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A Primer on Financial Contagion

by **Marcello Pericoli and Massimo Sbracia**



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A PRIMER ON FINANCIAL CONTAGION

by Marcello Pericoli and Massimo Sbracia*

Abstract

This paper presents a unified framework to highlight possible channels for the international transmission of financial shocks. We first review the different definitions and measures of contagion used in the literature. We then use a simple multi-country asset pricing model to cast the main elements of the current debate on contagion and provide a stylized account of how a crisis in one country can spread to the world economy. In particular, the model shows how crises can be transmitted across countries, without assuming market imperfections or *ad hoc* portfolio management rules. Finally, tracking our classification, we survey the results obtained in the empirical literature on contagion.

JEL classification: F30, C10, G10.

Keywords: contagion, financial crisis.

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1. Introduction¹

In the past few years, crises in one region have been followed by crises in countries that are geographically distant, have different economic structures, and do not share significant economic links. Recent crises with these features have raised three sets of questions.

First, what are the channels for the international transmission of area-specific shocks? Trade in goods and services is an obvious candidate, but financial markets and financial intermediaries also play an important role in propagating shocks across regions. If a crisis in one market induces a significant change in portfolio strategies of financial intermediaries and investors, this change may also affect asset pricing in markets that, in many ways than one, are distant from the one in which the crisis originated. Trade and financial spillovers may of course have different signs: some spillovers may amplify, while some may dampen or offset the initial shock. The international transmission of shocks is also influenced by the decisions of national and international policymakers. The international impact of a shock in one country may be magnified by the action of domestic policymakers, as well as by the reactions of those in other countries.

Second, are there discontinuities in the intensity of the international transmission mechanism? Are there channels of international transmission that are only active during a crisis? This is partly a question about the strategy to follow when building theoretical and empirical models of contagion. But it is also a relevant issue in the design of policies to contain the undesirable effects of transmission.

Third, should international investors and policy makers worry about the rise in correlation during periods of market instability? International investors may be concerned with the benefits of diversification. If correlation across assets is significantly higher in periods of crisis – the argument goes – diversification may fail to deliver exactly when its benefits are needed most. By the same token, the international transmission of negative shocks may spread to countries with very different fundamentals. If this is the case, national welfare may decline

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independently of the state of national economies, at least to some extent. What policies could mitigate this adverse side effect of international market integration?

The headlines of the debate along the lines sketched above usually refer to ‘contagion’. Currency and financial crises that spread abroad – such as those in Mexico in 1995, in Thailand in 1997, in Russia in 1998 etc. – are (at least potentially) contagious, as opposed to crises that do not spread. This is not to say that crises that are not contagious have no international spillovers. In principle, it could be argued that the spillovers from the 1999 Ecuador debt crisis were as strong as those from any other crisis in the previous few years. Yet the behavior of domestic and international institutions, both public and private, prevented or contained potentially disruptive international effects from this specific crisis. In equilibrium, all we saw was a crisis circumscribed to one country.

The current debate suggests that contagion has both a qualitative and a quantitative dimension. First, the label contagion – as opposed to, say, ‘systemic crises’ – conveys the idea that economic models stressing fundamental channels of international transmission without allowing for asymmetric information, learning, indeterminacy of equilibrium and the like, fall short of providing a convincing account of what is going on. If they do provide an account – critics would point out – they do so by engaging to at least some extent in *ex-post* rationalization of the events. Second, internationally integrated markets exhibit sizable co-movements in economic variables. Hence, tests for contagion versus interdependence should be based on the identification of structural breaks either in the data-generating process or in some of the statistics, such as the cross-country correlation of asset returns.

In the literature, there is a considerable amount of ambiguity concerning the precise definition of contagion, and how we should measure it: there exists no theoretical or empirical definition on which authors agree. The aim of this paper is to provide a state-of-the-art account of the analysis of contagion, while addressing a set of basic issues that, for one reason or another, have been left backstage in the current debate – and which we instead believe are at the core of any study of international transmission mechanisms.

The paper is organized as follows. We first provide an outline of definitions of contagion and different ways to approach the empirical evidence on it (section 2). In section 3 we introduce a simple model of interdependence in which the transmission of financial shocks

occurs without recourse to portfolio models and market imperfections. In light of this model, we then reconsider the theoretical literature on contagion. An important issue addressed in this review concerns the presence of discontinuities in international transmission, caused for example by panics, asymmetric information and learning. In section 4, we review the empirical evidence of the transmission of shocks and recent attempts to assess the presence of discontinuities.

2. What is contagion?

2.1 Definitions

While there is no consensus on exactly what contagion is, there are a few representative definitions that are commonly adopted in the literature. We list five of them.

Definition 1 Contagion is a significant increase in the probability of a crisis in one country, conditional on a crisis occurring in another country.

This definition is usually associated with empirical studies of the international implications of exchange rate collapses. It accounts for the observation that exchange rate crises tend to involve large sets of countries, while some of the countries in the sets may be able to avoid devaluation despite being hit by strong waves of speculative pressure. This definition is consistent with many different views about the international transmission mechanism, as it does not specify which factors underlie the initial crisis and its spread. For instance, a crisis may be systemic, in the sense that devaluations are an equilibrium outcome of a policy game among national governments, facing a shock to fundamentals. Such devaluations would nonetheless be labelled as contagious.

Definition 2 Contagion occurs when volatility spills over from the crisis country to the financial markets of other countries.

A stylized fact in international financial markets is the rise in asset price volatility that occurs during periods of financial turmoil. This definition exploits the fact that crises can be identified with peaks in volatility, and measures contagion as volatility spillovers from one market to another. Asset price volatility is generally considered a good approximation of market uncertainty. Hence, in an interpretation of this definition, contagion refers to the spread of uncertainty across international financial markets. Note that a simultaneous rise in

volatility in different markets might be due to normal interdependence between these markets or to some structural change affecting cross-market linkages. This distinction is at the base of the definitions that follow.

Definition 3 Contagion is a significant increase in co-movements of prices and quantities across markets, conditional on a crisis occurring in one market or group of markets.

The merit of this definition is its immediate appeal: it fits what is commonly perceived as contagion, such as the spread of financial instability after the Hong Kong stock market crash in October 1997, or after the Russian crisis in the summer of 1998. Note that, by stressing the quantitative dimension (a ‘significant increase’), it conveys the notion of contagion as ‘excessive co-movements’, relative to some standard. The open issue is thus to draw a distinction between excessive and normal co-movements in prices and quantities due to simple interdependence.

Definition 4 (Shift-)contagion occurs when the transmission channel is different after a shock in one market.

The implications of contagion according to this definition are somewhat similar to those of the previous one. Shift contagion occurs if the transmission mechanism somehow intensifies in response to a crisis in one country. The phenomenon could therefore also be measured in terms of excessive co-movements of prices and quantities across countries – although tests for structural breaks in the data-generating process would probably be more appropriate. A different identification of a standard for interdependence is at the core of the following definition.

Definition 5 Contagion occurs when co-movements cannot be explained by fundamentals.

This definition of contagion is theoretically precise in the framework of models that allow for the possibility of multiple instantaneous equilibria in the presence of a coordination problem. If the spread of a crisis reflects an arbitrary switch from one equilibrium to another, fundamentals cannot explain its timing and modalities. The state of fundamentals may nonetheless explain why some countries are vulnerable to crises while other countries are not. For instance, if contagion spreads via liquidity crises, then a low level of international reserves relative to short term total liabilities puts a country at risk.

Definition 5 may also apply, however, to cases in which coordination problems among economic agents are not associated with arbitrary mechanisms of equilibrium selection. Sudden discontinuities in the time series of prices and quantities are not necessarily driven by ‘sunspots’. Introducing incomplete information, for instance, may rule out multiplicity of equilibria in standard models of bank runs and currency crises. For given fundamentals, small differences in private information or in the degree of uncertainty of agents’ expectations can trigger significant changes in the behavior of economic agents. However, these events are more likely when fundamentals are weak.

Consistent with these definitions, theories explaining the spread of a crisis from one country to another can be classified in two broad groups, depending on whether or not they predict a structural break in cross-market linkages conditional on a crisis. While these two views are very different at the theoretical level, it is very hard – if not impossible – to distinguish between them on empirical grounds. One crucial issue is that multiple-equilibrium models of crises and contagion are not falsifiable, and there exists no universally accepted methodology to test them. Some authors try to circumvent this issue by assuming arbitrary processes regulating the switch across equilibria, and test the hypothesis of indeterminacy of equilibria conditional on these processes being true. Others proceed by testing many possible econometric models based on fundamentals, and interpret the failure of these models in explaining crises and contagion as evidence for multiplicity. The basic tenet of the latter approach is that, if the true model were based on fundamentals, the econometrician would surely include a test of this model in his work. Note however that, even if the true fundamental model were known to the econometrician, he would still have a hard time to distinguish between switches across possible equilibria due to sunspots, to changes in the degree of uncertainty of agents’ expectations or to information flows that are not publicly observable.

2.2 *Measures*

Corresponding to the broad definitions discussed above, empirical measurements of contagion are explicitly or implicitly based on the following methodologies.

Spread of currency crises and instability

Consider the first definition which focuses on the probability of currency collapses. For each country in the sample, consider some weighted sum of exchange rate changes, interest rate movements and variations in international reserves, capturing speculative pressures in the exchange and money markets. Define a crisis in country i as an extreme value of this indicator – say, above two standard deviations from the sample mean. Using an appropriate set of control variables, the econometrician can test whether a crisis in country i leads to a significant increase in the probability of a crisis in another country. In principle, a similar methodology could be applied to financial markets, but the identification of a ‘crisis indicator’ is more difficult in this case.

Studies based on this definition are often related to empirical analyses that look for an appropriate set of macroeconomic and financial ‘indicators’, in order to forecast currency crises correctly. A very recent development in this literature concerns the inclusion of indicators capturing vulnerability to contagion, often stemming from some sort of financial linkage between countries.

Volatility spillovers

One methodology commonly used to assess the occurrence and direction of volatility spillovers is based on the estimation of multivariate GARCH models. Consider the following data-generating process:

$$(1) \quad R_t = A + B\mathbf{f}_t + U_t, \quad U_t \sim (0, \Sigma_t)$$

$$(2) \quad \Sigma_t = C'C + D'\Sigma_{t-1}D + E'U'_{t-1}U_{t-1}E,$$

where $R = [r_1, \dots, r_n]'$ is a vector of rates of return, $A = [\alpha_1, \dots, \alpha_n]'$ is a vector of constant numbers, B denotes a matrix of factor loadings and $\mathbf{f} = [f_1, \dots, f_n]'$ is a vector of global factors. The vector of country-specific shocks $U = [u_1, \dots, u_n]'$ has a covariance matrix given by Σ , where C , D and E are matrices of constant numbers. Once this model is estimated one can measure the effects of, say, the country-specific shock $u_{i,t}$, on the volatility of country i , the covariance between markets i and j , and the volatility of country j . Stochastic volatility

models that generalize equation (2) by including a noise term could also be used in this perspective.

Correlation in rates of return

Next, let us turn to studies of co-movements in financial markets, as stated in the third definition. Consider the i -th and j -th rows of the process (1) and, for the sake of simplicity, assume a single factor model:

$$(3) \quad \begin{aligned} r_i &= \alpha_i + \beta_i \cdot f + u_i \\ r_j &= \alpha_j + \beta_j \cdot f + u_j . \end{aligned}$$

These expressions make it clear that an increase in the sample correlation of rates of return is not necessarily evidence for contagion, as it may be caused by an increase in the movements (variance) of global factors. Some empirical tests that attempt to address the issue of contagion versus interdependence compare cross-market correlation in tranquil and crisis periods. However, suppose that a crisis in country i is characterized by an increase in the variance of the global factor f and of the country-specific disturbance u_i . During the turmoil, some co-movement across markets is merely an implication of interdependence – as both markets i -th and j -th depend on f_t . Contagion will instead occur when the observed pattern of co-movement in asset prices is too strong in relation to what can be predicted when the mechanism of international transmission is held constant. Hence, the key to these studies is the specification of an appropriate theoretical measure of interdependence, able to capture the international effects of an increase in the volatility of asset prices for a given transmission mechanism.

A related approach consists in explicitly assuming a given joint distribution for $r_{i,t}$ and $r_{j,t}$, instead of starting from a process like (3). Once a crisis is defined as the event described by a particular subset of possible occurrences of r_i – say, a crisis is the event $r_i \in C$ – the sample correlation between the two rates of return conditional on $r_i \in C$ is compared with their unconditional correlation. Interestingly, one can show that for the commonly adopted hypothesis that (r_i, r_j) is a normal bivariate random variable, this approach is no more than a specific instance of the previous model.

Changes in the transmission mechanism

In the fourth definition, contagion occurs when the transmission mechanism intensifies during the crisis in country i . An example is a country-specific shock that becomes ‘regional’ or ‘global’. This means that there is some factor η for which factor loadings are zero in all countries but one during tranquil periods, and become positive during crisis periods. An illustration of this concept of contagion is provided by the following two-factor model:

$$(4) \quad \begin{aligned} r_i &= \alpha_i + \beta_i \cdot f + (\varepsilon + \varepsilon_i) \\ r_j &= \alpha_j + \beta_j \cdot f + \gamma_j \cdot \varepsilon + \varepsilon_j . \end{aligned}$$

If interdependence, $\gamma_j = 0$, so that the process is equivalent to the data-generating process (3) by setting $u_i = \varepsilon + \varepsilon_i$. Contagion occurs when the country-specific shock ε becomes a global factor, *i.e.* when $\gamma_j \neq 0$. Measures of interdependence based on factor model (3) are derived under the null hypothesis $\gamma_j = 0$. Thus, they will be unaffected by a change in the specification of the process for the rates of return, which uses the expressions (4) instead of the factor model (3).

Change in regimes

Empirical studies that incorporate discontinuities in the data-generating process are often based on Markov-switching models. This class of models specifies a number of regimes for relevant economic variables and estimates the probabilities, described by a Markov transition matrix, of moving from one regime to another. This approach has the advantage that discontinuities can be directly attributed to jumps between multiple equilibria. However, the number of regimes is arbitrarily fixed and the switch across equilibria is regulated by an exogenous process so that the nature of the phenomenon effectively captured by the regimes is not clear .

2.3 *Caveats*

Initial crisis and contagion

Definitions and tests of contagion work well in the presence of a clearly identifiable, exogenous initial shock in one market or group of markets. Starting from the ‘first’ crisis

country, one can apply the above methodologies to test whether the spread of instability is consistent with ‘business as usual’, or reflects something more than interdependence.

Some problems arise when the initial shock is not specific to a particular country or market. The eruption of a crisis in one particular country may itself be an equilibrium phenomenon, its causes residing elsewhere. Does a correct identification of the origin of a crisis matter? In many of the tests reviewed above, the answer is yes. For instance, in the third type of empirical test defined above, the measures of interdependence depend heavily on the variance of the return in the country that is assumed to be ‘first’.

By the same token, splitting the sample between ‘crises’ and ‘tranquil’ periods is often arbitrary. In the literature on currency collapses, such a split depends on an arbitrary cutoff value for the indicator of crisis. In tests based on a joint distribution of returns, periods of crisis coincide with periods of extreme values of the variable under consideration – say the rate of depreciation of the exchange rate. In other cases, econometricians need to use institutional information to date crisis periods. Note that this is true even in tests where crises are defined as an increase in the variance of rates of return – this information is not used in the identification of crisis periods, but only to correct the correlation coefficient within the period.

Frequency and lags

Consider again measures of contagion based on the correlation of rates of return defined by (3). Over which frequency should we expect a crisis in country i to trigger a correlation across country-specific disturbances? Early studies of contagion have focused on the correlation of intra-day price movements, under the null hypothesis that one market reacts to the information content of price movements in other markets. By the same token, event studies have analyzed the effect of news in one market on the instantaneous price volatility in other markets. Note that in either case contagion is expected to manifest itself as a persistent and significant increase in correlation in times of a crisis relative to tranquil periods.

One could think, however, that contagion may well take quite different forms. Contagion is likely to manifest itself in infrequent but significant changes in the pricing process that are correlated – with some lags – across markets. It is far from obvious that these changes should lead to higher correlation at daily, weekly or monthly frequencies: country-specific factors during a crisis may actually reduce correlation in price movements over some of

these frequencies. Consider for instance a crisis in country i leading investors to revise their expectations of average productivity in country j . As the coefficient α_j is adjusted downwards after a crisis in country i , contagion results in a one-time adjustment of the level of the stock market in country j .

Prices and quantities

In addition to affecting asset prices, a substantial change in default, exchange rate and political risk also affects the willingness of investors to extend their credit to a country. It is possible that movements in prices tell only part of the story – the crisis spreads primarily via a correlated withdrawal of international credit to a set of countries. Thus, an exclusive focus on rates of return may not be entirely appropriate.

3. Theory of contagion

3.1 A simple model of financial interdependence

This section introduces a simple model of international transmission drawing on Obstfeld and Rogoff (1996) and Lucas (1982). Notation and specification follow Obstfeld and Rogoff (1996) and Corsetti (2000). The objective is to classify the main elements of the current debate on contagion within the simplest model of portfolio allocation and asset pricing, providing a highly stylized account of how a crisis originating in one country can spread to the world economy.²

Consider a two-period economy comprising N countries.³ Each country n is endowed with a fixed quantity of output Y_t^n in the first period, and a stochastic quantity of output $Y_{t+1}^n(s)$ in the second period, where s denotes a particular state of nature. The process generating the cash flow Y_{t+1}^n has both common and country-specific components

$$(5) \quad Y_{t+1}^n = \gamma^n + \mathbf{\Gamma}^n \mathbf{f}_{t+1} + \varepsilon_{t+1}^n,$$

² In interdependent markets, a shock to the cash flow from one asset or a change in the statistical properties of this cash flow may lead to a portfolio rebalancing that alters the demand for all other assets. If the asset supply is infinitely elastic the shift in the demand curve does not produce any change in the vector of prices — the international transmission would only be reflected in investment flows. If the supply is not infinitely elastic, the portfolio rebalancing will alter the price vector, affecting all markets. This second dimension of the international transmission may be lost if the theorist or the econometrician specifies an exogenous process for asset supply.

³ The model could be easily extended to the infinite-horizon case; here we focus on a two-period model in order to provide some numerical examples.

where \mathbf{f} indicates the vector of global factors, and $\mathbf{\Gamma}$ is a vector of country-specific factor loadings. The disturbance ε has zero mean.

In each country there is a continuum of national consumers with mass 1. Consumers throughout the world have the same CRRA preferences

$$(6) \quad U = E_t \sum_{z=t}^{t+1} \beta^{z-t} \frac{C_z^{1-\rho}}{1-\rho}.$$

Each national consumer is endowed with a fraction of national resources. To write the budget constraint, denote with V_t^n the value at t of the uncertain stream of domestic output in country n at $t + 1$. We can think of V as the value of a mutual fund holding the universe of firms operating in country n . It may be worth noting that V_t^n does not necessarily coincide with the value of country n 's market, as this may also include firms operating abroad. Clearly, V_t^n is a price, and will be determined endogenously in equilibrium. Assume that claims to period $t + 1$ net national output are traded worldwide. The budget constraint of the national representative individual is then

$$(7) \quad \sum_{m=1}^N x_m^n V_t^m = Y_t^n + V_t^n - C_t^n$$

$$C_{t+1}^n(s) = \sum_{m=1}^N x_m^n Y_{t+1}^m,$$

where x_m^n denotes the share of the claim to country m output in period $t + 1$, owned by the representative consumer in country n .

Referring to the discussion in Obstfeld and Rogoff (1996) for details, we characterize an equilibrium allocation as follows. First, define μ^n as country n 's share of initial world wealth

$$(8) \quad \mu^n = \frac{Y_t^n + V_t^n}{\sum_{m=1}^N (Y_t^m + V_t^m)}.$$

In equilibrium, consumption at time t and $t + 1$ will be a fraction μ^n of global income

$$(9) \quad C_t^n = \mu^n \sum_{m=1}^N Y_t^m = \mu^n Y_t^W$$

$$C_{t+1}^n(s) = \mu^n \sum_{m=1}^N Y_{t+1}^m(s) = \mu^n Y_{t+1}^W(s),$$

where Y_t^W is world output in period t . In equilibrium, all individuals in the world will hold the same portfolio of risky assets, in proportion to the share of their endowment in world wealth. That is, country n will hold a share of country m mutual fund x_m^n in proportion to its own wealth

$$(10) \quad x_m^n = \mu^n .$$

The key to understand this equilibrium is that, because of CRRA preferences, the optimal portfolio of risky assets is invariant in relation to the level of wealth: all consumers invest the same share of their wealth in the country i fund. Consumers will, however, have different levels of wealth.⁴

The equilibrium price of the market index in country n is

$$(11) \quad V_t^n = E_t \left[\frac{\beta U'(C_{t+1})}{U'(C_t)} Y_{t+1}^n \right] = E_t \left[\beta \left(\frac{Y_t^W}{Y_{t+1}^W} \right)^\rho Y_{t+1}^n \right] = E_t \left[\beta \left(\frac{\sum_n Y_t^n}{\sum_n (\gamma^n + \mathbf{\Gamma}^n \mathbf{f}_{t+1} + \varepsilon_{t+1}^n)} \right)^\rho (\gamma^n + \mathbf{\Gamma}^n \mathbf{f}_{t+1} + \varepsilon_{t+1}^n) \right].$$

The above expression is useful to shed light on the basic structure of international transmission. We should note here that, in equilibrium, some countries may well run a current account deficit. For instance, for country j it may well be that $C^j = \mu^j Y_t^W > Y_t^j$.

Country j may finance its excess imports by issuing equity-like assets, but it could also issue debt. Using a straightforward application of the Modigliani-Miller theorem, we can interpret V_t^j as the price of a portfolio combining both equities and bonds, the latter issued at the current equilibrium interest rate. Country j could sell default-free bonds paying a cash flow B_{t+1} , provided that $B_{t+1} < \min Y^j(s)$ for all s . In equilibrium, the price of these bonds is

$$\frac{1}{1+r} = E_t \left[\frac{\beta U'(C_{t+1})}{U'(C_t)} \right] = E_t \left[\beta \left(\frac{Y_t^W}{Y_{t+1}^W} \right)^\rho \right].$$

⁴ In Lucas (1982), preferences are not necessarily CRRA, but are identical across individuals. Thus, in a perfect pooling equilibrium there can be no differences in individual wealth that could induce differences in individual portfolios.

In the equity market, country j would then issue claims to a stream of output equal to $Y_{t+1}^j(s) - B_{t+1}$. It is straightforward to see that the total value of these assets (bonds plus equities) is V_t^j .

To clarify the features of this model, consider a simple numerical example with two states of nature, each occurring with equal probability. The endowment of the first country – which we will refer to as the ‘industrial country’ – is $Y_t^1 = 20$ and $Y_{t+1}^1 = \{10, 20\}$, the first figure in curly brackets referring to the first state of nature with 50 per cent of probability. The endowment of the rest of the world – comprising all emerging market economies – is $Y_t^2 = 10$, and $Y_{t+1}^2 = \{20, 10\}$. Note that there are two key differences between the industrial country and the emerging markets: one is the level of initial output, the other the distribution of output across states of nature. Assuming for simplicity that the coefficient ρ is equal to 2, while $\beta = 1$, we see that the market value of both groups of countries is equal to

$$V_t^1 = V_t^2 = \left[\left(\frac{30}{30} \right)^2 \cdot 10 \right] \cdot 0.5 + \left[\left(\frac{30}{30} \right)^2 \cdot 20 \right] \cdot 0.5 = 15 ,$$

but their share in world wealth is different, namely

$$\mu^2 = \frac{(10 + 15)}{(10 + 15) + (20 + 15)} = \frac{5}{12} \text{ and } \mu^1 = \frac{7}{12} .$$

Note that at time t , the consumption by residents of emerging markets is larger than their output endowment:

$$\mu^2 Y_t^W = \frac{5}{12} \cdot 30 = \frac{25}{2} > Y_t^2 .$$

The group of emerging economies as a whole is a net debtor, while the first country is a net creditor in the world economy. Reinterpreting V_t^2 as the price of a portfolio combining both equities and bonds, we could assume that these countries sell a claim to a stream of output equal to $\{10, 0\}$, in the equity market. They then sell default-free bonds paying a cash flow equal to 10. Using the asset pricing equation above, we can see that the value of this bond at time t will be 10: in equilibrium, the rate of interest is endogenously determined and equal to $r = 0$. The value of the rest of the national portfolio – consisting of equities – will be 5. These figures provide a baseline scenario for simple numerical analyses of crises and contagion in the following.

3.2 *The transmission of shocks due to interdependence*

In this section we will use our simple model as a guide to map the main ideas in the current debate on contagion. First, we need a definition of crisis.

Definition 6 A crisis in country n at time t is an unexpected change in the distribution of Y_{t+1}^n that increases the risk of investing in country n .

Note that a crisis could correspond to a change in the distribution of any of the elements on the right hand side of (5). Examples include a mean-preserving shock affecting the country-specific disturbance ε^n , a drop in the expected average productivity of the country γ^n , a change in the distribution of global factors \mathbf{f} , or even a change in country-specific factor loadings Γ^n .

Starting from a baseline scenario, we will study the international effects on prices and consumption due to a crisis in country n . We will examine three main types of contagion. The first focuses on fundamental transmission. The second and the third analyze the propagation of shocks due to panics and to incomplete information, learning and updating by international investors. We will stress that the last two channels produce discontinuities in the international transmission of the initial crisis.

3.2.1 *Fundamental channels of international transmission*

International implications of country-specific shocks

A first set of contagion models focuses on fundamental channels of transmission abstracting from information imperfections. To start with, observe that a country-specific crisis will primarily affect V^n , but will also affect the price of all other assets through the stochastic discount rate $\beta U'(C_{t+1})/U'(C_t)$. As the stochastic discount rate depends on the world endowment in the two periods, the indirect effect of a crisis in country n will be larger, the larger the size of the economy that is hit by a crisis. It is well understood, for instance, that price movements in large markets, such as the US market, lead to price movements in many other markets. However, such co-movements are rarely referred to as “contagion”. Because of the relevance of size, one may expect this channel to be small in the case of crises in emerging markets.

To capture the flavor of the international transmission of disturbances that are specific to output from one country, we now present a few back-of-the-envelope numerical calculations based on our model. Starting from the numerical values presented at the end of the previous section, assume that, in the initial equilibrium, output flow of country 2 is $Y_t^2 = 5$ and $Y_{t+1}^2 = \{10, 5\}$ – note that this emerging market economy is rather large: perhaps the following example is best suited to a regional, rather than a national crisis. Initially, $V_t^2 = 10.3$ and $\mu^2 = 0.29$, so that this country (or region) is a net importer at time t .

Consider now a crisis in the form of a mean-preserving spread of the country-specific disturbance ε^n . According to our definition, a crisis consists of a change in the distribution of Y_{t+1}^2 : we assume $Y_{t+1}^2(\varepsilon^2 \text{ crisis}) = \{15, 0\}$. Relative to our initial set of numerical values, the distribution mean of Y_{t+1}^2 is the same (7.5), but its variance has increased. As expected, a mean-preserving spread in the distribution of country 2 national output leads to a drop of 27 per cent in its period t stock market price:

$$V_t^2(\varepsilon^2 \text{ crisis}) = \left[\left(\frac{25}{25} \right)^2 \cdot 15 \right] \cdot 0.5 + \left[\left(\frac{25}{20} \right)^2 \cdot 0 \right] \cdot 0.5 = 7.5 .$$

The shock is transmitted abroad, via the stochastic discount factor. Observe that a crisis increases the world interest rate, which becomes a positive number, and changes the relative price of future output in both states of nature. The price of output in states of nature $s = 1$ increases relative to output in state of nature $s = 2$. Country 1 – the developed country – has a distribution of output across states of nature tilted in favor of the second state of nature. Not surprisingly, its stock market looks much better after the shock. The equilibrium price increases by 16 per cent from 17.8 to:

$$V_t^1(\varepsilon^2 \text{ crisis}) = \left[\left(\frac{25}{25} \right)^2 \cdot 10 \right] \cdot 0.5 + \left[\left(\frac{25}{20} \right)^2 \cdot 20 \right] \cdot 0.5 = 20.6 .$$

This price movement could be interpreted as the result of a “flight to quality”, in the sense that international portfolios are re-allocated towards less risky investments. The weight of the industrial country in the international portfolio increases from 71 to 76 per cent.

The impact of a crisis needs to be not positive for countries with a different distribution of endowment across states of nature. In our example, the stock market value of the rest of the emerging markets as a whole falls from 10.3 to 7.5. Moreover, consider a country within this group, say country 3, with a more pronounced imbalance in the distribution of endowment across the two states of nature: $Y_t^3 = 5$ and $Y_{t+1}^3 = \{8, 1\}$. For this country a crisis in the second economy implies a sizeable drop in the market, from $V_t^3 = 5.3$ to $V_t^3 = 4.3$.

The intensity of the transmission through the stochastic discount factor also depends on risk aversion. Suppose risk aversion were higher, say $\rho = 3$ instead of 2. In this case, price and portfolio movements after a crisis would be more sizeable – say, the post-crisis stock market price in the second country would fall by 39 instead of 27 per cent.

To sum up. Country-specific shocks spread via the stochastic discount rate. Unless asset supply is perfectly elastic, any crisis will induce equilibrium price movements and some correlation across rates of return in different markets. Setting $\gamma^n = \mathbf{f} = 0$ we can write

$$V_t^m = E_t \left[\left(\frac{\sum_n Y_t^n}{\sum_n \varepsilon_{t+1}^n} \right)^\rho \varepsilon_{t+1}^m \right].$$

While the rate of return in this country falls, rates of return abroad can either rise or fall, depending on the distribution of output across states of nature, as well as on preferences.

Global shocks, spillovers and systemic crises

The spread of crises can of course be driven by global shocks – in our stylized model, these would correspond to a change in the perceived distribution of one of the global factors in the vector \mathbf{f} . The domestic impact from a global shock – both sign and magnitude – depends on the structural features of each economy: this idea is captured by allowing for country-specific differences in factor loadings γ^n .

It is worth stressing that factors and factor loadings are also a stylized way to capture international policy spillovers and policy interdependence. For instance, a country-specific shock that is matched by policies with international spillovers should be part of \mathbf{f} . Monetary spillovers, in the form of competitive devaluations, would be represented in this way. A *change*

in the distribution of f could correspond to a change in policy regime affecting the international economy – a notable example being the creation of the euro.

An extension

A popular example of global fundamental shocks affecting financial and exchange markets world-wide are movements in terms of trade and commodity prices – such as those preceding and accompanying the eruption of the Asian crisis. Many observers have discussed the significant impact of the crisis in countries as different as Canada, Chile and New Zealand, stressing that these economies are all suppliers of primary commodities.

As regards the international transmission of ‘policy’ shocks through trade links, Corsetti *et al.* (1998) revisit the logic of competitive devaluations in the context of the “new open economy macroeconomics”. The international impact of a devaluation in one country depends on the elasticity of substitution between foreign and domestic goods, as well as on the pricing strategies pursued by firms. Recent evidence on the importance of trade links in propagating currency crises is provided by Bentivogli and Monti (2001), Dasgupta (2000) and Forbes (2000).

Examples of policy shocks with strong international implications include the high interest rates pursued by the Bundesbank after the German re-unification and before the ERM crisis in 1992-93, the increase in the US interest rates in the months preceding the Mexican crisis, and the strength of the dollar, coupled by the weakness of Japan, before and during the recent crisis in South-East Asia. We will discuss this topic in depth below.

Effects of rules of thumb in portfolio allocation

The international impact of country-specific shocks is magnified when investors follow ‘rules of thumb’ in portfolio allocation, or are subject to regulations limiting the scope for portfolio diversification. We cannot explicitly model these rules within the framework presented above – after all, these rules must be adopted because of market imperfections that make the portfolio problems different from the one we have considered. We can, however, provide an equivalent equilibrium representation of the effects of rules of thumb in portfolio formation.

Observe that, in our calculations above, a mean-preserving spread of country 2 output induces a fall in the portfolio share invested in the (now) riskier, emerging markets (hereafter *EM*) from 29 to 24 per cent. Suppose that investors follow some arbitrary rules of thumb

$$\mu^{EM} = \mu(\sigma_p), \quad \mu' < 0,$$

such that they respond to increasing portfolio risk σ_p by substantially reducing their exposure to risky investments. As the emerging markets are now riskier, it is plausible to assume that the share of international portfolio invested in assets from these countries will fall below the equilibrium value, 24 per cent. After a crisis in country 1, international investors would mechanically reduce the share of their wealth invested in emerging markets to 20 per cent.

Now, using our model, we can calculate the theoretical mean-preserving spread in the cash flow from emerging markets that would support a 20 per cent portfolio share in equilibrium. In other words, we could build an equivalent equilibrium representation of any arbitrary rules of thumb, in terms of an implicit change in the perceived distribution of the cash flow in period $t + 1$. In our specific example, one of the possible theoretical cash flows (denoted with a tilde) would be $\tilde{Y}_{t+1}^{EM} = \{50, 0\}$.

Portfolio management rules and contagion

When investors follow rules such as the one specified above, a crisis in one country tends to reduce the availability of international resources for the emerging market economies as a whole. The role of investors' rules of thumb in spreading contagion is explored by Schinasi and Smith (1999). These authors assume an exogenous process driving rates of return. They therefore analyze contagion only in terms of correlated changes in portfolio allocation, rather than in prices, which are fixed by assumption. Similarly, some authors stress value at risk or prudential regulation as an implicit mechanism of amplification of financial shocks, via portfolio adjustment by financial intermediaries.

Schinasi and Smith (1999) show that the international transmission of shocks can be explained "with the basic principles of portfolio theory without recourse to market imperfections". The authors show that the transmission usually occurs even when a representative investor uses simple portfolio management rules (hereafter PMR) to allocate

her wealth among international assets. Indeed, if one views perfect markets as Arrow-Debreu economies with utility-maximizing agents, the very use of PMRs can be considered as a form of market imperfection. For instance, most of these rules can lead to the choice of dominated portfolios, which is inconsistent with expected utility maximization.

Let $\mu_{p,t+1}$ and $\sigma_{p,t+1}$ be the expected return and the standard deviation of a portfolio p at period $t + 1$. In a setup with two risky assets and one safe asset, Schinasi and Smith compare three different PMRs:

- PMR 1 (*Expected return benchmarking rule*). The investor chooses the portfolio which warrants at least an expected return $\mu_{p,t+1} \geq k$, and minimizes the risk $\sigma_{p,t+1}$.
- PMR 2 (*Trade-off rule*). The investor maximizes the following linear combination of expected return and risk, with degree of risk tolerance τ : $\mu_{p,t+1} - \frac{1}{2}\tau\sigma_{p,t+1}^2$.
- PMR 3 (*Loss-constraint rule*). The investor chooses the portfolio which warrants the largest expected return $\mu_{p,t+1}$, under the constraint that the probability that the return $R_{p,t+1}$ is below a given R^* , is smaller than a threshold m .⁵

The authors consider two kinds of shock: (a) an increase in the variance of a generic asset price at period $t + 1$ (*volatility event*); (b) a decrease in the market value of an asset (*capital event*). Following any of the two shocks on one asset, two distinct effects on the demand of all risky assets are at work: a *substitution effect*, which makes investment in the other asset more attractive, and an *income effect*, which makes the entire portfolio less attractive (because of its increased risk) than a risk-free asset. Moreover, the final outcome will depend on the covariance matrix of the returns on assets.

In the case of a volatility event, the transmission of the shock depends on the adoption of a specific PMR. Specifically, a volatility event on one asset never causes a decrease in demand for the other risky asset, if the investor uses the *expected return benchmarking rule*. With this rule, in fact, the substitution effect dominates and demand for the other asset increases.

⁵ The PMR 3 is also known among pundits as *value at risk* (VaR). In fact, it is possible to write the problem as

$$\begin{aligned} & \max \mu_{p,t+1} \\ & s.t. : \Pr [V_{t+1} < V^*] \leq m, \end{aligned}$$

where V^* is the *value at risk* chosen by the investor, $V_t = W_t - B_t$ is the market portfolio value, given by the algebraic sum of risky assets, W_t , and borrowings, B_t .

With the *trade-off rule*, a volatility event induces a reduction in the demand for all risky assets, provided that returns on assets are negatively correlated. By contrast, under the *loss-constraint rule*, a volatility event makes demand for all risky assets decrease, provided that the risk tolerance parameter is sufficiently ‘high’, whatever the sign of the correlation between risky assets.

In the case of a capital event, for any PMR and any unleveraged portfolio, optimal rebalancing involves reducing higher-yielding positions and investing the proceeds in lower-yielding assets. If the portfolio is leveraged, a capital event may lead to sales of all risky assets and to a corresponding reduction in leverage.⁶

Portfolio models with imperfect information

Kodres and Pritsker (1999) present a portfolio model which features four types of agent: informed traders, uninformed traders, liquidity traders and noise traders. Agents are informed or uninformed depending on their knowledge of expected returns from the asset. Feedback traders invest their assets following the market, i.e. buying when prices rise and selling when they fall. Liquidity traders invest on the basis of idiosyncratic shocks, corresponding to their needs of liquidity.

In a standard *single factor model*, the existence of a common risk factor determines the transmission of shocks. In particular, the authors consider a specific shock represented by the arrival of information on the expected return of a given asset. Such an information shock typically affects all asset prices whose fundamentals co-move with the common risk factor, with a sign and a magnitude that depend on the covariance matrix. In particular: (a) the magnitude of the price response in other markets to shocks in one market is larger if the shock originates in a market whose asset covariates more in relation to the common risk factor; (b) shocks are transmitted towards markets whose covariance in relation to the common risk factor is greatest; (c) the magnitude of the price response in all markets increases if information asymmetries increase.

⁶ Unlike Calvo (1999), in this framework the role of margin calls is not crucial. The requirement imposed by margin calls could be met by deleveraging, without affecting portfolio allocation. Since a capital event induces a decrease in leverage, margin calls can be effective on the demand for risky assets only if they require a larger decrease in borrowing than the one imposed by unconstrained optimization.

The authors also consider the following *multifactor model*:

$$\begin{aligned} Y^1 &= \gamma^1 + f^1 + \varepsilon^1 \\ Y^2 &= 0.5 \cdot f^1 + 0.5 \cdot f^3 \\ Y^3 &= \gamma^3 + f^3 + \varepsilon^3 \quad , \end{aligned}$$

where Y^1, Y^2, Y^3 are the cash flows from assets, γ^1, γ^3 are constants, f^1, f^3 are common factors, and $\varepsilon_1, \varepsilon_3$ are idiosyncratic shocks.⁷ This model is intended to represent a world with a developed country, like the United States (here labeled as country 2) and two emerging markets, say Russia and Brazil. In this framework, Russia shares a common factor with the United States, as well as Brazil, but the two emerging countries do not share any factor. Kodres and Pritsker show that even if emerging markets are not structurally linked and the idiosyncratic components are independent, the transmission of a shock from Russia to Brazil does occur. In fact, the transmission is channeled by the developed country although, surprisingly, prices in this country are not affected by the shock. This result provides a theoretical explanation for the role of mature markets in the mechanism of international transmission of shocks across countries that are not structurally linked.⁸

Note that in both the single factor and multifactor models, hedging does not affect the sign of the transmission. It may however affect the volatility of asset prices.

Amplification effects of prudential rules and regulation

A different approach to contagion – still related to the fundamentals of the economy – analyzes the empirical relevance of the so-called *common lender* effect. The focus is on the consequences of fluctuations in asset prices and default risk on the balance sheets of international financial intermediaries. Consider a crisis in one country increasing the risk levels of the international positions of an international bank. If the bank reacts by rebalancing its

⁷ In their original model Kodres and Pritsker use a multifactor model with returns on assets instead of cash flows. Our modification does not change their results.

⁸ On this topic, see also Calvo (1999).

portfolio and reducing its exposure to emerging markets, a crisis in one country may translate into a credit crunch elsewhere.

A related channel of contagion operates via the effect of fluctuations in asset pricing on the balance sheet of debtors. To the extent that creditworthiness depends on the value of *collateral*, firms owning assets in a crisis country may face higher borrowing costs and/or credit constraints in crisis periods.

In general, the banking system can also contribute to the transmission of financial shocks through bank runs and bank panics and through the moral hazard caused by the presence of explicit or implicit government guarantees on deposits. However, while the importance of the exposure to a common source of funding has been confirmed by many recent empirical studies, bank runs have been proven to be not very relevant as causes of financial distress, and evidence on the effects of public guarantees is still very controversial (Sbracia and Zaghini, 2001b).

3.2.2 *The international transmission of panics*

A different set of models focuses on panics and coordination problems. For this set of models we need to qualify our definition of crisis, since changes in the distribution of future output in a country are now conditional on a panic.

Consider a country that is a net borrower in period t . Suppose that in this country output endowment in period $t + 1$ is no longer exogenously given, but depends on the ability of the country to borrow on top of its endowment in the previous period. If this is not possible, the output endowment in the second period endogenously shrinks to some level that is consistent with this country not being a net borrower. This is of course an exceedingly simple way to capture the macroeconomic essence of a panic, where a credit constraint emerges as a result of a coordination problem among investors.

For instance, we have seen above that, in the initial equilibrium, country 2 borrows from the rest of the world (hereafter W) $\mu^2 \cdot Y^W - Y_t^2 = 0.29 \cdot 30 - 5 = 2.2$. Suppose that country 2 output at time $t + 1$ is conditional on the ability of this country to borrow 2.2 – we may think of a sort of productive consumption. If this country is denied international loans, however, its output becomes $Y_{t+1}^2(\text{no loans}) = \{2, 5\}$. Suppose also that all international investors are small and that there are limits to short sales, so that no single international investor can take

an arbitrarily large position in the stock market of country 2. The equilibrium allocation in the world economy will then depend on which particular set of expectations international investors coordinate. In a no-crisis equilibrium, we have seen that the second country has market value equal to 10.3, corresponding to a share in the world portfolio as high as 29 per cent. Given that all investors coordinate on this equilibrium, it is individually optimal to invest the equilibrium share 29 per cent, in country n .

If, however, international investors coordinate on an equilibrium in which they give no credit to this country, the share of their portfolio in country 2 assets is lower, and output in country 2 falls in a self-fulfilling way. The value of country 2 stock market becomes 6.8, while its share in the world portfolio shrinks to slightly more than 18 per cent. In equilibrium, this country is a net lender.

Coordination of investors may be driven by a sunspot, or by a different mechanism, such as the one studied by Morris and Shin (1998, 1999). Clearly, different models of panics may correspond to different mechanisms of international transmission.

Consider a crisis in country 2 that is driven by sunspots. It would be transmitted abroad in the same manner as a country-specific shock, as studied above. There is nothing about contagion in a sunspot-driven panic, unless one is willing to assume that coordination crises tend to be correlated internationally. But this assumption would be completely arbitrary and not very informative.

Conversely, models that attempt to study the determinants of swings in investors' confidence may provide a framework for the simultaneous analysis of crises and contagion. In Pauzner and Goldstein (1999), investors receiving private signals about the state of the fundamentals optimally follow trigger rules, such as a run on a bank if the signal about its fundamental investments is more negative than a certain endogenously derived threshold. In general, this trigger will depend on investors' wealth. A bank crisis reducing investors' wealth in one country may lead to a revision of the trigger. As a result, a bank crisis in one region may increase the probability of bank crises in other regions.

Contagion through multiple equilibria in currency crisis models

Multiple equilibria related to coordination problems form the base of second-generation models of currency crises (SGMs). In these models, first developed by Obstfeld (1994 and 1996), devaluation is the government's optimal response to the actions of speculators and can take place as a result of self-fulfilling beliefs, without a previous worsening of fundamentals.⁹ Since speculative attacks raise the cost of defending a fixed exchange rate, SGMs may exhibit self-fulfilling multiple equilibria. For instance, consider an economy where government policies are consistent with the maintenance of a pegged exchange rate, but the market is dominated by the sentiment that the currency will be depreciated. If a speculative attack raises the cost of defending the peg, it might eventually force the authorities to abandon its defence. Thus, speculators' beliefs turn out to be self-fulfilling.

Some of the most interesting results in SGMs concern the case of incomplete information. Building on some developments on the concept of common knowledge and global games (Carlsson and van Damme, 1993), recent studies have unraveled two main findings. First, if agents have (sufficiently informative) private information, the incomplete information game has a unique equilibrium (Morris and Shin, 1998) and there can be no sunspot equilibria (Heinemann and Illing, 1999). Second, when speculators have a (public) prior probability distribution on fundamentals, an increase in uncertainty (proxied by the variance of the prior distribution) may move the economy from multiple equilibria to a unique equilibrium with a speculative attack (Sbracia and Zaghini, 2001a).

The transmission of shocks in SGMs can involve additional channels with respect to those operating in first-generation models. In traditional models, a crisis in country A may be transmitted to country B only if it entails a worsening of the fundamentals of the latter country (e.g., because of 'structural' trade or financial links). Moreover, the deterioration in B's conditions must be large enough to induce a speculative attack. In SGMs, the transmission can also operate via an 'information channel'. Suppose that the economies A and B are not structurally linked, but B's fundamentals fall in the intermediate range of multiple equilibria. The news of a crisis in country A is a public signal that does not modify the structure of the equilibria (which remain multiple) and does not affect the state of B's fundamentals.

⁹ By contrast, in first-generation models – originally developed by Krugman (1979) and Flood and Garber (1984) – financial crises follow a deterioration in the state of fundamentals, typically due to inconsistent economic policies.

However, because of multiple equilibria, this new signal may be the sunspot that leads agents to coordinate their action towards a speculative attack equilibrium that forces B to devalue. In other words, the economy can experiment a ‘*jump*’ from a good to a bad equilibrium.

Incomplete information SGMs highlight other interesting channels of contagion. Any country is disseminated with public information that certainly affects its economy, even if this may occur in a way that it is not entirely clear to speculators. Political rumors or social events, for instance, are often very difficult to interpret. Although such information is public, it may be differently interpreted by different speculators. These public signals could therefore play the same role as private information,¹⁰ opening new channels for contagion.

Suppose that the fundamentals of country B are in the intermediate region, and suppose that the country has not experienced speculative attacks. Once a crisis in A occurs, although it does not produce a worsening of B’s fundamentals (as A and B are not structurally linked), it may produce some uncertainty among speculators about the way in which ‘the other speculators’ will interpret this new signal. Since agents’ reaction to this kind of news can be unpredictable, this public signal can be considered as private. The shift from a model with complete (or public) information to one with private information implies a shift from multiple equilibria to a unique equilibrium. Hence, it is possible that, with public information, the economy was in the intermediate region, and multiple equilibria allowed the authorities to sustain the peg. When private information arrives (or when a blurred public signal, like the news of the crisis in A, is observed), they determine a speculative attack.

A similar mechanism can also be caused by an increase in uncertainty. Sbracia and Zaghini (2001a) show that increased uncertainty – possibly due to a crisis in another country – can be sufficient to produce a speculative attack. Note that, unlike the case of sunspots, in these models there are no ‘jumps’ between multiple equilibria. Rather, private information and uncertainty determine a ‘shift’ from a multiple equilibria to a unique equilibrium model, where a speculative attack is the sole possible outcome.

¹⁰ Morris and Shin (1998) explain in this way why some speculative attacks seem to be triggered by events not directly connected with the economy, like rumors of political troubles in the Mexican crisis in 1994, or the announcement of a referendum in France, before the Exchange Rate Mechanism (ERM) crisis in Europe in 1992.

3.2.3 *Incomplete information, learning and updating*

A different set of models of contagion focuses on subjective beliefs, learning and updating. Suppose that a crisis in market n leads to a revision of the subjective probability distribution of country-specific disturbances elsewhere. A change in $\gamma^n + \varepsilon^n$ may lead to a change in the perceived distribution of $\gamma^m + \varepsilon^m$ for some m . The equilibrium effect on prices will now reflect both country-specific considerations, and a change in the world stochastic discount rate.

Suppose that a crisis specific to country 2 induces a new view among international investors, so that the output process for the emerging market economies as a group becomes $Y_t^{EM} = \{30, 0\}$. Overall, the stock market valuation of this group of countries falls from 15 to 8.4:

$$V_t^{EM}(\varepsilon^2 \text{ crisis}) = \left[\left(\frac{30}{40} \right)^2 \cdot 30 \right] \cdot 0.5 + \left[\left(\frac{30}{20} \right)^2 \cdot 0 \right] \cdot 0.5 = 8.4,$$

while the developed (first) country market is boosted. The stock market share in the crisis country is the 29 per cent of the world stock market.

The literature provides different examples of this line of reasoning. Some authors claim that, because of the cost of gathering information, international investors do not assess country-specific risk correctly, and treat different economies as if they were homogeneous group. A crisis in country n can be seen as a public signal that leads international investors to reassess profitability in any country m with similar characteristics to country n : geographical location, current account deficits, public sector deficits and so on.

Belief-updating and learning are at the core of the debate on the spread of the *Russian virus* to Brazil. Some observers stress the information content of the decision by the IMF to suspend financial guarantees to Russia. In light of the Russian crisis, the IMF appeared to be less ready to stand in support of crisis countries. Investors then reassessed the riskiness of their positions in Brazil (Corsetti *et al.*, 1998). Other authors highlight asymmetric information across investors. Assume that, realistically, investors who had taken long positions in Russia were (at least ex ante) significant and well-informed. Hit by the Russian crisis, these investors were needed cash to meet margin calls. Suppose that, for this reason, they sold Brazilian assets. If this were the case (it is a big 'if'), less-informed investors may not have been able to

see the true motivation for the sale. Suspecting that well-informed investors knew something about Brazil that the rest of the market ignored, they were willing to buy only at a substantial discount.

Herd Behavior

While in a standard Arrow-Debreu framework trades among agents occur simultaneously, in recent years many models have examined the consequences of *sequential* trades. Suppose that agents take *similar decisions* (e.g., buy/sell, attack/don't attack, withdraw/remain), choose *sequentially*, have *private information*, and *can observe each other's actions*. Since any action reveals at least part of the information on which it is based, any early decision can be rationally exploited by other agents in their subsequent choices. In other words, any early action has a feedback effect on later decisions. Several models have shown that, in this environment, agents tend to ignore their own information and prefer to take decisions by relying completely on the previous actions of other agents (*herd behavior*).¹¹ In particular, agents will all select the same action after a certain threshold of observed actions and, in financial markets, they will give rise to discontinuities.

Despite the large body of literature on herd behavior, few models have analyzed its connections with the international transmission of shocks. Calvo (1999) considers the huge fixed costs necessary to gather information about emerging economies. Such costs generate economies of scale, which induce the financial industry to organize itself in clusters of specialists. It is thus possible to distinguish between informed and uninformed agents in a given country. Informed agents are likely to have highly leveraged portfolios (they have more incentives to borrow in order to finance their investments, due to the precision of their information) and, therefore, are more vulnerable to margin calls. When uninformed agents observe an informed agent selling (or not buying) an asset, they cannot establish whether this action reflects negative information about the asset or is caused by margin calls. In this model, if fundamentals have a higher level of volatility than margin calls, when uninformed agents observe an informed agent shortening her position, they believe that this is due to a

¹¹ Note that herd behavior occurs even if there are no externalities in agents' payoffs. When payoff externalities are included in the analysis, Dasgupta (1999) shows that agents may either completely neglect their own information (*strong herd behavior*) or may be over-optimistic with respect to a situation where information-processing grants an efficient outcome (*weak herd behavior*).

sudden worsening of the fundamentals. They may then react by imitating the behavior of informed agents and causing a massive capital outflow, unjustified on the basis of changes in fundamentals.

In a related paper, Calvo and Mendoza (1999) examine the consequences of information costs. Obviously, the greater the cost of buying information, the higher the incentive to rely on the freely observable decisions of other agents. As the number of markets grows, the incentive to gather costly country-specific information weakens, whilst the incentive to imitate arbitrary market portfolios increases. In fact, when information is costly, the benchmark portfolio reflects an information set that is hardly obtainable by a single investor. Hence, investors do not update their costly information sets and rationally choose to imitate a pre-determined market portfolio. In this setup, agents' behavior becomes very sensitive to rumors, due to the cost of verifying their veracity. This tends to increase volatility in financial markets, facilitating the cross-border transmission of country-specific rumors.

4. A review of the empirical literature

Empirical literature on the international transmission of shocks is gathered and classified in many groups, following the definitions and measures given in section 2. Our classification does not claim to be exhaustive, but endeavours to cluster several tests into groups characterized by similar methodology and scope of analysis.

We distinguish two main kinds of study. The first considers empirical analyses that attempt to measure the effect of a shock in one country on other countries. This group includes **probit and logit models**, where the initial shock is an extreme value of an indicator of speculative pressures; the **leading indicators approach**, which builds on probit and logit models in an attempt to select a parsimonious set of indexes of vulnerability to external or internal shocks; and **GARCH models**, which deal with the transmission of volatility shocks.

The second group of studies considers empirical analyses in which contagion is defined in terms of discontinuities in the data-generating process. This group includes tests on structural breaks in correlation (also called **studies on correlation breakdowns**) and estimations of **Markov switching models**, which directly test the presence of multiple equilibria.¹²

¹² We neglect empirical studies on herd behavior, because they are still at a very preliminary stage and, to our

4.1 *Probit and logit models*

A seminal approach to the empirical analysis of contagion is made by Eichengreen *et al.* (1996). The authors construct an index of *exchange rate market pressure* (ERP), as a weighted average of changes in the exchange rate, short-term interest rates and international reserves. As a dependent variable, they define a ‘crisis dummy’ that takes a unit value for extreme values of ERP (and zero otherwise) and estimate a probit model with a set of macroeconomic and political fundamentals among the independent variables. Their estimates from a panel of 20 industrialized countries from 1959 to 1993 show that the occurrence of a currency crisis in one country increases the probability of a speculative attack in other countries by 8 percentage points. This effect is not only statistically significant, but the crisis dummy turns out to be the most significant variable in the model. The authors also try to compare two different causes for transmission: trade linkages and macroeconomic similarities. They build an indicator of trade linkages and one of macroeconomic similarities and find that when they include both indicators in the model only the first one is statistically significant.

This technique has since been widely used. Kumar *et al.* (1998), who refine the model by adding lagged financial and macroeconomic variables, claim that their model has a high explanatory power. In fact, major crashes (Mexico in 1994, Thailand and Korea in 1997) are correctly forecast; moreover, they show that trading strategies based on their out-of-sample forecasts could have yield positive profits during these two episodes. Caramazza *et al.* (2000) also estimate a probit model on a large data set of 61 industrial and emerging countries. They focus on the role of external and internal macroeconomic imbalances, financial weaknesses (proxied by the ratio between short-term debt and international reserves), trade and financial linkages. In particular, their model shows that trade linkages (measured by an index constructed to account also for third market competition) and financial linkages (represented by correlation with the stock market of the crisis country) play a significant role in explaining the transmission of currency crises.

knowledge, have never been used to analyze the international transmission of shocks. For a review of theoretical and empirical models of herd behavior, see Bikhchandani and Sharma (2000).

4.2 *Leading indicators*

A somewhat different approach to the analysis of currency crises is proposed by Kaminsky *et al.* (1998), who evaluate the ability of a set of macroeconomic and financial indicators to forecast the occurrence of a currency crisis correctly. In line with previous models, a crisis is defined as a month in which the variable ERP takes extreme values.¹³ For each indicator the authors establish a threshold S , so that the indicator is said to release a signal whenever it is larger than S . To fix the threshold optimally, the authors consider the indicator obtained from the following table:

	crisis within 24 months	no crisis within 24 months
signal	$A(S)$	$B(S)$
no signal	$C(S)$	$D(S)$

where A and B are the number of months in which the indicator gives a good and a bad signal, respectively, C is the number of months in which the indicator fails to release a signal, and D is the number of months in which the indicator does not release a signal correctly. For each indicator, an optimal threshold S^* is determined as the solution to the problem $\min B/A$.¹⁴ Kaminsky *et al.* (1998) identify with this method 12 useful indicators, defined as those indicators for which B/A is less than unity.

This approach has been refined and tested in several papers. Kaminsky (1999) computes a single composite indicator given by a weighted average of the previous indicators. Further refinements are performed by Bussière and Mulder (1999) and Borensztein *et al.* (1999) who tested the similar Early Warning System model developed by the International Monetary

¹³ Unlike Eichengreen *et al.* (1996), Kaminsky *et al.* (1998) do not consider changes in interest rates in their ERP variable.

¹⁴ The method is equivalent to minimizing the *adjusted noise-to-signal ratio*, given by $B/(B+D)/A/(A+C)$, because $(A+C)/(B+D)$ depends only on the number of crises in the sample and not on the threshold S .

Fund.¹⁵ Finally, Hardy and Pazarbaşıoğlu (1998) identify macroeconomic and financial indicators for banking crises.

In a recent paper, Berg and Pattillo (1999) show that the original set of indicators developed by Kaminsky *et al.* (1998) performed poorly in predicting the Asian currency crisis. They estimate the thresholds with data available until April 1995, and find that most of the months of crisis (about 91 per cent) were not signalled, while around 44 per cent of the crisis signals were false alarms. Recent econometric models that have started to include in the analysis indicators of vulnerability to contagion – often stemming from the so-called common lender channel – typically get better performances (Sbracia and Zaghini, 2001b).

4.3 *GARCH models*

Empirical studies of the transmission of shocks across financial markets with generalized autoregressive conditional heteroskedastic (GARCH) models have been proposed by Hamao *et al.* (1990), who analyzed the transmission of volatility after the stock market crash of October 1987. The authors find evidence of volatility spillover effects from the US and UK stock markets to the Japanese market. Interestingly, while these effects are statistically significant, spillovers in other directions after 1987 or in any direction before 1987 are much weaker.

Edwards (1998) focused on the transmission of volatility across Latin American bond markets after the Mexican crisis in 1995. He estimates a univariate GARCH model which shows that the increase in volatility in Mexico had a significant impact on the volatility of the bond market in Argentina, and not in Chile.

Engle *et al.* (1990) tackle the question of the causes of yen/dollar intra-day volatility. In particular, they wonder if such volatility has only country-specific autocorrelation (*heat waves*) or is affected by spillovers from other countries (*meteor showers*). In order to test the relative importance of the two hypotheses, they consider the intra-day volatility of the yen/dollar exchange rate from 3 October 1985 to 26 September 1986. Although Japanese news seems to have the largest impact on volatility, their GARCH model supports the hypothesis of meteor showers. Similarly, Fleming *et al.* (1998) analyze the co-movements of volatility in

¹⁵ The Early Warning System developed by the staff of the IMF features five variables: current account deficits as percentage of GDP, export growth, misalignments of the real effective exchange rate, short-term debt over international reserves, and percentage change in international reserves.

US, UK and Japanese bonds, showing that volatility in Tokyo and London is characterized by *meteor showers*, whilst in New York it is due only to *heat waves*.

4.4 *Studies of correlation breakdowns*

An influential study by King and Wadhvani (1990) examines the changes in correlation coefficients between different markets that occurred after the stock market crash of October 1987. The paper investigates why, in October 1987, almost all stock markets fell together, despite widely different economic circumstances. In their model, the transmission of shocks among stock markets of the United States, Japan and the United Kingdom occurs as a result of attempts by rational agents to infer information from price changes. The model assumes that there are two types of information, idiosyncratic and systematic. The former is country-specific, the latter affects all markets. Since the information set has two dimensions, the rational expectations equilibrium is such that stock prices do not fully reveal agents' private information. In this set-up, King and Wadhvani define excessive transmission as a change in the covariance matrix of returns. Their empirical estimates show that volatility in the London stock market is higher than usual when the New York Stock Exchange is open. Moreover, volatility correlation coefficients in the London, New York and Tokyo markets significantly increased after the 1987 crash.

Baig and Goldfajn (1998) analyze the stock market returns, interest rates, sovereign spreads, and currencies of five Asian countries in order to verify the occurrence of excessive co-movements of these variables during the 1997 Asian crisis. The authors first find that, for each variable, correlation across countries was significantly higher in the period July 1997 - May 1998 than in the period January 1995 - December 1996. They then estimate a linear regression model for each variable and test the effects of own-country good and bad news and common external factors such as the US stock index and the yen/dollar exchange rate. Their estimates for Asian stock prices and exchange rates show that bad news typically has a larger impact than good news, and that correlation coefficients of residuals are still significantly different from zero, providing evidence of cross-border 'contagion'.¹⁶

¹⁶ Similarly, Kaminsky and Schmukler (1999) build a set of economic, financial and political news and find that they have a significant effect on stock prices. Moreover, bad news seems to have a larger impact than good news.

The traditional tests of breakdowns in correlation coefficients, which typically find excessive transmission of shocks and discontinuities in the data generating process, have recently been challenged. Several papers (in particular, Forbes and Rigobon, 1999; Rigobon, 1999; Boyer *et al.*, 1999; Loretan and English, 2000; Corsetti *et al.*, 2001) showed that standard analyses do not consider the problem of *selection bias*, which occurs whenever tests are conducted on *ad-hoc* subsamples (like the periods of crises).¹⁷ In particular, when two random variables X and Y are positively correlated, their correlation coefficient may be an increasing function of the variance of each of them. In particular, this is always the case if X and Y are normally distributed (Loretan and English, 2000) or if one variable is a linear function of the other variable (Forbes and Rigobon, 1999).

In general, correlation coefficients in specific subsamples tend to be biased in the presence of heteroskedasticity and endogeneity or if some variables are omitted. Therefore, when comparing correlation coefficients over a specific subsample, one needs to correct the bias in the coefficients generated by the different variances assumed by the variables in that subsample. For instance, during the crisis periods, economic variables generally show an increase in volatility. Hence, empirical tests that do not correct for the bias, typically tend to favor the hypothesis of excessive transmission.

Forbes and Rigobon (1999) estimate a VAR model with daily returns of the stock market and short term interest rates of several industrial and emerging countries, with reference to three financial crisis (the Wall Street crash on October 1987, the Mexican crisis in 1994-95 and the Asian crisis in October 1997). When correlation coefficients are adjusted for the increased volatility, the hypothesis of correlation breakdown is rejected in most of the cases.¹⁸ In fact, they argue that the increase in correlation observable after a shock in one country is simply due to the interdependence among stock markets and not to a change in linkages. Similarly, Rigobon (1999) builds an instrumental variable estimator for testing the correlation breakdown hypothesis relative to 36 stock markets of industrial and emerging countries during

¹⁷ King and Wadhani (1990) are aware of the relationship between volatility and correlation as they write: “we might expect that the contagion coefficients would be an increasing function of volatility” (pp. 20). However, in calculating correlation between markets, they do not correct for the increase in volatility.

¹⁸ Their methodology rejects the hypothesis of correlation breakdown for all countries during the Wall Street crash on October 1987 and during the Mexican crisis in 1994-95. In the case of the Asian crisis, they find excessive transmission of the shock originated in Thailand only for Hong Kong and Italy.

the same crisis episodes, showing that, unlike traditional analyses, the hypothesis is almost always rejected.

Boyer *et al.* (1999) and Loretan and English (2000) refine the methodology by calculating corrected correlation coefficients under the assumption of normally distributed variables.¹⁹ They compute these coefficients for the correlation between daily returns on the UK FTSE 100 and the German DAX stock indices, between daily returns on German and British bonds, and between daily returns on the dollar/yen and dollar/mark exchange rates. The estimates show that the link between volatility and correlation during the Mexican crisis is remarkably close to what the theory would suggest, showing no evidence of structural change.

Corsetti *et al.* (2001) propose a factor-model approach to the empirical analysis of correlation breakdowns that gathers all the previous tests into a unique theoretical framework. They show that previous tests derive their measures of interdependence by making a specific yet arbitrary identification assumption about a key parameter, called λ -ratio. This is the ratio between the variance of the country-specific shock and the variance of the global factor weighted by its factor loading. Tests that implicitly select a low value for the λ -ratio tend to accept the null hypothesis of interdependence, while tests that select a high value for the λ -ratio tend to reject the null hypothesis of no contagion. Corsetti *et al.* (2001) apply their model to the case of the October 1997 stock-market crisis in Hong Kong. They show that when the λ -ratio is estimated – rather than arbitrarily fixed – the null hypothesis of interdependence is erroneously accepted by existing tests in a number of cases, while it should be rejected in favor of contagion.

4.5 *Markov switching models*

In the last years, a different kind of empirical analysis has been developed to test discontinuities in the data-generating process, which is based on the Markov switching model developed by Hamilton (1994) and others.²⁰ This framework has the advantage that discontinuities can be directly attributed to jumps between multiple equilibria.

¹⁹ Boyer *et al.* (1999) extend their results to the case of normal random vectors that make it possible to account for the case of time series.

²⁰ Markov switching models have been applied to many economic phenomena, including the business cycle, the term structure of interest rates, the dynamics of floating exchange rates and, more recently, currency crises. General applicability to the case of models with multiple equilibria is discussed in Jovanovic (1989).

Jeanne (1997) considers a second generation model of currency crisis in which, for a given range of fundamentals, multiple equilibria arise and determine three different probabilities of a devaluation. In his setting, jumps between multiple equilibria correspond to jumps between the probabilities of a devaluation. Similarly to the classical models illustrated in the theoretical section, once fundamentals enter a multiple equilibria zone, jumps can occur as a result of a sunspot, without any further change in the economy. Moreover, such a sunspot can be represented by a 3×3 Markov transition matrix, which defines the probability that the economy will jump from one given probability of a devaluation to another. Jeanne applies the model to the exchange rate of the French franc with the German mark from January 1991 to July 1993. He considers a set of fundamentals that includes the unemployment rate, the trade balance to GDP ratio and the real exchange rate. He then estimates a Markov switching model, finding the following results: (i) after August 1992, the fundamentals of France entered a multiple equilibria zone; (ii) this event was mainly determined by a worsening of the unemployment rate and an appreciation of the real exchange rate;²¹ (iii) estimates of the Markov transition matrix show that, once fundamentals had entered the multiple equilibria zone, the economy was likely to jump to the highest probability of devaluation; (iv) the model performs remarkably better than a simple linear regression model.

Jeanne and Masson (1998) extend both the empirical and the theoretical framework, by including non-linearities and the possibility of chaotic dynamics. In particular, they estimate a model where fundamentals also include a time trend, intended to capture reputation effects that, as suggested by Masson (1995), should grow gradually as a result of Bayesian learning of speculators. In this model, the sunspot is represented as a 2×2 Markov transition matrix. Their estimates, performed over a longer horizon (February 1987 - July 1993), yield essentially the same results as Jeanne (1997).

In a recent paper, Fratzscher (1999) built a model in which the exchange rate pressure in one country depends on a set of fundamentals of this country, some measures of its real integration (trade linkages) and of financial integration with other countries, and the

²¹ The appreciation of the real exchange rate can be surprising, because France had a lower inflation rate than Germany. However, a closer inspection shows that the appreciation was mainly a consequence of the weakness of the US dollar. As also Giavazzi and Giovannini (1986) documented, when the dollar was expected to weaken, investors tended to reallocate their portfolio towards Deutsche mark denominated assets, generating tensions in the European Monetary System. Jeanne (1997) suggests that this effect may have been more important in the French crisis than is usually acknowledged.

possibility of regime-switching.²² He estimates both a 2-regime and a 3-regime Markov switching model on data from 25 emerging countries from 1986 to 1998. Interestingly, he finds that, although Markov switching models without real and financial integration perform well for most countries, any regime-switching is eliminated when integration is included in the analysis. In particular, the model indicates that the transmission of shocks (from both real and financial channels) plays a major role in determining exchange rate pressure both in tranquil times and during crisis periods. Fratzscher (1999) also uses his estimates in order to obtain, for any country, a prediction of the severity of the exchange rate pressure during the Mexican and the Asian crisis and a rank of the vulnerability of countries for both episodes. A comparison with analogous predictions from some leading indicator models highlights that Fratzscher's model with fundamentals and regime-switching does not perform much better. However, when integration is included, the model provides much better forecasts.

²² Fratzscher (1999) proposes a measure of real integration that is a weighted average of bilateral trade and competition in third markets. The index of financial integration is, instead, based on correlation among stock market returns, after controlling for country-specific factors.

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