}}|) + (1 - \lambda) g (e_d |R_2 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}}|) \).

Since \( g \) is smooth, so is \( r_{\mathrm{aut}} \). The first and second derivatives are:

\[
\begin{align*}
\frac{\partial}{\partial \gamma_{\mathrm{aut}}} r_{\mathrm{aut}} (\gamma_{\mathrm{aut}}) &= \lambda \left| R_1 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}} \right| g' (e_d |R_1 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}}|) + \\
\frac{\partial^2}{\partial \gamma_{\mathrm{aut}}^2} r_{\mathrm{aut}} (\gamma_{\mathrm{aut}}) &= \lambda \left| R_1 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}} \right| g'' (e_d |R_1 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}}|) + (1 - \lambda) \left| R_2 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}} \right| g'' (e_d |R_2 \gamma_{\mathrm{aut}} + 1 - \gamma_{\mathrm{aut}}|).
\end{align*}
\]

\( \text{The restriction } 0 < \kappa < 1 \text{ comes not from theory but from data. } \kappa = 0 \text{ is a cashless economy, whereas } \kappa = 1 \text{ is a cash-in-advance economy. It stands to reason that most economies stand somewhere in between.} \)
\[ r_{aut}'(\gamma_{aut}) = e_d \lambda (R_1 - 1) g' \left( e_d [R_1 \gamma_{aut} + 1 - \gamma_{aut}] \right) \]
\[ + e_d (1 - \lambda) (R_2 - 1) g' \left( e_d [R_2 \gamma_{aut} + 1 - \gamma_{aut}] \right) \cdot \]
\[ r_{aut}''(\gamma_{aut}) = e_d^2 \lambda (R_1 - 1)^2 g'' \left( e_d [R_1 \gamma_{aut} + 1 - \gamma_{aut}] \right) \]
\[ + e_d^2 (1 - \lambda) (R_2 - 1)^2 g'' \left( e [R_2 \gamma_{aut} + 1 - \gamma_{aut}] \right) \cdot \] Since \( g \) is strictly concave, \( r_{aut}'' < 0 \). There are two possibilities, \( r_{aut}'(0) > 0 \) and \( r_{aut}'(0) < 0 \). If \( r_{aut}'(0) > 0 \), \( \gamma_{aut}^* > 0 \). If not, \( \gamma_{aut}^* = 0 \). Thus, \( \gamma_{aut}^* \) is unique. ■

**B.2.2 The Helgert Recursions**

Let \( x \) be a Bernoulli random variable whose realizations, \( x_j \), are governed by a first-order Markov chain.\(^{126}\) Define \( S_n = \sum_{j=1}^n x_j \). Let \( h_0(k, n) = \Pr(S_n = k) \) and \( x_n = 0 \)\(^{127}\) and \( h_1(k, n) = \Pr(S_n = k) \) and \( x_n = 1 \). Clearly \( b(k, n) \equiv \Pr(S_n = k) = h_0(k, n) + h_1(k, n) \).

**Lemma 4** The following four recursions hold:

\[ h_1(k + 1, n + 1) = p_0 h_0(k, n) + p_1 h_1(k, n) \quad (B.1) \]

\[ h_0(k, n + 1) = (1 - p_0) h_0(k, n) + (1 - p_1) h_1(k, n) \quad (B.2) \]

\[ h_1(k, n + 1) = p_0 h_0(k - 1, n) + p_1 h_1(k - 1, n) \quad (B.3) \]

\[ h_0(k + 1, n + 1) = (1 - p_0) h_0(k + 1, n) + (1 - p_1) h_1(k + 1, n) \quad (B.4) \]

\(^{126}\) The notation for this section follows that of Helgert.

\(^{127}\) That is, the probability that there have been \( k \) “successes” in \( n \) “trials” and the \( n^{th} \) trial was a “failure.” The language of success and failure is somewhat confusing in a bank runs paper, since a “success” is a bank run, which is sometimes called a bank failure.
Proof. Recursion (A.1) states that if there have been k successes in n trials and the $n^{th}$ trial was a failure, the chain will transit to the success state with probability $p_0$. Conversely, if there have been k successes in n trials and the $n^{th}$ trial was a success, the chain will remain in the success state with probability $p_1$. Given that there have been k successes in n trials, these are the only two ways to achieve $k + 1$ successes in $n + 1$ trials; the sum of the probabilities of these two events is the probability of having $k + 1$ successes in $n + 1$ trials. Recursions (A.2) through (A.4) are similar. ■

Lemma 5  $h_1 (k + 1, n + 2) - (1 - p_0) h_1 (k + 1, n + 1)$

$- p_1 h_1 (k, n + 1) + (p_1 - p_0) h_1 (k, n) = 0.$

Proof. By (A.3) twice and (A.2), rewrite the 1st term as

$$p_1 [p_1 h_1 (k - 1, n) + p_0 h_0 (k - 1, n)] + p_0 [(1 - p_0) h_0 (k, n) + (1 - p_1) h_1 (k, n)].$$

By (A.1), rewrite the 2nd term as $-(1 - p_0) [p_0 h_0 (k, n) + p_1 h_1 (k, n)].$

By (A.2), rewrite the 3rd term as $-p_1 [p_0 h_0 (k - 1, n) + p_1 h_1 (k - 1, n)].$

Adding the 1st and 3rd terms: $p_0 [(1 - p_0) h_0 (k, n) + (1 - p_1) h_1 (k, n)].$

Adding the 1st, 2nd and 3rd: $p_0 (1 - p_1) h_1 (k, n) + p_1 (1 - p_0) h_1 (k, n).$

After factoring and cancelling: $h_1 (k, n) |p_0 - p_1|.$

Now it is obvious that the sum of the four terms is zero. ■

Lemma 6  $h_0 (k + 1, n + 2) - (1 - p_0) h_0 (k + 1, n + 1)$

$- p_1 h_0 (k, n + 1) + (p_1 - p_0) h_0 (k, n) = 0.$

Proof. The proof is similar to that of the previous lemma and is omitted for brevity. ■
Lemma 7 \[ b(k + 1, n + 2) - (1 - p_0) b(k + 1, n + 1) \\
\quad - p_1 b(k, n + 1) + (p_1 - p_0) b(k, n) = 0. \]

**Proof.** This follows immediately from the previous two Lemmata and the definition of \( b \), given above. \( \blacksquare \)

**Lemma 8** The following boundary conditions hold:

\[ b(0, n) = p (1 - p_1) (1 - p_0)^{n-1} + (1 - p) (1 - p_0)^n \quad \text{(B.5)} \]

\[ b(n, n) = p p_i^n + (1 - p) p_0 p_i^{n-1} \quad \text{(B.6)} \]

\[ b(0, 0) = 1 \quad \text{(B.7)} \]

**Proof.** Boundary condition (A.5) concerns the case where there have been no successes in \( n \) trials. This can occur in two ways. If the \( 0^{th} \) trial is a success, the chain must transit to the failure state with probability \( 1 - p_1 \) and then remain there for \( n - 1 \) trials.\(^{128}\) Alternatively, if the \( 0^{th} \) trial is a failure, the chain must remain in the failure state for \( n \) trials. The sum of the two probabilities is the probability of \( 0 \) successes in \( n \) trials. Boundary condition (A.6) concerns the case of \( n \) successes in \( n \) trials. If the initial condition is a success, the chain must remain in the success state for \( n \) trials. If the initial condition is a failure, the chain must transit to the success state and remain there for \( n-1 \) trials. Boundary condition (A.7) is the only possible value of \( b(0, 0) \) that satisfies \( \sum_{k=0}^{n} b(k, n) = 1 \). This condition is, of course, one of the definitions of a distribution function. One may describe the Helgert distribution completely with the recursion \[ b(k + 1, n + 2) - (1 - p_0) b(k + 1, n + 1) - p_1 b(k, n + 1) + (p_1 - p_0) b(k, n) = 0 \]

\(^{128}\)The \( 0^{th} \) trial is an initial condition. Even if the \( 0^{th} \) trial is a success, this does not count in the number of successes in the chain. Helgert (1970) uses this numbering convention.
B.2.3 Proofs of Theorems in the Main Text

Proof of Theorem 1. Recall that foreigners are risk neutral in dollar terms. If there are no domestic bank runs, and foreigners arrive in period 2 demanding liras, they will receive $\rho_2 e_f$ liras, whose real value is $\rho_2 e_f$ dollars. If foreigners come in period 1, they receive $\rho_1 e_f$ liras whose real value is: \( \min [\rho_1 e_f, (1 - \eta) e_d + \tau \lambda c_I] \). Since $\rho_1 \leq \rho_2$, \( \min [\rho_1 e_f, (1 - \eta) e_d + \tau \lambda c_I] \leq \rho_2 e_f \). Thus foreigners always prefer to arrive in period 2 if they know that there will be no domestic bank runs.

Proof of Theorem 2 (Part One). In this part I prove the following assertion. Suppose all agents except a small group of domestic agents act in accordance with $\sigma_{d,1}$, and $s_d = 1$, it is optimal for that small group of agents to use $\sigma_{d,1}$ as their strategy function. Let $\varepsilon$ be the measure of that group of patient agents. Suppose that $a_d = \frac{(1 - \gamma_b + R_1 \gamma_b) (\eta e_d + e_f)}{c_I} \equiv \psi$. Note that $L(\psi) = \gamma_b (\eta e_d + e_f)$ and, for all $a_d > \psi$, $L(a_d) = \gamma_b (\eta e_d + e_f)$. Consider any number $\varepsilon$, where $0 < \varepsilon < 1 - \psi$. If a group of size $\varepsilon$ does not run on the bank, it will receive zero utility with certainty. If the members of the group were to run on the bank they would receive expected utility of $\psi g(c_I) + (1 - \psi) g(0) > 0$.

Proof of Theorem 2 (Part Two). The previous proof depended on the fact that $\psi < 1$, that is, that $(1 - \gamma_b + R_1 \gamma_b) (\eta e_d + e_f) < c_I$. For the sake of brevity, I omit the proof where $\psi = 1$. It is available upon request.

Proof of Theorem 2 (Part Three). In this part, I consider the analogue to parts one and two, but here, $s_d = 0$. Let $\varepsilon$ be the size of a group of patient agents. Let $\chi = \frac{(1 - \gamma_b) (\eta e_d + e_f)}{c_I}$. For all $\varepsilon < \min [\chi, \psi] - \lambda$, the bank need not liquidate productive assets to accommodate the defecting group of measure $\varepsilon$. Members of the
defecting group receive \( g(c_I) \), whereas they receive \( g[A|c_P, m] \) if they did not defect. Since \( A[c_P, m] > c_I \), no domestic agent will run on the bank when \( s_d = 0 \). ■

**Proof of Theorem 2 (Part Four).** In this part of the proof, I examine deviations from by foreign agents when \( s_f = 0 \). Let PRA
\[
= \frac{\pi_1 (1 - \pi_2)}{\pi_1 (1 - \pi_2) + (1 - \pi_1) (1 - \pi_3)}.
\]
If there is no deviation, foreigners receive expected utility \( (1 - \text{PRA}) \rho_2 I + \text{PRA} \min (\rho_2 e_f, (1 - \eta) e_d) \). If some foreigners deviate, they receive expected utility \( (1 - \text{PRA}) \min (\rho_1 e_f, (1 - \eta) e_d + \tau \lambda c_I) + \text{PRA} \min (\rho_2 e_f, (1 - \eta) e_d) \). It is easy to see that foreigners who deviate receive less expected utility than those play \( \sigma_{f,1} \) when \( s_f = 0 \). ■

**Proof of Theorem 2 (Part Five).** The final portion of the theorem cannot be verified analytically. But here is the condition to be verified numerically. Let PRB
\[
= \frac{\pi_1 \pi_2}{\pi_1 \pi_2 + (1 - \pi_1) \pi_3}.
\]
Let \( \varepsilon \) be the size of the deviating group. The return to deviation is:
\[
\text{PRB} \left( \max [0, (1 - \eta) e_d - (1 - \varepsilon) \rho_1 e_f] \right)
+ (1 - \text{PRB}) \left( \min (\max [0, (1 - \eta) e_d - (1 - \varepsilon) \rho_1 e_f + \tau \lambda c_I] + \tau (1 - \lambda) c_P, \varepsilon \rho_2 e_f) \right).
\]
The return to following \( \sigma_{f,1} \) is:
\[
\varepsilon \left[ (1 - \eta) e_d + (\text{PRB}) \tau ((1 - \gamma_b + R_1 \gamma_b) (\eta e_d + e_f)) + (1 - \text{PRB}) \tau \lambda c_I \right].
\]
For small values of \( \varepsilon \), the difference between these two returns is zero. ■

**Proof of Theorem 3.** Clearly, if \( (1 - \gamma_b + R_2 \gamma_b) (\eta e_d + e_f) < c_I \), bank runs are possible, since not all domestic agents can be served by the bank. See Chang and Velasco (2000a) for more discussion. From Theorem 2, Part 2,
\[
c_I = (1 - \gamma_b + R_1 \gamma_b) (\eta e_d + e_f)
\]
is insufficient to guarantee the absence of bank runs. So \( (1 - \gamma_b + R_1 \gamma_b) (\eta e_d + e_f) > c_I \) is necessary to prevent runs. If \( A[c_P, m] < c_I \), domestic agents prefer to consume in period 1, even though they could be served in period 2. \( A[c_P, m] \geq c_I \) is also necessary to prevent runs. Note that if both conditions
hold, no patient agent has an incentive to represent himself as impatient; thus, a run
will never occur. These conditions are also sufficient. ■

**Proof of Theorem 4.** If \((1 - \gamma_b + R_1 \gamma_b) (\eta e_d + e_f) \leq c_I\), there is a non-zero probability that patient agents will not be served in period 2. This probability is a function of how many domestic agents represent themselves as impatient in period 1. This is the case discussed by Diamond and Dybvig (1983). ■

**Proof of Theorem 6.** Assume that domestic agents are running on their banks according to the sunspot signals. Let \(\text{Res}_t\) be the reserves at the central bank’s disposal in period \(t\), \(t = 1, 2\). Thus, \(\text{Res}_1 = n(1 - \eta) e_d + (n_3 + n_4) \tau \lambda c_I\) and \(\text{Res}_2 = n(1 - \eta) e_d + (n_3 + n_4) \left[\tau \lambda c_I + \tau (1 - \lambda) c_p + \rho_2 I\right]\). Here \(n_3\) and \(n_4\) are second first two components of \(n\) which is distributed \(\mathcal{AH}(n; p)\). A foreign agent arriving in period \(t\) receives \(\min\left[\frac{\text{Res}_t}{n}, \rho t e_f\right]\). I need to show that there exists a value of \(\rho_1\) such that Theorem 9 is true. Let \(\rho_1 = 0\). Then a foreign agent arriving in period 1 receives 0 and a foreign agent arriving in period 2 receives a positive expected return. ■
B.3 Data Description

The source for all countries except Turkey is DataStream, either the DSWindows version or the newer DataStream Advance version. The data for Turkey comes from the website of the Central Bank of the Republic of Turkey. Unless otherwise indicated, data are not seasonally adjusted. Money supply data and deposit data are measured in current prices.

Argentina

Money Supply (M0) ARS millions; Money Supply (M1, M2) USD millions
Consumer Price Index (1999=100); Interest Rate: deposit rate
CPI and interest rate data range: 1989:1 to 2002:10

Bangladesh

Money Supply (M0) BDT billions; Money Supply (M1, M2) BDT millions
Interest Rate: call money rate, 1997:1 to 2002:5

Chile

Money Supply (M0, M1, M2) USD millions, 1985:1 to 2002:8.
Consumer Price Index (1998=100); Interest Rate: 30-89 day average
Interest and CPI exchange rate data range: 1982:6 to 2002:1
Colombia

Money Supply (M0, M1, M2) USD millions, 1982:11 to 2002:10
Consumer Price Index (1998=100), 1980:1 to 2002:10
Interest Rates: demand deposits, 3 month deposits, 1986:1 to 2002:10

France

All deposits are in EUR millions
Deposits: sight, time under 2 years, time over 2 years, 1993:3 to 2000:4
Consumer Price Index (1998=100), new methodology, 1980:1 to 2000:12
Interest rates: sight deposits, deposits under 2 years and over 2 years.
Interest rate data range: 1995:11 to 2002:9

Indonesia

All deposits are in IDR billions.
Deposits one, three, six months, one, two years maturity,
Consumer Price Index (1995=100), not seasonally adjusted
Interest rates at state banks, one, three six months, one, two years
Data range for all Indonesian data: 1991:1 to 2002:6

Mexico

All deposits are in MXN millions, with range 1980:1 to 2001:10
MXN Deposits: demand, deposits under 1 year, deposits over 1 year
USD Deposits: demand, deposits under 1 year, deposits under 1 year
Consumer Price Index (2002=100), 1980:1 to 2002:9
Interest rates: chequing accounts, saving accounts

Time Deposit interest rates: 28, 60, 90, 180 days

Interest rate data range: 1993:8 to 2002:8

New Zealand

Money Supply (M0,M1,M2) NZD millions, 1988:3 to 2002:12


Interest rate, 1, 2 weeks, 1, 2, 3, 6 months, 1 year deposits, middle rate

Interest rate data range: 1988:2 to 2002:12

Portugal

Money Supply (M0, M1, M2) millions of PTE, 1982:11 to 1998:12

Consumer Price Index (1997=100), 1980:1 to 2002:10

Interest rate: 3 month time deposit, middle rate, 1993:1 to 2001:6

Singapore

Money Supply (M0, M1, M2) USD millions, 1982:11 to 2002:10

Consumer Price Index (1998=100), 1980:1 to 2002:10

Interest rates: savings, 3, 6, 12 month deposits, 1980:2 to 2002:10

South Korea

Money Supply (M0, M1, M2) USD millions, 1982:11 to 2002:10

Consumer Price Index (2000=100), 1980:1 to 2002:8

Interest rate, 91 days, 1980:1 to 2002:8
Sri Lanka

Money Supply (M0, M1, M2) SLR millions, 1980:1 to 2001:10
Consumer Price Index (1952=100); 3 month T-bill rate, 1985:1 to 2001:10

Switzerland

All Deposits are in CHF millions.
Consumer Price Index (2000=100), 1983:1 to 2003:1
Interest rates: Euro-Franc, 1 week, 1, 3, 6 month, 1 year, 1980:1 to 2003:2

Turkey

All Turkish deposit data are in TRL billions
Domestic currency deposits, sight deposits
Domestic currency deposits, deposits less than 1 month
Domestic currency deposits, deposits 3, 6 months
Domestic currency deposits, deposits more than 1 year
Foreign currency deposits, sight and time
Deposits data range: 1986:1 to 2002:6
Consumer Price Index (1994:1)
Interest rates, weighted average of sight deposits, 1, 3, 6, 12, months
Interest rate and CPI data range: 1988:10 to 2002:9

B.4 Graphs

B.4.1 Graph of $c_i^+(\lambda)$

116
Figure B.1: Theoretical Relationship between $\lambda$ and $c_f$. 
B.4.2 Graphs of the regressions

Figure B.2: Regression Graph: Chile

Figure B.3: Regression Graph: Colombia
Figure B.4: Regression Graph: Mexico

Figure B.5: Regression Graph: Switzerland

Figure B.6: Regression Graph: Turkey
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121


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