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WORKING PAPERS

"Working Papers" provides a review of significant working papers in investment management. This section draws from recent research in order to highlight an area of topical interest. In selecting papers pertinent to a prominent topic, "Working Papers" acknowledges current trends in the investment management business, while simultaneously directing the reader to interesting and important recent work.

CONTAGION

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Webster's dictionary defines "contagion" as the transmission of a disease by direct or indirect contact. In this light, financial contagion might well be described as the spread of financial malaise across economies and markets, through some form of linkage.[1] While this aspect of the idea is well understood in economics, it is the "direct" versus "indirect" spread of the disease that is more controversial, and leads to disagreement in the literature.

A single agreed-upon definition of contagion in the finance literature is hard to find. While the spirit of most definitions seems to be in the realm of what the dictionary specifies, the precise interpretation seems a lot more murky. The first issue that arises is the tendency for correlation to be confused with contagion. High correlations between markets may be necessary for a verdict of contagion, but are surely not sufficient. Also, the underlying causes and mechanisms behind the correlations are important in rendering a judgment on the presence of contagion. Time leads and lags between different markets also need to be considered. Hence, we shall first focus on a working definition of contagion in this review.

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1 What is contagion?

There are two widely accepted views of contagion that permeate most papers in this area of work. These are:

- Contagion is correlation amongst securities or markets in excess of that implied by economic fundamentals (see Bekaert *et al.* [2]). Also see Bae *et al.* [3] who define contagion as the correlation of extreme shocks that cannot be explained by linear propogation models. The basic idea here is that contagion is an effect not captured by a factor model.
- Another definition of contagion states it to be a "spillover" effect on some markets caused by

an initial effect in the "seed" market. Hence, it is a lagged effect in this class of models. This class of models suggests there is less of a contemporaneous effect to correlation than in the former type (see Forbes and Rigobon [9]). In this structure, a local effect over time rapidly becomes a global effect, and behavior in a limited number of markets spreads to all others (see Morris [13]).

Contagion has also been characterized by the underlying mechanism that drives the linkage between markets. There are two broad forms that this takes:

1. "Pure" contagion, based on linkages that arise from a trigger event, and are not explainable within a factor framework. See the work of Brewer and Jackson [4] for a delineation of this effect. Pure contagion is also similar to the definition of correlation in excess of fundamentals (the first type described above).
2. "Information"-driven contagion, which arises when a trigger event releases information that cuts across all other markets as well, resulting in the spillover effect symptomatic of contagion. This type of contagion corresponds to the second form described above. Contagion in this case arises from information updating. Therefore, what distinguishes this form of contagion from the first one is the presence of an information effect. In the absence of this effect, Bae *et al.* [3] argue, contagion is simply a deadweight cost imposed on the system. Indeed, it may simply be a behavioral outcome.

We may also delineate these two forms of contagion into "direct" and "indirect" types, conforming to the dictionary definition. The former type is direct, whereas the latter, relying on the information driver, is indirect. While this might seem like splitting hairs, it would be useless to de-emphasize the importance of this distinction, for the extant literature seems to go one way or the other.

It may instead, be more relevant to ask, what is *not* contagion? For one, there seem to be many articles dealing with *systemic risk* which needs to be carefully separated from contagion. Systemic risk is large-scale co-movement in markets, caused by the presence of a systemic factor, and is, therefore, explainable by fundamental factors. The absence of a common explanatory factor or the presence of an information effect is what distinguishes contagion from systemic risk, even though *ex post*, they appear, in effect, to be the same. The term "interdependence" is also used widely in this literature, alluding to systemic risk in contrast to contagion.

Therefore, while there exist papers which examine correlations over "large" events, careful specification is required to distinguish systemic risk from contagion. For example, the mere presence of high correlation is not evidence of contagion, but the presence of higher correlation in the presence of a trigger event may be contagion. No doubt, this subtle difference, makes the conceptual description of contagion hard, and makes specification testing even more complicated.

2 Drivers of contagion

Bifurcating contagion into pure and information driven categories provides a framework within which various mechanisms that drive contagion may be embedded. Underlying the resultant linkages lies a physical mechanism which breeds the economic dynamics leading to contagion.

Kyle and Xiong [12] offer a theory in which wealth effects in a microstructure setting lead to contagion-like co-movements in asset returns. Their two-asset model has noise traders, financial intermediaries, and long-term investors who provide liquidity. An economic shock to the financial intermediaries in this model results in the need to sell down both types of assets simultaneously, leading to enforced

return linkages from the trigger event. Thus, contagion in the model is a wealth effect characterized by a sharp drop in liquidity. Note, here, how this notion of contagion is quite distinct from a systemic effect. No common factor across asset returns is required, rather contagion is a pure effect emanating subsequent to an economic shock, which propagates through the model.

This aspect of contagion, that it can be propagated by trading, either of a speculative or hedging nature, permeates much of the literature. Therefore, many papers focus on whether trading swamps legitimate trade flows in creating the contagion. There seems to be evidence for both. Qin [15] finds that financial (trading) linkages are more the cause for contagion than trade linkages. Confirming this, Connolly and Wang [6] find that international equity market linkages are characterized by contagion arising from trading. Eichengreen *et al.* [8] find that trade linkages tend to lead to contagion rather than macroeconomic linkages. Fratzscher [10] also notes that financial interdependence is a major driver of contagion.

This examination of empirical work seems to suggest that contagion is an outcome of an active physical process, which is more than just a common macroeconomic fundamental. At one level, this may be purely tautological, having defined contagion as a linkage in excess of fundamentals, finding its presence must imply the existence of another exogenous physical process that spurs co-movements in markets.

There are many statistical problems that arise in the detection of contagion. The main one seems to be that an increase in correlation is simply an effect of an increase in volatility. Rigobon [17] calls this the problem of heteroskedasticity. This is easy to show in a simple factor model. Similar results are also presented in a recent paper by Forbes and Rigobon [9]. The most direct exposition appears in a paper by Sancetta and Satchell [18]. We provide a quick summary of this technical issue in measuring contagion here.

Assume two risky assets, whose returns are generated from a single-factor (X) model as follows:

$$R_i = \alpha_i + \beta_i X + e_i, \quad i = 1, 2.$$

As usual, it is assumed that $E(e_i) = 0$ and $E(e_1 e_2) = 0$. Then, by a simple calculation, we get the well-known result

$$\begin{aligned} \mathrm{Var}(R_i) &= \beta_i^2 \sigma_X^2 + \sigma_{e_i}^2, \quad i = 1, 2 \\ \mathrm{Cov}(R_1, R_2) &= \beta_1 \beta_2 \sigma_X^2, \end{aligned}$$

This implies that the correlation takes the following form:

$$\begin{aligned} \rho(R_1, R_2) &= \frac{\beta_1 \beta_2 \sigma_X^2}{\sqrt{\beta_1^2 \sigma_X^2 + \sigma_{e_1}^2}\sqrt{\beta_2^2 \sigma_X^2 + \sigma_{e_2}^2}} \\ &= \frac{\beta_1 \beta_2}{\sqrt{\beta_1^2 + (\sigma_{e_1}^2/\sigma_X^2)}\sqrt{\beta_2^2 + (\sigma_{e_2}^2/\sigma_X^2)}} \end{aligned}$$

As σ_X^2 increases, i.e. the common component becomes more volatile, the correlation also increases. Forbes and Rigobon [9] present a simple correction for this effect when testing for contagion. The important aspect of this result is that one needs to be careful when arriving at a conclusion that a market crisis trigger results in a contagion-like increase in return co-movement, as some of the increase is attributable to purely statistical artifact. This shortcoming may be present in many empirical studies, as contagion is often characterized by the presence of enhanced volatility stemming from a recent financial crisis.

Another shortcoming of tests for contagion comes from the nature of the definition itself, i.e. by controlling for common factors, and then looking for remaining co-movement triggered by a causal event. The tests are biased towards a finding of contagion

whenever there are missing factors, and it is impossible to deny the possible presence of a missing factor.

3 Evidence of contagion

Given the definitions of contagion, and the various means and difficulties in detecting contagion, what are the empirical findings? As it turns out, there is widespread presence of contagion in equity, currency, and bond markets.

Kodres and Pritsker [11] examine Asian market contagion and find that it is driven greatly by macroeconomic factors. They also find evidence for the information type of contagion. Most interestingly, they find that hedging pressures lead to contagion. Markets are linked via hedging transactions, and consistent with this fact, contagion tends to prevail more in the presence of liquid derivatives markets, which provide an outlet (and thereby the contagious consequences) for hedging transactions. Brewer and Jackson [4] examine the inter-industry spread of contagion, and find that this too, is mainly an information driven phenomenon. Acharya and Yorulmazer [1] argue in a model of bank contagion that information channels cause contagion amongst banks after a systemic risk event.

A commonly used approach to characterize contagion is to look beyond simple correlations, and examine "co-exceedances." These are bivariate extremal dependence measures that look at whether co-movements tend to increase substantially when the contagion causing event occurs. Chan-Lau *et al.* [5] find higher co-exceedance in down markets than up markets. They also note a general increase in this form of contagion after the 1998 financial crises in many parts of the world. They argue that the use of extreme value theory (EVT) works around the deficiency of heteroskedasticity that we examined earlier. The idea of using EVT is that it is one way to capture the fact that contagion is not just higher co-movement realizations from the same statistical process; rather, it detects structural changes caused by contagion, by looking at extremal observations. Finding contagion simply becomes the detection of a shift in tail-dependence in a bivariate distribution from independence to dependence. Using these techniques, they find that contagion was triggered in 1998 by the confluence of the LTCM debacle, the Russian debt crisis, and the Brazilian currency crisis. In contrast, the 1994 Mexican debt problem did not seem to trigger a contagion effect, and the Asian crisis in 1997 was minor in effect, constituting only a local contagion.

Tail dependence has a simple statistical definition. It is based on the notion of a "copula." A copula is a function that couples univariate distribution functions into a multivariate distribution function. Many different copulae exist and hence, the multivariate distribution is not unique. Sklar [19] provided a comprehensive theory of copulae. Given two random variables X_1 and X_2, with corresponding distribution functions $F_{X_1}(x_1)$, $F_{X_2}(x_2)$, a copula function would be written as $C[F_{X_1}(x_1), F_{X_2}(x_2)]$. The measure of tail-dependence (χ) is related to this function, and is defined as follows.

$$\begin{aligned}\chi &= \lim_{u\to 1} \Pr[X_1 > u | X_2 > u] \\ &= \lim_{u\to 1} \chi(u)\end{aligned}$$

which depends on the precise functional form chosen for the copula. Computation of tail-dependence determines how much contagion related co-movement exists.

Corsetti *et al.* [7] undertake an analysis of contagion using bivariate correlations, taking care to avoid the heteroskedasticity pitfall. They recognize that a correction to correlation is required to account for the fact that correlation increases with variance in times of financial crisis. However, they find that in past work, making the correction obliterates all evidence

of contagion. Therefore, peaks in cross-country linkages are simply manifestations of "interdependence," not contagion. They posit that this may just be an artifact of the testing procedures traditionally used with correlation corrections. They provide a nice test in which it is possible to separate the effects of contagion from interdependence, and find that many of the past findings of no contagion in the literature end up being reversed.

Bae *et al.* [3] also recognize the heteroskedasticity problem, i.e. that even after holding unconditional correlation constant, it is possible to obtain higher conditional correlations when large events are characterized by higher volatility. Therefore, they abandon the correlation framework in favor of looking at large absolute value deviations. Joint occurences of large absolute daily returns are examined, in a manner analogous to the tail-dependence measure above. Borrowing an approach from the field of epidemiology, they use the multinomial logistic regression model to assess the presence of contagion. One of the main findings is that contagion appears to be higher for Latin American markets than for Asian markets. The former contagion seems to be more in downside markets, whereas in Asia, contagion is symmetric. They also find that the US market seems insulated from Asian markets.

Another useful approach in detecting contagion is to employ a Vector Auto-Regression (VAR). However, since trigger events induce changes in volatility, these must also be accounted for. Panshikar [14] employs a VAR-cum-GARCH model to examine six Asian countries for evidence of contagion. This empirical specification is useful in a predictive sense as well, since the calibrated model may be used to examine how a shock to any part of the system propagates itself. Standard impulse–response functions can be used for this analysis. Further, the benefit of VAR is that it endogenizes the variables in the system. The study finds the presence of contagion in Asian markets, with the interesting conclusion that Thailand seems to play the role of the trigger market.

Fratzscher [10] undertakes the detailed examination of three different possible ways in which contagion may occur. He posits (i) the pure form of contagion, (ii) sunspots, i.e. unobservable shifts in agent's beliefs, and (iii) weak economic fundamentals. He finds that country fundamentals are not responsible for the phenomenon of contagion. Sunspots are also found to be lacking as a means of explanation. The finding is that pure contagion arising from financial linkages between different countries is the cause of return co-movements in these markets. He also develops an innovative new approach to estimating contagion. This methodology uses a nonlinear Markov-switching VAR model to examine each of the three posited causes of contagion for their presence. Equity market linkages are found to be a primary driver of the connectedness of financial malaise.

A very interesting technical paper by Quintos [16], uses tail-dependence to measure contagion without invoking copula functions. The approach uses tail indexes to estimate extremal correlation. This nonparametric approach is very useful in obtaining exceedance correlations for the purposes of detecting contagion.

4 Summary

In this article, we considered three different aspects of contagion. First, we explored the various definitions of contagion that exist in the literature. We found that, broadly, there are two types of contagion, pure contagion and informational contagion. Second, we examined the various approaches adopted to detect contagion. We found that there were many pitfalls in the statistical estimation of contagion, and many approaches have been proposed to correct for some of these deficiencies.

Therefore, there is now a vast technical literature that addresses the estimation and measurement of contagion effects across equity markets, bond markets, and currency markets. There seems to be empirical consistency for the causal phenomenon of contagion being financial market linkages rather than macroeconomic fundamentals, or trade linkages. Third, we explored the varied empirical evidence that demonstrated the existence of contagion as a major phenomenon in many markets.

In conclusion, we discuss the future development of this research stream. There are four areas in which much promise is predicated. First, is the understanding of the portfolio effects of contagion, as opposed to those of systemic risk. In this area of inquiry, we can set up models that enable us to understand the differences between portfolio choices when systemic effects are present as opposed to contagion effects. Second, we need to understand the empirical impact of contagion on current portfolios—very little of the literature has addressed this issue. Third, much remains to be said in terms of policy issues and regulatory guidance that is required over the next few years given the growing extent of globalization which makes regulation an important area of inquiry in the context of contagion and its fallout. Finally, having understood portfolio effects, and the financial and economic impact of contagion, we would like to know whether contagion is forecastable, which would determine how manageable this phenomenon is. Much remains to be done in this rich area of work, especially as the world becomes an increasingly smaller place.

Notes

[1] Not all papers treat financial contagion as a bad outcome. While there is greater evidence of contagion in times of financial crises, there are also occassions when positive events in markets also show aspects of contagion. See, for example, the findings of Bae *et al.* [3].

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