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SYSTEMIC RISK: A SURVEY

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ABSTRACT

Systemic Risk: A Survey*

This Paper develops a broad concept of systemic risk, the basic economic concept for the understanding of financial crises. It is claimed that any such concept must integrate systemic events in banking and financial markets as well as in the related payment and settlement systems. At the heart of systemic risk are contagion effects, various forms of external effects. The concept also includes simultaneous financial instabilities following aggregate shocks. The quantitative literature on systemic risk, which has evolved swiftly in the last couple of years, is surveyed in the light of this concept. Various rigorous models of bank and payment system contagion have now been developed, although a general theoretical paradigm is still missing. Direct econometric tests of bank contagion effects seem to be mainly limited to the United States. Empirical studies of systemic risk in foreign exchange and security settlement systems appear to be non-existent. Moreover, the literature surveyed reflects the general difficulty in developing empirical tests that can make a clear distinction between contagion in the proper sense and joint crises caused by common shocks, rational revisions of depositor or investor expectations when information is asymmetric (‘information-based’ contagion) and ‘pure’ contagion as well as between ‘efficient’ and ‘inefficient’ systemic events.

JEL Classification: E49, G12, G21, G29
Keywords: banking crises, contagion, currency crises, financial markets, financial stability, payment and settlement systems, systemic risk

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NON-TECHNICAL SUMMARY

In this Paper we discuss the various elements of systemic risk with a view to first develop a broad concept of this risk, which is underlying the understanding of financial crises, and that can be used as a baseline for financial and monetary policies to maintain stable financial systems. We argue that a comprehensive view of systemic risk has to integrate bank failure contagion with financial markets spillover effects and payment and settlement risks. At the very basis of the concept (in the 'narrow' sense) is the notion of contagion – often a strong form of external effect – working from one institution, market or system to the others. In a 'broad' sense the concept also includes wide systematic shocks which by themselves adversely affect many institutions or markets at the same time. In this sense, systemic risk goes much beyond the vulnerability of single banks to runs in a fractional reserve system.

We identify three interrelated characteristics that may justify why financial systems can be more vulnerable to systemic risk than other sectors of the economy: the structure of bank balance sheets, the complex network of exposures among financial institutions and the intertemporal character of financial contracts and related credibility problems. However, not all systemic events in financial systems need to be inefficient. Some financial crises might just eliminate inefficient players in the system, in particular when asymmetric information has prevented the market mechanism from doing its job *ex ante*. We therefore also discuss the relevance of systemic risk for economic policy. In relation to the threat of inefficient and destabilising systemic events systemic risk can justify preventive (*ex ante*) policies like financial regulation and prudential supervision or maintaining a stable macroeconomic environment. If problems could not be prevented *ex ante*, they may justify *ex post* measures in the form of crisis management. A widely debated issue is whether crisis management should include lender-of-last-resort action, be it in the form of macroeconomic monetary policy ('lending to the market') or in the form of microeconomic emergency liquidity assistance ('lending to individual banks').

We review the quantitative literature in the light of our concept of systemic risk. Some important new contributions have appeared in this literature in the last couple of years. First of all, and probably most importantly, a considerable number of theoretical studies have now directly addressed the issue of bank contagion. Although a generally accepted paradigm has not yet emerged, these models have greatly enhanced our understanding of the potential propagation of problems in the banking and payment system. The second important theoretical development in the area of systemic risk is the development of 'third-generation' models of currency crises, addressing both 'pure' and 'information-based' contagion effects. In contrast, the theoretical

literature on contagion in other financial markets is still progressing, in particular regarding the distinction between inefficient but ‘normal’ price propagation and real crisis situations.

On the empirical side a few valuable developments on the explanation of banking crises across countries have recently taken place, but insights into payment system contagion remain scarce, particularly outside the US and on other than net settlement systems. Whereas the empirical literature has provided some evidence of the existence of systemic risk, in particular in the ‘broad’ sense, it is more puzzling that many tests for bank contagion do not control for all the macroeconomic factors that might be behind the observation of joint bank failures in history. These difficulties in identifying empirically the importance of contagion as opposed to joint banking crises as consequences of macro shocks is not innocuous, since it has some implications for crisis management polices. Bank crises emerging from contagion could be stopped at an early stage at the individual bank level through emergency liquidity assistance – if identified in a timely manner – whereas macro problems would normally be addressed through more standard stabilization policies, such as open market operations. In other words, the current empirical literature cannot resolve the old policy debate about emergency lending to individual banks versus lending to the market. Moreover, most traditional tests for bank contagion are not conclusive about whether spillovers are ‘information-based’ or ‘pure’ sunspot phenomena, and whether the former constitute efficient or inefficient systemic events. Finally, the overwhelming part of existing econometric tests for bank contagion effects is still limited to data for the United States. Event studies of bank equity returns, debt risk premiums, deposit flows or physical exposures for European, Japanese or emerging market countries are rare or virtually absent. Clearly, more empirical research is needed about the actual importance and character of bank contagion, but this agenda will not be easy to fulfil due to the presence of safety nets in many countries.

Similar reservations about the empirical importance and character of securities market contagion are also advisable, but with less direct policy implications. Particularly, the widely used conditional correlation measure may be subject to various statistical biases. Most recently, multivariate extreme-value theory has been successfully applied to extreme co-movements in equity, bond and money market returns, but as a consequence of the low frequency of macroeconomic statistics it cannot be easily linked to the literature on ‘excess’ co-movements. The recent econometric literature on contagious currency crises seems to have made considerable progress in disentangling different channels of contagion and joint crises. However, empirical studies about contagion risks in foreign exchange and security settlement systems are simply non-existent. Research in this field is needed desperately.

CONTENTS

SYSTEMIC RISK: A SURVEY

1. INTRODUCTION

In the last couple of years significant concerns about the stability of national and international financial systems have been raised. These concerns are reflected in a series of official summits and reports, private initiatives and academic papers,[1] and they have been underlined by the recent East-Asian crisis, the Russian crisis and also the Brazilian crisis. Fears exist that in an environment of relatively free international capital markets such events are becoming more frequent and that such developments may easily spill over to other countries. Although the increase in theoretical, empirical and policy analyses of financial instability has been substantial, practically all writings share - in our view - the following limitation: while "systemic risk" is now widely accepted as the fundamental underlying concept for the study of financial instability and possible policy responses, most work so far tackles one or several aspects of that risk, and there is no clear understanding of the *overall* concept of systemic risk and the linkages between its different facets.

In this paper we attempt to set a starting point for a more comprehensive analysis of systemic risk, as the primary ingredient to understand financial crises and as the main rationale for financial regulation, prudential supervision and crisis management. In a first step we bring together the most important analytical elements of systemic risk and integrate them into a coherent working concept, which could be used as a baseline for monetary and prudential policy decisions to preserve the stability of financial systems. While the "special" character of banks plays a major role, we stress that systemic risk goes beyond the traditional view of single banks' vulnerability to depositor runs. At the heart of the concept is the notion of "contagion", a particularly strong propagation of failures from one institution, market or system to another. Especially nowadays the way in which large-value payment and security settlement systems are set up as well as the behaviour of asset prices in increasingly larger financial markets can play an important role in the way shocks may propagate through the financial system. While in the presence of rapidly evolving financial institutions and markets and the particular characteristics of each financial crisis it might be futile to look for the single, ultimate definition of

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[1] Financial stability issues have recently been addressed on the G-7 1995 Halifax, 1996 Lyon and 1997 Denver summits. Among the reports and papers are Cole and Kehoe (2000), Committee on Payments and Settlements Systems (1996), Federal Reserve Bank of Kansas City (1998), Goldstein (1998), Goodhart et al. (1998), Group of Thirty (1997), International Organization of Securities Commissions (1998), Kaminsky and Reinhart (1998), Lindgren, Garcia and Saal (1996), Peek and Rosengren (1997), Working Party on Financial Stability in Emerging Markets (1997), Hunter, Kaufman and Krueger (1999), Agénor et al. (2000) and Shiller (2000). During the preparation of this paper, the G-7 countries also adopted a plan by former Bundesbank President Hans Tietmeyer to establish a Financial Stability Forum (FSF), gathering national and international authorities in charge of ensuring financial stability to further improve international co-operation

systemic risk, it may still be useful to give some general structure to our thinking in this area in order to help avoiding piece-meal policy making.

In a second step we review the existing theoretical and empirical literature about systemic risk in the light of the overall concept developed before, in order to also identify areas in which future research efforts are needed. More specifically, the survey of the empirical evidence on systemic effects, in particular on contagion effects, endeavours to clarify the practical relevance of several risk elements identified in the conceptual and theoretical parts. Our review focuses *primarily* on the quantitative theoretical and empirical literature. This should not be interpreted as meaning that we consider the more descriptive literature of particular crisis periods in history as not being important. This choice has rather been taken, first, to limit the amount of information to be surveyed to one which can be dealt with within a single paper and, second, to focus on analyses formulating and testing very specific hypotheses with the most advanced techniques.[2]

The somewhat unusual procedure to proceed from the general concept to a survey of the current literature is motivated by the fact, that when we started studying the issue of systemic risk more than two years ago this literature appeared to be very incomplete, when one confronted it with the issues raised by actual crisis situations (De Bandt and Hartmann, 1998). In this sense we try to set out, first, what we think is important for the understanding of systemic risk and second study where – in our view - satisfying answers have been given and where not. In fact, the theoretical and empirical literature on systemic risk evolved at a very rapid pace during the second half of the 1990s and many of the gaps – though by far not all – we discovered in our early work have now been filled.

Despite the considerable development of the systemic risk literature in the last years some important gaps are remaining. First, there is hardly any theoretical or empirical work on contagion in foreign exchange and security settlement systems and most empirical analyses of contagion effects in payment systems seem to be limited to net payment systems, widely ignoring "network externalities" potentially resulting from "gridlock" situations in real-time gross payment systems. Second, the overwhelming part of econometric tests for bank contagion effects is limited to data for the United States. Event studies of bank equity returns, debt risk premiums, deposit flows or physical exposures

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in financial market supervision and surveillance (Tietmeyer, 1999). The FSF, chaired by BIS general manager Andrew Crockett, published various reports of its working groups during the year 2000 (Financial Stability Forum, 2000a,b,c,d).

2 The only other large literature surveys in the area of systemic risk we are aware of have been written by Kaufman (1994) and Davis (1995). However, the former is narrower in scope than ours, focusing on bank contagion alone, mainly but not exclusively taking an empirical perspective. The latter is broader than this, building its case from the basics of the debt contract, but it does not interpret the literature within one coherent concept of systemic risk. Both papers cannot consider the more recent developments. Bartholomew and Kaufman (1995) contains a useful selection of non-technical essays about various aspects of systemic risk. Freixas and Rochet (1997, chapter 7) give a thorough theoretical exhibition of a selection of key models in the bank run literature, which are also surveyed in Bhattacharya and Thakor (1993). Dowd

for European or Japanese data are rare or virtually absent. Third, for both banking and financial markets it appears to be hard to disentangle empirically information-based revisions of expectations from “pure” contagion, “efficient crises” from “inefficient” ones and contagion from macro shocks. In the area of banking markets this difficulty has implications for the policy debate about the lender of last resort.

We very much hope that our paper (i) provides readers with an efficient access to the literature on systemic risk and (ii) helps stimulating further research efforts aiming at filling the remaining gaps identified as quickly as possible. This future research should provide additional important conceptual inputs for the understanding of concrete examples of financial crises and for potential policies to prevent or alleviate future crises. However, undertaking this research is beyond the scope of the present paper and we will only marginally scratch over policy issues, such as optimal crisis prevention and management.

The remainder of the paper is organised as follows. Section 2 contains the general conceptual discussion. It provides the framework within which the theoretical and empirical literature will be interpreted in the following parts and briefly discusses its relevance for economic policy. Section 3 gives a detailed account of systemic risks in banking markets, financial markets and payment and settlement systems, surveying theoretical models explaining them and adding theoretical considerations where no model is available. Section 4 surveys a large number of econometric tests and some other quantitative assessments of the various facets of systemic risk described before, focussing particularly on contagion but also on joint crises and crashes. Section 5 concludes.

2. THE CONCEPT OF SYSTEMIC RISK

Systemic risk in a very general sense is by no way a phenomenon limited to economics or the financial system. Maybe the most natural illustration of the concept is possible in the area of health and epidemic diseases. In severe cases (e.g. the Great Plague in the Middle Ages) widespread contamination with a disease may wipe out a significant portion of a population. In the area of economics it has been argued that systemic risk is a particular feature of financial systems. While contamination effects may also occur in other sectors of the economy, the likelihood and severity in financial systems is often regarded as considerably higher.[3] A full systemic crisis in the financial

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(1992a) reviews this literature critically. Masson (1998) provides a short survey in the area of contagious currency crises and Jeanne (1999) reviews more broadly theoretical developments in the currency attack literature (see 3.2.1.2).

[3] However, see e.g. Lang and Stulz (1992) for a study of stock market value spillovers among non-financial firms. One challenge to the existence of systemic risk is provocatively summarised by Sheldon and Maurer (1998, p. 685):

system may then have strong adverse consequences for the real economy and general economic welfare.

The objective of this section is to provide a framework for the economic analysis of systemic risk. We start out by proposing a specific terminology, clarifying some important elements of the concept of systemic risk and leading to a general working definition of it. Then, the main arguments are discussed why financial systems can be regarded as more vulnerable to systemic risk than other parts of economic systems. Since information asymmetries can play a crucial role we proceed in the next sub-section by distinguishing between self-fulfilling systemic events and those that can be regarded as individually rational responses to the revelation of new information between agents. Finally, the relevance of systemic risk for public policy is briefly examined and its challenge by the free banking school.

2.1 Systemic events

In order to reach a definition of systemic risk in financial systems, we first clarify a number of concepts - illustrated in Table 1 below - needed for that definition. We define a *systemic event* in the *narrow* sense as an event, where the release of "bad news" about a financial institution, or even its failure, or the crash of a financial market leads in a sequential fashion to considerable adverse effects on one or several other financial institutions or markets, e.g. their failure or crash. The shaded area in Table 1 encompasses these systemic events in the narrow sense. Essential is the "domino effect" from one institution to the other or from one market to the other emanating from a limited ("idiosyncratic") shock.[4] Systemic events in the *broad* sense – indicated by ticks in both the shaded and the non-shaded areas of Table1 – include not only the events described above but *also* simultaneous adverse effects on a large number of institutions or markets as a consequence of severe and widespread ("systematic") shocks. Obviously, to the extent that this impact is simultaneous this category also includes widespread effects as a consequence of the release of new information ("signals").

A systemic event in the narrow sense is *strong*, if the institution(s) affected in the second round or later actually fail as a consequence of the initial shock, although they have been fundamentally solvent ex ante, or if the market(s) affected in later rounds also crash and would not have done so without the

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"Systemic risks are for financial market participants what Nessie, the monster of Loch Ness, is for the Scots (and not only for them): Everyone knows and is aware of the danger. Everyone can accurately describe the threat. Nessie, like systemic risk, is omnipresent, but nobody knows when and where it might strike. There is no proof that anyone has really encountered it, but there is no doubt that it exists."

4 Notice that such systemic events do not include, for example, the failure of a *single* financial institution as a consequence of a wild decline of some asset value. Failures confined to single institutions lack the systemic element. See also Calomiris and Gorton (1991) and Bhattachary and Thakor (1993).

initial shock.[5] We denote these strong instances of systemic events in the narrow sense as *contagion*. Otherwise, i.e. if the external effect is less than a failure or a crash, we denote a systemic event in the narrow sense as weak. Similarly, systemic events related to systematic shocks are strong (weak), if a significant part of the financial institutions/markets simultaneously affected by them (do not) actually fail/crash.

Based on this terminology a *systemic crisis* (in the narrow and broad sense) can be defined as a systemic event that affects a considerable number of financial institutions or markets in a strong sense, thereby severely impairing the general well-functioning (of an important part) of the financial system. The well-functioning of the financial system relates to the effectiveness and efficiency with which savings are channelled into the real investments promising the highest returns. For example, a systemic financial crisis can lead to extreme credit rationing of the real sector ("credit crunch").[6] The distinction between the narrow and the broad concept of systemic events and crises is important, since crisis management measures, tackling the source of the problem, might be different in the case of an idiosyncratic shock that risks causing contagion compared to the case of a systematic shock that might have a broad simultaneous destabilisation effect (see 2.4). However, in practical crisis situations both aggregate shocks and contagious failures may sometimes become intertwined, since macroeconomic downturns might weaken financial institutions, making contagion of single failures more likely. Similarly, it might be necessary for contagion effects to materialise that the initial shock impairs more than just one financial institution, for example.

Systemic risk (in the narrow and broad sense) can then be defined as the risk of experiencing systemic events in the strong sense.[7] In principle, the spectrum of systemic risk ranges from the second-round effect on a single institution or market (column "single systemic events" in Table 1) to the risk of having a systemic crisis affecting most of the (or even the whole) financial system at the upper extreme (column "wide systemic events" in Table 1).[8] The geographical reach of systemic risk can be regional, national or international.

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5 A market crash can be defined as an unusually large general price fall. In statistical terms this fall can be made more precise by relating it to the extreme percentiles of the respective market's empirical return distribution. E.g. cases where a representative price index decreases by a higher percentage than the 1 or 5 percentile of the historical return distribution (i.e. the extreme left tail of the distribution) could be defined as crashes (Jansen and de Vries, 1991).

6 Other accompanying factors of a systemic crisis may include severe liquidity shortages in various markets, major inefficiencies in the allocation of risks and severe misalignments of asset prices.

7 Bartholomew and Whalen (1995) as well as Goldstein (1995) review various definitions of systemic risk. We think that this definition, derived from our conceptual framework, encompasses most other definitions explicitly or implicitly used so far. See also Aglietta and Moutot (1993) and Davis (1995).

8 However, as pointed out by Kaufman (1988), due to "flight to quality" it is unlikely in practice that, for example, all banks of a country face a deposit run at the same time. A similar point will apply to financial market crashes. For a discussion of the "flight to quality" phenomenon in the context of bank runs, see Benston et al. (1986, chapter 2). Hartmann, Straetmans and de Vries (2000) measure "flight to quality" in financial markets.

Table 1: Systemic events in the financial system

Type of initial shock	Single systemic events (affect only one institution or one market in the second round effect)		Wide systemic events (affect many institutions or markets in the second round effect)	
	Weak (no failure or crash)	Strong (failure of one institution or crash of one market)	Weak (no failure or crash)	Strong (failures of many institutions or crashes of many markets)
Narrow shock that propagates				
• **Idiosyncratic shock**	✓	✓contagion	✓	✓contagion leading to a systemic crisis
• **Limited systematic shock**	✓	✓contagion	✓	✓contagion leading to a systemic crisis
Wide systematic shock			✓	✓systemic crisis

Note: ✓ means that the combination of events defined by the cell is a systemic event. The shaded area describes cases of systemic events in the narrow sense. Systemic events in the broad sense *also* include the cells with ✓ in the last row.

The key element in this definition of systemic risk, the systemic event, is composed of two important elements itself, shocks and propagation mechanisms. Following the terminology of financial theory, *shocks* can be idiosyncratic or systematic. In an extreme sense *idiosyncratic* shocks are those which, initially, affect only the health of a single financial institution or only the price of a single asset, while *systematic* (or widespread) shocks - in the extreme - affect the whole economy, e.g. all financial institutions together at the same time.[9] An example of an idiosyncratic shock to a national financial system is the failure of a single regional bank due to internal fraud. The sudden devaluation of a non-internationalised currency due to an unsustainable domestic budget deficit can be regarded as an idiosyncratic shock to the world financial system. Systematic shocks to national financial systems are e.g. general business cycle fluctuations or a sudden increase in the inflation rate. A stock market crash in itself acts as a systematic shock on most financial institutions, even though due to different exposures they will usually not be affected uniformly. The same applies to a liquidity shortage in an

[9] Since it is widely used in finance, we prefer the term "systematic" for wide shocks. A systematic shock may imply a systemic event (in the "broad" sense), as explained above, but a systemic event does not need to originate in a systematic shock (e.g. in the case of contagion). Therefore, the two terms have to be distinguished.

important financial market, which can be related to a crash or to some other event throwing doubt on the financial health of counterparties usually trading in this market.

Of course, there is a continuum of intermediate types of shocks (e.g. sector-wide or regional) between the theoretical extremes of idiosyncratic and wide systematic shocks. Idiosyncratic shocks that do not propagate widely are “insurable”, in the sense that an investor can protect herself against them via diversification, whereas wide systematic shocks are often “uninsurable” or non-diversifiable. Negative systematic shocks, such as a severe recession, will - when they reach a certain strength - always adversely affect a wide range of financial institutions and markets, so that their consequences have been included in the broad concept of systemic risk.

The second key element in systemic events in the narrow sense is the mechanism through which shocks propagate from one financial institution or market to the other. In our view, this is the very core of the systemic risk concept. Systematic shocks, e.g., are equally important for the non-financial sectors in the economy. The propagation of shocks within the financial system, which work through physical exposures or information effects (including potential losses of confidence), must be “special”. In what follows we shall look at the various propagation chains in banking and financial markets in much detail. However, from a conceptual point of view it is important that the *transmission* of shocks is a natural part of the self-stabilising adjustments of the market system to a new equilibrium. What one has in mind with the concept of systemic risk (in the narrow sense) is propagation that is not incorporated in market prices ex ante or can lead to general destabilisation. Such propagation, including those taking the form of externalities, may show particularly “violent” features, such as cumulative reinforcement (“non-linearities”) and price “jumps” (“discontinuities”), for example through abrupt changes in expectations.

Regarding the type of systemic event caused in a simultaneous fashion by a systematic shock, the mechanism leading to defaults or crashes may often involve a macroeconomic propagation that includes interactions between real and financial variables. For example, a cyclical downturn may trigger a wave of failures by corporate firms, not only rendering many loans by all types of banks non-performing, but also inducing them to cut down further lending. This in turn can deepen the cyclical downturn. Also, part of the propagation may be “internal” to each financial institution or market but somewhat uniform. For example, in the case of banks the widely observed non-conditionality of deposit contracts vis-à-vis macroeconomic shocks hitting asset values has been mentioned as one major cause why banking crises in the form of simultaneous failures are often associated with severe macroeconomic fluctuations (Gorton, 1988; Hellwig, 1998).

Obviously, both the occurrence of shocks as well as the subsequent propagation is uncertain. So the importance of systemic risk has two dimensions, the severity of systemic events as well as the likelihood of their occurrence. Strong systemic events, in particular systemic crises, are low probability events, which might lead some to consider them as less of a concern. However, once a crisis strikes the consequences could be very severe.

This leads to another dimension of the concept of systemic risk, namely the impact of systemic events occurring in the financial sector on the real sector, more precisely on output and general welfare. One may distinguish a *horizontal* view on the concept of systemic risk, in which the focus is limited to events in the financial sector alone (through the bankruptcy of financial intermediaries or the crash of financial markets), from a *vertical* view on systemic risk, in which the impact of a systemic event on output is taken to gauge the severity of such an event.[10] In many of the papers discussed below real effects play some role. However, in order to keep the scope of the paper manageable we concentrate the discussion on the horizontal dimension.[11]

2.2 The financial fragility hypothesis

Why is it then that systemic risk, in particular potential contagion effects, are of special concern in the financial system? There are three interrelated features of financial systems that can provide a basis for this "financial fragility hypothesis": (i) the structure of banks, (ii) the interconnection of financial institutions through direct exposures and settlement systems and (iii) the information intensity of financial contracts and related credibility problems.

(i) Traditionally, commercial banks take fixed-value deposits that can be withdrawn (unconditionally and at fixed value) at very short notice and lend long term to industrial companies (Bryant, 1980; Diamond and Dybvig, 1983). Normally, i.e. when the law of large numbers applies, only a small fraction of assets needs to be held in liquid reserves to meet deposit withdrawals. This fractional reserve holding can lead to illiquidity and even default, when exceptionally high withdrawals occur and long term loans cannot be liquidated, although the bank might be fundamentally solvent in the long run.[12] Moreover, single bank loans do not have an "objective" market price. Since usually the lending bank alone has most information about the real investments funded, they are largely non-fungible. (However, nowadays this statement needs to be qualified to the extent that single loans to certain types of borrowers (or the credit risk incorporated) can be bundled and traded via securitisation

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10 We would like to thank Lorenzo Bini-Smaghi, who suggested this distinction and terminology.

11 See Lindgren, Garcia and Saal (1996) for a synthesis of the output effects of a large number of financial crisis situations. As is evident from systematic shocks as one potential source of systemic crises (Table 1), the relationship between the performance of the real and financial sectors can go in both directions (see e.g. sub-section 3.1.1.2).

12 Diamond and Rajan (2000a,b) argue that this fragility in the structure of banks is a necessary side-effect of an efficient performance of their role as liquidity providers to the economy. See sub-section 3.1.2.

techniques (or credit derivatives). See e.g. Goodhart et al., 1998, chapter 5.) So, the health of a bank not only depends on its success in picking profitable investment projects for lending but also on the *confidence* of depositors in the value of the loan book and, most importantly, in their confidence that *other* depositors will not run the bank. Notice that this "special" character of banks does not apply to most other financial intermediaries, such as insurance companies, securities houses and the like (see e.g. Goodhart et al., 1998, chapter 1).[13] However, if banks and other intermediaries belong to the same financial entity, as is now more often the case, non-bank intermediaries' problems might still become a source of bank fragility. Obviously, the more depositors are protected through some deposit insurance scheme – as it exists now in most industrialised countries -, the less likely (ceteris paribus) confidence crises will become.[14]

(ii) There is a complex network of exposures among banks (and potentially some other financial intermediaries) through the interbank money market, the large-value (wholesale) payment and security settlement systems (Humphrey, 1986; Folkerts-Landau, 1991; Committee on Payment and Settlement Systems, 1992, 1996). In fact, banks tend to play a key role in wholesale and retail payment and settlement systems. At certain points during the business day, these exposures can be very large, so that the failure of one bank to meet payment obligations can have an immediate impact on the ability of other banks to meet their own payment obligations. Even worse, a crisis situation can trigger difficulties in the technical completion of the different steps of the payment and settlement process, which would amplify effective exposures and "domino" effects. Various techniques used in securities and derivatives markets, such as margin requirements and portfolio insurance, although intended to limit risk ex ante can also account for large and immediate payments needs by banks and other intermediaries ex post, namely in times of large asset price changes. To the extent that financial conglomerates encompass banks and other financial intermediaries, securities or insurance subsidiaries might also play a role in these interlinkages. Various risk management measures are usually applied to limit the potential of contagion in payment and settlement systems.[15]

(iii) The third feature is, more generally, the information and control intensity of financial contracts (e.g. Stiglitz, 1993). Financial decisions aim at the intertemporal allocation of purchasing power for consumption and are, therefore, based on expectations on what the value of the respective asset is going to be in the future or whether the future cash flows promised in a financial contract are going to be met. (The use of deposit contracts described in (i) provides a specific example.) Hence, when uncertainty increases or the credibility of a financial commitment starts to be questioned, market

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[13] The speciality of banks and their vulnerability to runs is widely recognised in the economic literature, which will be surveyed in detail in section 3.1.

[14] The problems associated with deposit insurance and their relationship to systemic risk are addressed in sub-section 2.4.

[15] Financial intermediaries' interconnection through payment and settlement systems is further studied in section 3.3.

expectations may shift substantially and "individually rationally" in short periods of time and so may investment and disinvestment decisions. For example, this can lead to large asset price fluctuations, whose sizes and sometimes also directions are virtually impossible to explain through "fundamental" analysis alone (Shiller, 1989b).[16]

These three features taken together seem to be the principal sources for the occasionally higher vulnerability of financial systems to systemic risk than other sectors of the economy.

2.3 "Efficient" versus self-fulfilling systemic events

Regarding the assessment of various systemic events, the information intensity of financial contracts underlines the importance of the distribution of information among the agents acting in the financial sector. General uncertainty and agents' awareness of potential asymmetries of information highlight the role that expectations can play for the occurrence or not of systemic events. In fact, systemic events driven by expectations might be individually rational but not socially optimal.

It is useful to distinguish three potential causes of narrow systemic events related to asymmetric information and expectations. These are, first, the full revelation of new information about the health of financial institutions to the public; second, the release of a "noisy signal" about the health of financial institutions to the public; and, finally, the occurrence of a signal which co-ordinates the expectations of the public without being actually related to the health of financial institutions ("sunspot"; Cass and Shell, 1983). Analogous cases apply to the release of information about asset values in financial markets, but for the purpose of illustration we shall continue with the example of banks.

Suppose that, hidden from depositors, a bank has made a number of loans that turn bad, so that it is basically insolvent but continues to survive for some time since it can roll over debts in the interbank market. Suppose further that other banks – having neglected to monitor their counterparties properly – develop substantial exposures to it. If the information about these facts were then released in full, it would be individually rational for depositors to withdraw their funds and force those banks into liquidation. Ceteris paribus such an outcome, which can be denoted as a "fully revealing" equilibrium, would also be "efficient", as opposed to a scenario where the bank continues to accumulate losses.[17]

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[16] Fundamental analysis attempts to explain or predict asset price changes through the factors influencing the "intrinsic" values of assets. For example, "fundamentals" influencing shares are companies' earnings, "fundamentals" influencing exchange rates include inflation rates.

[17] The efficiency holds under the assumption that there would not be any subsequent problems in the payment system amplifying the problem beyond the group of unsound banks. In a somewhat related vein, Kaufman (1988) points to a

Second, suppose that the information about bad loans and interbank exposures is not revealed in full but that depositors only receive imperfect information (a "noisy" signal) from some outside source, which from their point of view increases the likelihood for those facts. In such a situation it might still be rational for them to try and withdraw their funds early and thereby force the default of those banks. Whether the signal has been "right" or "wrong" would determine, ceteris paribus, whether this outcome is "efficient" or not. As it is triggered by imperfect information on fundamentals, this type of contagion could be denoted as "information-based".[18]

Finally, suppose that the level of deposit withdrawals in itself provides an imperfect signal for all depositors about the health of their own banks and the respective banks' interbank counterparties. This "endogenous uncertainty" enters an element of circularity and causes depositors to behave in a way that results in multiple equilibria. In these circumstances, even if all the banks have been healthy ex ante, any event that co-ordinates depositors' expectations about other depositors' withdrawals might induce them to rush to withdraw even from different banks and force those banks into liquidation. The related systemic event might still have been "individually rational" ex ante, while the outcome in the form of a self-fulfilling panic or "pure" contagion is inefficient, since depositors lose the benefits from financial intermediation (and might also incur capital losses if the liquidation leads to asset values declining below the "normal", non-crisis market levels).[19]

The asymmetric information problems also illustrate how financial problems can build up over an extended period of time before an "efficient" or "inefficient" crisis occurs. In other words, the systemic event is only the effect of a more fundamental underlying problem, which has been hidden from policy makers or the general public for some time. For example, reckless lending and bad loans might have built up for some time in the banking sector before some explicit shock triggers a systemic event. Similarly, stock market prices might have stayed overvalued for an extended period until specific news make the bubble burst. Or, the exchange rate level defined by a fixed-rate arrangement might have become out of line with economic fundamentals for quite some time until some news trigger speculative attacks, potentially resulting in considerable "undershooting" and also contagion. Hence, before we now turn to potential policy responses to inefficient systemic events, it needs to be stressed that ex ante policies, measures trying to prevent a fundamental problem from actually arising (such as financial regulation and supervision or measures allowing market forces to be more effective),

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"benefit" of bank crises, forcing governments to step in and close all insolvent banks so that asymmetric information between the public and bank managers is removed.

18 See Gorton (1985) for a model of fully revealing equilibria and information-based depositor runs without interbank contagion.

19 For a related discussion of "pure" contagion as a phenomenon of self-fulfilling switches between multiple equilibria in the context of currency crises, see Masson (1999a) as summarised in 3.2.1.2 below. Masson also discusses common shocks and "real" exposures – formally similar to those mentioned above – between countries as sources of joint currency crises. However, he does not consider information channels for contagion through asymmetric information.

should always be the primary defence line, so that the use of ex post policies in the form of crisis management is limited as much as possible.

2.4 Systemic risk and public policy

On the basis of the conceptual considerations presented so far, a first assessment to which extent systemic risk is relevant for economic and financial policies can be undertaken. Musgrave and Musgrave (1973) have introduced the "classical" distinction of three functions for public policies: the allocation function, the stabilisation function and the distribution function. It appears that systemic risk is, first, relevant for allocation policies. Strong systemic events, such as contagious failures, may involve external effects; i.e. the private costs of the initial failure can be lower than the social costs. As a consequence, individually rational bank management may lead to a higher level of systemic risk than would be socially optimal. This is one, may be even the fundamental rationale for the regulation and supervision of banks; an "ex ante" (or pre-emptive) policy to avoid the emergence of systemic problems (in contrast to "ex post" polices, i.e. crisis management). Notice that in this sense, the socially optimal probability of bank failures is *not* zero. However, the socially optimal probability of "pure" contagion (a self-fulfilling systemic event as described above) and certain cases of "information-based" contagion are. Apart from investor protection considerations, this point is sometimes also brought forward as a rationale for the introduction of deposit insurance schemes, one element of the safety net for financial systems often found. Another element of the safety net and of crisis management that has been widely debated is emergency liquidity assistance by the central bank to *individual financial institutions* in distress, the default of which may trigger contagion effects. Moreover, to the degree that *any* systemic event might involve payment and settlement system problems, which may amplify the strength and extent of any externalities, it also provides a rationale for ex ante policies to ensure the safety of those systems (oversight, collateral requirements, position caps etc.).

Second, a systemic crisis affecting a large number of financial institutions or markets can - via a "credit crunch" or "debt deflation" - lead to a recession or even to a depression. In such situations macroeconomic stabilisation policies, such as monetary or fiscal expansions, may be used to maintain an adequate level of liquidity in the *banking system as a whole* ("lending to the market" by the central bank) and dampen the recessionary impact on the real economy. Interestingly, in the case of systemic risk, allocation and stabilisation problems can be closely intertwined. If contagion is very strong, then the microeconomic risk allocation problem can degenerate to a macroeconomic destabilisation. So, the ex ante (regulation and supervision) and ex post (crisis management) policies described in the previous paragraph can both be seen as stabilisation policies.[20]

Now it is also clear how the concept of systemic risk developed above links to the debate about the role a central bank can take on as "lender of last resort". There are two different types of lender of last resort action. The first, a general monetary policy expansion ("lending to the market"), is one potential policy response to a systemic event resulting from an aggregate shock that affects many banks simultaneously. By definition, "lending to the market" is not sterilised, but any monetary impulse could normally be taken out of the economy at a later stage (when the crisis is over) through a more contractionary monetary policy stance.[21] The second type of lender of last resort action, emergency liquidity assistance to individual banks, is a potential policy response to individual failures that, in the absence of such emergency lending, have a high likelihood of causing contagion (systemic risk in the "narrow" sense). Individual emergency loans can be sterilised through opposite monetary policy transactions vis-à-vis the market as a whole. For various reasons, the literature about the lender of last resort showed much more controversy regarding this second type of activity than about the first one (see Goodfriend and King (1988) and Goodhart and Huang (1999) for two opposite views). This is one main motivation for developing the concept of systemic risk, distinguishing a "narrow" and a "broad" type, and for putting a lot of emphasis on the empirical evidence of contagion in section 4 of this paper.[22]

It is now widely recognised that public (and private) safety nets, whether they take the form of deposit insurance or lender of last resort facilities, apart from the beneficial stabilisation effects bear the risk of creating moral hazard. For example, if deposit insurance premiums do not reflect the banks' relative portfolio risks, then the protection may incite the insured to take on higher risks (Merton, 1976, 1978). Moreover, market expectations could be created that large financial institutions with substantial market, clearing and settlement links with many other players in the financial system are "too big to fail" or "too sophisticated to fail". Such effects may be countered by very effective prudential supervision, as for example shown by Kareken and Wallace (1978), Buser, Chen and Kane (1981) and Furlong and Keeley (1989) for the case of deposit insurance. They also create a case for "constructive ambiguity" vis-à-vis the potential use of public emergency lending. However, if the measures to

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[20] In principle, systemic crisis can also have distribution effects. Since less wealthy people will have a higher share of their, relatively small, savings invested in relatively simple bank deposits etc., and not in physical property for example, and since they might be even less able to judge the health of a bank, they are particularly exposed to lose out. In virtually all industrialised countries at present this problem is dealt with in the form of a deposit insurance scheme.

[21] For example, Friedman and Schwartz (1963) argued that a more expansionary monetary policy by the Fed during the Great Depression could have prevented banking panics and reduced the severity of the real contraction.

[22] Although systemic risk provides an analytical basis for potential lender of last resort action, it is impossible to also survey the lender of last resort literature in the present paper. A new theoretical literature about the foundations of the lender of last resort and optimal crisis management arrangements is currently emerging. For recent surveys, see Fischer (1999) and Freixas, Giannini, Hoggart and Soussa (1999). Bordo (1990) reviews the earlier literature.

control moral hazard are not successful, then the insured institutions could become more vulnerable to adverse shocks, so that the likelihood of propagation across institutions may rise as well. This latter scenario would imply a higher level of systemic risk through inadequate safety net provisions or, in other words, high costs of maintaining the safety net.

Any difficulties in implementing theoretically advisable policies to contain systemic risk also raise the issue of market-oriented approaches to deal with financial instabilities. There is an ongoing academic debate about whether "free banking" or private payment arrangements could be more efficient and equally stable than current regulated banking systems and partly public payment systems in industrial countries. "Free bankers" point to the disciplinary effects of demandable bank deposits (Calomiris and Kahn, 1991), which can also be relevant in interbank markets, and historical episodes of relatively unregulated and publicly unprotected banking systems in various countries that appeared, in the view of these authors, to be (at least) as stable as their more regulated counterparts (see e.g. White, 1984; Rolnick and Weber, 1986; Dowd, 1992b, 1996, chapter 7).[23] Apart from the ex ante disciplinary effects of greater market forces, the conceived success of the examples discussed in this literature is also seen as a result of private and self-regulated safety provisions against financial instabilities, such as clearing houses (Gorton and Mullineaux, 1987; Calomiris and Kahn, 1996; Rolnick, Smith and Weber, 1999). The more conventional view points to the risk of non-competitive practices by private "bankers clubs" or monopolies in charge of these provisions (Goodhart, 1988; Rolnick, Smith and Weber, 1998). It also highlights the "inherent instability" of free banking, as evidenced by frequent bank failures and historical episodes of systemic crises in free banking systems, and the difficulty of a private and heterogeneous club to step in decisively in a crisis situation (Goodhart, 1969, 1988).

Whereas historical analogies bear the risk of neglecting the considerable differences between today's and former financial systems, many industrialised countries have market-oriented elements in their safety net provisions; for example, the "solidarité de place" for failing banks in 1984 French banking law and "life boat" arrangements in the UK or the Liquiditätskonsortialbank fulfilling the function of a semi-private "lender of penultimate resort" in Germany.[24] A few industrialised countries have also established deposit insurance arrangements on a largely private basis (see Kyei, 1995, for a survey). Such arrangements aim at imposing the cost of financial crises on the financial sector itself, thereby working against potential moral hazard. However, the existence of public crisis prevention and crisis

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[23] Historical episodes chosen in this literature include the US free banking period (1837-63), the Scottish free banking period (late eighteenth, early nineteenth centuries), Australia (early 1890s) and Canada (late nineteenth, early twentieth centuries). White (1984), for example, argues that the English bank instabilities in the early nineteenth century did not affect Scottish free banks, and Rolnick and Weber (1986) do not find evidence that regional (intrastate) clusters of bank failures in the US free banking era spilled over across state borders.

[24] Two thirds of the Liko bank's capital are held by private and public banks domiciled in Germany and the rest by the Deutsche Bundesbank. The publicly co-ordinated but privately financed bail-out of Long Term Capital Management in September 1998 provides an example of private sector involvement of the "life boat" type.

management provisions in today's financial systems make it difficult to assess the importance of systemic risk in private financial markets, since one can never be certain about the counterfactual, i.e. the likelihood and severity of systemic events in the absence of these public provisions. In this sense the historical experience with "free banking" episodes has some value, even for the formulation of today's policies.

3. THEORETICAL MODELS OF SYSTEMIC RISK

We now consider in greater detail the forms that systemic risk may take, distinguishing between banking, financial markets and payment systems. The focus is on "horizontal" systemic risk, i.e. within the financial system. Many of the models also indicate some real implications, but we will not put them at the centre of the discussion. The theoretical literature on systemic risk is surveyed in the light of the concept discussed in the previous section.

3.1 Systemic risk in banking markets

As has been observed numerous times in the past, banks may, in the absence of a safety net, be prone to runs. At some occasions, individual runs may spill over to other parts of the banking sector, potentially leading to a full-scale panic. While the theory of individual runs is well developed, the same did *not* – until very recently – apply to bank contagion, which brings in the *systemic* component. One can distinguish two main channels through which contagion in banking markets can work: the "real" or exposure channel and the informational channel.[25] The former relates to the potential for "domino effects" through real exposures in the interbank markets and/or in payment systems. The information channel relates to contagious withdrawals when depositors are imperfectly informed about the type of shocks hitting banks (idiosyncratic or systematic) and about their physical exposures to each other (asymmetric information). In principle, these two fundamental channels can work in conjunction as well as quite independently. More elaborate theories of bank contagion, which explicitly model these channels, starting with Flannery (1996) or Rochet and Tirole (1996a), have only recently begun to be developed. Traditionally, many systemic banking panics have been associated with recessions and macroeconomic shocks (systemic risk in the "broad" sense), but formal theories beyond individual bank run models have been scarce. We start in the next sub-section with the classical bank run literature to juxtapose it with the more recent bank contagion literature. Then we discuss the small literature taking the traditional view of systemic bank panics as a consequence of macroeconomic shocks and lending booms.

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[25] See, e.g., Saunders (1987, pp. 205f.).

3.1.1 Bank runs versus bank contagion

The banking literature in the last 15 years has developed sophisticated models of *single* banks' fragility (see also point (i) in 2.2). However, regarding systemic risk the speciality of "the bank contract" is only part of the story. The other part of it are interbank linkages through direct exposures (and payment systems), which can only be studied in a model of a multiple bank system (point (ii) in 2.2). In other words, one should distinguish between a "run" which involves only a single bank and a "banking panic" where more than one bank is affected (Calomiris and Gorton, 1991; Bhattacharya and Thakor, 1993). We still start by reviewing the traditional bank run literature before covering the more recent models of contagion in multiple bank systems; encompassing models applying the logic of the single bank run literature to multiple bank systems, theories explicitly modelling physical interbank exposures and extensions of the credit rationing literature to the interbank context.

3.1.1.1 The classical bank run models

The first class of models, following Diamond and Dybvig (1983), was designed to address the issue of the instability of single banks with fractional reserve holdings. Banks transform short term deposits into long term investments, with a liquidity premium, while depositors face a pay-off externality due to a "sequential service constraint" (when depositors withdraw their deposits, a first-come-first-served rule applies) and there is no market for investment or bank shares. A fraction of bank customers experience a liquidity shock and wish to withdraw their deposits "early". The crucial element is that the fear of "early" withdrawals by a too large number of depositors may trigger a run on the bank in the form of a self-fulfilling prophecy ("sunspot").[26] Due to the stochastic nature of "early" withdrawals, this model has also led to the interpretation of bank runs as random phenomena. Whereas in the Diamond and Dybvig model banks are seen as providers of insurance for depositors against liquidity shocks, Waldo (1985) sees them as a mechanism for small savers to indirectly access primary securities markets at rates equal to their expected yields. In this model runs can also occur as self-fulfilling prophecies as a consequence of the sequential service constraint, but when they occur they imply fire sales of primary long-term securities that lead to interest rate increases and declines in the deposit-currency ratio.

In the second class of models depositor runs are caused by the release of new information about the viability of bank investments, such as a leading business cycle indicator. Gorton (1985) shows how, under complete information, rational and efficient depositor runs can occur. Under incomplete information the noisy signal can sometimes trigger rational but inefficient ("information based") runs.

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[26] Both "run" as well as "no run" are possible Nash equilibria.

The author shows that within his model this problem can be resolved by adding a suspension of the withdrawal possibility to the deposit contract, so that banks can signal the mutually beneficial continuation of investments and thereby approximate the complete information world. (No sequential service constraint is imposed.) In another model of "information based" or "efficient" bank runs by Jacklin and Bhattacharya (1988), some informed depositors receive an imperfect signal that the risky investment made by the bank may yield a lower than expected payoff. They may therefore decide to withdraw their deposits (facing a sequential service constraint), forcing the bank to liquidate its assets prematurely. In this model a trade-off arises in that equity contracts are vulnerable to asymmetric information but not runs (since they are conditional on the performance of bank assets) whereas (unconditional) deposit contracts are vulnerable to runs but not so much to asymmetric information.[27] As indicated by Chari and Jaghanathan (1988), agents can only identify the real performance of a bank *ex post*. In their model, which provides a synthesis between the first two approaches (but without a sequential service constraint), some agents receive information about the performance of the bank's assets. Although the other agents can observe the length of the "queue at the bank's door", they are not informed about the actual proportion of informed withdrawers, having received a negative signal about the bank's assets, as compared to agents simply experiencing a liquidity shock. The related signal-extraction problem can lead to uninformed depositors running the bank when the queue is too long, even if informed depositors had not received any negative signal.

Calomiris and Kahn's (1991) model points to the benefits of the demandability of deposit contracts as a disciplining tool against moral hazard by bank managers, if interbank competition is imperfect. Carletti (1999a) shows that there is a trade-off between the role of demand deposits as a disciplinary tool and as a source of bank runs, since uninformed depositors might erroneously run in response to liquidity problems (and informed depositors might follow suit) or not run in spite of solvency problems. Hence, she argues that the risk of runs might be an inefficient disciplinary tool. The beneficial role of demandable debt is also analysed by Diamond and Rajan (2000a,b) in an incentive framework without asymmetric information and loan liquidation costs. They show that deposit contracts enable banks, in spite of their relationship-related power in loan collection skills, to commit to liquidity creation by satisfying depositors' withdrawal needs while at the same time isolating banks' long-term borrowers from these shocks. In other words, in their framework liability-side fragility is a necessary condition for efficient credit provision in the economy.

[27] In general share contracts are superior to deposit contracts in the model. However, when the underlying asset is not too risky, a deposit contract, even with possible runs, may be welfare superior to a share contract.

3.1.1.2 Extensions of the classical bank run models to multiple bank systems

Garber and Grilli (1989) extend the model by Waldo (1985) to a two-country open economy environment. They show that – with fixed exchange rates or a gold standard – a bank run in one country will lead to fire sales of long term securities to the other country and higher interest rates there. If the income effect of the increased securities holdings abroad is larger than the substitution effect, then the increased foreign consumption can lead to a run abroad as well.[28] Smith (1991) extends Diamond and Dybvig's model to correspondent banking in the US during the National Banking Era. In his model, local correspondent banks may run the money centre banks following a local shock. De Bandt (1995) extends Jacklin and Bhattacharya's (1987) model to a multiple banking system and considers how an aggregate and an idiosyncratic shock affect the return on banks' assets. If depositors in one bank are the first to be informed about the difficulties experienced by their bank, depositors in other banks will then revise their expectations about the aggregate shock, and hence also the return on deposits in their own bank. This creates a channel for the propagation of bank failures. Temzelides (1997) develops a repeated version of the Diamond and Dybvig model where agents adjust their choices over time through learning from past experience with the banking system. One of the two Nash equilibria of panic/no panic is selected and learning introduces some state-persistence. The author also introduces a multiple banking system, where depositors observe bank failures in their own region and may shift to the panic equilibrium for the next period. In this specific framework, more concentrated banking systems are less sensitive to idiosyncratic shocks and are therefore less prone to contagious panics.

3.1.1.3 The modern bank contagion literature

In a recent contribution, Chen (1999) presents a rich model combining an extension of the bank run models to a multiple banking system with the literature on rational herding mentioned in 3.1.2 below (Bikhchandani, Hirshleifer and Welsh, 1992). In period 0 consumers decide whether they deposit their endowments in banks or not and the banks invest the funds they receive in uncertain long-term projects. At the start of period 1 depositors at a subset of banks learn simultaneously about liquidity shocks and about their banks' exact long-term investment outcome ("bank-specific information"), and they decide whether to withdraw or not. As a result a subset of these banks might be run and fail. Then depositors of the remaining banks learn how many of these banks failed, update their expectations in a Bayesian fashion about the likelihood that investment projects succeed in general and decide whether to withdraw or not. In the next step, still in period 1, the liquidity shocks and information about these banks are revealed and, if a panic has not taken place yet, depositors can withdraw again. At the end of

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[28] Paroush (1988) already modelled bank contagion by *assuming* that the failure of any single bank entails a chain reaction of many failing banks. He focuses on the conflict between the public's and private banks' differential interests in taking such externalities into account, and draws some policy conclusions. We focus here more on *why* such external consequences of individual banks' failures may occur in the first place.

this period, all banks that are not liquidated can invest their funds in a speculative short-term project ("gamble for resurrection"). In period 2 all remaining (long- and short-term) projects mature and remaining depositors are reimbursed.

There are two externalities in this model that cause contagious bank runs, a pay-off externality through the first-come, first-served rule for servicing withdrawing depositors and an information externality through the Bayesian updating of beliefs about the macroeconomic situation as a function of observed failures. In this framework Chen shows that, even when depositors choose (in the presence of multiple equilibria) the Pareto-dominant equilibrium, there is a critical number of early failures above which a run on the remaining banks in the system will always be triggered. This critical number is decreasing in the a priori probability for low investment returns in the economy and the pay-off for early deposit withdrawals and (weakly) decreasing in the pay-off for late withdrawals. The first fact links this model to the literature on systemic risk in bank markets in the broad sense (see 3.1.2 below). Finally, Chen shows that even if the deposit contract is designed to maximise depositors' welfare, there are cases in which systemic crises occur with positive probability in equilibrium, but there also exists a deposit insurance scheme that could eliminate any contagious bank runs in this model.

A further step are models of the interbank market and direct exposures. Rochet and Tirole (1996a) present a model of the interbank market, where peer monitoring among banks in this market solves the *moral hazard* problem between bank debt holders and bank shareholder-managers, but also induces contagion risk. In period 0 banks decide upon liquid reserves and invest available assets in risky projects ("commercial loans"). In period 1 they are hit by a liquidity shock, which – if exceeding reserves – has to be met by raising debt from outside agents. If additional debt cannot be raised, the projects have to be liquidated and do not yield any return, which can lead to banks' failures. Otherwise the project is further executed in period 2 and, if successful, a positive return is realised and shared between shareholder-managers and debt holders. However, since debt holders cannot contract on the level of effort applied by shareholder managers in the execution of projects, a moral hazard problem emerges, increasing the likelihood of zero project returns.

By assumption, under "period-1" peer monitoring among the banks the private benefits from making a low effort ("shirking") become less important relative to the private costs of proper peer project monitoring, giving the right incentives against moral hazard.[29] However, because of the existence of economies of scope between the execution of interbank peer monitoring and the effort in commercial lending in the model, the profitability and therefore the closure of the monitoring peers become

[29] The authors also analyse the case of "period 0" peer monitoring for two banks, which focuses on the precautions against liquidity shocks. Interlinkages between monitoring and monitored banks also occur in this case, but only in one direction (failure of the monitored bank impairing the situation of the monitoring bank).

intertwined with the profitability and closure of the monitored banks. For example, the authors show that, even under a Pareto optimal contractual arrangement between all debt holders and shareholder-managers in the economy, for any two banks the likelihood of one being liquidated increases with the size of the liquidity shock hitting the other. More dramatically, for certain parameter values of the framework chosen, a small increase in the size of the liquidity shock hitting any of the banks can lead to the closing down of the entire banking system, a particularly severe case of contagion.

Allen and Gale's (2000) model of bank contagion also addresses the role of interbank lending; not by focussing on peer monitoring though, but rather by focussing on the physical exposures among banks in different regions and the "real" linkages between regions, as represented by the correlation of liquidity needs of the respective depositors. Since only symmetric equilibria are analysed by the authors, each of the four regions considered can be characterised by one representative bank, taking in period 0 retail deposits (insuring depositors against liquidity shocks), lending or borrowing in the interbank market and investing in (non-risky) short or long term projects of outside firms ("loans"). In period 1 depositors whose region faces a negative liquidity shock withdraw. The bank can meet the withdrawals from maturing short-term investments, by liquidating interbank deposits it made earlier in other regions (if it is long in the interbank market), or – as a last resort at a high cost, if the other two options are exhausted – by liquidating long-term project lending. In period 2 long term projects mature, interbank and retail deposits are reimbursed, except for those banks that became bankrupt since not all retail or interbank deposit withdrawals could be served.

Normally in this model, liquidity shocks across regions fluctuate randomly, with aggregate liquidity staying constant. Banks know in period 0 the different states of nature and their probabilities, but not the effective realisation of liquidity needs, which are observed only in period 1. In this situation the interbank market serves as an insurance mechanism among banks of different regions, leading to the efficient sharing of liquidity risks and no bank failures, irrespective of the particular structure of interbank lending. However, in a "special", unexpected state of the world, which all agents in the model give zero probability in period 0, one region (A) faces additional withdrawals, so that aggregate liquidity is not sufficient to serve all depositors. The authors show that inter-regional contagion of bank failures can occur, depending on how much liquid assets the bank in A has available and how much banks in other regions have that will be affected if bank A has to withdraw its interbank deposits. Whether and how much propagation occurs depends on the parameter values. For example, for a circular lending structure (region A lends to B, B to C, C to D and D back to A; "incomplete" markets), they prove within the model chosen that for certain parameter values the unexpected liquidity perturbation can lead to the failure of the banks in all regions.[30] They argue that for more "complete" markets (each bank has lending relationships with two other regions) the system is likely to be more stable.

In a related paper Freixas, Parigi and Rochet (2000) discuss physical interbank lending exposures as a consequence of uncertain geographical consumption preferences by depositors.[31] In period 0 depositors give their endowment to their local bank (N regions with one bank each), which invests it long term or stores it. In period 1 a fraction of all depositors learn that they have to consume in a different location in period 2, and they either withdraw their endowment to transport it themselves or submit a bank payment order for transferring it. To minimise liquidation of long-term investments and foregone investment return, banks execute these orders via credit lines to each other. The resulting network of exposures are eliminated in period 2 through transfers, long-term investments mature and depositors consume.

In the case where all banks are solvent and only the liquidity shocks through geographical preferences occur, (given some parameter constraints) two pure strategy equilibria are possible. In the "credit line equilibrium" efficient interbank lending takes place, all obligations are honoured and no contagious runs occur. In the "gridlock equilibrium" depositors cause inefficient and contagious bank runs for fear of lacking reserves in the system and all investments are liquidated, although credit lines are honoured up to the total of period 2 resources. For the cases of one failing insolvent bank and of liquidity shocks, the authors discuss three scenarios of interbank exposures through credit lines: a "credit chain" (analogous to the circular, "incomplete" case in Allen and Gale (2000) above), "diversified" lending (credit lines between any two banks exist) and a money centre case (one bank is central, since the other two only have interbank lending with it and not directly with each other). In the model contagious failures occur more easily in the "credit chain" case than in the "diversified" lending case. However, in the "diversified" case withdrawals occur more easily in general (less "resiliency" of the system). In the money centre case contagious failures can happen depending on the parameters of the model.

Aghion, Bolton and Dewatripont (1999) focus again on the trade off related to interbank lending, namely that the advantage of insurance against liquidity shocks from the interbank market (resulting in fewer individual failures) comes at the price of systemic risk (contagious character of bank failures). In the model banks invest in partly illiquid projects and are subject to uncertain depositor withdrawals

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30 Allen and Gale (2000) use an example to argue that their main results are not sensitive to the zero probability assumption regarding this special shock.

31 This paper is also closely related to the authors' earlier work on interbank payment systems (Freixas and Rochet, 1998), discussed further below. In fact, it could be interpreted as a payment system contagion paper.

in periods 1, 2 and 3. If withdrawals exceed the liquid project returns, then banks can either liquidate the remaining project at a discount or enter the interbank market. If the overall available liquid funds are sufficient, then no failure occurs since interbank loans by other banks save the ones with a liquidity shortage, who can then serve their depositors. However, if one bank cannot acquire the liquidity from the interbank market and fails, then contagious runs can occur, because other depositors interpret the failure of an institution as a signal of general lack of liquidity in the banking system. In this fashion one bank failure can result in the closure of the entire banking system in this model.

Already Mishkin (1991) suggested that the classical *adverse selection* model (Akerlof, 1970) and its application to rationing phenomena in credit markets (Stiglitz and Weiss, 1981) are useful tools in explaining financial crises in history. As conjectured by Davis (1995), this literature on credit rationing can be extended to the relationships among banks in the interbank market. If banks face a demand for credit by banks of *ex ante* unknown quality, lenders may decide to ration the amount of credit to all banks instead of raising interest rates, in order to avoid the proportion of bad risks to increase with interest rates. In the same vein, Flannery (1996) suggests a model of adverse selection in the interbank market. It is assumed that banks receive imperfect signals about the quality of prospective borrowers. In this simple model, banks only lend when they receive a "good" signal. However, at some occasions, following a large shock in the financial system, banks may become uncertain about the accuracy of their assessment of the borrowing banks' credit quality. As they feel less able to distinguish between "good" and "bad" banks, lenders raise interest rates across the board. If the loan rate becomes too high, "good" banks might not be able to repay their interbank loans any more, so that illiquid but solvent banks may go bankrupt. There is no successive process of propagation in this model, so that we would rather include it in our concept of systemic risk in the "broad" sense.

Huang and Xu (1999) relate the occurrence of interbank market crises as a consequence of adverse selection to the structure of project financing in the economy and its implications for the interbank market. They compare the possibility of crises in the case of single-bank financing (one bank finances one project) and multiple-bank financing (two banks finance one project). It turns out that multiple-bank financing systems are more stable, because – as shown in the corporate finance literature (Bolton and Scharfstein, 1996) – decentralised multiple-lender debt structures can function as a commitment device to create a separating equilibrium in which insolvent banks cannot mimic solvent banks. Since under these circumstances only solvent banks can borrow in the interbank market, idiosyncratic shocks will never lead to a crisis beyond the insolvent banks. In contrast, under single-bank financing renegotiation costs are low, favouring restructuring over liquidation of projects, so that good and bad projects will be pooled and therefore an idiosyncratic shock can lead to a collapse of the interbank market, as long as the quality differences between projects are large enough.

3.1.2 Macroeconomic fluctuations, aggregate shocks and lending booms

It has been observed that many banking crises have occurred in conjunction with cyclical downturns or other aggregate shocks, such as interest rate increases, stock market crashes or exchange rate devaluations (see e.g. Gorton, 1988; Lindgren, Garcia and Saal, 1996; and also section 3.2.2). Why is it that banks get simultaneously in trouble through those events (included in the concept of systemic risk in the "broad" sense according to the terminology of section 2.1), even in the absence of direct interbank contagion, and why are most banks, the prudent ones, not better protected than the imprudent ones? One answer could be given on the basis of the individual bank run models discussed in 3.1.1.1. News about a cyclical downturn, for example, could provide the negative signal about the bank's loans to all or a subset of depositors. To the extent that the banking system is competitive, the behaviour of a representative bank can be interpreted as a parable for the banking sector as a whole. In a similar vein, Cukierman (1991) writes down a macroeconomic model in which after long-term loan contracts have been made an unexpected decline in the supply of deposits occurs, inciting banks to increase their deposit rates to attract new depositors. In other words, interest rate changes and bank profits are inversely correlated. He derives from this fact a rationale for the US Federal Reserve to smooth interest rates in attempts to stabilise the financial system.

Hellwig (1998) also stresses banks' vulnerability to macroeconomic shocks and downplays the scope for contagion. In this context he highlights the demandable and non-contingent nature of the bank deposit contract, which in contrast to the equity contract has a fixed value irrespective of the return realisations of banks' asset holdings (except in the case of bankruptcy), so that their risks on the asset side cannot be passed on to creditors. For example, interest rate changes may have a large impact on present values of banks' loan books. In Hellwig (1994) he studies the efficient allocation of interest rate risk induced by technology shocks and argues that, optimally, part of it should also be borne by agents with urgent liquidity needs, i.e. early withdrawing depositors. In fact, within the framework chosen Bertrand competition would lead to the implementation of the second-best allocation, that has this feature. Of course, this leaves the question open why in practice the market mechanism does not generate bank deposit contracts like this. Allen and Gale (1998a) take issue with the interpretation of bank runs as random phenomena, because of their historical association with severe business cycle fluctuations. They model the occurrence of runs on a representative bank in response to (aggregate) asset side risk, as reflected say by the realisation of a leading business cycle indicator, and without resorting to a "sequential service constraint" for (fixed-value) deposits. They argue that in this framework the first-best allocation can be implemented in spite of the non-contingent character of the deposit contract, when depositors make their withdrawal decisions contingent on the realisation of the leading indicator. However, the result breaks down when early withdrawals are costly, in which a public intervention is necessary to restore the first best.

Chen (1999) shows that within his model, discussed in greater detail above, an adverse macroeconomic shock will also increase the likelihood of contagion. In turn, restrictions in bank lending due to financial fragility affect the business cycle, thereby creating adverse acceleration or feedback effects.[32]

A related issue in this context is why banks expand so much credit, implying risks that can bring them simultaneously in trouble at business cycle turning points, even though they know they cannot pass on the risk to deposit values. This has been addressed in the lending boom literature. Minsky (1977, 1982) believed that the post-World War II free market economy has a natural tendency for financial instability at the aggregate level. In good times agents consume and invest, generating more income. As *euphoria* and *gregarious behaviour* pick up, more speculative or even "Ponzi finance" is undertaken, as opposed to safer "hedging finance". The boom is fed by an over-expansion of bank credit until some exogenous outside shock to the macroeconomic systems ("displacement") brings it to an end. Kindleberger (1978/1996) shares the basic model, although perhaps being more moderate in pointing out that the market system "occasionally" faces such bubbles leading to financial crises. In contrast to most of the more recent literature, these early writers emphasised the role of uncertainty (of the "Knightian" type, where agents even have no information about the probability distribution of asset returns) as opposed to risk and the inability of banks to take the appropriate decisions in some circumstances. For example, Guttentag and Herring (1984) develop a simple model of credit expansion and discuss the consequences of "Knightian" uncertainty about catastrophic shocks on investment returns and default risk premiums as priced by the market. On the basis of results from psychology they also argue that the subjective probabilities attached to catastrophic events will decline as time elapses after the realisation of such an event. This "disaster myopia" will lead to a widespread underestimation of the likelihood of extreme events that could question the health of banks.

Related explanations for credit over-expansion and lending booms can be found in the more recent rational expectations literature on *herding* in investment and loan decisions. Banerjee (1992), Bikhchandani, Hirshleifer and Welsh (1992) as well as Avery and Zemsky (1998) introduce formal models of information externalities leading to herding, where each agent only observes the actions of other agents and uses Bayesian updating to derive his or her own subjective probabilities of future returns for his investment decisions.[33] Scharfstein and Stein (1990) model managers' incentives to

[32] See in particular Bernanke (1983), Bernanke and Gertler (1990) as well as Mishkin (1991). However, the introduction of a banking sector is still a task for future research (Bernanke, Gertler and Gilchrist, 1999).

[33] In Kindleberger's (1996, p. 13) words, "monkey see, monkey do".

mimic others in investment or loan decisions, when their own evaluation and reputation depends on their performance relative to the rest of the market. They quote Gwynne's (1986) description of a typical credit analyst's behaviour in lending decisions to less developed countries (LDCs): "His job would never be measured how correct his country risk analysis was. At the very least, Herrick was simply doing what hundreds of other large international banks had already done, and any ultimate blame for poor forecasting would be shared by tens of thousands of bankers around the globe; this was one of the curious benefits of following the herd".

In this literature, as in the writings by Minsky, Kindleberger and others, the systemic component comes in, since banks' herding and credit over-expansion to specific sectors, regions etc. will result in simultaneous problems for a large number of banks once the non-sustainability of this sector's or this region's growth becomes apparent after a negative aggregate shock (or a signal of it). A problem of this literature is, however, that it does not give clear explanations which events can start a herding wave and when it breaks down. It is also not so clear why herding should be more of a concern in banking markets than in other sectors regarded less fragile.

A further branch of the literature relates excessive or excessively risky lending by banks to *moral hazard* (see also section 2.4), mentioning features of banking markets that do not exist for other industries. For example, Merton's (1976) model shows how fixed-rate deposit insurance premiums that are insensitive to banks' portfolio risks (as observed in many countries) may lead them to increase risk-taking in order to maximise the put-option value on the insurance corporation's funds. Boot and Thakor (1993) further argue that such deposit insurance can, under certain assumptions on the form of the costs banks incur in the monitoring of funded projects, lead to an inefficiently low level of monitoring efforts. Applying modern corporate finance models of firms' capital structures to the case of banks, Dewatripont and Tirole (1993) argue that banks' excessive reliance on debt financing (partly related to their provision of retail payment services to a large number of small and relatively uninformed depositors) also leads to more risk-taking in lending. Due to the existence of explicit or implicit government guarantees for financial institutions, the issue of moral hazard has also been raised in the context of the US savings & loans crisis (Kane, 1989) or more recently regarding the lending boom that partly led to the East Asian crisis (Krugman, 1998). However, in a recent paper Goodhart and Huang (1999) show that a positive level of moral hazard resulting from safety net provisions, such as lending of last resort, might be unavoidable or even optimal to contain the systemic costs or monetary disturbances associated with financial crises.

This lending boom literature also relates to the potentially slow build up of structural problems in the financial sector. These structural problems increase the likelihood as well as the severity of systemic events.

3.2 Systemic risk and financial markets

The role of financial markets is perhaps the most difficult element in the analysis of systemic risk. On the one hand, their tremendous growth over the previous decades has made them much more important, even in the more bank-based financial systems of Continental Europe. On the other hand, despite a general awareness about the occasional occurrence of market crashes, their role in systemic events, as defined in the preceding sections, has not really been explored in a systematic fashion. This contrasts with the existence of some theories of systemic risk in banking markets and some practical studies of systemic risk in payment and settlement systems. In particular, theoretical models explicitly focussing on securities market contagion are extremely scarce.

In fact, markets are different from financial corporations. They do not go bankrupt, as single institutions can, but tend to recover after some time.[34] While there can be price crashes/liquidity shortages and propagation of them from one market to the other, the main concern will be with the shocks that financial market crashes and temporary liquidity crises - be they contagious or not - impose on the rest of the financial sector and the real economy. This has led Anna Schwartz even to the conclusion that financial market crashes alone are only “pseudo” financial crises and not “real” ones, unless they affect the stability of the banking *system* and thereby endanger the availability of a means of payment (Schwartz, 1986; Bordo, Mizrach and Schwartz, 1995). However, due to the high fungibility of the instruments traded in secondary markets and the possibility of leveraged position taking their prices can be extremely information sensitive and fluctuate sharply. Whereas financial institutions and agents acting in the real economy should be able to adapt to and protect themselves against the normal amplitude of financial market price changes (“regular volatility”), this cannot be taken for granted for some truly extreme and widespread fluctuations, in particular if they are contagious. These extreme events may be, among others, the consequence of the burst of a “bubble” (e.g. following an episode of widespread herding), possibly reinforced by certain trading techniques, such as program trading and positive feedback strategies.[35]

In the remainder of this sub-section the potential for contagious and joint financial market crashes is reviewed first, distinguishing explanations building on asymmetric information, multiple equilibria,

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[34] While the shares or bonds of a defaulting company will disappear from markets, it is hard to imagine a situation in industrial countries in which a previously existing stock, bond or foreign exchange market disappears, let alone the disappearance of several of those markets through contagion. An exception might be some segments of high-risk markets, which might disappear after a crisis and not come up again. Whole financial market segments might also disappear as a consequence of hyperinflation.

[35] See De Long et al. (1990) as well as Gennotte and Leland (1990) for models showing how these trading strategies can cause multiple equilibria and non-linearities in financial market prices. Models of herd behaviour, such as Banerjee (1992), Bikhchandani, Hirshleifer and Welsh (1992), Avery and Zemsky (1998) and Scharfstein and Stein (1990), have been briefly summarised in the sub-section on lending booms (3.1.2).

chains of physical exposures and aggregate/common shocks. Then it is looked at financial market crashes and liquidity crises as *shocks* to financial institutions and the real economy.

3.2.1 Contagion and joint crashes in financial markets

The first step is a discussion of contagion effects and joint crashes in financial markets. The theoretical literature is limited to two branches, one dealing with contagion between securities markets from a microeconomic perspective and the other dealing with contagious and joint currency crises using rather macroeconomic approaches.

3.2.1.1 Contagion across securities markets

Contagion from one securities market to the other may be due to technical factors (e.g. collateral sell-offs may lead to the propagation of price changes across markets, or arbitrage between cash and futures markets may cause co-movements between the two markets).[36] However, the few theoretical models really dealing with financial market contagion we could identify are mostly based on the revision of expectations. In spite of the absence of a unified framework, a fraction of the post-1987 finance literature has attempted to uncover possible contagion effects among international securities markets, often defined either as changes in securities prices (conditional mean or variance) that affect other countries beyond what would be justified by fundamentals or as unexpected volatility spill-over effects during crisis periods. Similar as for banking markets, we review contagion explained by information channels ("information-based") and contagion explained by exposure channels. Interestingly, and in sharp contrast to the currency crisis literature, we could not find a single theoretical paper dealing with "pure" contagion.

3.2.1.1.1 Contagion based on noisy signals under asymmetric information

"Information-based" contagion should be distinguished from "fully revealing" equilibria, i.e. equilibria in which the price adjustment mechanism leads to the full revelation of all (even private) information through the general observability of prices. In particular, if agents have rational expectations and assets and goods markets are fully integrated, news about fundamentals revealed in one market will be transmitted to other markets. In the presence of asymmetric information across borders, it depends on the complexity of information structures whether this transmission is efficient ("fully revealing") or not (Grossman, 1976).

In the model of King and Wadhwani (1990), information is not fully revealing, since foreign shocks or news are imperfectly observable at home and their meaning has to be inferred from foreign price changes. There is a signal extraction problem for domestic traders, since the foreign prices mix relevant systematic shocks with foreign idiosyncratic shocks. Hence, effects of *idiosyncratic* shocks in market *i* on prices in market *j* emerge, i.e. transmissions of "mistakes". Moreover, the existence of different trading hours for different markets will lead to (cross-border) price jumps, because of the accumulation of news during closing times that get revealed when the first prices become available again. In this sense, one could speak of contagion (a strong systemic event in the narrow sense, in terms of the concept developed in section 2). The authors also argue, outside of the model, that a severe common shock could increase the correlation between markets. In particular, an incipient crash could incite agents to update their beliefs about the variance of the "common news" signal, which would increase the international spill-over (contagion) coefficient in the model.[37]

Kodres and Pritsker (1999) use a multiple-asset version of the noisy rational expectations model by Grossman and Stiglitz (1980) to study cross-asset market price propagations. The two-period asset trading model contains informed, uninformed, liquidity and positive-feedback traders as well as macroeconomic and idiosyncratic risks. It is shown that cross-market price propagation tends to be more severe in markets with stronger asymmetry of information and with common macroeconomic risk factors. Idiosyncratic shocks can propagate through investors' portfolio re-balancing across markets. Also, if some traders underestimate the positive feedback-trading strategies of other traders, then even volatility in other markets than the one in which the feedback trading occurs may be exacerbated. However, these effects do not necessarily describe extreme, crisis-type propagation (such as price jumps). The same mechanism would work in "normal times".[38]

3.2.1.1.2 Contagion through direct trader exposures

In some analogy to the recent bank exposure models (interbank markets or payment systems) discussed in sections 3.1.1.3 and 3.3, Lagunoff and Schreft (1998) discuss contagious failures of "investments" without a role for financial intermediaries. In this model investors can at the start of

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[36] Referring to the introduction of futures markets Guesnerie and Rochet (1993) make the distinction between gains in terms of volatility reduction and the greater difficulty for agents to co-ordinate expectations.

[37] See also the discussion of the empirical results of King and Wadhwani (1990), Hamao, Masulis and Ng (1990) and others in section 4.2.1.1.

[38] Some models do not explicitly address multiple asset price propagation, but are nevertheless relevant since they highlight propagation mechanisms between trading agents. For example, Morris and Shin (2000) develop a simple information game of trading in an asset, in which traders update their beliefs about the asset value in a Bayesian fashion. In this framework each trader's decision to sell depends on his beliefs about whether other traders are likely to sell. This interdependent choice can lead to price externalities that may cause undesired losses to traders using simplistic value-at-risk management techniques. However, they do not need to lead to multiple equilibria, if the distribution of information signals across traders is not too dispersed. Calvo (1999) develops a trading model of a single asset in which informed investors that have to sell the asset to meet margin calls can contaminate uninformed investors, who take the asset supply observed as a signal for bad fundamentals. In a multi-asset representative agent framework Calvo and Mendoza (2000) argue that an internationally diversified equity investor's incentives to gather costly information may decrease as the number of countries in which he can invest increases ("globalisation"). This may lead to types of "herding" in which all investors become more sensitive to react to country-specific rumours or mimic arbitrary "benchmark"/"market" portfolios. These papers have, of course, some strong links to the herding literature briefly surveyed in 3.1.2.

period 0 put their cash endowment in a very limited sub-set (max. 2) of a large number of available risky projects or assets (a loan or a bond, for example), in a non-risky asset or consume (part of) it. This creates a network of direct and indirect exposures between investors/assets through chains created by common investments ("financial structure of the economy"). All aspects of the economy are common knowledge except that investors do not know who else invested in the same asset.

If investors do not foresee the possibility to be affected by contagious defaults and a project or asset breaks down (idiosyncratic shock), so that the two exposed investors lose their money, they reshuffle their remaining funds between non-risky assets and consumption, shunning the remaining risky assets. This reduces the funds available for two risky assets (per investor), which then default and so on. The resulting sequential unravelling of the economy's financial structure (contagion) becomes a systemic crisis. In the other case where investors factor in the possibility of being affected by contagious failures, a different type of crisis can occur in which all investors simultaneously shift their funds in safe assets or consumption (an adverse selection problem similar to the one discussed at the end of 3.1.1.3). In this model, greater diversification would lead to a lower probability of systemic crises, but also every single asset failure would affect a larger number of other investors and assets.

Kyle and Xiong (2000) develop a model in which two fundamentally uncorrelated assets can exhibit high correlation, high volatility and low liquidity ("contagion") when cross-asset "convergence traders" incur capital losses (negative wealth effects) and have to liquidate open positions in response to reduced risk-bearing capacity. This continuous-time trading model considers three types of agents. Convergence traders usually make money by using their information about noise traders' behaviour, whereas long-term investors provide market liquidity by following simple "fundamentalist" rules. In this model convergence traders have an, at first sight, counterintuitive volatility amplifying effect, since in equilibrium overall asset risks depend endogenously on the wealth of convergence traders and on the positions of noise traders. Depending on the parameterisation the model can generate extreme price co-movements, but the transmission mechanism would be the same as with parameterisations leading to more regular co-movements.

3.2.1.2 Single currency attacks versus contagious and joint currency crises

In analogy to the discussion in the bank run versus bank contagion sub-section 3.1.1 we first look briefly at the literature on single currency attacks and subsequently at contagious or joint currency crises, which enter the systemic element in this literature.[39] The so-called "first generation" models of

[39] Since the emphasis for the purposes of the present article is on contagious crises, we can only provide a selective picture of the abundant single currency attack literature. For more complete surveys of it, see Agénor, Bhandari and Flood (1992), Blackburn and Sola (1993), Agénor and Flood (1994), Garber and Svensson (1995) and, more recently, Drazen (1998) and Jeanne (1999). Jeanne also offers a thoughtful conceptual discussion of speculative attack models.

currency attacks, describing an investor run on and a consequential collapse of a fixed exchange rate arrangement with a sharp devaluation, is associated with the papers by Krugman (1979), Flood and Garber (1984) and Obstfeld (1986). These papers view currency crises as an attack by speculators on central banks' foreign exchange reserves in response to unsustainable (conflicting) macroeconomic (exchange rate, monetary or fiscal) policies. The unsustainable macroeconomic policies, such as fixing the exchange rate while financing a budget deficit via money creation, are exogenously given and speculators precipitate the devaluation, given that the exhaustion of a limited amount of reserves to defend the peg can be perfectly foreseen.

The so-called "second generation" models of single currency attacks consider endogenous exchange rate policies with optimising policy makers (De Kock and Grilli, 1993; Drazen and Masson, 1994; Obstfeld, 1994, 1996, 1997; Ozkan and Sunderland, 1995, 1998; Bensaid and Jeanne, 1997). There is an option ("escape clause") to abandon the fixed rate arrangements, which is exercised by policy makers when the costs of maintaining the arrangement outweigh the benefits. The costs of maintaining a peg may include high interest rates, potentially destabilising the banking sector or reducing short-term growth perspectives/increasing cyclical unemployment, whereas the benefits may include monetary stability and credibility gains through unhampered international trade and investment and political advantages from international co-operation. Investors stage an attack, when they expect that policy makers are at the brink of exercising the option (or when they believe that other investors might expect that). Since there can be a two-way relationship between economic fundamentals (in a broad sense) and investor expectations, currency attacks can be self-fulfilling (similar to self-fulfilling bank runs à la Diamond and Dybvig (1983)). However, both "first generation" and "second generation" models can but need not exhibit multiple equilibria. For example, Morris and Shin (1998) have shown that if speculators have heterogenous information sets, then the multiplicity of equilibria can disappear in "second generation" models.

So-called "third generation" models of currency attacks extend the picture to particular features of recent financial crises. For example, Miller (1996) shows that a speculative attack can give rise to a banking crisis, if deposits are used for currency speculation and banks are "loaned-up". Other models address the contagious features of some of these currency crises. As for the case of contagious bank runs, this is the main type of currency crisis we are interested in for the purposes of the present paper, since it has the systemic component of a domino effect.[40] In this context of contagious currency crises Paul Masson (1999a,b) has made a useful distinction between joint exchange market crises as a

[40] Notice that a single currency crisis with a subsequent sharp devaluation could also produce a systemic crisis *within* the respective country. For example, in a country with large short-term liabilities in foreign currency, the sharp devaluation can be an aggregate shock that causes a systemic banking crisis (systemic risk in the "broad" sense, as defined in section 2).

consequence of a common macroeconomic shock to fundamentals ("monsoonal" effects in Masson's terminology), spillovers of one country's crisis on other countries' fundamentals – triggering a crises in those countries too –, and, in the presence of multiple equilibria, a shift from a good equilibrium in one country to a market crisis equilibrium in this country as a consequence of a market crisis in another country ("contagion" in the author's terminology). In fact, these channels are economically very similar to the channels discussed in section 3.1 for the case of systemic risk in bank markets, although limiting contagion to a multiple-equilibrium phenomenon narrower than the view presented across this paper and although the channels presented by Masson concern a different set of (mainly macroeconomic) variables. "Monsoonal" effects correspond to joint crises as a consequence of a common aggregate shock (3.1.2), spillovers to fundamentals correspond to the physical or real exposure channel and the last type is akin to contagious bank runs as "sunspot" phenomena ("pure" contagion in 2.3 and 3.1). The only channel lacking is the information channel ("information-based" contagion), which is introduced in the literature of contagious currency crises by Drazen (1998).[41]

The real exposure channel for contagion has already been modelled by Gerlach and Smets (1995), who apply a two-country version of the "first generation" model by Flood and Garber (1984) and extended by a real sector with sticky wages as in Willman (1988) to this problem. A successful speculative attack against one currency boosts the competitiveness of that country at the expense of a neighbouring country, which is likely to be its direct trade competitor. Even if the parity arrangement of the neighbouring country is fundamentally viable, it could be broken through a contagion effect in this model, if its reserve level is low. A very similar exchange rate channel is also present in the model of Masson (1999a), an otherwise simplified two-country version of Jeanne (1997). Masson also highlights the possibility of simultaneous currency crises in two (or more) countries as a consequence of the same aggregate shock in that model. For example, an increase in the risk-free world interest rate or an appreciation of the (foreign) debt denomination currency, which both can make the debt service higher for all countries participating in a fixed rate regime and can cause joint reserve outflows, increase the probability of a devaluation.

Miller (1998) demonstrates how a bank run in one country can cause a speculative attack on a foreign currency, providing a financial exposure channel for the international transmission of crises. The intuition is that when banks invest abroad, then a domestic bank run will induce them to repatriate capital from abroad, potentially causing a depletion of reserves in the foreign country and a devaluation. However, since the devaluation itself can render domestic banks insolvent, currency attacks can be precipitated. Moreover, the circular nature of the relationship can make such a currency crisis self-fulfilling.

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41 Signal extraction problems as a cause for *single* currency crises have been modelled by Bensaid and Jeanne (1997) and

Choueiri (1999) analyses a type of financial exposure channel for contagion by extending the model by Flood and Marion (1998) to a second (exogenous) country. The argument follows standard portfolio theory. A representative international investor is assumed to hold government bonds of the two emerging market countries that have a pegging arrangement against, say, the dollar. If the (given) return covariance between both currencies is not too small, then a break of one currency's peg and subsequent devaluation will lead the investor to also sell the (highly correlated) other currency, potentially breaking the second peg too.

Buiter, Corsetti and Pesenti (1997, 1998) point out that "systemic" currency crises in multi-country exchange rate arrangements function differently from contagion under single countries' unilateral pegs. They offer an optimal monetary policy game, covering centre and periphery countries in a multilateral arrangement in which national authorities co-operate only to the extent that their joint actions preserve their relative welfare ("national horizontal equity"). It is shown that in response to a large asymmetric shock between centre and periphery, the optimal co-ordinated response by the periphery is joint small devaluations by a large number of countries, whereas the optimal unco-ordinated response involves a few large devaluations in the periphery. In the tradition of the real exposure channel, the causes can be found in the economic interdependencies and the policy spillovers between the countries in the arrangement.

"Pure" contagion can occur in the model of Masson (1999a), because for both of the two countries the probability of a large enough current account deficit so that reserves reach a critically low level, potentially triggering a crisis devaluation, depends in a circular fashion on the probability of the devaluation itself, since a devaluation increases the cost of foreign currency debt service. For very bad fundamentals (large floating rate debt, low foreign exchange reserves and large trade deficits) devaluations are almost unavoidable (unique equilibrium), whereas for intermediate levels of the fundamentals both no devaluation and crisis devaluations are equilibria. Since for economically integrated countries the state (devaluation probability) of one country becomes part of the fundamentals for the other country, cross-border interdependence can also become a source of multiplicity of equilibria and "pure" contagion in this framework. However, whereas for certain ranges of parameter values and levels of the fundamentals multiple equilibria exist, equilibrium selection is not part of the theory.

Recently Drazen (1998) presented a contagious currency crisis model addressing the asymmetric information channel. Investors are uncertain about the political commitment of the respective

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Drazen (1999), for example.

governments to maintain a fixed rate arrangement between countries. The motivation for the arrangement is basically political, e.g. to achieve a common currency bloc in the world economy or a co-operative club against internal beggar-thy-neighbour policies. For each country the arrangement is only valuable, if certain other countries also participate. Therefore, the devaluation of one country is a negative signal for speculators about the commitment by other countries to keep exchange rates fixed. The updating of speculators' beliefs about the likelihood of devaluations in response to observed exchange rate policies can lead to information-based contagion from one member country to another.

3.2.2 Financial markets as sources of systematic shocks

Large general price fluctuations or liquidity crises are themselves shocks to financial institutions and other agents. Extreme events in any of the major financial markets (stock market, government bond market etc.) affect a large number of agents at the same time and are therefore often of a "systematic" nature. Such systematic shocks from the markets will be even more widespread if they are contagious across markets, as discussed in section 3.2.1.

3.2.2.1 Shocks to financial institutions

In the recent past formerly "commercial" banks have become more and more involved in financial market trading activities (as opposed to traditional lending). Their larger trading books potentially lead to larger exposures to shocks originating in those markets. This implies that the structurally higher systemic risk in banking markets due to fixed value deposits and cross-exposures, as described in 2.2 and 3.1, will be more dependent on financial market fluctuations than has been previously the case. Similarly, it may have also become more dependent on the safety of the security settlement process (see 3.3.2). The same applies to the banks' participation in financial conglomerates where other units are involved in securities activities.

Investment banks, securities houses, hedge funds etc. are generally more risky than traditional commercial banks (e.g. in terms of earnings volatility), but as separate entities they are less vulnerable to the type of contagion that may affect the latter.[42] However, to the extent that they are involved in wholesale money market borrowing their failure due to a large shock originating from market crashes may still spill over to the banking system (see 3.1.2).

Alternatively, various events in financial markets (such as the failure of a large institution or a significant price fall) may increase uncertainty about the ability and willingness to trade by the main

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[42] One study investigates the effect of the announcement of OTC derivative losses by four clients of Bankers Trusts on other investment banks' stock prices during the first 9 months of 1994 (Clark and Perfect, 1996). The results tend to indicate that capital markets discriminate between derivative dealers on the basis of their exposure levels.

participants acting in these markets, in particular among market makers (Davis, 1994). Somewhat analogous to the case of the interbank money market discussed above, liquidity in the respective financial instruments traded may dry up through adverse selection (Flannery, 1996). For example, market makers might increase bid-ask spreads to reduce the likelihood of being hit by a transaction (price rationing) or even "refuse" to trade at all (quantity rationing). Such a liquidity "freeze" could involve a systematic shock on all those banks and non-bank financial institutions, whose risk management strategies depend on the ability to trade in these markets.[43]

3.2.2.2 Shocks and propagation to the real economy

Already Irvin Fisher (1933) in his debt-deflation theory examined the connection between the poor performance of financial markets and the Great Depression. He saw declining asset prices as a principal means how financial forces can propagate an economic decline. This notion has been formalised more recently by Kiyotaki and Moore (1997). In their model loans have to be collateralised by assets, which also serve as production factors. In response to negative shocks credit-constrained firms have to sell assets to unconstrained firms, so that the asset price has to fall. Both effects further tighten producers' borrowing constraints. This link between asset prices and credit constraints constitute a powerful transmission mechanism through financial markets. Already earlier Bernanke and Gertler (1989) wrote down an overlapping-generations model in which real investors having to finance fixed-size projects face a costly state-verification problem. In this framework the optimal contract turns out to be a bond contract and a negative relationship between the borrower's net worth and the agency costs (for monitoring and bankrupcty) of the borrower-lender relationship occurs. Hence, real shocks to investors get amplified by the related decline of investors' wealth and ability to borrow in the bond market. This approach has developed into the "financial accelerator" literature (see Bernanke, Gertler and Gilchrist (1996), and Bernanke, Gertler and Gilchrist (1999) for a survey.) These models do not explicitly address the issue of systemic risk, but rather stress explanations for business cycle fluctuations. However, the same or similar mechanisms might work with greater strength in times of financial market crashes.

However, Bacchetta and Caminal (1999) show that not all shocks are amplified. Under asymmetric information fiscal or anticipated productivity shocks' effect on output, for example, can get dampened. In a similar vein, Aghion, Bacchetta and Banerjee (1999) develop a model of macroeconomic fluctuations in a small open economy with credit market imperfections. In this framework they show that an intermediate degree of credit market imperfections can cause endogenous boom-bust cycles.

[43] A recent event that has raised these issues in practice is the (private) bail-out of Long Term Capital Management (LTCM), a large hedge fund, in September 1998.

They regard the situation of intermediate credit market development as particularly characteristic for the emerging market economies that faced recent financial crises.

3.3 Systemic risk in payment and settlement systems

By providing the technical infrastructure through which banking and securities market transactions are settled, payment and settlement systems determine to an important extent the physical exposures among financial institutions. In a way, looking at payment and settlement systems is like looking at the network of interbank exposures with a magnifying glass. Hence, depending on their internal organisation they also determine how shocks may propagate through the financial system, in particular how severe contagion can be. The analytical literature on systemic risk has until very recently largely overlooked their importance. The fundamental underlying risks in these systems are similar to those encountered by financial institutions in general: operational risk (such as the failure of a computer, as for the Bank of New York in 1985), liquidity risk (reception of final or "good" funds, not being realised at the desired time but at an unspecified time in the future), credit risk (failure of an insolvent participant with a subsequent loss of principal).

3.3.1 Interbank payment systems

There are three main types of interbank payment systems: net settlement systems, gross settlement systems and correspondent banking. In what follows we shall first describe "prototypes" of these systems and then refer to the most important practical deviations from these types. In *net settlement systems* payments among members are collected over a certain period of time, e.g. a whole day or several hours, and at the settlement time the gross payments between members are netted against each other, so that only the net balances have to be settled with finality. With bilateral net settlement the members effectively remain the only counterparties to each other, while in multilateral net settlement systems debit and credit positions are accumulated vis-à-vis a central counterparty (usually a clearing house) until they are offset at the settlement time. Net settlement systems involve relatively low costs, because actual settlement is relatively rare - normally occurring only once at the end of the day (and in some cases twice a day) - and thus liquidity costs are low. Because of the more limited number of direct counterparties, these cost savings are usually more pronounced in multilateral systems than in bilateral netting. The netting of reciprocal gross positions between institutions can considerably reduce the effective debit positions, and thereby systemic risk, as compared to pure gross settlement undertaken at the same time scale, where incoming and outgoing payments are settled independently (without any netting). However, without additional provisions, net settlement systems are still comparatively vulnerable to systemic risk, since gross exposures accumulating between settlement times can become very large.

In *real-time gross settlement systems* (RTGS) payment finality is virtually immediate for every transaction, so that the systemic risk from unsettled claims appears to be very limited, at least at first glance. Due to the heavy charge for intra-day liquidity management (in order to have always enough liquid funds available during the day) it is comparatively costly for member banks. Moreover, banks' ability to pay out may depend on the timeliness of incoming payments, but counterparties may sometimes have the incentive to delay outgoing payments. Therefore, RTGS can be characterised by relatively frequent queuing phenomena, which can lead to wide-spread liquidity ("network") externalities or even system "gridlock" when participants economise on their intra-day liquidity or default. This shows that even RTGS may not be totally free of systemic risk, at least not in the "weak" sense (see section 2.1).

Most real-life systems have specific additional institutional features in order to reduce systemic risk or liquidity costs (and gridlock risk) in net and gross systems, so that both types become actually more similar. For example, net settlement systems now often introduce caps on the exposures between settlement times and loss-sharing arrangements between members for cases of defaults. Regarding the latter, "decentralised" multilateral net systems are to be distinguished from "centralised" systems, where the central counterparty takes over the risks and can, therefore, default itself. Also, legally binding netting-arrangements can apply for the periods between settlement times or the number of settlement times during the day could be increased.[44] In order to reduce the liquidity costs of real-time gross systems the possibility of intra-day overdrafts vis-à-vis the settlement agent are now often allowed. Since they are a potential source of systemic risk, these overdrafts are either secured through collateral requirements, as is the case for the Trans-European Automated Real-time Gross settlement Express Transfer System (TARGET) and the connected national RTGS, or through daylight overdraft fees, as in the case of Fedwire in the United States. Alternatively, routine queuing facilities can be established, which however imply similar risks as net settlement systems.

Correspondent banking relationships appear to be very diverse. Correspondent banks provide payment services for groups of usually smaller or foreign banks, which do not have cost-effective access to the primary domestic net or gross systems. Each of the latter groups of banks settle bilaterally with the correspondent via debits and credits on nostro and loro accounts, whereby gross exposures can be netted against each other.[45] Therefore, the failure of an important correspondent bank can directly affect a large number of those institutions. Moreover, correspondent banking is used by large credit

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[44] The legal enforcement of these netting arrangements can be particularly difficult for international transactions. For example, in some jurisdictions a liquidator may be able to engage in "cherry picking" favouring the domestic creditors of a failed institution (BIS, 1990).

[45] In a way correspondent banking can be seen as a step from bilateral net settlement towards multilateral net settlement, although happening at a smaller scale.

institutions for international transactions. In this respect, it could become one of the major channels for the transmission of the so-called Herstatt risk (see the next sub-section). [46]

There is only an incipient literature of theoretical models describing the risks of different payment system arrangements. Angelini (1998) models profit-maximising banks' behaviour in an RTGS where intraday liquidity is available from the central bank against a fee proportional to the size of the overdraft. (Following the example of the US Fedwire system, overdrafts are not collateralised.) Delaying payments has also a cost in terms of customer dissatisfaction. Angelini derives in the framework chosen that the competitive (Nash) equilibrium is not welfare optimal, since the cost of intra-day credit induces banks to delay payments rather than to draw on the overdraft facility. These payment delays result in network externalities, since payees attempt to free ride on other banks' reserves, thereby reducing overall liquidity. (However, the author does not address explicitly the question whether a "gridlock" equilibrium can exist, in which payment activity comes to a standstill; a stronger form of a systemic event). He concludes that in RTGS intra-day overdrafts (by the central bank) must be made sufficiently cheap, so as to remain lower than banks' customer dissatisfaction costs through payment delays. Moreover, he suggests that banks could be induced to pay earlier during the day via variable overdraft fees, which penalise late payments. In contrast, Humphrey (1989) has argued that payment delays in gross systems with uncollateralised overdraft facilities may be desirable to reduce the actual overdrafts and therefore systemic risk or the costs of the system guarantor.

Schoenmaker (1995) compares multilateral net settlement systems (à la US CHIPS) and collateralised RTGS systems both theoretically and through the simulation of average costs with real transactions and historical bank default data. It turns out that the average costs through settlement failures (defined as historical failure rates times maximum open intraday positions) are higher in the net than in the gross system, but those through settlement delays (or gridlock) and collateral requirements are lower in the net systems. This might explain why central banks often prefer "safer" gross systems while market participants favour "less costly" net systems, and it also reflects the trade-off between risks and costs described in Berger, Hancock and Marquardt (1996). In particular, Schoenmaker explicitly derives the potential occurrence of systemic events in the form of gridlock in the RTGS variant (proposition 4.1).

Elaborating on Schoenmaker's comparative approach and using a theoretical framework akin to Angelini's, Kobayakawa (1997) provides a broad analysis of multilateral net settlement and both types of RTGS, with full collateralisation of intraday overdrafts ("EU type") and with fees on

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[46] For other reviews of practical payment system arrangements and the risks involved, see Folkerts-Landau (1991), Borio and Van den Bergh (1993), Summers (1994), Berger, Hancock and Marquardt (1996), Rochet and Tirole (1996), Schoenmaker (1996b), Kobayakawa (1997) and Rossi (1997).

uncollateralised overdrafts ("US type"). However, as Angelini he focuses on their relative efficiency and (apart from externalities through payment delays) he does not derive explicitly any "strong" systemic events that might occur.

In contrast, in a careful theoretical study of foreign exchange netting (see also 3.3.2) Yamazaki (1996) focuses entirely on the relative importance of systemic exposures in bilateral net settlement as compared to multilateral net settlement (decentralised variant with loss-sharing among participants and without a clearing house). He establishes that for single failures multilateral netting reduces other banks' exposures as compared to bilateral netting, if the initial loss is not "extreme". However, when a chain reaction of failures occurs, he shows that there are plausible cases in which the systemic event under multilateral netting is more severe than under bilateral netting. Moreover, he points to moral hazard that can be associated with multilateral netting.

In a more elaborate model, Freixas and Parigi (1998) (building on McAndrews and Roberds, 1995) introduce geographical consumption preferences in a Diamond-Dybvig-type model, which lead to "interbank payments" between two regions. With "gross settlement" banks have to liquidate investments to the full amount of outgoing payments in the same period, which imposes a relatively high opportunity cost through foregone interest on investments. With "net settlement" the banks can, first, offset incoming and outgoing payments and, second, extend credit lines to each other in order to finance future consumption of "foreign" consumers. In this framework the "gross system" is free of contagion but exhibits high opportunity costs. The "net system" exhibits systemic risk and potential welfare losses in so far as inefficient banks may stay open for longer. Holthausen and Rønde (2000) study the implications of co-existing international gross and net settlement systems for cross-border systemic risk, when bank supervisory information is only generated at the national level.

3.3.2 Foreign exchange and security settlement systems

In contrast to national interbank payments, foreign exchange and securities transactions involve the settlement of two "legs". Foreign exchange transactions involve the opposite payment of the same principal amount in each of the two currencies, and securities transactions involve the "delivery" of the security in one direction and the "payment" of funds in the other. On the one hand, the two sides of foreign exchange and security settlement operations can enhance credit and liquidity risks. On the other hand, if the exposure on one side of the transaction is collateralised by the asset involved in the other side of the transaction and vice versus, the scope for contagion may also be reduced. Any credit risk related to the danger of defaulting counterparties in these transactions may not only cause the loss of principal ("principal risk"), but it has also a market risk component known as "forward replacement cost", the potential loss implied by having to replicate a transaction in the market when the counterparty has defaulted and the market price has become less advantageous for the non-defaulting party.[47]

Asynchronous settlement of the two legs leads to additional channels through which contagion between financial institutions and markets can work. Regarding international transactions the existence of different time zones can create "Herstatt risk", the danger that one leg is already settled while the counterparty in charge of settling the other leg defaults before the systems in the respective other time zone operate.[48] Similarly, in the case of national securities market transactions, the payment leg through interbank transfer systems may have a different timing than the delivery leg of Central Securities Depositories (CSDs). Increased concerns about principal risk in securities settlement has led to major initiatives to achieve "delivery versus payment" (DVP), the simultaneous settlement of both transaction legs (Committee on Payment and Settlement Systems (CPSS), 1992). On the other hand, it is also true that DVP mechanisms by connecting real time payment systems and security settlement systems accelerate the transmission of risks from one system to another (i.e. if settlement of cash cannot take place because of a problem in the settlement system, securities will not be settled either and vice versa). Alternatively, securities can also be used to offset other securities transactions in a simultaneous fashion ("delivery versus delivery", DVD).

The CPSS identified three main approaches to security settlement systems in G-10 countries: 1) systems that settle both securities and funds on a gross basis and in a simultaneous fashion, 2) systems that settle securities on a gross basis and funds on a net basis at the end of the settlement cycle, 3) systems that settle both legs on a net basis in parallel at the end of the settlement cycle. Practical implementations of the first approach share many of the risks of RTGS in interbank payments and operational responses to those risks are very similar (e.g. collateralised intraday or even overnight credit facilities). In most implementations of the second model the risk of unsettled payment legs is limited through "assured payments" via guarantors, which however could fail themselves. In many type 3) systems the failure of a counterparty to settle a net funds debit position leads to an unwinding procedure, which may create considerable systemic risk through liquidity pressures on other participants. Therefore, in several cases the systems operator or a clearing corporation guarantees the completion of settlement.

CSDs, which play the role of the settlement agent in national securities transactions, may sometimes also be at risk to fail, potentially implying substantial systemic repercussion due to "custody risk". If

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[47] The systemic dimension of principal risks associated with bilateral and multilateral forex netting systems are studied in the paper by Yamazaki (1996) discussed in 3.3.1.

[48] This risk is named according to the German Bankhaus Herstatt, whose failure in 1974 caused repercussions across the Atlantic.

claims of financial institutions on the securities in custody with the depository are not clearly segregated, some of them may experience unexpected losses. A similar problem may arise with "global custodians" at the international level. These custodians, usually big investment banks, maintain accounts with the different national CSDs in order to execute securities transactions for other banks which do not have access to foreign CSDs. While playing an important intermediary role in connecting separated national CSDs, their failure can be an element in the international transmission of crises since, unlike CSDs, global custodians are normally also large participants in payment systems.

The payment and the delivery side of securities transactions show the potential for contagion working from members of interbank payment systems to those of security settlement systems and vice versa. In fact, most credit institutions are active in both interbank payment and security settlement systems. Experiences from the 1987 stock market crash reported in Brimmer (1989) and Bernanke (1990) show that these types of cross-system propagations can easily become real in a major crisis. However, we are not aware of any theoretical models describing the particular risks of security settlement systems in a rigorous way.

The risk of cross-system spillover effects may be more severe between foreign exchange settlement and national interbank payment systems. The CPSS (1996, fn. 3) reports system operator estimates that "FX settlements account for 50% of daily turnover value in CHIPS and CHAPS, 80% of the daily turnover value of EAF, and 90% of the daily turnover value of SIC".[49] Industry groups such as FXNET, S.W.I.F.T. or VALUNET provide various bilateral foreign exchange netting services for various groups of banks. ECHO (Exchange Clearing House Organisation) and Multinet provide multilateral netting services. A major new development will be the establishment of a continuously linked settlement (CLS) bank in New York by 20 major banks in the forex settlement business.

4. EMPIRICAL EVIDENCE ON SYSTEMIC RISK

In this section we survey the existing empirical evidence on systemic events and systemic crises in the light of the concepts developed in section 2 and the theoretical literature in section 3, mainly focusing on rigorous empirical analyses of contagion. The objective is to identify how much we know about how pervasive the elements of systemic risk are in different countries and on the international platform. Another objective is to detect those areas of the empirical analysis of systemic risk, which have not yet received enough attention to be properly understood. This will point us to necessities for future research efforts. As in the theoretical section, we will first look at banks, then at financial markets and finally at payment systems.

4.1 Evidence on bank contagion and joint banking crises

As has been pointed out in section 3, the risk of contagious bank failures may be viewed as the "classical" case of systemic risk. Testing for bank contagion amounts to testing whether "bad news" or the failure of a specific bank (or group of banks) adversely affects the health of other banks. On the other side, systemic risk in banking markets in the "broad" sense also includes simultaneous bank failures (widespread panics without necessarily the occurrence of contagion), for example as a consequence of macroeconomic shocks. In this sub-section we will first address the larger number of econometric papers that attempt to identify contagion effects and subsequently the few econometric papers dealing with joint crises and aggregate fluctuations.

4.1.1 Bank contagion

The empirical literature that developed around this theme can be separated in several groups. One group of papers tries to link bank failures with subsequent other bank failures directly by measuring autocorrelation. A second approach tests whether the survival time of banks decreases during historically identified episodes of panics or through failures of other banks. Third, many studies estimate the relationship between bank failures or "news" and other banks' stock market values. A fourth group looks at the link between "news" or failures and deposit withdrawals at other banks. A fifth group analyses the effect of "news" or failures on the *probability* of other banks' defaults, as perceived by market participants and reflected in risk premiums in interbank lending. Finally, one can measure the physical exposures among operating banks (or between those and banks which have been "bailed out" by the government) to evaluate whether a default would render other banks insolvent. We proceed in successive order.

4.1.1.1 Intertemporal correlation of bank failures

The common ground of this first branch of the bank contagion literature is a test for autocorrelation in bank failures. Basically, the rate of bank failures in a period *t* is regressed on the rate in the previous period (*t*-1) and a number of macroeconomic control variables. Provided that all macroeconomic shocks are effectively covered by the control variables a positive and significant autocorrelation coefficient indicates that bank failures and periods of tranquility cluster over time, which is consistent

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[49] CHIPS (Clearing House Interbank Payments System) and CHAPS (Clearing House Automated Payment System) are the main net settlement systems in the US and the UK, respectively. EAF (earlier Elektronische Abrechnung mit File-Transfer, now Euro Access Frankfurt) is a corresponding system in Germany.

with the contagion hypothesis. Since the safety net provisions in modern financial systems, such as deposit insurance schemes and lender-of-last-resort facilities tend to prevent that a single bank failure can lead to effective failures of competitors, these tests have to be undertaken for historical periods in countries without strong (public) safety nets.

Grossman (1993) finds with an instrumental variable regression analysis of quarterly US data for the period between 1875 and 1914 (i.e. before the establishment of the Federal Reserve System) that a 1 per cent increase in failures in a quarter led on average to a 0.26 per cent increase in the following quarter. Hasan and Dwyer (1994) and Schoenmaker (1996) have substantially refined this approach and provide more evidence of intertemporal failure clustering in "free banking" markets. Hasan and Dwyer (1994) apply a probit analysis to data from the US Free Banking Era (1837 through 1863). Depending on the crisis considered in this interval and the respective region they find evidence compatible with contagion or not. By applying an autoregressive Poisson (count data) model to the number of bank failures, Schoenmaker (1996) finds strong results for a sample of monthly data covering the second half of the US National Banking System and the early years of the Fed (1880 through 1936). The autoregressive parameters are strongly significant up to a lag of 3 months and they increase in size and significance for the sub-sample encompassing the Great Depression, while macroeconomic factors appear to become less informative for the prediction of failures.

In sum, this approach seems to have been relatively successful in making the case in favour of the contagion hypothesis. However, the main disadvantages of this approach are that, first, the negligence of macroeconomic factors exhibiting autocorrelation themselves would cloud any "evidence" of contagion and, second, it can only detect intertemporal contagion at the frequencies of macroeconomic data and not at shorter time intervals.

4.1.1.2 Duration of bank survival unexplained by fundamentals

In a new study of US bank crises during the Great Depression, Calomiris and Mason (2000) have estimated the average survival time of several thousand Fed member banks between January 1930 and March 1933. They apply a microeconometric duration model in which bank survival is explained by a host of economic fundamentals (such as individual bank balance sheet items, regional and national macroeconomic variables) and some proxies of contagion, panics or liquidity crises. These proxies include a series of dummy variables, denoting the "panic" episodes identified in the historical works of Friedman and Schwartz (1963), Wicker (1996) and others, and the level of deposits in other banks that failed in the same county (measuring regional contagion effects).

Grosso modo it turns out that bank level micro fundamentals as well as regional and national aggregate fundamentals are able to explain a large part of the variation in the duration of bank survival during the Depression (see also 4.1.2 below). However, apart from a highly significant time trend, regional aggregates seem to explain bank survival time much better than national aggregate fundamentals. The historical panic dummies provide some support for the occurrence of the regional bank panics during 1930 and 1931 described by Wicker (1996), but less support for the national panics during 1930 and 1931 described by Friedman and Schwartz (1963). Dummies for the 1932 Chicago bank panic and the January and February 1933 national panics appear very significant, but the authors caution that according to their earlier paper (Calomiris and Mason, 1997; discussed below) only banks that were already unhealthy before actually failed during the Chicago episode and that a good deal of the "flight to currency" in early 1933 might have rather been related to the anticipated departure from the gold standard. Last, but not at all least, the regional contagion coefficient is highly significant in all specifications tested, but the inclusion or not of this variable does not have a very large effect on the aggregate survival duration.

In sum, this study seems to indicate the presence of some bank contagion effects in specific episodes during the Great Depression, but also that in most of these episodes they seem to have been rather contained, remaining limited to a specific region of the US. The authors point also out that some of the reductions in survival duration they observed might still be related to some unobservable regional or national fundamentals.

4.1.1.3 Event studies on stock price reactions

The most popular approach to test for contagion effects turned out to be event studies of bank stock price reactions in response to "bad news", such as the announcement of an unexpected increase in loan-loss reserves or the failure of a commercial bank or even of a country to serve its debt. The presence of contagion is usually tested by comparing the "normal" return of a bank stock, as predicted by a standard capital market equilibrium model (such as the CAPM) estimated with historical data, to the actually observed returns at the announcement date or during a window around this date. "Bad news" for a bank *i* leading to significantly negative "abnormal" returns of another bank *j* is interpreted as evidence in favour of contagion.

The forerunners in applying this approach were Aharony and Swary (1983) who studied the effects of the three largest bank failures in the United States before 1980: United States National Bank of San Diego (1973), Franklin National Bank of New York (1974) and the Hamilton National Bank of Chattanooga (1976). The sources of each of these three failures seem to have rather been of an idiosyncratic nature, related to in-house fraud, illegal real-estate loans or foreign exchange losses. The

Franklin National case, the failure of the 12th largest US bank at the time, caused substantial negative abnormal returns in money-centre, medium-size and small banks, whereas no external effects of the smaller two other cases occurred.[50]

Swary (1986) applies the same approach to the Continental Illinois National Bank failure in 1983-84, the 8th largest bank in the United States. Although larger than Franklin National and confronted with somewhat less idiosyncratic problems (bad domestic and international loans), negative abnormal returns of 67 other US banks turned out to be weaker and somewhat proportional to these other banks' own pre-crisis solvency situations. Wall and Peterson (1990) find that part of these negative stock market reactions can also be explained by more general "bad news" arriving about the Latin American debt crisis. Jayanti and Whyte (1996) show that stock market values of British and Canadian banks with significant LDC debt exposures were also adversely affected by Continental's failure but not those British banks which were unexposed to debt crisis countries. Peavy and Hempel (1988) show that the Penn Square Bank failure of Oklahoma in 1982 had only regional repercussions.

In a similar vein, Madura and McDaniel (1989) analyse the effect of the 3 billion-dollar loan-loss reserve announcement of Citicorp in 1987 on the stock prices of the 11 other US money-centre banks, which also issued loan-loss announcements later this year. Their results indicate that most of the losses have been anticipated earlier by the market. Docking, Hirschey and Jones (1997) study the effects of 188 loan-loss reserve announcements by nine leading money-centre banks and 390 announcements by 102 regional banks in the United States from 1985 to 1990. It turns out that there is little impact of money-centre bank announcements on other money-centre banks' stock prices, but regional banks' announcements (from certain areas) can have detrimental effects on other regional or money-centre banks. These results are compatible with the hypothesis that investors better anticipate unfavourable announcements from the large and "visible" money-centre banks than from regional banks. Slovin, Sushka and Polonchek (1999) undertake yet another event study of bank stock-price reactions in response to "bad news", but the conditioning events are taken to be 62 dividend reduction announcements and 61 regulatory enforcement action announcements in a sample of US money-centre and regional banks between 1975 and 1992. In contrast to the evidence on loan-loss reserve announcements, the authors find large negative effects of single money-centre banks' dividend reductions on many other money-centre banks and regional banks. Instead, such announcements for regional banks only lead to positive competitive effects on other regional banks in the same geographical area. Regulatory enforcement actions against money-centre banks do not cause any

[50] However, Aharony and Swary caution that there were a number of other banks which faced foreign exchange losses similar to those of Franklin National Bank of New York shortly after the switch to floating exchange rates (notably Germany's Herstatt bank).

negative bank-industry effects, whereas they generate the positive competition effects among regional banks within the same area.

The early results of adverse "external" stock market reactions to "bad news" triggered a debate about whether they can be interpreted as evidence of "pure" contagion effects or whether they rather reflect rational investor choices in response to the revelation of new information. In a series of papers the strength of abnormal returns during the international debt crisis of the 1980s was linked to banks' own exposures to problem countries. Cornell and Shapiro (1986) undertook cross-sectional regressions for 43 US bank stocks and for various sub-periods during 1982 and 1983 and Smirlock and Kaufold (1987) seemingly unrelated regressions for 23 exposed and 37 non-exposed US banks around the 1982 Mexican debt moratorium. Musumeci and Sinkey (1990) and Karafiath, Mynatt and Smith (1991) study the effects of the 1987 Brazilian debt moratorium on US bank stocks. The former use an OLS cross-section regression for 25 banks, the latter a Generalised Least Squares (GLS) cross-section regression for 46 bank holding companies. Madura, Whyte and McDaniel (1991) assess the impact of Citicorp's announcement of substantial loan-loss reserves on share prices of 13 large British banks. The general result of this debate was that abnormal returns varied in proportion to banks' exposures to problem countries, which is consistent with the hypothesis of rational investor choice.[51]

Since most of these results are found for US data, an interesting question to ask is whether they carry over to other financial systems. Unfortunately, not much seems to have been published for other countries. An exception is Gay, Timme and Yung (1991) who chose to examine bank failures in Hong Kong during the 1980s. These cases are interesting, because first Hong Kong did not have an explicit deposit insurance scheme (which could have dampened any contagion effects) and second at least two of the three failures studied (Hang Lung Bank in 1982 and Overseas Trust Bank in 1985) seem to have had rather idiosyncratic sources, such as management misconduct and embezzlement, while the third (Ka Wah Bank in 1985) seems to be related to the failure of Overseas Trust Bank and to that of a specific foreign borrower. In the first two cases strong negative abnormal returns occurred for locally listed bank stocks, but the evidence provided on rational investor reactions differentiated according to exposures seemed to be rather inconclusive.

In terms of the concept developed above this literature shows *weak* systemic events, since stock price fluctuations do not imply failures. A lot of those studied seem to have been "efficient" though, namely

[51] However, there is one early study, Schoder and Vankudre (1986), that challenges the market efficiency hypothesis. These authors examine the stock price behaviour of 169 US banks around the August 1982 Mexican debt crisis. They estimate a two-factor (market and industry) stock return model and find that the average return of the 45 banks with exposures to Mexico was abnormally negative when rumours about Mexico spread on 19 August, whereas it was not for the whole sample of banks. However, the individual returns, net of market and industry factors, did not discriminate between banks according to the relative size of their (with one exception unpublished) Mexico exposures.

in proportion to actual exposures (see section 2.3). Also, several of the cases studied rather represent systemic repercussions in the "broad" sense, since for example events related to the LDC debt crisis could be regarded as caused by an aggregate shock.

4.1.1.4 Analyses of deposit flows

Another test of contagion measures the reaction of depositors (wholesale and retail) to "bad news". If in response to problems revealed about a bank (or a group of banks) *i* depositors also withdraw funds from another bank *j*, there is evidence of a contagious bank run.

Saunders (1987) examines whether two key announcements about the shape of Continental Illinois Bank in April and May 1984 had any discernible effect on other banks' US or overseas deposits. The April 18th announcement of a US$ 400 million increase in Continental's problem loans seemed to have no effect on US deposits, while the May 10th "denial of rumours" by the US Office of the Comptroller of the Currency (OCC) seems to have triggered "flight to quality" (i.e. shifts to safer banks and more secure deposits) by large US banks but not a general run. The total of non-sterling deposits at either American, Japanese or other overseas banks in London did not decline in April or May (but risk premiums on these deposits generally increased, see 4.1.1.5 below).

Saunders and Wilson (1996) study the annual deposit flows of 163 failed national banks and 229 surviving banks (of similar size and location) in the United States during the Great Depression (1929 through 1933). They compare the deposit movements of both groups for each year of the Depression to each other and to the three years preceding the year under examination. It turns out that for the years 1929 and 1933 withdrawals at failed banks are associated with *deposit increases* at non-failing banks. However, for the sub-period 1930-32 accelerations of deposit withdrawals at failing banks are associated with significantly *higher withdrawals* at non-failing banks. The authors point out that their evidence is consistent with panic-type "pure" (regional) contagion effects between 1930 and 1932 and with "flight-to-quality" (non-panic) phenomena in 1929 and 1933. However, they also observe that the level of withdrawals at failing banks was always significantly higher than at non-failing banks, which could be interpreted as higher levels of "informed" withdrawals at unhealthy banks as compared to "uninformed"/"purely contagious" withdrawals at banks that in the end turned out to be healthy. Again, in our terminology this approach can only address the occurrence of ("narrow") systemic events in the "weak" sense. However, it cannot be excluded that some of the failing banks considered in this paper collapsed as a consequence of "uninformed" withdrawals, while being fundamentally solvent.

Calomiris and Mason (1997) examine the June 1932 Chicago bank panic during the Great Depression to study whether some ex ante healthy banks collapsed during this episode. They group their sample of 114 Chicago banks into 3 categories: non-panic failures, panic failures and survivors. Statistically significant deposit withdrawals from the 62 survivors, which are only weakly smaller than those from the 28 panic failures, indicate the presence of systemic events in the narrow sense due to asymmetric information regarding individual banks' solvency situation. The authors further ask whether these contagious withdrawals led to contagious failures or whether the failures observed were rather those of relatively weak banks in the face of a common asset price decline. To that end they apply a logit estimation of "ex-ante" failure probabilities (based on balance-sheet data) for these groups, either including panic failures or excluding them. Since in both cases panic failures received a higher *predicted* failure probability than survivors, the authors conclude that only already ex ante weaker banks actually failed during the panic, which is consistent with the hypothesis that "pure" contagious *failures*, or "strong" systemic events (in the "narrow" sense), did not occur. They explain this finding with the existence of private co-operative arrangements among banks. In a section of their more recent paper about the whole Great Depression, discussed in 4.1.1.2 above (Calomiris and Mason, 2000), they show that the regional 1930 bank panic identified by Wicker (1996) was associated with greater deposit withdrawals than could have been predicted from bank level micro data, regional and national fundamentals, but they question the notion that uniform withdrawals, unexplained by fundamentals, have happened on the national level before 1933.

4.1.1.5 Examinations of bank debt risk premiums

A little bit of work has been done to see whether contagion effects can be detected in the market prices of bank debt instruments. Carron (1982, table 1) shows that the Franklin National failure in New York (and perhaps also the Herstatt failure in Germany) in mid-1974 led to an increase in the quarterly average spread between US "jumbo" certificates of deposits (CDs) and 3-month Treasury bills by a factor of at least six, which is consistent with systemic events via risk premiums. Giddy (1981) argues that bid rates for Eurodollar deposits of 30 banks in London during July and August 1981 varied only very little between individual banks and that the differentials were hardly related to proxies of individual bank or country risk. Saunders (1986) computes correlations of interbank rate risk premium indices for three different country groups before and after the start of the 1982 debt crisis. He observes statistically significant increases of the correlation of risk premiums between industrial countries and middle-income LDCs and between middle income and low-income LDCs, which he considers to be consistent with contagion between those two groups of countries. However, in a follow-up study (Saunders, 1987) he derives that the correlation of risk premiums between industrial countries, non-oil exporting LDCs and countries with debt re-scheduling was actually *lower* in the "crisis period" 1974 through 1978 than in the "non-crisis period" 1979 through 1983, so that "there appears to be no evidence of contagion in the crisis period" (p. 215). In any case, the simple correlation approach cannot distinguish between systematic shocks and contagion, as defined in the conceptual section above (section 2).

Karafiath, Mynatt and Smith. (1991) undertake an event study of the effect of the 1987 Brazilian debt moratorium on bond prices of 22 US bank holding companies (all with country exposures to Brazil). In contrast to the equity price reactions reported in the previous sub-section, the cross-section of weekly bond yields in excess of Treasury note yields were far from being significantly abnormal. One interpretation of their differential results between equity and bond returns is that the market expected that those banks would earn lower profits (and therefore pay less dividends) due to the debt crisis, but that none of the bank holding companies would actually default on its debt. Cooperman, Lee and Wolfe (1992) examine the effect of the 1985 Ohio Deposit Insurance crisis on the pricing of retail (insured) six-month certificates of deposits (CDs) for a sample of 69 federally-insured Ohio banks and savings & loans. The results indicate a significant unexpected rise in weekly CD prices for less solvent Ohio depository institutions (lasting approximately seven weeks), which is consistent with risk-based pricing as suggested by Kane's (1989) contingent insurance guarantee hypothesis. Finally, Jayanti and White (1996) estimate statistically significant increases in the average certificate of deposit (CD) rates - at constant Treasury bill reference rates - for both UK and Canadian banks after the Continental Illinois failure in the United States in May 1984. In their case this result is consistent with the international contagion effect visible in equity returns mentioned in the previous sub-section. Saunders (1987, fn. 28) also acknowledges that the average spread between 3-month Euro-dollar deposits and T-Bills doubled during the Continental Illinois problem months of April and May, which again is consistent with international systemic risk in the "weak" sense. An even stronger effect was visible in the average monthly domestic risk premium, as measured by the difference between 3-month CD rates and 3 month T-Bill rates, which more than tripled during April and May (Saunders, 1987, fn. 27).

The evaluation of the event study approach applied to risk premiums in debt rates, as a test for contagion effects is, of course, similar to the application to equity returns. It usually cannot show the occurrence of systemic events in the "strong" sense. Occasionally, it is also not clear whether the effects measured originate in an aggregate shock (potentially revealed by a specific event) or are a reflection of a sequential propagation.

4.1.1.6 Measurement of effective exposures

A last approach is to directly measure whether exposures to certain (potentially or effectively failing) banks are larger than capital. While prudential rules limiting large exposures should usually prevent banks from lending more than a small share of their capital to a single borrower, very large exposures can occur temporarily vis-à-vis "core institutions", namely large clearing banks.

Kaufman (1994) reports some results from the US inquiry into the Continental Illinois case, one of the "core institutions" at the time. Shortly before the failure, 65 financial institutions had uninsured exposures in excess of their capital to the bank. It was estimated by the Congressional study that, if Continental's losses would have been 60 per cent (i.e. creditors would lose 60 cents of every dollar lent), then 27 banks would have been legally insolvent and 56 banks would have suffered losses above 50 per cent of their capital. The actual losses of Continental finally amounted to below 5 per cent, so that none of its correspondents suffered solvency-threatening losses. Michael (1998) reports some effective exposures from London interbank markets.

This approach is strongly linked to empirical research on the impact of failures in payment and settlement systems, which we survey in 4.3 below. However, it cannot show the actual occurrence of systemic events but it can only tell something about the ex ante risks that such events might materialise in the future.[52]

4.1.2 Banking crises, aggregate fluctuations and lending booms

Whereas there are numerous descriptive accounts of banking crises referring to macroeconomic fluctuations, the number of econometric papers is much scarcer.[53] In the paper by Gorton (1988) the case is made that during the US National Banking Era (1865-1914) widespread banking panics did not occur as random events à la Diamond and Dybvig (1983) or Waldo (1985), but rather as "normal" widespread reactions of depositors to severe cyclical downturns. In contrast, during the Great Depression panics appeared much more special events. The former result is derived with the help of a non-linear non-parametric estimation of the determinants of the aggregate deposit-currency ratio in the US economy (notably time trends, the predictable rate of return on deposits and the predictable co-variability between aggregate consumption and capital losses on deposits). When this model is estimated for the National Banking Era, an additional dummy variable indicating panic times is not

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52 Benston et al. (1986, chapter 2) review a number of older and non-quantitative studies, discussing the banking crises in US history between 1873 and 1933, as well as quote a number of contemporaneous observers. They argue (on p. 70) that "systemwide contagious bank runs were not a frequent occurrence in U.S. history (probably occuring at most only in 1878, 1893, 1908, and 1931-1933 and doing major damage probably only in 1893 and 1931-1933), and that fear of widespread ripple effects did not appear to be of major concern to most students of U.S. banking before 1932". And they conclude (on p. 77) that "U.S. history suggests that runs on individual banks or groups of banks only rarely spread to other banks that are not subject to the same conditions that started the runs, and that most bank runs have been contained by *appropriate action*, with only minimal or short-lived effects on national financial stability and economic activity. Generally, the instability of individual banks or groups of banks has not translated into instability in the banking system as a whole. The major exception was the run on all banks in late 1932 through early 1933, which caused the banking system to grind to almost a complete halt and substantially reinforced the economic crisis at the time. Although an exception, this event was so traumatic that it has coloured analysis of bank runs and failures ever since." See also Park (1991) and Wicker (1996 and forthcoming) for broad studies of banking crises in the history of the United States.

53 There is, of course, a fairly broad literature about early warning indicator systems to predict individual bank failures and banking system crises for micro- and macro-prudential purposes. The indicators identified in this literature are obviously related to the factors explaining banking crises, but for reasons of space we abstain from reviewing it systematically in the present paper.

significant, suggesting that the regular explanatory variables are sufficient to explain widespread deposit withdrawals both in normal *and* in crisis times. For the period following the establishment of the Fed (1914-1934), the relationship between explanatory variables and deposit-currency ratio breaks down. However, the relationship between non-predictable changes in the liabilities of failed businesses and the share of failed banks (or the share of bank losses) is more stable over time. Exploiting this relationship Gorton estimates counterfactuals, indicating that bank failures and losses were many times greater during the 1930s than what could have been expected from the parameters holding for the National Banking Era, assuming the shocks of the 1930s. The author therefore concludes that the banking panics in US history were not generally random "sunspots", but that many of them can be explained by regular consumer/depositor behaviour over the business cycle.

Gonzalez-Hermosillo, Pazarbasioglu and Billings (1997) and Gonzalez-Hermosillo (1999) estimate fixed effects logit models for various panels of banks to study the determinants of bank "distress" in various episodes in the United States (Southwest, 1986-92; Northeast, 1991-92; California, 1992-93), Colombia (1982-87) and Mexico (1994-95). "Distress" is measured by the "coverage ratio", the ratio of capital equity and loan reserves minus non-performing loans to total assets, exceeding a certain threshold. It turns out that market and liquidity risk factors played a role in "distress" episodes across the board, whereas the role of credit risk and moral hazard is more case specific. However, the introduction of aggregate variables, such as macroeconomic fundamentals and regional variables, significantly improved the predictive power of the models tested, providing evidence in favour of the macro explanation of systemic bank difficulties in the "broad" sense.

Demirgüç-Kunt and Detragiache (1998) study the macroeconomic and structural determinants of banking crises in 45 to 60 developing and industrial countries between 1980 and 1994. With the help of a multivariate logit model they estimate the impact of a set of macroeconomic, financial and institutional fundamentals, such as GDP growth, real interest rates, inflation, private credit growth, the liquidity position of the banking sector, the existence or not of an explicit deposit insurance scheme and some law and order indexes, pooling the data for all countries. The presence or not of a banking crisis is not measured by a strong systemic event in the broad sense but rather as a situation in which at least one of a list of four criteria is met.[54] Consistent with the business-cycle hypothesis for bank crises, in all specifications GDP growth is a highly significant explanatory variable. The same applies to real interest rates and inflation rates. However, private sector credit growth, whether contemporaneous or lagged, has only explanatory power in some specifications, providing only mixed

[54] These criteria include threshold shares of total non-performing loans, the costs of any rescue operations, the occurrence of widespread bank runs or large-scale bank nationalisations and the implementation of emergency measures. Because of the occurrence of crisis management operations, concentrating only on the number or size of bank failures would have run the risk of underestimating the systemic breadth of a crisis in the absence of policy responses.

evidence in favour of the lending boom hypothesis. In contrast, the evidence in favour of the moral-hazard hypothesis regarding explicit deposit insurance schemes is stronger. Since data for crises and non-crises times are pooled, this study can claim to isolate the factors causing full-scale banking crises from those only causing a gradual increase in financial fragility or single bank failures.

Gourinchas, Valdés and Landerretche (1999) examine more narrowly the properties of lending booms in a sample of 91 industrial and developing countries between 1960 and 1996 and link them to the likelihood of banking and currency crises. In fact, the unconditional probability of banking or currency crises directly *after* lending boom periods is higher than during tranquil periods. However, only few robust results are found when specific characteristics of boom periods are related to crises. For example, the size of the boom seems to increase bank crisis probabilities but not currency crisis probabilities. Whereas the occurrence of high real investment during a lending boom decreases bank crisis probabilities, it increases currency crisis probabilities. Somewhat contrary to the common wisdom Gourinchas, Valdès and Landerretche also find that the build-up and ending phases of booms are fairly symmetric, so that on average abrupt and crashing ends are not consistent with the data.

To conclude the empirical part on systemic risk in the banking sector, it appears fairly clear that many banking crises in history have been related to macroeconomic fluctuations and other aggregate or regional shocks. However, the interpretation of the results on the importance of bank contagion is less straightforward. Whereas there seem to be episodes of strong autocorrelation in the number of bank failures, of strong co-movements in bank equity and debt prices and of cross-bank deposit withdrawals, many of the results do not allow for a clear statement about whether these constitute contagion phenomena or rather represent cases of joint exposures to aggregate shocks. Similarly, the studies surveyed illustrate well a general difficulty to distinguish empirically between "information-based" contagion and "pure" contagion of the sunspot type. Hence, on the basis of the available information it seems to be very hard to resolve one of the main policy debates in the area of banking crisis management (see 2.4), namely whether emergency liquidity assistance to individual banks should sometimes be provided by central banks or whether lending to the market is usually an efficient answer (Goodfriend and King, 1988). This remains a major issue to be addressed in future research efforts.

4.2 Evidence on contagion and joint crashes in financial markets

An early forerunner in the market crisis literature is the challenging study of 23 stock exchange panics by Oskar Morgenstern (1959, chapter X), starting with the collapse of the Gründerjahre boom in Germany (1873) and finishing with the 1931 European stock exchange closures in the midst of the Great Depression. Morgenstern gives a broad account of panics in New York, London, Berlin, Paris, Vienna, Amsterdam and Zurich and assesses each panic's effects on the stock markets in foreign financial centres (see Morgenstern, 1959, tables 139 and 140, charts 71 and 72). Although not employing the term "contagion" in the international context, he distinguishes the "statistical extremes" in stock market movements and their transmission abroad from more regular cycles and general international co-movements. Some of the panics appear independent, such as the two in Paris and New York in 1879; others appear to originate in common shocks, such as the start of World War I, causing "second order magnitude" panics and stock exchange closures in several European countries; again others appear to involve cross-border contagion, such as the first of two New York panics in 1907, inducing "severe panics" in Berlin and Amsterdam. Patel and Sarkar (1998) provide a contemporaneous study of 9 joint stock market crashes for a sample of 18 industrial and emerging countries between 1970 and 1997. One natural quantitative extension of Morgenstern's approach is modern extreme-value theory (see e.g. Jansen and de Vries, 1991, and Embrechts, Klüppelberg and Mikosch, 1997), focussing in a multivariate framework on extreme co-movements (see 4.2.1.2 below).

We start with the evidence on securities (mainly stock and bond) markets, a more micro/finance-oriented literature, and then discuss currency crises (related to fixed exchange rate arrangements), a more macroeconomic literature. We abstract from the ample literature on financial market integration, regular price transmission and non-crisis related co-movements.[55]

4.2.1 Contagion and joint crashes in securities markets

In this sub-section we are looking at the co-movements in stock and bond markets during crisis periods. We first review papers looking at correlation between securities markets, many of them applying some variant of the ARCH (autoregressive conditional heteroskedasticity) model, then we sketch the incipient literature on extreme co-movements based on statistical extreme-value theory (EVT), and, finally, we study papers measuring "excess co-movements" between securities, i.e. those unexplained by economic fundamentals. The literature has dedicated by far most attention to the October 1987 stock market crash. The global nature of this crisis is documented by Roll (1988, 1989) and Bertero and Mayer (1990), showing that a large number of industrial and emerging countries experienced extraordinary stock market falls around October 19 – often by 20 per cent in one day or more.

[55] See Hilliard (1979), Eun and Shim (1989, who quote a list of earlier equity market papers), Engle, Ito and Lin (1990), Longin and Solnik (1995), Karolyi and Stulz (1996), De Santis and Gerard (1997), Fleming, Kirby and Ostdiek (1998), Bodart and Reding (1999) and Solnik and Roulet (2000) among others in this literature.

4.2.1.1 Return and volatility correlation across securities markets

The first type of test employed in the literature to measure contagion is simply based on the correlation of returns across markets. The main hypothesis is that correlation increases when markets are more volatile ("correlation breakdown"), hence reducing the completeness of financial markets and the gains from international diversification. This may undermine the stability of financial institutions. Strictly speaking contemporaneous correlation does not directly measure contagion, which, in principle, would require studying the transmission of shocks over time. However, in securities markets the speed of transmission of a shock may be such that the propagation of the disturbance may be almost instantaneous. In addition, the econometrician may not be able to use data at a sufficiently high frequency, if she wants to control for changes in fundamentals.

4.2.1.1.1 Simple correlation

Bennett and Kelleher (1988) perform simple bilateral daily regressions to determine whether *stock price movements* in Japan, the UK, the US and Western Germany are correlated. By comparing the results for the 1972 to 1979, 1980 to September 1987 and the October 1987 periods, they find that these markets had become more integrated already before the crash, but the intensity of co-movements in returns and volatility increased way above the previous levels during October. Roll (1988) examines whether institutional micro-market features as opposed to the world market factor have power in explaining the cross-sectional variation of returns in a cross-section of 23 industrial and emerging countries during the month of the crash. It turns out that differences in institutional market features explain very little of the severity of the crash in different countries. Only the presence of continuous auction trading seems to have slightly worsened the downturn, whereas the presence of an official monopolist specialist or of computer-directed trading (such as portfolio insurance or index arbitrage) seem to have had a weak dampening effect. In contrast, the systematic world factor has by far the largest explanatory power.

Bertero and Mayer (1990) also examine the role of institutional market features on the severity of the crash (conditional on the systematic factor), considering the same set of countries but a slightly different set of micro features. They confirm Roll's result of only statistically weak effects of these features in general. However, different to Roll their regressions show some small dampening effects of circuit breakers and capital controls on residents' foreign investments. They also find a significant increase in international correlation around the crash. The strength of the correlation shows some group-like pattern that seems to be associated with the trading of overseas securities in domestic markets.[56]

[56] See Roll (1989) for a survey of the early literature on the causes and international ramifications of the crash, as well as its regulatory implications.

By looking at half-hourly returns from July 1987 to February 1988, King and Wadhwani (1990) show that the enhanced London unconditional volatility at the opening of New York came forward in time in the crash period compared to before and after. This suggests intensified communication and accelerated information transmission between these two markets during the crash. Estimating at a lower frequency their signal extraction model described in 3.2.1.1.1 above, they also find with ordinary least squares (OLS) and instrumental variable (IV) regressions that their "contagion coefficients" (a measure of unconditional correlation) between New York, Tokyo and London increased during this period.

The recent occurrence of financial crises in many emerging market countries has also triggered cross-country equity market correlation analyses about these episodes. Calvo and Reinhart (1996) show for 7 Latin American countries that around the December 1994 Mexican peso crisis correlation between weekly stock returns increased, whereas co-movements with several Asian stock markets even turned negative. A principal component analysis further shows the existence of two common factors that together account for 80 % of the stock return volatility. The authors interpret the increase in explanatory power of the second component for the post crisis period as a "Mexico effect".

In an intriguing study Frankel and Schmukler (1998) track the price and net asset value (NAV) co-movements in 7 Latin American and 22 Asian closed-end country funds, also with an eye on the effects of the 1994 Mexican peso crisis. Based on Frankel and Schmukler (1996), the authors argue that differences between New York quoted and traded fund prices and the corresponding local net equity values reflect information asymmetries between foreign investors, often trading the funds via New York, and home investors trading the underlying equities in their own countries. Comparing the cross-country co-movements in fund prices with those in the corresponding NAVs then allows to examine whether international stock market spillovers between these countries are mainly transmitted through New York by foreign investors or directly through local investors. In fact, a simple correlation analysis of weekly returns between 1992 and 1996 shows that for a majority of Latin American country fund pairs the correlation of New York prices is lower than the correlation of local NAVs, suggesting that Latin American investors played a bigger role in the transmission of shocks within that region around the 1994 crisis than outside investors. In contrast, for the cross-correlation between Latin America and Asia a large majority of the bilateral fund prices are more highly correlated than the corresponding local net equity values. Hence, in this cross-continental case outside investors based in or acting via New York might have driven the spillovers. These results are further substantiated by a Granger causality analysis integrated in a bilateral error-correction model for a longer period (1985 to 1996). Within this framework, Frankel and Schmukler show that the largest Mexican fund (Mexico Fund) Granger-caused a large majority of other Latin American funds in terms of NAVs and a smaller majority in terms of New York prices. However, the same Mexico Fund Granger-caused a majority of Asian funds in terms of prices but hardly any of them in terms of NAVs. In other words, outside investors active in New York seemed to have played a major role in the transmission of equity price shocks from Latin America to Asia.[57]

Much less work has been done on *bond markets* compared to stock markets. For example, Borio and McCauley (1996) provide - to our knowledge - the only systematic study of international bond market spillovers in very volatile periods. By looking at weekly data of implied volatilities from option prices for 10-year benchmark government bonds of 13 industrial countries during the period of August 1992 to May 1995, they test whether lagged volatility in a foreign market adds explanatory power to the (implied) volatility process in the domestic market. In some analogy to the equity market literature, the US bond market emerges as an “unmoved mover”. However, the Japanese bond market appears neither as an important source nor as an important recipient of external volatility. When introducing dummy variables for the 20 observations with the highest joint volatility for each pair of countries (usually indicating the period of the bond market turmoil from February to June 1994), then the high-volatility periods are characterised by significantly higher international correlation. For emerging markets Calvo and Reinhart (1996) show a marked increase of Brady bond return correlation among Latin American countries during the Mexican crisis of 1994, but less so with the Philippines.

Baig and Goldfajn (1998) provide a broad empirical study of the daily co-movements in exchange rate returns, stock market returns, interest rates and sovereign spreads between 4 to 5 Asian emerging market countries during the Asian crisis starting in 1997, compared to the more tranquil time in the 2 to 3 years before. The results of simple difference in correlation tests indicate that co-movements in currency markets and for sovereign spreads increased substantially, whereas the reactions between stock markets and interest rates were slightly more mixed. Kaminsky and Reinhart (forthcoming) use a simple vector autoregression model to run Granger causality tests between the interest and exchange rates of 5 Asian economies before and after the Asian crisis. In their case, no causal relationships are

[57] Wolf (2000) undertakes a panel estimation of 400 to 1300 monthly individual stock returns in 16 to 24 emerging market and developing countries between 1988 and 1995. Fixed effects account for country effects and sector effects (21 sectors are considered). He argues that only correlation of the country effects are relevant for the measurement of contagion (“in its typical usage”), so that any return co-movements resulting from sector or idiosyncratic shocks have to be eliminated. After doing that he shows that average pure country effect correlation is 3 to 4 times larger than the average correlation between the standard stock indices of these countries. Moreover, he undertakes a simple cross-sectional regression of country effect correlation on a large list of economic and financial variables measuring the relative similarity between the two countries forming a pair. These variables include domestic characteristics, such as economic and financial structures and growth rates, as well as external exposure and transmission characteristics, such as trade openness, ease of foreign investment and profit repatriation, distance etc. It turns out that economic structures, notably trade linkages (in analogy to the contagious currency crisis literature discussed below), have the strongest power in discriminating between high and low equity market correlation country pairs. Surprisingly, risk factors, such as debt service or current account deficits, have only minimal explanatory power in this sample. (The results are further substantiated with a classification tree analysis.) It should be made the remark though that the similarities explaining equity market co-movements may have little to do with contagion related to crisis situations.

detected before the Asian crisis, but many instances of Granger causality are detected during and after the crisis.

It has recently been argued that observed increases in asset price correlation – as measured by standard correlation coefficients (?) – during periods of high volatility ("correlation breakdown") are not a good indicator of contagion, since they can arise as a simple statistical artefact (according to the "theorem on normal correlation"; Liptser and Shiryaev, 1977). As to our knowledge first pointed out in the context of financial stability in the paper by Boyer, Gibson and Loretan (1997), for any bivariate normal return distribution, the correlation coefficient of the two marginal distributions conditional on the marginals' standard deviations increases with the level of the conditioning standard deviation. In other words, partitioning a sample of bivariate normal returns into sub-samples with high and low volatility will automatically lead to a higher measured correlation coefficient in the high-volatility data and a lower measured correlation in the low-volatility data, without any effective increase in dependence. Forbes and Rigobon (1999a) show this correlation bias for two asset returns connected through a linear relationship, without recourse to normality, and derive an analytical correction for it. They then apply their methodology to international equity market correlation, net of interest rate shocks, during the 1997 Asian, the 1994 Mexican and the 1987 stock market crisis. It turns out that virtually all instances of "contagion", as measured by increased contemporaneous or intertemporal international equity market correlation coefficients during the crisis periods, disappear as soon as the estimated ?'s are adjusted for the correlation bias. Forbes and Rigobon (1999a,b) therefore conclude that referral to contagion during all the three episodes has been very much overstated, and that the equity markets involved faced nothing else than their usual international interdependence. However, even the results based on adjusted coefficients might be misleading, since correlation ignores potential non-linear dependencies that might become particularly relevant in crisis situations.

4.2.1.1.2 Correlation derived from ARCH models

Another branch of the literature on the 1987 stock market crash and its international repercussions applies ARCH-type models to determine whether stock market co-movements became stronger during the crash compared to non-crash times. It also broadened the analysis to address the direction and the lagged character of international spillovers as well as the symmetry or asymmetry between crash periods and boom periods.

Hamao, Masulis and Ng (1990) decompose daily returns in open-to-close and close-to-open returns and estimate various GARCH models for New York, Tokyo and London, accounting for volatility surprises in the respective foreign markets. By comparing the effects of foreign volatility surprises for the April 1985 to March 1988 period (i.e. including the October 1987 crash) with those of the April

1985 to September 1987 period (excluding the crash), they argue that significant price spillover effects between those markets occurred only for the crash period and after. They also identify an asymmetry insofar as Tokyo seemed to be heavily affected by the other markets but not vice versa. Malliaris and Urrutia (1992) perform a Granger causality analysis of daily (close-to-close) index returns for 6 major stock markets (S&P 500, London FT-30, Tokyo Nikkei and other Asian markets) between May 1987 and March 1988. Their data hardly show any lead-lag relationships for the pre- and post crash periods, but for the month of the market crash (October) many bilateral Granger causal relationships are discovered. These relationships confirm the passive role played by the Tokyo market, and the authors claim that an increase in the contemporaneous correlation between the markets considered points to the joint character of the crisis.

In contrast, Lin, Engle and Ito (1994) find significant bi-directional relationships between the New York and Tokyo markets between October 1985 and December 1989 (excluding the crash episode), when accounting for differences in trading time zones. Moreover, during the October 1987 crash the contemporaneous correlation between New York (Tokyo) daytime and Tokyo (New York) overnight returns exhibits a decrease whereas the lagged correlation between New York (Tokyo) daytime returns and Tokyo (New York) daytime returns increases. One interpretation of this result would be that, other than King and Wadhwani's (1990) results for New York and London, during the crash traders in New York and Tokyo needed more time to extract the information content from foreign price changes. In a follow-up Lin and Ito (1995) argue that high trading volumes observed in New York around the crash days and low volumes in Tokyo suggest that the New York-Tokyo spillovers were efficient (although delayed) price propagations, because the low Tokyo turnovers indicate little heterogeneity of opinions or liquidity trader sentiments.

Susmel and Engle (1994) further elaborate on the conditionally heteroskedastic estimation techniques and on the consideration of intraday returns as well as trading time zones for the New York and London markets. Whether the sample covers January 1987 to February 1989 or November 1987 to February 1989 (post crash period), they find little evidence of lagged volatility spillovers (across non-overlapping trading times) between the two markets, except around New York opening (2.30pm GMT) during London trading times. These latter spillovers, however, die out relatively quickly. Susmel and Engle also undertake an exercise in conditioning spillovers on the sign and size of the external shocks. The overall results are not very clear, but for the 3pm to 5pm GMT segment *negative* news in one market appears to increase volatility in the other market by more than positive news. Lin and Ito (1995) also undertake an examination of these sign and size effects, finding only a few instances of their occurrence (but excluding the October 1987 crash period). Koutmos and Booth (1995) apply tri-variate EGARCH models to New York, London and Tokyo stock indices (open to close returns) between September 1986 and November 1993 in order to study sign and size effects further. The estimations show that for the post-crash period, larger and negative innovations increase spillovers across borders. Kanas (1998) finds comparable results when applying the same methodology to close-to-close daily returns for a sample of European stock markes (London, Paris and Frankfurt) for the period 1984-1993.

A different approach is to assume that high-variance and low-variance states are not drawn from the same probability distribution, but that the data-generating process is rather regime dependent. In this vain, Ramchand and Susmel (1998) estimate bivariate switching ARCH (SWARCH) models, each linking weekly returns of the US stock market with weekly returns of one of a series of foreign markets for the period 1980 to 1990. Inter-market correlation is a function of two volatility states. It turns out that the correlation between the US and other stock markets is on average 2.5 to 3 times higher when the US is in the high variance state as compared to the low variance state. Another advantage of the SWARCH model compared to the approaches adopted in the papers discussed above is that "crisis episodes" (here periods in which the high volatility state pertains) are determined by the data and not chosen somewhat subjectively. However, the fact that the high-volatility state is statistically significant does not necessary imply that the related volatility level is critically high. The following sub-section looks at an empirical approach focussing exclusively on extreme returns and extreme volatility. A further lesson from the above is that the Boyer, Gibson and Loretan (1997) and Forbes and Rigobon (1999a) critiques of the "correlation breakdown" literature is not as devastating as it seemed at first sight.

4.2.1.2 Extreme dependence of securities market returns

Financial market crashes constitute a natural field of application for extreme value theory (EVT), the analysis of tail events in statistical distributions. For example, Mandelbrot (1963), Jansen and de Vries (1991) and Longin (1996) study the tail behaviour ("booms and crashes") of stock market returns. Similarly, Hols and de Vries (1991) address exchange rate return tails. Recent applications of "extreme value" theory (Embrechts, Klüppelberg and Mikosch, 1997) to financial markets have started to address the dependence between the tails of the distribution of returns in financial markets. This is consistent with our concept of systemic risk in the "strong" sense (contagion or joint crashes), which puts the emphasis on extreme co-movements, more compatible with genuine crisis situations, rather than statistical dependence for the whole return distribution. Another methodological issue is that, unlike correlation, extreme dependence is not limited to linear dependence or predisposed to the multivariate normal distribution, which are unsuitable for fat-tailed financial market returns.

Using non-parametric techniques, Straetmans (1998, chapter 4; 2000) derives the asymptotic conditional probability that two financial markets crash simultaneously (i.e. that they jointly exhibit returns in excess of a certain threshold) given that at least one of the two markets experiences a crash. For daily G-7 stock returns he finds that, apart from high linkages between the US and Canada as well as between France and Germany, extreme market linkages seem to be weak (compared to regular correlation). For daily G-7 exchange rate returns there is more substantial dependence in the tails. In addition, conditional crash probabilities seem to be higher between freely floating currency pairs than between pairs in the pre-EMU European ERM (exchange rate mechanism) target zone. Hartmann, Straetmans and de Vries (2000) apply these non-parametric extreme dependence measures to study the extreme co-movements not only within asset classes but also between stock, bond and money markets. They find that, whereas the univariate probability of having, say, a stock market crash of the size of the 1987 one in the US is extremely low, the conditional probability of having a stock market crash of this size in a G-5 country, given a crash in another G-5 country, is markedly higher. Moreover, they show that regular return correlation among all these three asset classes in G-5 countries are very different from the co-movements in the tails. Finally, they study phenomena like "flight to quality" (a boom in government bond markets, given a crash in stock markets) and "flight to liquidity" (a boom in money markets, given a crash in stock or bond markets). It turns out that the probability of experiencing "flight to quality" is at least as high as the probability of experiencing a co-crash in bond and stock markets.

Longin and Solnik (2000) apply EVT to the extreme co-movements in monthly G-5 equity returns between 1958 and 1996, assuming that each pair of returns follows the relatively parsimonious logistic distribution function. Under the logistic law there exists a one-to-one relationship between a dependence parameter and the correlation coefficient for the extremes. Hence, the authors can estimate the extreme correlation for each pair of equity markets. They can also test for normality in the tails. The data reject the hypothesis of normality for the left tail (crashes) but not for the right tail (booms), and extreme correlation seems to be more related to the trend, notably bear markets, rather than to volatility per se. So far the EVT approach has – to our knowledge – not been linked to movements in fundamentals. However, truly extreme co-movements (serious contagion or joint crashes) would probably always be of some concern for market participants and prudential supervisors.

4.2.1.3 Securities market co-movements not explained by fundamentals

In another part of the literature "contagion" is not interpreted as a succession of large or even extreme negative movements across different securities markets, but rather as the share of co-movements that cannot be explained by economic fundamentals. For example, Shiller (1989a) shows that for constant discount rates the covariance between the US and the UK *stock market* indices for annual data between 1917 and 1987 was much higher than what would have been implied by estimations of the dividend present value model for both markets. However, when allowing discount rates to vary with commercial paper returns "excess co-movements" become statistically insignificant. Pindyck and Rotemberg (1993) divide 42 US companies into 6 groups, so that in each group the companies included produce different goods and exhibit low earnings correlation with each other. Then, for each group OLS regressions of stock returns on current and lagged macroeconomic fundamentals (such as growth, inflation, effective exchange rates, short-term interest rates and corporate profits) are run for quarterly data ranging from 1969 to 1987, and it is tested whether the residuals of these regressions are correlated across (within-group) firms. It turns out that in all cases residuals are highly correlated for all groups of companies. These results are also robust when better information than current or lagged macroeconomic variables in investors' expectations about the future is captured through a latent variable approach.[58]

King, Sentana and Wadhwani (1994) analyse monthly returns of 16 stock markets during the period January 1970 to October 1988, assuming that the innovations on equity returns follow a multivariate GARCH (1,1) process, containing "observable" as well as "unobservable" components. In their study only a small proportion of the covariance between national stock markets can be explained by "observable" economic variables. While the "unobserved" components might include omitted variables, they can also reflect market sentiment and contagion. In particular, it appears that the observed factors fail to explain the substantial increase in correlation during the 1987 crash. The authors also argue that the apparent long-term upward trend of the equally weighted average of conditional correlation between national excess equity returns may actually be explained by a dummy variable accounting for the 1987 stock market crash.

Similar studies have also been undertaken for *debt markets*. Doukas (1989) regresses a domestic production index (composed of major exportable commodities as a measure of creditworthiness) on some macroeconomic fundamental variables for three emerging market economies, Argentina, Brazil and Mexico, between 1978 and 1983 to derive expected and unexpected news for countries borrowing in the public and publicly guaranteed syndicated Euro-loan market. For each country he then runs an OLS regression of the respective country's change of loan rate spread above LIBOR in the Euro-syndicated credit market on the production surprises from all the three countries. A significantly negative coefficient of the two foreign "news" variables in all the three equations estimated is interpreted as evidence of "contagion" in the Euro-syndicated loan market. However, there is no

[58] This equity market research is methodologically based on Pindyck and Rotemberg's (1990) earlier study of co-movements in monthly price changes of 7 important, but fairly different commodities (wheat, cotton, copper, gold, crude oil, lumber, and cocoa) in the US between 1960 and 1985. For each of the 7 time series price changes are explained by industrial production, inflation, the effective exchange rate, short-term interest rates, money supply and stock prices. Then it is tested for the absence of cross-sectional correlation in the regression residuals. The null of no residual correlation is strongly rejected, and even more so for longer holding periods like one quarter. Similar to their equity market study, they further substantiate the case for "excess co-movements" in commodity markets with a latent variable analysis for expectations about future values of macroeconomic fundamentals.

control for variables that might affect all the countries simultaneously, such as US interest rate changes.

In another attempt to make the case of bond and credit market contagion in emerging market countries Valdés (1997) explains monthly long-run benchmark bank debt prices (1986-1994) in each of 7 Latin American countries and biannual credit ratings (1979-1994) in 8 Latin American countries by a series of macroeconomic fundamentals. He shows that, after controlling for domestic *and* international fundamentals, the regression residuals of 7 separate bond price equations and of a pooled ratings equation still exhibit substantial cross-sectional correlation. In contrast, for a sample of 4 OECD countries co-movements of ratings completely disappear after controlling for fundamentals (and similarly for a sample of US corporate bond returns). Baig and Goldfajn (1998) also extend their daily analysis of currency, equity, interest rate and sovereign spread co-movements during the Asian crisis to a test of cross-country residual correlation from individual country regressions controlling for (good and bad) news announcement effects (collected from financial information services), US stock market returns and the dollar-yen exchange rate.[59] It turns out that the observed correlation well exceeds co-movements that can be explained by the identified "fundamentals" in most instances. Finally, in several cases news from foreign Asian countries also affected the four domestic variables considered.

From the studies surveyed in this sub-section it appears that financial market co-movements regularly exceed the level "justified" by observable fundamentals, at least for emerging market countries. However, apart from difficulties in capturing all relevant fundamentals, it might be objected that this measured "inefficiency" or "excess co-movement" does not necessarily imply financial instability or destabilisation. Therefore, it would not always qualify for the notion of contagion advanced in section 2, but often rather constitute systemic risk in the "weak" sense.

4.2.2 Contagious and joint currency crises

Eichengreen, Rose and Wyplosz (1996) provide the first broad econometric analysis of contagious currency crises. They investigate a panel of 20 main industrial countries for the period 1959-1993. They estimate a binary probit model for the pooled quarterly data, in which the explained variable is an index of exchange rate crises.[60] The authors test the null hypothesis that the probability of a crisis in

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[59] The good news considered include, for example, better than expected macroeconomic news, the successful formation of bailout arrangements and the announcement of a rescue package by an international organisation. The bad news include the collapse of an exchange rate arrangement, the breakdown of negotiations with multilateral agencies, a credit rating downgrade, worse than expected macroeconomic news, civil unrest etc.

[60] Countries with all types of exchange rate regimes are considered. A crisis is defined as a situation in which an index of exchange market pressure exceeds the sample mean by 1.5 standard deviations or more. The index of exchange market pressure is a weighted average of the exchange rate return, the change of the short-term interest rate and the change in official foreign currency reserves during a quarter for a given country (relative to a "centre country"). The advantage of such an index is that situations of stress and currency attack can be identified even when policy measures prevented a devaluation.

one of the countries is unrelated to contemporaneous crises elsewhere in the world, after controlling for a variety of political and economic (fundamental) variables.[61] The hypothesis is strongly rejected in a series of specifications. A crisis somewhere in the world appears to increases the probability of a speculative attack on other countries by an economically and statistically significant amount of 8 percentage points. However, this approach – as many others – cannot distinguish clearly between cases of joint crises resulting from a common shock and those that have the sequential type characterising contagion.

Sachs, Tornell and Velasco (1996) run a simple cross-section regression for 20 emerging market countries during the 1994/1995 "tequila" crisis. They interpret the fact that country-specific fundamentals, such as a high initial real exchange rate or a domestic lending boom, explain most of the variation of an exchange market pressure index (a weighted average of the depreciation rate and the change in reserves) as evidence of the absence of contagion during this episode. Baig and Goldfajn (1998) observe that exchange rate correlation between Indonesia, South Korea, Malaysia, the Philippines and Malaysia went up between July 1997 and May 1998 compared to 1995 and 1996. They also estimate with simple regressions on daily data that, occasionally, bad news about one of the countries (defined as eight dummy variables, capturing events such as the collapse of an exchange rate arrangement, the breakdown of negotiations with multilateral agencies, a large scale bankruptcy, a credit rating downgrade, political instability or civil unrest etc.) led to a depreciation of the currency of another country (in particular when Indonesia was the source of bad news).

Glick and Rose (1999) show that currency crises tend to be regional in scope and usually do not reach a global dimension. Their argument is based on the observation that for 5 major crises in recent history – the 1971 Bretton Woods crisis and the 1973 break-up, the 1992 ERM crisis, the 1994 Latin American "tequila" crisis and the Asian crisis of 1997 – the initial crisis in one country was followed by crises in neighbouring countries with strong trade links to the first. This observation is confirmed by different cross-section estimations for each of the five episodes, usually including a large number of industrial and developing countries (except for 1997). First, probit estimations of a binary variable (crisis/no crisis) on an interaction variable of trade linkages and a crisis elsewhere (but excluding such a variable for financial linkages) and on several domestic macroeconomic fundamentals is undertaken. Then OLS regressions of two continuous exchange market pressure variables on the same set of explanatory variables are conducted. The result is that in many of the specifications chosen, there was a significantly positive effect of the importance of trade linkages with the "starting country" on the likelihood and extent of currency crises elsewhere.

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[61] The economic and political control variables include e.g. the current account and budget positions, the unemployment

It has been objected to the trade channel argument that trade flows tend to be much smaller than capital flows (in gross terms) and that the latter are likely to be of greater relevance for contagion phenomena. This argument, among other things, has been taken up by Kaminsky and Reinhart (2000a). These authors use a monthly data set of 20 emerging and European countries (excluding most of the current euro area and the US) for 1970 to 1998, defining a currency crisis as a situation in which an indicator of exchange market pressure (composed of exchange rate depreciation and reserve losses) exceeds the sample mean by at least 3 standard deviations. They then compare the unconditional crisis probability, with the probability of a crisis conditional on the state of macroeconomic fundamentals (synthesised in a fragility index composed of 18 financial and macroeconomic data) and with the probability of a crisis conditional on both macroeconomic fundamentals and the occurrence of a currency crisis elsewhere. The fact that the forecasting error – as measured by a quadratic probability score – of the latter approach is lower than the one of the others is interpreted as evidence of contagion. Moreover, grouping countries according to their main bank creditor countries, according to emerging market mutual fund holdings by funds of industrial countries or according to the intensity of stock market correlation, results in further reductions of forecasting errors, conditional on crises elsewhere but in the same group. These effects are found to be stronger than the ones resulting from similar groupings along the lines of trade links. From this analysis it appears that financial linkages could, indeed, be more important than trade linkages (for the countries considered). However, once again the approach chosen cannot distinguish contagion – as defined above – from joint crises as a consequence of common shocks.

Van Rijckeghem and Weder (1999) present various refined tests of financial contagion in currency crises through a common bank lender country. After controlling for macroeconomic fundamentals common lender effects appear to have played a role in the 1997 Asian crisis (Thailand), to a somewhat lesser extent in the 1994 Mexican crisis, but not so much during the 1998 Russian crisis. Some of the results are sensitive to the collinearity between lending and trade linkages. In a follow-up to their previous work Kaminsky and Reinhart (forthcoming) add a simple vector-autoregression analysis with daily data showing, similar to Baig and Goldfajn (1998), that exchange rate interdependence among five East Asian countries increased during the Asian crisis, as compared to the one and a half years before. Caramazza, Ricci and Salgado (2000) undertake another probit analysis of the determinants of currency crises in emerging market economies during the Mexican, the Asian and the Russian episodes. They basically find that most of these crises seem to have been related to macroeconomic fundamentals, notably GDP growth and current account positions, and to financial contagion through a common lender country. The model employed works less well for industrial countries, including the 1992/1993 ERM crisis, pointing to differences in the factors leading to crises in the two groups of

rate, output and credit growth, inflation, the presence or absence of capital controls and election results.

countries. However, their results appear sensitive to the size of the crisis-no crisis threshold for the indicator variable of exchange market pressure.

Fratzscher (1999) also develops a framework to test for different channels through which currency fluctuations can propagate, after controlling for domestic fundamentals. The data is 1986 to 1998 for 24 open emerging and transition countries. He lets exchange rate changes outside a given country interact with trade linkages ("real integration contagion") and financial linkages ("financial integration contagion"). The former is measured through bilateral trade exposures or exposures to a common market and the latter through bilateral stock market correlation, net of the part explicable with economic variables. He then undertakes two types of estimations, each for two types of crisis measures as explained variables (a measure of exchange market pressure similar to the one used by Eichengreen, Rose and Wyplosz (1996) and a measure of market credibility based on professional forecasts).

In a first step he estimates a Markov-switching vector autoregression model (MSVAR) for each individual country in the sample, in which the varying intercepts and variances reflect jumps in beliefs unrelated to fundamentals or "contagion". At 10% significance in most of the countries displayed there is evidence of "financial contagion", but in much less countries "real contagion" seems to occur. Some countries (such as Argentina, Chile, India and Mexico) exhibit significant regime shifts that cannot be explained by fundamentals or "contagion" and others don't. This would be consistent with the occasional occurrence of sunspots. However, since the significance of these unexplained shifts in beliefs is not informative about the severity of these shifts, in the terminology of section 2.1 it does not necessarily constitute pure contagion, but could well reflect only pure systemic risk in the "weak" sense (i.e. inefficient price propagation without destabilisation). In the second step the country data are pooled and a country fixed-effects estimation (without regime switching) is applied. Again, there is stronger evidence of "financial contagion" and less but significant evidence of "real contagion", but no time effects are introduced to control for remaining aggregate shocks.

To conclude, the finance and the international economics literatures provide considerable evidence in favour of occasional contagious or joint crises and crashes in securities and currency markets. However, similar as for the studies on banking contagion discussed in the previous section, in many empirical financial market studies the evidence is not conclusive on (i) whether the joint occurrence of crises is really due to contagion or rather a consequence of aggregate shocks and (ii) whether the instances of contagion identified are of the "pure" and inefficient type or rather constitute efficient reactions by traders to the release of new information. Future research trying to draw sharper lines would certainly be desirable here. Moreover, linking the literature on extreme financial market co-movements with the one on co-movements unexplained by fundamentals appears particularly promising.

4.3 Evidence on contagion in payment systems

Published empirical studies about the importance of systemic risk in payment systems are very rare. To our knowledge, there are only three rigorous analyses of it, which all apply a simulation approach to examine the scope for contagion effects in large-value interbank net payment systems.

Humphrey (1986) simulates the potential effects of a major participant's failure in the US CHIPS by "unwinding" all the transactions involving such a participant on two randomly selected business days in January 1983. When this event rendered another bank's net debit position larger than its capital this banks' transactions were also cancelled due to "insolvency", and so on. This simulation suggested that a large share of all CHIPS participants could default (around 37 percent), with a high value of deleted payment messages. Also, Humphrey finds that the institutions affected by the initial failure were quite different between the two days examined.

In a very careful study, Angelini, Maresca and Russo (1996) apply a substantially generalised simulation exercise to the Italian net settlement system, considering end-of-day bilateral net balances for all 288 participants during January 1992. Basically, the authors generate frequency distributions of defaults, eliminated payments etc. by letting each system member alone fail once per business day. From these simulations, the systemic risk in the Italian settlement system seems to be lower than that for CHIPS (on the basis of a comparison with Humphrey's (1986) results). Recorded chain defaults involved on average less than 1 per cent of system participants and never more than 7 banks. The share of participants potentially triggering a systemic crisis amounted to 4 per cent of the total, and the "suspects" did not change a lot over time (many of them being foreign banks).[62]

McAndrews and Wasilyew (1995) undertake a similar study of systemic risk in net systems with unwinding provisions based entirely on Monte Carlo simulations. In each run the number of system participants and their bilateral payments are drawn from random distributions. Then the participant with the largest overall net debit position is made to fail on all its payment obligations. It turns out that system-wide repercussions of such a failure increase with the average size of bilateral payments, the number of system participants and with the degree of "connectedness" between the participants (as measured by the likelihood that any two banks exchange payments).

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[62] The largest individual worsening of a net position was 18.5 times capital (as compared to 32.4 times capital in Humphrey (1986)).

In close connection to the "measurement of effective exposures" approach in sub-section 4.1.1.5 presented above, Furfine (1999) examines interbank positions resulting from 719 commercial banks' US fed funds transactions settled through the Fedwire real-time gross settlement system during February and March 1998. (Notice that Fedwire intra-day overdrafts are priced but not collateralised, so that the entirety of the bilateral positions from these transactions can be regarded as credit exposures at any point in time for the life-time of the contract.) He assesses the contagion risk through these exposures by making assumptions about which banks fail and how large the recovery rate of the failure is likely to be. These parameters determine what the effective losses of other banks are going to be and, conditional on these other banks' own capital, whether any further failures will be caused. The author shows that the degree of systemic risk depends dramatically on the recovery rate. If only 60 percent of the failing bank's (banks') exposures can be recovered, then the failure of the most significant bank alone would cause between 2 to 4 (depending on the date of the initial failure) other banks to fail directly, whereas the joint failure of the two most significant banks would raise the direct contagion effect to 4 to 8 other banks in this sample. Interestingly enough, it also turns out that second-round failures appear to be extremely rare (only at isolated dates 1 bank fails as a consequence of a second round effect, but never more). If the recovery rate is 95 percent (a figure close to the effective recovery rate experienced in the Continental Illinois case of 1983-84; see Kaufman (1994) discussed in 4.1.1.5 above), then simulated contagion even vanishes almost entirely in this study. In none of the scenarios or dates considered more than 1 bank would ever fail in the first round, and second-round failures disappear entirely. However, Furfine also cautions that since the concentration on Fedwire and overnight contracts alone ignores many other sources of interbank exposures his estimates should be regarded as "a reliable lower bound on the risk of contagion".

One advantage of this type of simulation approach to payment system risk is the quantitative measurement of the extent of contagion and its very practical implications, in particular when real payments data are considered. It can be objected that this approach does not allow for reactions of other payment system participants to initial failures and might therefore either overstate contagion risk (if banks manage to undertake hedging transactions quickly) or understate contagion risk (if adverse selection phenomena in relation to banks' health in a crisis situation would lead market participants to hold back payments). Moreover, nowadays many net payment systems reduced or removed potential unwinding of transactions for exactly the reason that they might enhance systemic risk. Most other evidence of systemic problems in payment (and settlement) systems seems to be of rather anecdotal nature, such as that described in the context of the 1987 stock market crash (see e.g. Brimmer, 1989, and Bernanke, 1990).

5. CONCLUSIONS

In this paper we discussed the various elements of systemic risk with a view to first develop a broad concept of this risk, which is underlying the understanding of financial crises, and that can be used as a baseline for financial and monetary policies to maintain stable financial systems. We argue that a comprehensive view of systemic risk has to integrate bank failure contagion with financial markets spillover effects and payment and settlement risks. At the very basis of the concept (in the narrow sense) is the notion of contagion – often a strong form of external effect – working from one institution, market or system to the others. In a broad sense the concept also includes wide systematic shocks which by themselves adversely affect many institutions or markets at the same time. In this sense, systemic risk goes much beyond the vulnerability of single banks to runs in a fractional reserve system.

We reviewed the quantitative literature in the light of our concept of systemic risk. Some important new contributions have appeared in this literature in the last couple of years. First of all, and probably most importantly, a considerable number of theoretical studies have now directly addressed the issue of bank contagion. Although a generally accepted paradigm has not yet emerged, these models have greatly enhanced our understanding of the potential propagation of problems in the banking and payment system. The second important theoretical development in the area of systemic risk is the development of "third-generation" models of currency crises, addressing both "pure" and "information-based" contagion effects. In contrast, the theoretical literature on contagion in other financial markets is still progressing, in particular regarding the distinction between inefficient but "normal" price propagation and real crisis situations.

On the empirical side a few valuable developments on the explanation of banking crises across countries have recently taken place, but insights into payment system contagion remain scarce, particularly outside the US and on other than net settlement systems. Whereas the empirical literature has provided some evidence of the existence of systemic risk (as defined in section 2), in particular in the "broad" sense, it is more puzzling that many tests for bank contagion do not control for all the macroeconomic factors that might be behind the observation of joint bank failures in history. These difficulties in identifying empirically the importance of contagion as opposed to joint banking crises as consequences of macro shocks is not innocuous, since it has some implications for crisis management polices. Bank crises emerging from contagion could be stopped at an early stage at the individual bank level through emergency liquidity assistance – if identified in a timely manner –, whereas macro problems would normally be addressed through more standard stabilisation policies, such as open market operations. In other words, the current empirical literature cannot resolve the old policy debate about emergency lending to individual institutions versus lending to the market. Moreover, most traditional tests for bank contagion are not conclusive about whether spillovers are "information-based" or "pure" sunspot phenomena, and whether the former constitute efficient or inefficient systemic events. Finally, the overwhelming part of existing econometric tests for bank contagion effects is still limited to data for the United States. Event studies of bank equity returns, debt risk premiums, deposit flows or physical exposures for European, Japanese or emerging market countries are rare or virtually absent. Clearly, more empirical research is needed about the actual importance and character of bank contagion, but this agenda will not be easy to fulfil due to the presence of safety nets in many countries.

Similar reservations about the empirical importance and character of securities market contagion are also advisable, but with less direct policy implications. Particularly, the widely used conditional correlation measure may be subject to various statistical biases. Most recently, multivariate extreme-value theory has been successfully applied to extreme co-movements in equity, bond and money market returns, but as a consequence of the low frequency of macroeconomic statistics it cannot be easily linked to the literature on "excess" co-movements. The recent econometric literature on contagious currency crises seems to have made considerable progress in disentangling different channels of contagion and joint crises. However, empirical studies about contagion risks in foreign exchange and security settlement systems are simply non-existent. Research in this field is needed desperately.

Overall, we feel that the recent financial crises (Nordic banking crises, Mexico, East Asia, Japanese banking crisis, Russia etc.) sufficiently underline the importance of understanding systemic risk as a tool in defining policies and encouraging market initiatives aiming at financial stability. It was not our objective to explain any of these crises in itself. If we succeeded in convincing some researchers to try filling some of the remaining gaps we identified regarding the more fundamental issues about systemic risk, which could then help explaining and preventing real crisis situations, then we have achieved what we could hope for.

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