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Contagion or interdependence? Comparing signed and unsigned spillovers

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Abstract

Differentiating between ‘good’ and ‘bad’ spillovers we disentangle sources of potential crisis from the intricately complex web of connections across international equity markets. In particular, we analyze the behaviour of 30 global equity markets and compute multiple spillover measures, which encapsulate many large and small crises episodes. Instead of relying on ex-post-crisis information, our model identifies crises periods. Moreover, we are able to detect newly emerging contagion in the system.

Keywords

Systemic risk, signed spillover, contagion, interdependence

JEL Classification Numbers

C3,C32,C45,C53,D85,G10

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1 Introduction

The multiple crises of the last two decades provide an ideal testing ground to identify systemic risks facing global equity markets. Understanding systemic risks using empirical tests on contagion, spillovers and financial networks has been a long standing research question. While the literature stretches back as early as King et al. (1994) on spillovers and Allen and Gale (1998) on contagion, the empirical literature on networks and financial spillovers is more recent. Allen and Gale (2000) and Gai and Kapadia (2010) evaluated network effects within the financial sector, while Acemoglu et al. (2015) showed, how real economy shocks can become the source of crises that spread dramatically via financial interconnectedness as ‘fragility’, affecting otherwise ‘robust’ networks. Empirical representations show how the networks themselves change over time, between calm and crisis periods, and with the development and growth of emerging financial markets (Billio et al., 2012; Khandani et al., 2013; Demirer et al., 2018a). The changing nature of the links between those institutions can be considered a measure of contagion (Dungey and Gajurel, 2015), while the links between spillovers and networks are highlighted in Diebold and Yilmaz (2014) via unsigned forecast error variance decompositions providing a single index of system’s vulnerability. This paper overcomes the limitations of the unsigned single vulnerability index by highlighting vulnerability via newly proposed identification approaches using the signed return spillover index (Dungey et al., 2017b) complemented with a novel signed volatility spillover index.

We investigate spillover patterns in the global equity market using the Diebold and Yilmaz (DY) connectedness index (Yilmaz et al., 2018; Demirer et al., 2018c,b; Yilmaz, 2017; Diebold et al., 2017; Diebold and Yilmaz, 2015; Diebold and Yilmaz, 2014) and the multivariate historic decomposition (MHD) index (Dungey et al., 2017b). The DY provides information on the direction and size of spillovers, while the MHD provides the direction, size and sign, that is, whether the linkages dampen or amplify shock transmission. We calibrate the MHD further by the estimating signed index with realised variances, and separate out the self exciting transitory signed volatility evolution from the signed return spillovers with our proposed signed volatility decomposition (SVD). This approach can be considered as an extension of vulnerability and transmission representations with MHD.

This paper makes several contributions into the current domain. First, we propose a risk matrix that also identifies out sources of crisis. Then, we provide a rationale regarding the recent surge in speculation around crisis sources, and explore whether there is enough evidence aligning with these postulations. We examine if China is a potential source of crisis as suggested in Engle (2018). We produce evidence that it is unlikely that China will trigger a financial crisis any time soon. Finally,

we address some key questions that have long puzzled researchers. Can we extract more contagious markets out of sample clusters? Are these markets generating crisis episodes drawn towards a continuum conducive to predictive patterns? How diabolic are contagion patterns in more recent times compared to before? Can we disentangle substantially large contagion patterns driving global economies towards a potential crisis? Identifying potential sources of contagion and patterns underpinning contagious markets will allow regulators to take timely action attenuating the exposure of domestic markets to a large-scale crisis.

A primary objective of this paper is to show that signed risk measures are better suited to model crises than popular unsigned risk measures. It examines market dynamics across all episodes of crisis and compares the derived signals with actual events juxtaposed against popular unsigned risk measures. Such comparison concentrates on the degree of mis-identification if crisis modelling is reliant on a single framework, and more than one framework may not only complement each others' findings but also reduce the gaps in the outcome. Hence, this objective addresses that running multiple important risk analysis frameworks simultaneously may have important implications in understanding both the degree and direction of crisis and in better modelling of crisis episodes.

A secondary objective of this paper is to detect major contagious markets in the past and newly emerging contagious markets using a single framework. A major gap in extant literature is the effects of 'interdependence' is often enveloped within the potential effects coming from 'contagion', and as such is not well studied. This gives rise to a bias resulting from heteroscedasticity and often leading to failure in adopting a proper policy response to an imminent crisis. Interdependence bears less negative connotation compared to contagion and the voluminous literature simply fails to incorporate major perspectives in crisis studies. This has resulted in an abundance of incomplete crisis examinations. Among the 124 papers reviewed in the taxonomy of Seth and Panda (2018), only 4 mention contagion, interdependence and integration. Simultaneous increase in volatility facing a crisis is often wrongly attributed as resulting from contagion. It is because such amplifications in risks pertains to interdependence and overcasts the effect of contagion for a particular market. An important significance of the current paper is that we propose a tractable novel approach building on methods we have been experimenting with, that separates contagion effects out of effects due to interdependence, yet offers better crisis demarcation without prior knowledge on crisis.

More recently, Dungey and Renault (2018) relying on Forbes and Rigobon's (2002) findings showed how to distinguish contagion from interdependence. Dungey and Renault (2018) suggested that swings in the volatility of common factors may transpire from reasons pertaining to 'source' or 'target' markets and may induce simultaneous volatility jumps. The evolution of innovations in one entity that is immediately

reflected in another when a crisis does not precede and as such may not pertain to contagion. However, a crisis period co-movement in volatility requires careful exploration, as volatility in the common factor of a ‘target’ itself may overcast the effects coming from the ‘source’. In our work, we adopt a combined yet simpler approach considering the nexus between two issues and, distinguishing markets with different levels of contagion.

A novelty in our method is that crisis demarcation is not a necessary condition for contagion identification, unlike earlier methods. We do not need to concur with Forbes and Rigobon (2002) in knowing the crisis and calm periods to separate contagion from interdependence. We support the work of Dungey and Renault (2018) while progressing the current tenet by identifying the more contagious markets from the less contagious or not contagious markets with a single approach. This is a key contribution to the current literature investigating the real time evolution of contagion and, by extension, the early warning literature.

We apply DY, MHD and Signed Volatility Decomposition (SVD) approaches to a large panel of international equity markets. The DY provides a profile of increasing spillover effects between the markets across the sample period, highlighting periods of change in the intensity for these effects. However, the DY is limited in identifying the direction of contemporaneous risk measures. MHD analysis enhances the DY by identifying linkages between markets that amplify or dampen shocks and, further, how the system of markets fluctuates around the average relationship by accumulating shocks over time. MHD helps discerning negative in-shocks from positive out-shocks with signs. SVD analysis complements MHD by calibrating the model with innovations from realised variance estimates put into an impulse response framework. The results are robust to different rolling sample sizes and data frequencies.

We use a balanced sample of 30 financial markets in this paper¹. We classify the markets into export crisis (EC) markets (i.e., leaders in commodity export), oil exporters into both emerging (OEE) and developed (OED) markets, European markets that have been directly affected by the Greek crisis (GC) of 2010 onwards and high-yield Asia-Pacific markets directly affected by the Asian crisis (AC) of 1997–1998. We also include in the OED group the so-called conduit markets of the USA and Japan (BIS, 1998; Baur and Schulze, 2005). Table 3 provides the classification of the markets into five clusters, which is common in the literature. Our results also allow us to focus on the potential risks of crisis, and the emergence of China as an important conduit market as outlined in a number of studies (Elliott, 2017; Mullen, 2017; Quijones, 2017; Mauldin, 2017; Friedman, 2016; Jolly and Bradsher, 2015).

We identify the most crisis-prone markets and explain how the effect of innova-

¹Australia, Austria, Belgium, Canada, Chile, China, Croatia, France, Germany, Greece, India, Iraq, Ireland, Israel, Japan, Kuwait, Malaysia, New Zealand, Nigeria, Norway, Portugal, Russia, Saudi Arabia, Singapore, South Korea, Sri-Lanka, Thailand, the Philippines, the USA and the UK

tions in these markets are different from the less crisis-prone markets. The inclusion of an oil index allows us to examine the system’s sensitivity to shocks, especially during periods of stress in oil supplies. The stress coming from exogenous shocks are examined only with the unsigned spillover measure.

Finally, five important questions concerning the time-varying nature of systemic risk estimates leading to the detection of crisis transmission patterns are addressed. First, we examine whether policy interventions that restrict significant transmission paths help interconnected financial markets to deal with shocks. Second, we find that the changing interactions between markets result in changing patterns of shock spillovers. Third, we examine whether it is possible to detect which markets are more shock resistant in the sample period from 1998–2017. Fourth, we determine if a parametric signed identification approach can be used as an extension to the unsigned identification approach of return spillovers. Fifth, we examine if signed indices² identify self-exciting volatility transmissions and return transmissions.

The remainder of the paper proceeds as follows. Section 2 discusses a history of crisis episodes across the global equity market. Section 3 presents the empirical framework concerning GVD, static and dynamic networks, MHD and SVD. Section 4 outlines the dataset, consisting of 30 equity markets, the oil index and the commodity index. This section also presents the filtering method and descriptive statistics on filtered data. Section 5 discusses the empirical results based on ‘system-wide connectedness’ and the resultant network among the markets, before following on to the dynamic analysis and MHD measures explaining the effect of positive and negative shocks in the sample markets. We compare the results of MHD with SVD in this section. Section 6 presents the conclusion to this paper.

2 A brief history of crises episodes in global equity markets

2.1 Asian crisis

With the unveiling of the 1997–1998 Asian financial crisis, supervisors attempted to stem the falling markets by responding differently from each other. As the ground zero of the crisis, Thailand adopted a structural adjustment package. The crisis disproportionately affected other countries, driving the supervisors of Malaysia, Indonesia and South Korea to adopt policies pulling in different directions. While Malaysia reverted to a fixed exchange regime, Indonesia’s inflation targeting policy and South Korea’s currency devaluation floated the exchange rates in both the countries (Khan and Park, 2009). Among others, Singapore continued with its managed currency float, while Chinese authorities avoided any degree of intervention into the markets

²This yields realised volatility transmissions within a system.

(Raghavan and Dungey, 2015). While the Asian markets successfully stopped the crisis from propagating further, the resulting changes in the interconnections within and outside the markets provided a clearer picture of the strengths and weaknesses of the AC cluster.

2.2 War and oil shock

The extant literature posits a perennial question associating war with crisis. Major relevant studies have attributed this to holding either a ‘liberalist’ view or ‘realist’ view, taking opposite stands while describing the economic costs of war (Morrow, 1997; Barbieri, 2002; Li and Sacko, 2002; Schneider and Troeger, 2006b). As war erupts, provided there is heightening of military goods trade relative to little or no drop in bilateral trade, Morrow (1997); Barbieri and Levy (1999); Barbieri (2002) supported the ‘relative gain’ concept. Albeit belonging to the liberalist view, Schneider and Troeger (2006a) supported the realist view provided short-term spikes in financial markets reflected increased investor confidence. This is partly due to investors’ belief that positive anticipation of war outcome is conducive to escalating trade and asset returns. This anticipation also held for higher oil returns during the Iraq invasion. However, there exists little empirical evidence in the extant literature in support or in opposition to this view, resulting mostly in exacerbation or downplay of the true economic casualty that may emerge from war.

Li and Sacko (2002) and Schneider and Troeger (2006a) also presented two financial market scenarios with fundamental models prevailing in finance. If a long term uncertainty is associated with a conflict, investors collectively sell off stocks and seek investment into less risky assets elsewhere, sending local markets into a cascade. In contrast, positive expectations stemming from news related to the quick resolution of war may increase investment as higher returns are attributed to the winning of war. In any case, all different views in outbreak of the wars affecting financial markets converge into an accord that war has a negative effect on economic exchange (Barbieri and Levy, 1999; Barbieri, 2002).

Rigobon and Sack (2005) reported a subsequent decline in the equity prices, treasury yields and dollar rates as the USA invaded Iraq. Leigh et al. (2003) provided an extension to gauge the direction of equity investments from a ‘Saddam Security’ futures, suggesting a global decline in asset values once the full extent of effect of Iraq is realised. This also lends support to heightened capital flights as explained by Schneider and Troeger (2006a), causing increased connectedness and systemic risk. Schneider and Troeger (2006a) further suggested that investors generally fail to adapt to prolonged political uncertainty, and this is reiterated by transmitting crisis globally, especially through stock markets.

Leigh et al. (2003) provided a rationalisation for cascading international equity markets resulting from systemic transmission of crisis immediately after the Iraq invasion. For each 10 per cent increase in the probability of war the drop in the the stock prices of Germany, Sweden, Taiwan, Israel, Venezuela and, Hong Kong accounts for over 3 per cent. The price drops for the USA, Portugal, Netherlands, Singapore, China, France, the Philippines, the UK, Russia, Norway, Canada remains within 2 to 3 per cent. Australia, Belgium, Chile, Thailand, India, Japan, Greece, Malaysia, Sri Lanka, Austria and, Indonesia are burdened with 1 to 2 per cent drops in asset prices. Indeed, as the war deepens longer than expected, the drops continue to escalate for each additional degree of probability, sending many markets into a downward spiral.

Leach (2003) addressed the conditions in Japan and the European Union zone particularly concerning the worsening economic spirals transmitted by the USA recession. In the past, the buoyant Japanese and the European Union stock markets successfully offset crisis build-up when the USA was at war with Vietnam, and vice versa. However, in the impending Iraq invasion period, both economies were submerged in domestic crises that were compounded by the burdening Iraq War. The systemic failure in the Japanese economy was well advanced, with bank loan defaults adding upto 35 per cent of its GDP, leading to cascades of bank failures. This situation escalated with constraints imposed on further stimulus facing a phenomenal public debt level. The Eurozone faced imposing fiscal constraints outlined in the ‘Growth and stability pack’ coupled with accelerated inflation as Germany slipped into recession.

In contemplating the global economic contraction facing a war-like crisis between two players, a key state variable is oil price fluctuation. Leach (2003) held that because the cost of oil is implicit in the cost of business, the conflicting inflationary pressure on the oil market that conflicts leads to contractionary monetary policies that hike interest rates. This, in turn, spurs unemployment and sets the economy off on a cascade. The downturn is severe, particularly for oil exporting countries, and results from exchange rate jumps that is termed as the ‘petrocurrency effect’. Nordhaus (2002) presented a predictive analysis for the USA market; in the advent of an Iraq-invasion, that an oil shock may bring about a US\$17 billion gain compared to a US\$800 billion loss in the years that follow the invasion. In this study, we attempt to disentangle the oil effect in gauging systemic risks by including oil as an entity in the system.

The number of commentator concerns over the issue of war causing oil price fluctuation subsided as the GFC ensued. Early 2006 marked a period of general buoyancy in the markets across all sectors. Lending contractions in the financial sector that followed were due in large part to the unprecedented level of subprime mortgages, which led to the entire USA economy becoming susceptible to an imminent melt-

down.. Dungey et al. (2018c) illustrated that, despite the economy facing an overall subprime crisis, the abrupt offloading of risky exposures through credit risk transfers only exacerbated the economic downturn. In the full form of the USA subprime crisis in September 2008, several leading investment institutions started to feel the pinch with a series of events, which led to the Lehmann Brother bankruptcy, sheer fall of mortgage-backed securities reflected in the ABX index, government bailing the AIG out and taking Fannie Mae and Freddie Mac over. While in the US, supervisors tried to control the swings of crisis with bailout packages and a TARP contract, the high degree of international investments into the cascading USA mortgage backed securities sent markets across borders into a downward spiral.

2.3 Eurozone crisis

The fiscal crisis in Greece in 2009 mutated into a deep recession through a sovereign debt crisis. The announcement of Greece's budget deficit had increased to five times higher than the target stipulated by Growth and Stability Pact spurred fear over the future of eurozone. Matsaganis (2013) held that with the adoption of new austerity measures by the local government in the following years, coupled with depletion of Greece's credit rating, investors naturally cause further degradation of returns on investment in Greek market. This resulted in cascading capital in the Greek market that pushed the economy into a solvency crisis. The conditions to adopt more austerity measures that came with bailout packages by the International Monetary Fund and the European Union only exacerbated the worsening spiral for Greece. Consequently, by the end of 2013, the Greek standard of living had dropped to 34.3 per cent below average (Matsaganis, 2013). This crisis had spread quickly, with Spain and Portugal each losing about 8 per cent living standards. The economic contraction, as indicated in the Eurostat statistics database, stood at 23.5 per cent for Greece, and had simultaneously contracted the economies of Spain by 5.5 per cent, Portugal by 7.4 per cent, Italy by 7.8 per cent and Ireland by 5 per cent (Matsaganis, 2013).

The escalating European debt crisis provided an ideal foundation from which to investigate the channels of GFC that expedited European debt crisis's build-up. The work of Reinhart and Rogoff (2011) is considered the first to have proposed causal connections between the banking and debt crisis. While endorsing this concept, Candelon and Palm (2010); Angeloni and Wolff (2012) and De Bruyckere et al. (2013) empirically established the notion that the subprime crisis mutated into sovereign debt crisis, rationalising the systematic build-up of the European crisis stemming from the GFC. Recently, Calabrese et al. (2017) indicated that systemic risk due to simultaneous debt holdings between Greece, Italy, Ireland, Portugal and, Spain (GIIPS) was responsible for spurring the European debt crisis. Rušćáková and Se-

mančíková (2016) classified the crisis channels into banking and fiscal.

Risks generated from the financial sector disproportionately affect the real economy, especially when the effects of financial sector stocks are separated from non-financial stocks, as Dungey and Renault (2018) suggested. By disentangling risk transmission from different sectors in the USA stock markets, Dungey et al. (2018c) provided evidence that non-financial sector equities shield the real economy as a crisis intensifies. Having access to alternative sources of credit, non-financial sector portfolios decouple with the heightening of systemic risk, and provide a partial hedge to domestic investors. This finding explains how some smaller economies with a disproportionate allocation of financial sector and non-financial sector undertakings offset the effects of crisis despite domestic banks bearing the full brunt of a crisis emitting from global banks and not the other way around.

More recently, Dungey et al. (2018a) provided the rationale that all euro-zone markets do not have the same reassessment for potential default risk. Dungey et al. (2018a) found evidence for prolonged crisis regimes with ‘durations’ of high-volatility for GIIP, including Belgium, Spain and Netherlands. Conversely, crisis regimes for Germany and, the UK were more short-lived. Moreover, Dungey and Renault (2018) asserted that Germany provides a safe haven during crisis, as markets susceptible to volatility resulting from contagion distance themselves somewhat from Germany.

2.4 The emergence of Brazil, Russia, India and China (BRIC)

The relative importance of systemic risk pertaining to interdependence, or risk emerging from sufficiently proximate contemporaneous small shocks for Brazil, Russia, India and China (BRIC) is, a priori, attributable to their recent transformation into leading investment avenues. The impetus given by the utmost global depository receipt issuance, coupled with hasty equity market liberalisation, positioned the Chinese (Shanghai Stock Exchange) and Indian (Bombay Stock Exchange) markets as the fourth- and fifth-largest trading platforms in the world. However, these markets did not suffer from the same market reassessment of default risk when faced with the 2007 meltdown, as India and Russia observed a sharp increase in negative inflows while for China, these inflows remained positive (Chittedi, 2014). This led to a cascade, as liquidity that drained from the emerging markets brought about local currencies falling sharply against dollars (Ferreiro and Serrano, 2011).

There is a strand of literature both supports and contradicts such views. Immediately following GFC, Dooley and Hutchison (2009) and Dimitriou et al. (2013) dismissed contagion transmissions into BRIC, including East Asia emanating from the US. More recently, Wang (2014) and Syriopoulos et al. (2015) complemented this notion by finding increased interconnections between the USA and East Asian markets alongside their BRIC counterparts; however, this was observed only after the

GFC. In contrast, Bekiros (2014) found that contagion spurred the relevant markets with the unfolding of GFC.

2.5 Equity shortfall in Europe during GFC

Similar to BRIC and the Asian markets, capital flights from equity markets of Eastern Europe in the advent of the GFC pushed the market values of stocks down by 50 per cent. Syllignakis and Kouretas (2011) asserted that institutional investors shifting investment preferences from stocks and bonds to treasury bills, with the preceding investment withdrawal from institutional to investor-managed, emerging market hedge funds and private equity by investors as the USA subprime crisis unfolded exacerbated crisis transmission and contagion in the emerging Eastern European markets. Evidently, connectivity between emerging and European export dominant countries had resurfaced, especially with Germany, Russia, the UK and the USA (Syriopoulos, 2007; Lucey and Voronkova, 2008; Syllignakis and Kouretas, 2010).

3 Empirical framework

3.1 Diebold and Yilmaz spillover index (DY)

Diebold and Yilmaz (2012) proposed a VAR forecast error variance decompositions (FEVD) to compute DY spillover indices. The FEVD matrix is termed as the adjacency matrix (or ‘connectedness matrix’), where orthogonal shocks are projected on N co-variance stationary variables. Across the rows and down the columns give signs of in-shocks to the targets and effects of out-shocks to potential recipients. Summing up all non-diagonal elements of the decomposition gives unconditional variances in a squared matrix.

From a VAR(p) of the form³

$$x_t = \sum_{i=1}^p \varphi_i x_{t-i} + \varepsilon_t \quad (1)$$

Here x_t is the returns vector $x_t = (x_{1,t}, \dots, x_{N,t})'$, φ is a $N \times N$ parameter matrix and $\varepsilon_t \sim N(0, \Sigma)$ the moving average representation is

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}. \quad (2)$$

³An intercept is suppressed for simplicity and without loss of generality.

Here,

$$A_i = \phi_1 A_{i-1} + \phi_2 A_{i-2} + \dots + \phi_P A_{i-p}$$

From here we can extend

$$x_t = \sum_{i=0}^{\infty} (A_i P) (P^{-1} \varepsilon_{t-1}) = \sum_{i=0}^{\infty} (A_i P) (\tilde{\varepsilon}_{t-i}) = \sum_{i=0}^{\infty} \tilde{A}_i \tilde{\varepsilon}_{t-i} \quad (3)$$

P is a lower triangular Cholesky matrix. Diebold and Yilmaz (2009) propose using the H -step-ahead forecast error variance decomposition (GVD) that is constructed from VAR (see (Koop et al., 1996)) to circumvent the order dependence issue. We denote this GVD by $\theta_{ij}^g(H)$ and that gives

$$\theta_{ij}^g(H) = \frac{a_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_j)} \quad (4)$$

Here, the co-variance is \sum and a_{jj} is square root of error variance of j th equation and in the i th element, A_h is the moving average coefficient from VAR and e_j is a selection vector of ones.

Now $\sum_{j=1}^N \theta_{ij}^g(H) \neq 1$. However, after normalizing, the rows in the FEVD matrix gives

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)} \quad (5)$$

in which we get $\sum_{j=1}^N \tilde{\theta}_{ij}^g(H) = 1$ and $\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H) = N$.

The static spillover or the unconditional variances are computed by taking the sum of off-diagonal elements as proportion of sum of all elements, representing system wide connectedness. Notably, the directional spillover index identifies the return spillover of all other markets to market i

$$S_{i \leftarrow all}(H) = \frac{\sum_{j=1, j \neq i}^N \tilde{\theta}_{ij}^g(H)}{N} \times 100. \quad (6)$$

The return spillover from market i to the other markets in reverse gives by simply transforming to

$$S_{i \rightarrow all}(H) = \frac{\sum_{j=1, j \neq i}^N \tilde{\theta}_{ji}^g(H)}{N} \times 100. \quad (7)$$

Pairwise directional connectedness identifies gross shock transmission to and from the markets in a holistic associated framework of networked data which is

$$S_i^g(H) = S_{i \leftarrow all}^g(H) - S_{i \rightarrow all}^g(H). \quad (8)$$

3.2 Multivariate historical decomposition (MHD)

MHD, pioneered by Dungey et al. (2017a), produces a signed contribution of shocks from one to another that captures the magnifying and dampening effects of contemporaneous shocks in the intertwined markets. Here, the connectedness elements measured with B_{ij} explain the fraction of variation of i due to shocks in j at time t (excluding self-loops in a network). The parameters are estimated from the following VAR

$$x_t = \sum_{i=1}^k \phi_i x_{t-i} + \varepsilon_t \quad (9)$$

Here, $x_t = [x_{1,t} \dots x_{n,t}]^T$. Next, re-writing the reduced form VAR with disturbances and representing with moving averages we have

$$x_t = \text{initial values} + \sum_{i=0}^{\infty} S_i \varepsilon_{t-i} \quad (10)$$

Here, $S_j = \varphi_1 \varphi_{j-1} + \varphi_2 s_{j-2} + \dots$ with $j = 1, 2, \dots$, $S_0 = I_N$ and $S_j = 0$ for $j < 0$. Re-writing this equation for any individual element $x_{j,t}$, which can be explained with contributions of all other elements, the third step, represents the historical decomposition of j at time t . This is presented in the equation as follows,

$$HD_{t+j} = \sum_{i=0}^{j-1} IRF_i \odot \gamma_{t+j-i} + \sum_{i=j}^{\infty} IRF_i \odot \gamma_{t+j-i} \quad (11)$$

Here, $\gamma_{t+j-i} = [\varepsilon_{t+j-i}, \dots, \varepsilon_{t+j-i}]$ is an $N \times N$ sized residual matrix, with N representing the length of a vector. $IRFs'$ are one unit impulse responses (non-orthogonalised) and \odot is the Hadamard product. The estimated MHD produces an $N \times N$ sized matrix providing negative in-shocks across the rows and positive out-shocks down the columns of the matrix without any sign restriction. This approach accommodates the non-linear dynamics of the data.

MHD produces signed weights of shocks throughout the channels, as a function of impulse responses weighted by residuals ε_t . The system uses unconditional variance estimates as innovations for the impulse response estimates and, as such, are considered to represent spillovers in the returns of the variances.

3.3 Signed volatility decomposition

In this section we propose SVD extracting spillover information drawn from realised variances associated with volatility transmissions within networks. We take the dif-

ference between return and volatility spillovers to identify whether a particular market is driven more by intrinsic volatility than by risks emerging from the network.

We take a non-parametric approach to estimate SVD, which follows the same algorithm as MHD. Unlike MHD computed from daily returns, we compute MHD from realised variance drawing from five-minute intervals in prices and, as such, the historic decomposition is depicted as SVD.

We begin by calculating log returns with $r_t = \log(P_t) - \log(P_{t-1})$. Next, we take squared returns of five-minute intraday data and sum them up to find daily realised variances as

$$RV_t = \sum_{i=1}^N r_t^2$$

All else remaining constant, SVD is the historic decomposition presented earlier

$$SVD_{t+j} = \sum_{i=0}^{j-1} IRF_i \odot \gamma_{t+j-i} + \sum_{i=j}^{\infty} IRF_i \odot \gamma_{t+j-i}$$

To identify contagion in the holistic associated network from volatility of common factors localised to a given market we simply take the spread between SVD and MHD.

$$Spread_{t+j} = SVD_{t+j} - MHD_{t+j}.$$

4 Data

The data are daily dollar denominated stock returns from 30 developed and developing countries' markets across Asia-Pacific, Europe, the Americas and the Middle East.⁴ The beginning of the sample corresponds to the Asian financial crisis period. Daily returns are generated from price indices for 1 January, 1998 to 15 September, 2017. Global economies endure 10 major crisis periods and several minor turmoils within the sample periods as outlined in Table 3. Further, we include the West Texas Intermediate index to investigate shocks coming from the oil market and S&P GSCI commodity index to investigate the effect of commodity inclusion.

Taking natural logarithms of the data we transform price to returns data. We further use a two-day moving average filter, removing time zone effects as in Forbes and Rigobon (2002).

Discussions concerning properties of asset returns dominate in both the current and early literature. Among early studies, Fama (1976) suggested that daily asset

⁴The data are sourced from Thompson Reuters, and we follow the mnemonics indexed in (Pukthuanthong and Roll, 2009).

returns series are more non-Gaussian than are shorter frequency return series. Additionally, Cont (2001) emphasized persistence and non-linearity, while Stărică and Granger (2005) focused more on non-stationarity inherent within stock returns data.

Recently, Joseph et al. (2017) classified stock returns as non-Gaussian and time varying, with smooth compact support over low-frequency spectral content. Others suggested that the daily stock returns data are negatively skewed, nonlinear, noisy and volatile (Joseph and Larrain, 2008; Atsalakis and Valavanis, 2009; Joseph et al., 2011; Kremer and Schäfer, 2016; Zhong and Enke, 2017). It is crucial to use appropriate filtering and transforming techniques for better detection and decoding of cycles in source data.

Of the relevant studies examining prediction, Zhou et al. (2012) supported on the dissent in theory and practice regarding asset returns. Only the pre-possessing of returns circumvents such misalignment, as suggested by Joseph et al. (2017, 2016); Atsalakis and Valavanis (2009) and Zhong and Enke (2017). A central context of data pre-processing with filtering is, there is no discord in its importance in the relevant studies investigating returns (Joseph et al., 2017).

Finally, Smith et al. (1997) suggested that despite its simplicity as a method, moving average filters do much better compared to other digital signal processing techniques, such as single pole. Precisely, moving average handles discrete time series in a subtle manner (Smith et al., 1997).

Within the context of considering raw returns as non-Gaussian, nonlinear, time-variant random data, the importance of spectrum density/frequency domain analysis for pre-processing is undeniable. Hence, moving average is the chosen signal processing technique here. On another note, ‘spectral windowing’ is important to extract detectable edges and avoid aberrations caused from discontinuity in the raw data. Naturally, the chosen window size is 2 in our paper, which is consistent with (Oppenheim and Schaffer, 2014) and (Forbes and Rigobon, 2002).

The transform function

$$a(1)y(n) = b(1)x(n) + b(2)x(n-1) + \dots + b(n_b+1)x(\eta - \eta_b) \\ - a(2)y(n-1) - \dots - a(\eta_b+1)y(\eta - \eta_a)$$

handles both infinite and finite impulse responses. The moving average filter derived from the rational transfer function allows input of different window size (ws) $y(n) = \frac{1}{\omega_s}(x(n) + x(n-1) + \dots + x(n - (\omega_s - 1)))$.

Indeed, our pre-processed data characterised by the frequency contents of the signals, better detects the periodicity than does the raw unprocessed returns data. Table 5 presents a selection of statistics for the 30 return indices; including average, minimum, maximum, standard deviation and Jarque-Bera test results for normal-

ity in distribution. The greatest spread between minimum and maximum is found for Venezuela, Kuwait and Iraq, all of which have high standard deviations. As is usual for returns normality is rejected at the 5 per cent significance level. Rather, these indices have more leptokurtic and skewed distributions, consistent with the crisis effects throughout the sample period (Brown and Warner, 1985; Fama and French, 1988; Kim et al., 1991; Corhay and Rad, 1994; Longin, 1996). In addition to robustness tests with different rolling windows, we have examined the possibility of multicollinearity in residuals. We found correlation coefficients to be null and insignificant in the residuals, ruling out the possibility of loss of consistency in our estimation outputs.

In the following section, we present a comparison in the estimates gauged from DY, MHD and SVD. Note that, while DY and MHD estimates are computed drawing on data from the complete sample size, the MHD-SVD spread draws on from 5 minute interval prices for September 2009 until September 2017. Due to the limited availability of five-minute interval prices for important South Asian countries, such as Singapore, we trim the data down to fit vector sub-spaces within the specified matrix space, for all other vectors retaining Singapore. For similar reasons, we also remove Middle Eastern markets. We include Mexico in the sample, as it represent an important, emerging oil exporting market.

5 Empirical Results

In this section, we discuss the empirical results presented in Table 1 and Table 2 and Figures 1 to 26. A detailed explanation of the amplifying and dampening of transmissions and vulnerability is also presented in Table 1 and Table 2.

The analysis holds for two fundamental principles.

1. First, a common phenomenon that largely holds is that big transmitters are generally more susceptible to global contagion shocks, and that propagation of crisis with contagion is one-directional.
2. Second, in identifying contagion from an aggregate risk assessment, our economic prior is that for the markets in which locally induced volatility swings together with spillover, the increases coming from interconnection amplify the aggregate risk estimates, which reverts the market to a steady state by releasing excess risks onto others. Hence, in times of excess volatility, markets are more epidemic in nature.

Next, we discuss comparisons by market blocks (see Table 4): Asian crisis (AC), export crisis (EC), Greek crisis (GC), oil exporting developed (OED) and oil export emerging (OEE).

Table 1 and Table 2 show that India, Singapore and Thailand in the AC cluster are highly susceptible to their own market shocks, but this holds less so for Malaysia, South Korea and the Philippines. While many past studies have contended (including our DY estimates) that Malaysia and the Philippines are more resilient for not being deeply connected to global networks as others (Raghavan and Dungey, 2015), our MHD estimates further suggest the latter set of markets receive strong shocks in major events. As given in Figure 1, Figure 6, Figure 11, Figure 16, Figure 21, Figure 26, and Table 1, Table 2, we suggest that the Indian, Malaysian and South Korean markets are more vulnerable to globally induced contagion than are the rest. The transmission estimates uphold this phenomenon by depicting these markets as low transmitters that are highly vulnerable to an epidemic in the holistic network. As Thailand, Singapore and the Philippines remain more susceptible to local volatility, unsurprisingly they emerge as strong transmitters as they release ‘excess volatility’ to other peripheries (see Table 1 and Table 2). This ‘excess volatility’ refers to the accumulation of instantaneous self-exciting stochastic volatility in excess of volatility spillovers coming from the networks itself.

Simultaneous volatility changes in common factors with large scale events often pollute the degree of actual spillovers as suggested in (Dungey and Renault, 2018). In the tables (Table 1, Table 2) and the figures (Figure 2, Figure 7, Figure 12, Figure 17, Figure 22, Figure 26), we identify risks generated out of interconnections in the network from localised volatility changes for the EC (i.e., Germany, Chile, France, China, the UK and Australia) market cluster with MHD-SVD spread. We identify that Germany, Chile and the UK are predominantly more vulnerable to instantaneous transitory spikes in volatility, polluting the actual degree of shocks received from interconnections within the network. Consistent with the principle of high spreaders being less susceptible to vulnerability coming from a global contagion, the UK and France turn out to be high transmitters of crisis, especially during the GFC and eurozone crisis. For Australia, transmissions are triggered strongly with ‘excess volatility’ and, as such, it is highly vulnerable to epidemic shocks in the network. As opposed to Dungey and Renault (2018), who suggested Germany does not suffer from the same market reassessment risk as major markets and is distanced from other connections, we find Germany and China are highly susceptible to crisis received from other markets with ‘excess volatility’ most recently. Consequently, this indicates the degree of systemic risk found within these markets is due to contagion. At the onset of the Chinese and export crises, the heightened volatility in the German and Chinese market starts spilling excess risks onto others, resulting in amplified transmission in the network as laid out in the second principle.

In comparing DY and MHD, we find MHD rejects DY’s depictions of Germany and France as the highest spreaders of crisis. Despite occasional spikes in resilience responding to major global events spanning our sampling periods, Germany remains

more vulnerable to crisis coming from contagion than does France or the UK. While we may attribute the degree of transmissions coming from France as neutral to dampening, the UK is largely a spreader with strong resilience to contagion.

Table 1, Table 2 and Figure 3, Figure 8, Figure 13, Figure 18, Figure 23, and Figure 26 depict that the GC countries' (i.e., Greece, Portugal, Ireland, Belgium, Croatia and Austria) markets are very sensitive to events contributing to global contagion. These markets are less characterised by local shocks and the shocks generated in the neighbouring nodes, except for Greece and Belgium. However, the MHD measure selects Greece and Austria as becoming more resilient as the eurozone crisis subsides, while Portugal and Ireland becomes more vulnerable. This can be attributed to investments moving out of Greece and Belgium and into Portugal and Ireland, making the latter deeply connected. Moreover, MHD captures Croatia remaining strongly resilient to shocks across the periods spanning our sample, which DY fails to detect.

Our transmission estimates for GC countries and the transmission vulnerability mechanism are in line with what we provided in the first principle. As Portugal becomes more vulnerable to global contagion more recently, it is of no surprise to find that Portugal and Ireland transmit stronger shocks in the past. This suggests Portugal and Ireland remain deeply connected with the other peripheries since before the GFC. Moreover, with dropping vulnerability coupled with 'excess volatility', Croatia emerges as a strong transmitter during the eurozone crisis.

Figure 26 shows the volatility jumps unique to Greece and Ireland, in which the excess vulnerability also sets off network transmissions to other markets. In contrast, transmissions emerging from Portugal and Austria that corresponds to excess vulnerability is coming from volatility and, hence, is short-lived. Notably, there is little risk of spillover over-identification for Belgium and Croatia.

Table 1, Table 2 and Figure 4, Figure 9, Figure 14, Figure 19, Figure 24, and Figure 26 concerning OED countries' (i.e., the USA, Canada, Russia, Norway, Japan and New Zealand) markets depicts that stochastic local volatility predominantly affects the vulnerabilities of the USA, Norway and Mexico. In fact, the recent degree of risks stemming from the USA and Russia is emanating mostly from 'excess volatility'. In contrast, exceeding return spillovers following the onset of export crisis for Norway, Japan and New Zealand suggests these markets are especially contagious. The spread falls for Canada and, very recently, for Mexico, suggesting the spillovers in these markets are driven less by local volatility and more by their dominance in the holistic network.

Taking a more granular view with our MHD and DY comparison, the Japanese and New Zealand transmissions provide further reassurance as to the nature of these markets' vulnerabilities. Japanese volatility transmission is depicted as contagion transmission, which corresponds with Japan emerging as a highly connected market

out of its long-lasting economic stagnation in early 2000. Neutral to dampening volatility transmissions stemming from the USA, but also a curving up of its transmission swings with a shifting regime, gives credence to BIS (1998) suggestion that both the USA and Japan are ‘conduits’ for contagion transmission. Conversely, the upheavals in the global oil market influence the nature of New Zealand’s contagion, more so than for other global events.

Comparing DY and MHD estimates we further find that, the USA and Japan are more susceptible to contagion risk transmissions than to the degree of risks they transmit themselves. The exaggeration of risk susceptibility is overlain with risks transpiring within, especially for the USA and Japan. Moreover, dismissing what is gauged from DY estimates regarding Russia, MHD substantiates Russian resilience spanning across the entire sample period. Additionally, Russian transmissions pick up in all major events. To a much lesser extent, this holds true for Norway as well.

Finally, turning to OEE countries’ (i.e., Saudi Arabia, Israel, Iraq, Kuwait, Nigeria and Venezuela) markets, we conjecture these markets are not at all contagious by examining Table 1, Table 2 and Figure 5, Figure 10, Figure 15, Figure 20, Figure 25, Figure 26. Although the countries in this cluster dominate the global oil market, an upheaval in the oil market increases market strength in these markets. Consequently, they demonstrate strong resilience in phases of price or supply shocks in the oil market.

In several occasions for the OEE cluster, DY estimates fail to produce convincing evidence that aligns with MHD. DY fails to capture the amplifications in vulnerability for Saudi Arabia corresponding to the advent of the GFC and the diminishing systemic risks emitting from Iraq. MHD captures this successfully. Further, more recently, DY fails to capture the increases in vulnerability for Venezuela, which is more sensible given the heightening of the Venezuelan economic crisis, but is depicted in the MHD curves. With MHD, we disentangle the spikes in volatility transmissions for Kuwait, which naturally responds to the Iraq invasion and oil supply shock. In both cases, confidence build-up occurs dramatically in the Kuwait market. Again, DY fails to capture the dampening of Nigerian systemic risk transmission with the oil price crash following the Iraq invasion. On balance, we sufficiently provide evidence of MHD better capturing larger effects on the economy than DY.

5.1 Identifying contagion

A key contribution of the current paper is ‘contagion’ identification in the pool of markets from interconnection, for which crisis demarcation is not a necessary condition. While all interconnections and amplifications in the systemic risk that is found within this sample markets do not lead to contagion, contagion poses the unique threat of a financial pandemic. Hence, contagion is a necessary condition for

a widespread crisis to ensue. We propose a tractable and simple technique to identify contagious markets while the condition remains dynamic. Thus, a key question at this stage is, ‘How diabolic is a contagious market today compared to the past?’ In other words, are we going to experience a global meltdown similar to that of the GFC if a crisis is triggered from a contagious market?

From Figure 26, we separate out Singapore, China, Australia and Japan as more contagious markets than the rest, especially in more recent times. Despite observing that the 2016 Chinese stock market crash sends shocks tumbling globally, the carnage is not as pronounced as in the GFC.

The models presented here shows that the Chinese stock market crash unfolding in January 2016 sets off a global rout, dragging down the stocks across the USA, Germany and rest of Europe and Brazil to 2 to 3 per cent. Chinese economic growth plunges to 25-year low. Leading up to this, speculations and warnings reflected engendered fears of a global meltdown, including warnings issued by the International Monetary Fund (Mauldin, 2017; Liang, 2016; Mao, 2009; Elliott, 2017; Cheng, 2017). The Chinese authority responded by imposing new trading curbs and devaluing currency. While commentators, including the China Securities Regulatory Commission blamed surging speculation and irrational investment behaviour for sourcing the crisis, Mao (2009) suggested that the colossal shadow banking industry was responsible for heightening the risks in the Chinese markets much earlier. Presumably, potential risks are predominant in the shadow banks in China, which have quadrupled at an annual rate of 34 per cent since 2008, and at that time the size of the Chinese shadow banks (US \$8 trillion) is equal to 4.3 per cent of Chinese GDP (Mao, 2009). Liang (2016) asserted that the burgeoning shadow economy, amidst the goal of boosting productivity against an overall drop in the labour market, posed a high risk to the financial stability of China given its current regulatory framework.

We do not experience a replay of the 2008 GFC. Recently, Dungey et al. (2020) provided evidence of no new systemic crises emerging from China to other global markets given the resurgence in systemic risk. While our study purports to identify sources of crisis, the case for China is particularly interesting. Generally, the results capture a unique case of shadow banking and securitisation. There is a plethora of studies showing bank securitisation leads to higher systemic risks, while increasing bank profitability and ensuring a buffer of liquidity for the bank (Adrian and Shin, 2009; Uhde and Michalak, 2010; Nijskens and Wagner, 2011; Nadauld and Weisbach, 2012; Georg, 2013; Battaglia et al., 2014; Bakoush et al., 2019). Although securitisation allows banks to shed their own idiosyncratic risks into financial markets and confirms a buffer of liquid assets coupled with higher profitability, a vicious cycle forms as banks’ exposure to credit risk intensifies. The shadow banking industry is evolving to retain risks while pursuing regulatory arbitrage by means of retaining rollover risks pertaining to maturity mismatch. These pose a significant threat for

the sponsors assuming these risks. In effect, conduits are attributed with systemic risk involving commercial banks, insurance institutions and equity market components. This also explains the USA or other advanced markets posing no significantly new threat in recent times, partly because the post-2008 credit crisis saw several restrictions imposed on banking securitisation, particularly in advanced economies. The Association for Financial Markets in Europe (2017) reported a significant reduction in securitisation activities within 10 years, especially for the USA and European banks. Evidently, this has impaired the capital and profitability of these banks, as suggested by the Bank for International Settlement (2018).

Moreover, we do not observe a re-emergence of global meltdown from China or other contagious markets because of the structural differences between cross-border capital diffusion to what was occurring with the USA during the GFC. Shirai and Sugandi (2018) reported that Hong Kong, Japan and Singapore are the major financiers of cross-border capital in the Asia-Pacific economies. While Singapore has the largest financial centres and is also the largest equity investor to the People's Republic of China (PRC), Japan, Republic of Korea (ROK), and others in the Association of Southeast Asian Nations, Japan invests largely in Australian debt securities. Conversely, Hong Kong invests mostly in the equities issued by the PRC.

Issuing US\$3.5 trillion cross-border portfolio assets, Japan's exposure to the Asia-Pacific region is mostly through Australia (US\$572 billion), and vice versa. Despite this, the Asian Bond Funds administered and managed by banks for international settlement exclude Australia, Japan and New Zealand. The Asian Bond Funds ABF1 and ABF2 were introduced to develop the sovereign and quasi-sovereign bond markets dominated by the USA dollar and local markets, respectively. However, these countries are the main pathway for the USA and EU to invest in the region. Hence, 60 per cent of the total shares issued in the USA and EU forms the cross-border portfolio for Japan, Australia and the ROK in the region establishing a strong bridge between the continents. Singapore is the largest investor in shares issued by the USA and EU. While the cross-border portfolio assets of Hong Kong, China, sum up to US\$1.1 trillion, its portfolio shares mostly concentrate on the PRC (50 per cent) followed by the Association of Southeast Asian Nations-5 (37 per cent). The USA and EU shares constitute only 24 per cent of the cross-border portfolio trading in Hong Kong, China. Hong Kong invests US\$404 billion in the PRC-issued shares, compared with US\$235 billion by Japan and US\$218 billion by Singapore. Hong Kong has only US\$99 billion invested in USA assets and US\$165 billion invested in EU assets. In contrast, Australian foreign assets include 42 per cent USA-issued securities, with only 26 per cent from the EU (Shirai and Sugandi, 2018).

In terms of cross-border portfolio liabilities, 73 per cent of Japan's total cross-border portfolio liabilities (US\$1.7 trillion) are financed by the USA and EU, while the USA and EU finances 33 per cent and 29 per cent, respectively, of total liabilities

of Australia (US\$966 billion). Interestingly, while the USA and EU finances 66 per cent of the total cross-border portfolio liabilities of Hong Kong (US\$390 billion), Hong Kong finances 42 per cent of the total liabilities of the PRC (US\$710 billion). As a net debtor of cross-border portfolio investments to the world, Australia remains highly exposed to the USA and EU, which account for over 70 per cent. Since 2001, For Japan, Australia also remains its biggest investment destination, increasing investing into Australia by four times (US\$118 billion) in the post-GFC. The foreign portfolio asset and liabilities of Hong Kong and Singapore exceed that of Japan in the post-GFC, and for Hong Kong these grow by 157 per cent and 142 per cent, respectively (Shirai and Sugandi, 2018).

In summary, as highly contagious markets, Japan and Singapore are not causing widespread crisis, as no crisis is revealed in these markets, or in the USA or EU in more recent times. In fact, the restrictions applied in the USA securitisation induce calmness in these markets. Hence, we are also observing calmness in the Australian markets. However, given the degree of exposure to each other and connectivity between these markets, a large enough shock in any of these markets may destabilise the other. In contrast, Hong Kong, China, concentrates investments mostly in the PRC. As both the economies are part of the PRC, this creates a closed-circuit transmitting wealth within. This is also a reason why the 2016 crash was absorbed mostly within the circuit and did not turn diabolical, despite having all the potential. In fact, this allows the central Chinese authorities to apply new restrictions, such as short selling bans or bans on stock investments as appeared in 2015, without inciting a global response.

6 Conclusion

In this paper, we have identified contagious and more volatile markets relying on time-varying systemic risk in an associated network of markets. We began by exploring the transmission of risks and vulnerability to risks spanning across the sample period of nearly 20 years with unsigned return measures (DY), a well-known method proposed by Diebold and Yilmaz (2012). Next, we estimated return spillovers with signed spillover measures computed with MHD proposed recently by Dungey et al. (2018b), and concluded that signed spillover measures capture all or more information than unsigned spillover measures. Third, we estimated signed volatility transmissions and vulnerabilities computing from MHD, and drew on realised variances from five-minute intraday returns. Finally, we plotted the differences between time-varying volatility and return spillover estimates, which showed the markets that are epidemic in the complex network structure and the markets that are endemic in nature but predominantly volatile with a higher core volatility. Hence, we have

addressed the issue of over-identification in the degree of systemic risk, which the markets emit in calm and crisis periods

We found that mis-identification of contagion issues is prevalent when explaining risk transmissions and the build-up of market resilience across time with the unsigned spillover method only. We addressed these issues by re-estimating systemic risks with MHD. In the absolute representation of time-varying unsigned spillover measure, we found that unsigned spillover overestimates the level of actual resilience building for South Korea, the Philippines, Singapore, Germany, China and Israel. This measure also overestimates the degree of risk transmissions coming from Iraq, Venezuela, the USA (prior to the GFC) and, more recently, Nigeria and Greece. While the DY underestimates Greek, Croatian and Russian resilience building in recent years, it also underestimates the risks emanating from Kuwait, South Korea and Germany. Severe changes in market micro-structure corresponding to profound economic degradation is rather misrepresented as resilience building with DY for its absolute representation of spillovers. We found this holds for both Iraq and Venezuela. The signed spillover estimates captures the convergence in the swings of systemic risks as the economies in both the countries collapse.

We provided evidence of a crucial phenomenon as we separated out the influence of stochastic local volatility as opposed to the actual degree of systemic risks found within a market. First, a market is not likely to be transmitting shocks and remain vulnerable at the same time. Moreover, during high-risk transmissions, markets turn more resilient or vice versa. However, it is more likely that high transmissions lead to a phenomenal increase in vulnerability for the market to negative in-shocks transpiring within the network. Second, in the amplification of total risk generation with the accumulation of self-exciting intraday local volatility added to systemic risks coming from the network, markets respond by casting off ‘excess volatility’ onto others. In other words, it is likely that a highly volatile market gives strong episodes of risk transmission at the start of an event without becoming an epidemic market. Nevertheless, such spikes may accompany a fall in the local market, as outlined in Bates et al. (2019).

Complementing the work of Dungey and Renault (2018), our technique identified the degree of systemic risks free of simultaneous volatility increases accompanying a rise in volatility in common factors, and may have various contributions to the field of economics and machine learning. First, it may enable managers of risk to better rebalance portfolios, parsing information concerning epidemic and non-epidemic elements in the portfolio. Supervisors may find it useful to understand risks coming with big links, and to target issues amplifying risks. Machine-learning enthusiasts may find it interesting to feed forward networks of markets scaled with proper degrees of systemic risk indices. Further, Bayesian priors can be generated weighted with amplifications and dampening in signed risk estimates, and predictability of mar-

ket risks can be improved. In all, the methods combined not only serve a purpose by producing comparisons, but produces better information regarding a market's susceptibility to realised crashes and volatility evolution.

We attempted to explore complex market associations spanning across the last two decades, encapsulating major global events across many markets. The markets were selected to represent dynamic shifts that each subsequent event provides and were then grouped into a closed system. As with the precursors of systemic risk studies, limitations arose from the limited intraday data availability for the Middle Eastern markets. However, we substituted with additional markets that depicted a similar pattern. Alternatively, a target should be an investor sentiment analysis corresponding to risk patterns, leading to a better understanding of strong amplifications in risk propagation.

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7 Appendix

7.1 Figures

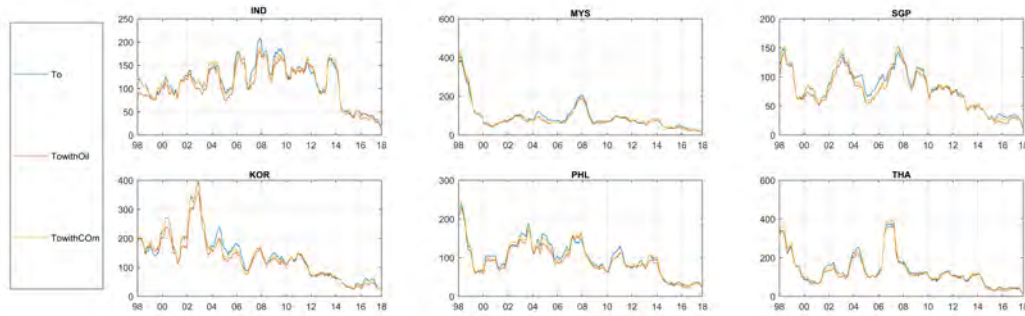


Figure 1: DY: Transmission - Asian crisis markets

Note: This figure represents the transmission of systemic risk from the Asian crisis markets to all others, derived from the DY conditional variance index.

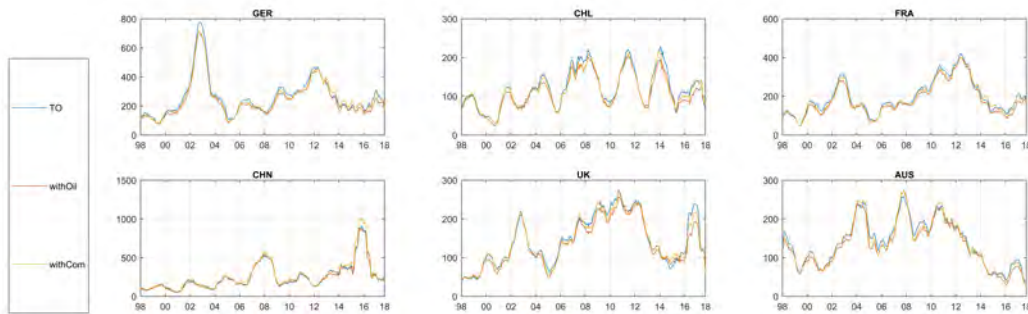


Figure 2: DY: Transmission - export crisis markets

Note: This figure represents transmission of systemic risk from Export Crisis markets to all others, derived from DY conditional variance index.

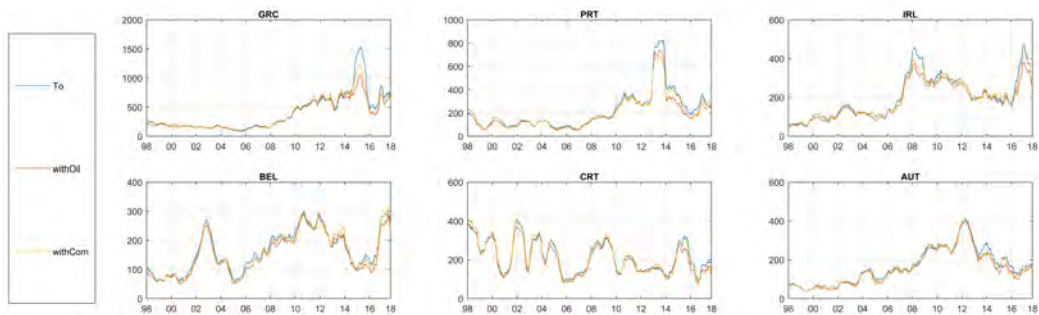


Figure 3: DY: Transmission - Greek crisis markets

Note: This figure represents the transmission of systemic risk from the Greek crisis markets to all others, derived from the DY conditional variance index.

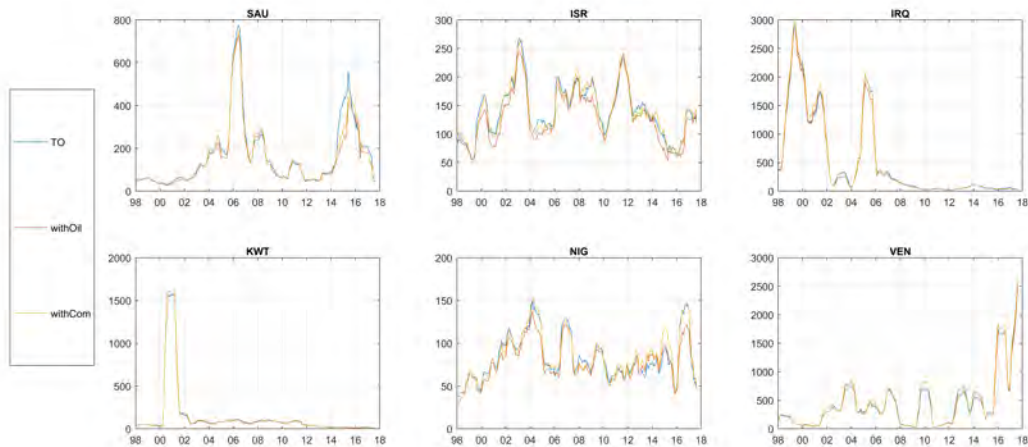


Figure 4: DY: Transmission - oil exporting emerging markets

Note: This figure represents the transmission of systemic risk from major oil exporting emerging countries' markets to all others, derived from the DY conditional variance index.

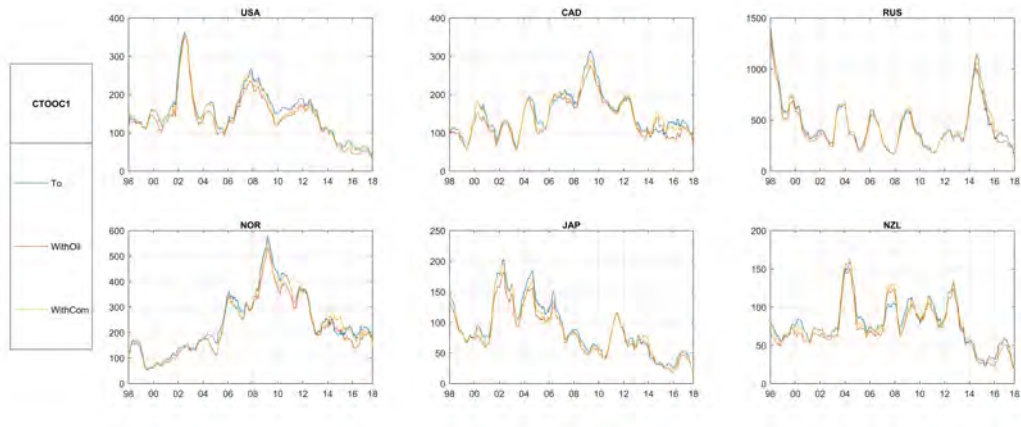


Figure 5: DY: Transmission - Oil exporting developed markets

Note: This figure represents the transmission of systemic risk from major oil exporting developed countries' markets to all others, derived from the DY conditional variance index.

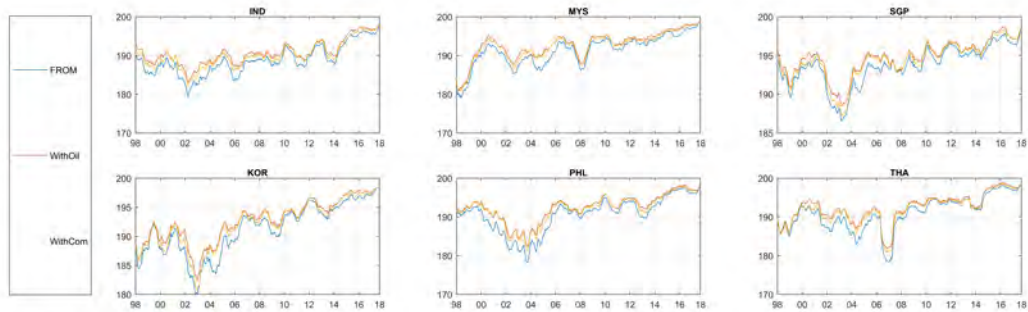


Figure 6: DY: Vulnerability - Asian crisis markets

Note: This figure represents the vulnerability of Asian crisis countries' markets to systemic risk transmitted from other markets to own markets, derived from the DY conditional variance analysis.

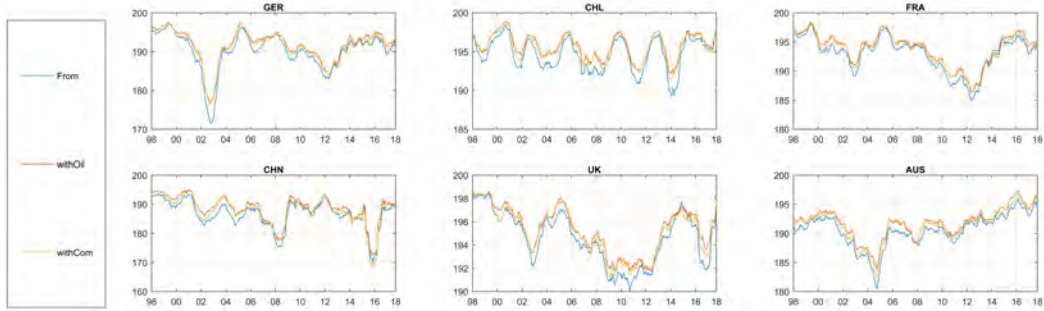


Figure 7: DY: Vulnerability - export crisis markets

Note: This figure represents the vulnerability of export crisis countries' markets to systemic risk transmitted from other markets to own markets, derived from the DY conditional variance analysis.

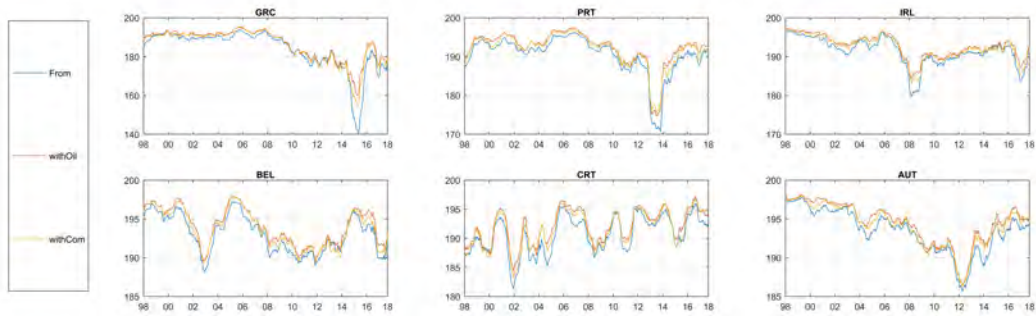


Figure 8: DY: Vulnerability - Greek crisis markets

Note: This figure represents the vulnerability of Greek crisis countries' markets to systemic risk transmitted from other markets to own markets, derived from the DY conditional variance analysis.

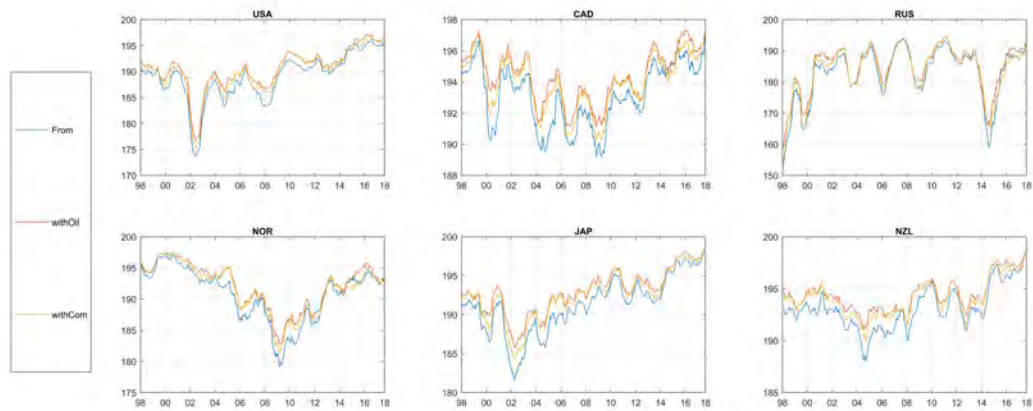


Figure 9: DY: Vulnerability - oil exporting developed countries' markets

Note: This figure represents the vulnerability of major oil Exporting developed countries' markets to systemic risk transmitted from other markets to own markets , derived from the DY conditional variance analysis.

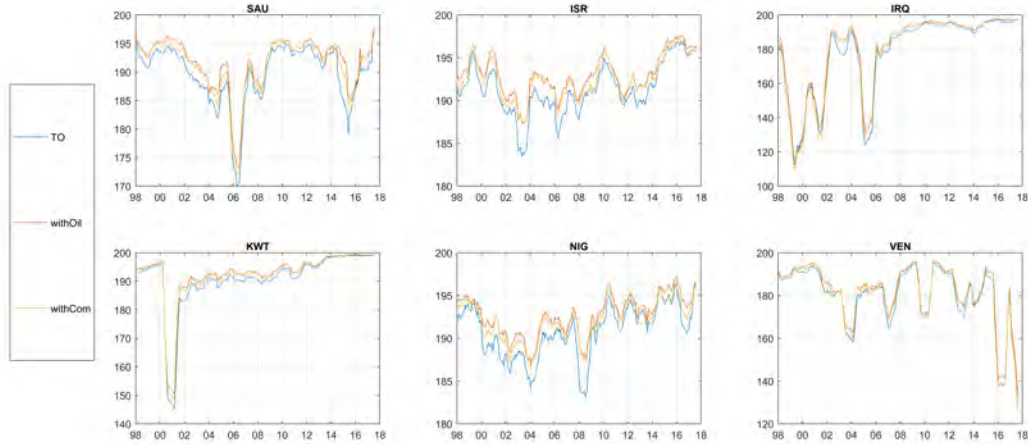


Figure 10: DY: Vulnerability - oil exporting emerging countries' markets

Note: This figure represents the vulnerability of major oil Exporting emerging countries' markets to systemic risk transmitted from other markets to own markets, derived from the DY conditional variance analysis.

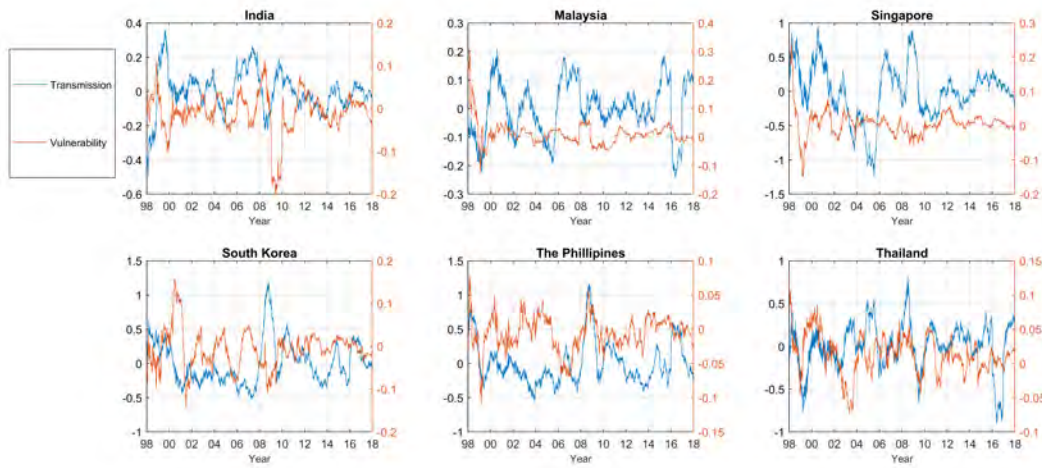


Figure 11: MHD: Asian crisis markets

Note: This figure shows the signed spillover indices of both the transmission and vulnerability of Asian crisis countries' markets, to and from all other markets, respectively.

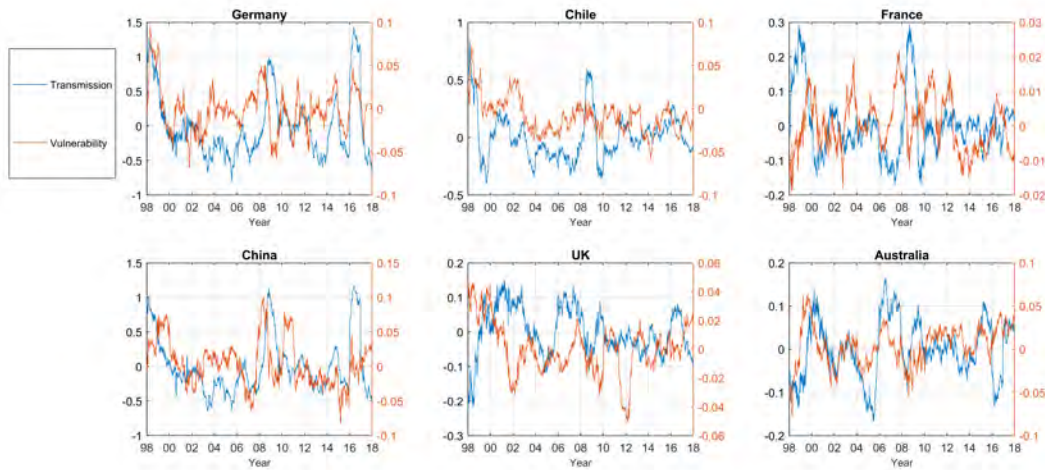


Figure 12: MHD: export crisis markets

Note: This figure shows the signed spillover indices of both the transmission and vulnerability of export crisis countries' markets, to and from all other markets, respectively.

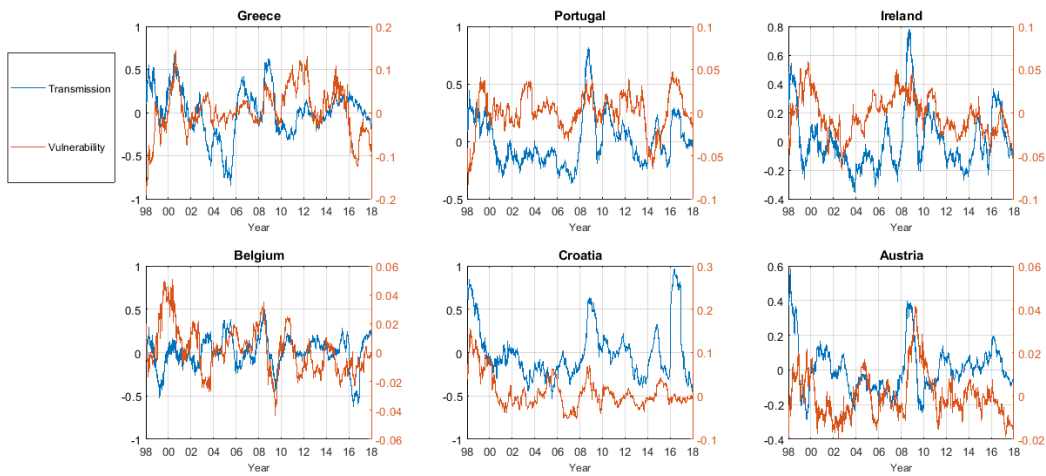


Figure 13: MHD: Greek crisis markets

Note: This figure shows the signed spillover indices of both the transmission and vulnerability of Greek crisis countries' markets, to and from all other markets, respectively.

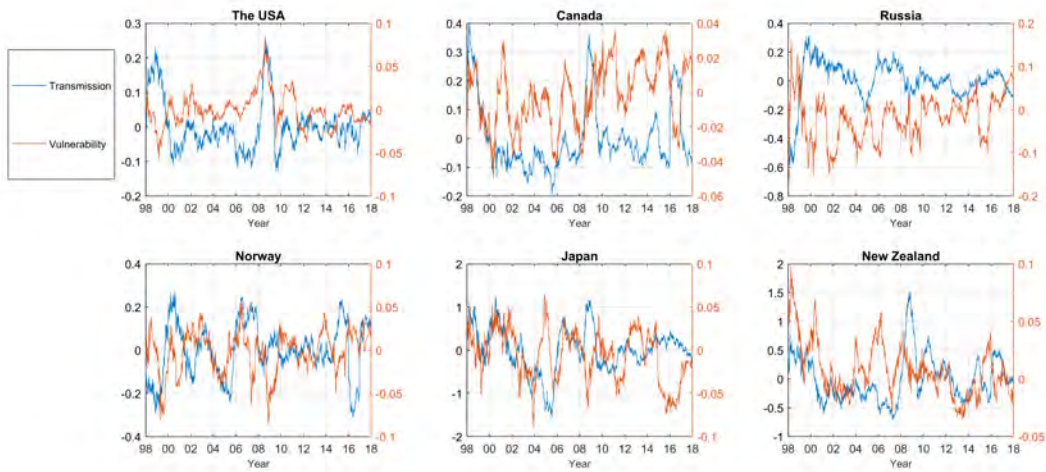


Figure 14: MHD: oil exporting developed countries markets

Note: This figure shows the signed spillover indices of both the transmission and vulnerability of oil exporting developed countries' markets, to and from all other markets, respectively.

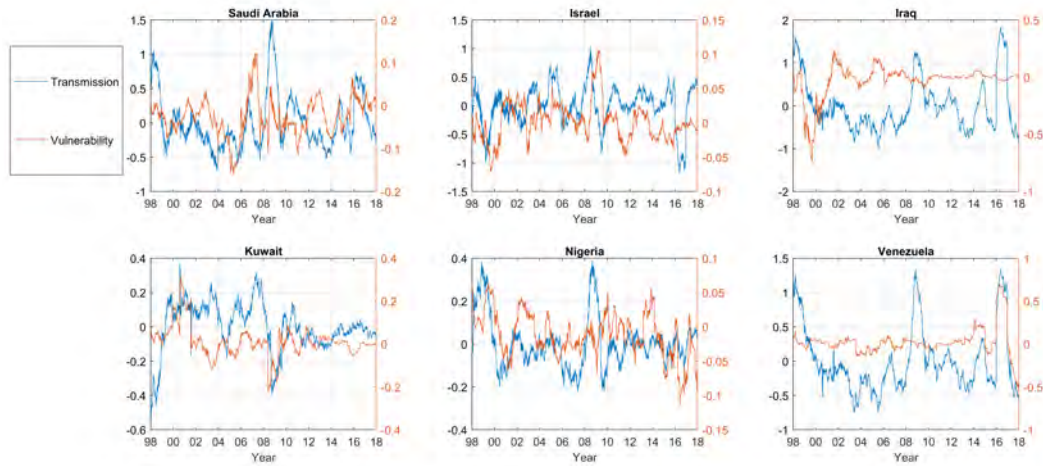


Figure 15: MHD: oil exporting emerging countries' markets

Note: This figure shows the signed spillover indices of both the transmission and vulnerability of oil exporting emerging countries' markets, to and from all other markets, respectively.

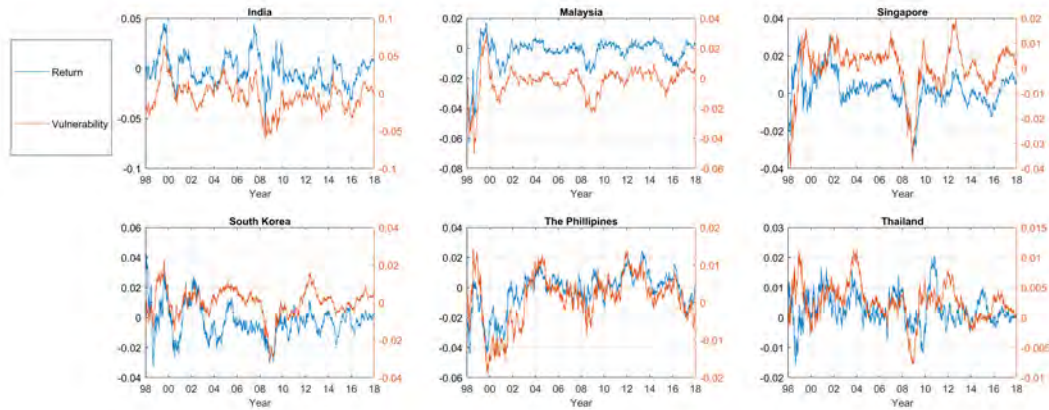


Figure 16: MHD and SVD vulnerabilities: Asian crisis market

Note: This figure shows the signs of in-shocks sourced from the Asian crisis countries' markets to targets listed in the AC cluster gauged in signed spillover index and the signed volatility index .

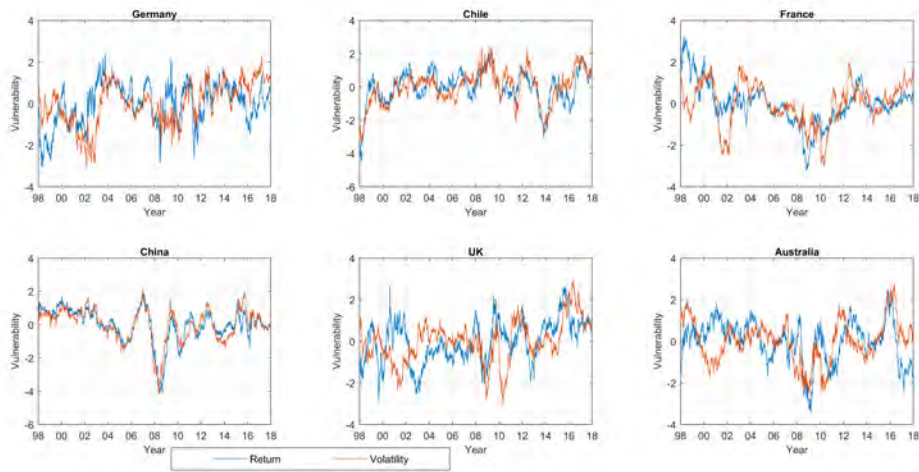


Figure 17: MHD and SVD vulnerabilities: export crisis Market

Note: This figure shows the signs of in-shocks sourced from export crisis countries' markets targets listed in the EC cluster gauged in signed spillover index and the signed volatility index.

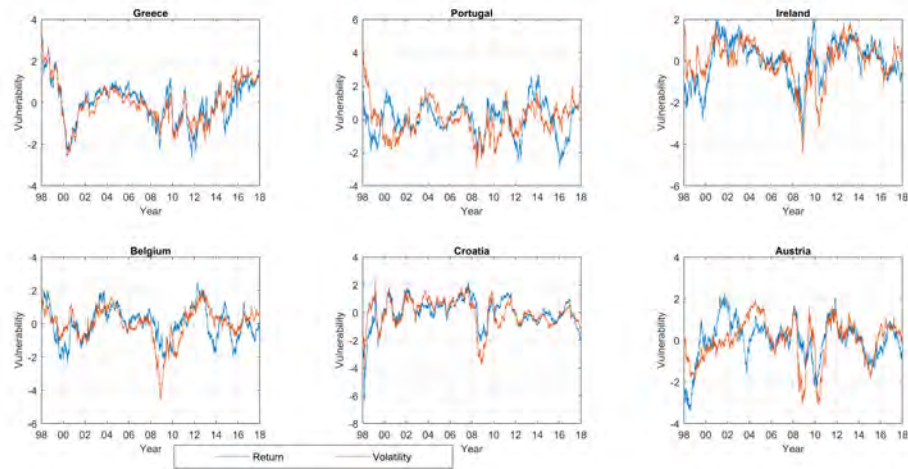


Figure 18: MHD and SVD vulnerabilities: Greek crisis market

Note: This figure shows the signs of in-shocks sourced from Greek crisis countries' markets targets listed in the GC cluster gauged in signed spillover index and the signed volatility index .

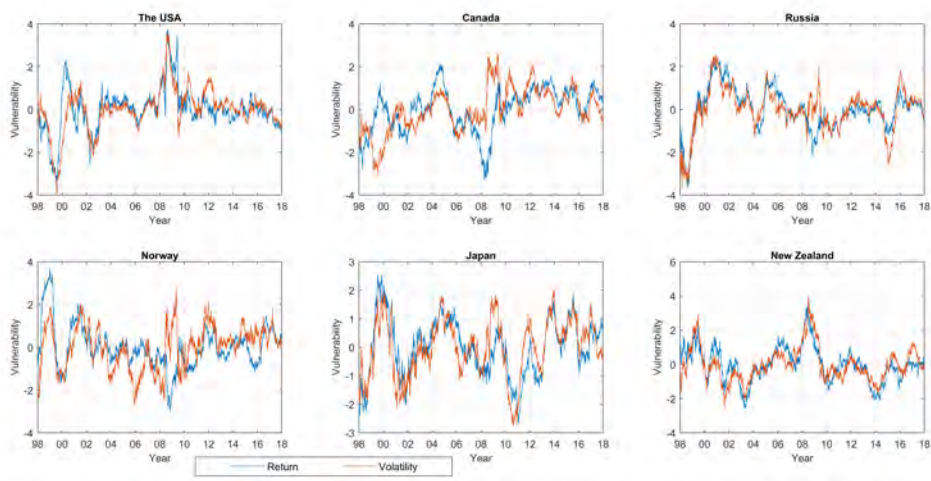


Figure 19: MHD and SVD vulnerabilities: oil exporting developed countries' markets

Note: This figure shows the signs of in-shocks sourced from oil exporting developed countries' markets targets listed in the OED cluster gauged in signed spillover index and the signed volatility index .

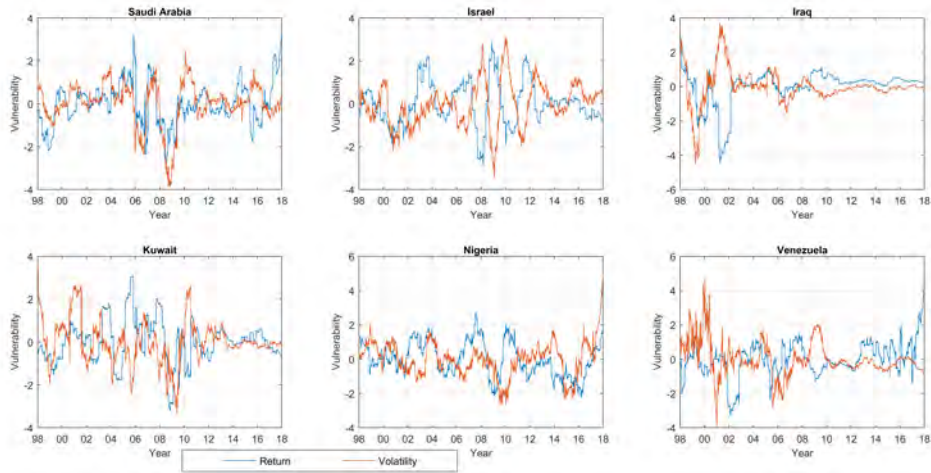


Figure 20: MHD and SVD vulnerabilities: oil exporting emerging countries' markets

Note: This figure shows the signs of in-shocks sourced from oil exporting emerging countries' markets targets listed in the OEE cluster gauged in signed spillover index and the signed volatility index .

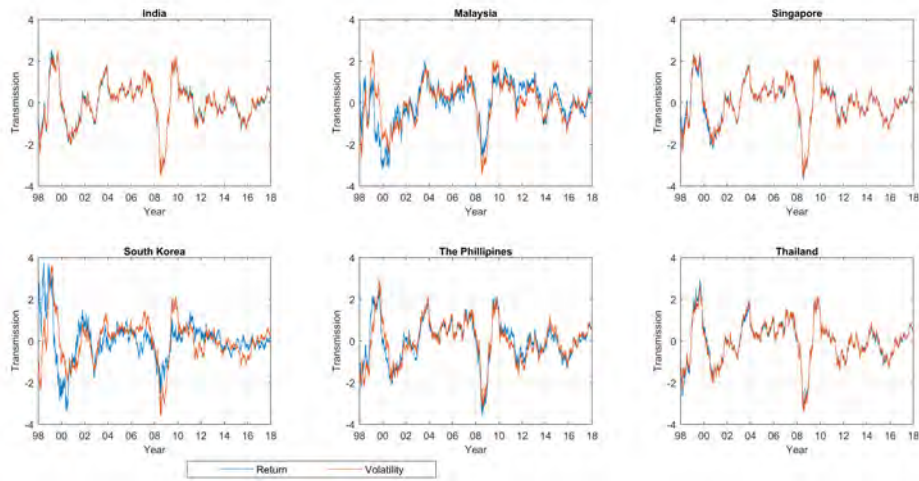


Figure 21: MHD and SVD transmission: Asian crisis countries' markets

Note: This figure shows the effects of out-shocks sourced from Asian crisis countries' markets to recipients listed in the AC cluster gauged in signed spillover index and the signed volatility index .

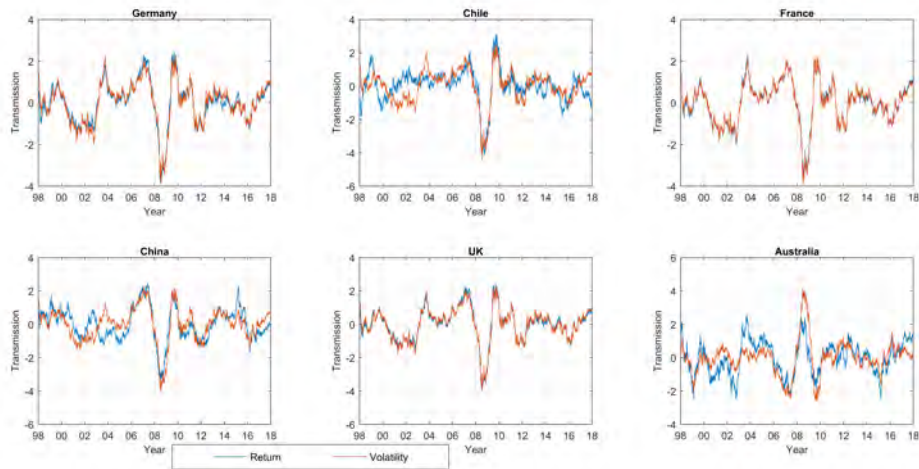


Figure 22: MHD and SVD transmission: export crisis countries' markets

Note: This figure shows the effects of out-shocks sourced from Export crisis countries' markets to recipients listed in the EC cluster gauged in signed spillover index and the signed volatility index .

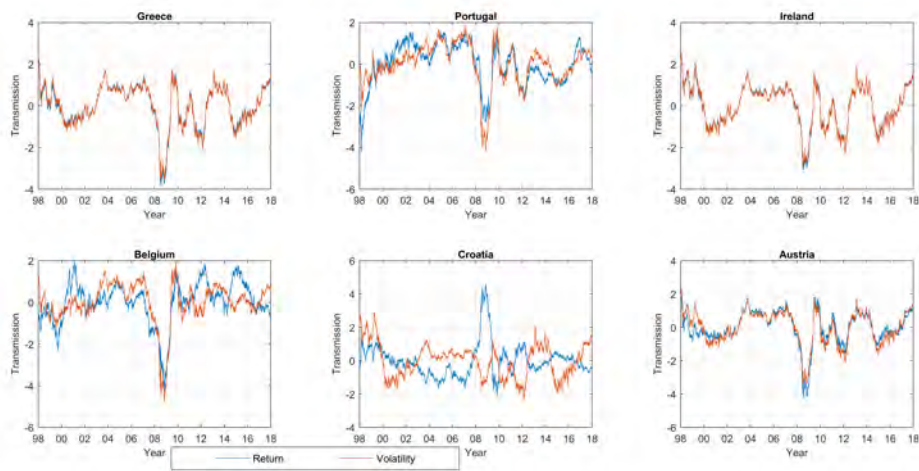


Figure 23: MHD and SVD transmission: Greek crisis countries' markets

Note: This figure shows the effects of out-shocks sourced from Greek crisis countries' markets to recipients listed in the GC cluster gauged in signed spillover index and the signed volatility index .

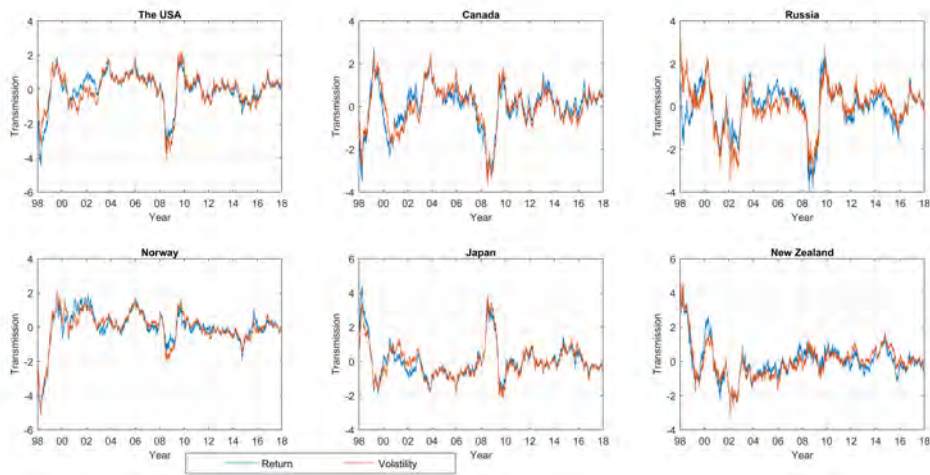


Figure 24: MHD and SVD transmission: oil exporting developed countries' markets

Note: This figure shows the effects of out-shocks sourced from oil exporting developed countries' markets to the recipients listed in OED cluster gauged in signed spillover index and the signed volatility index .

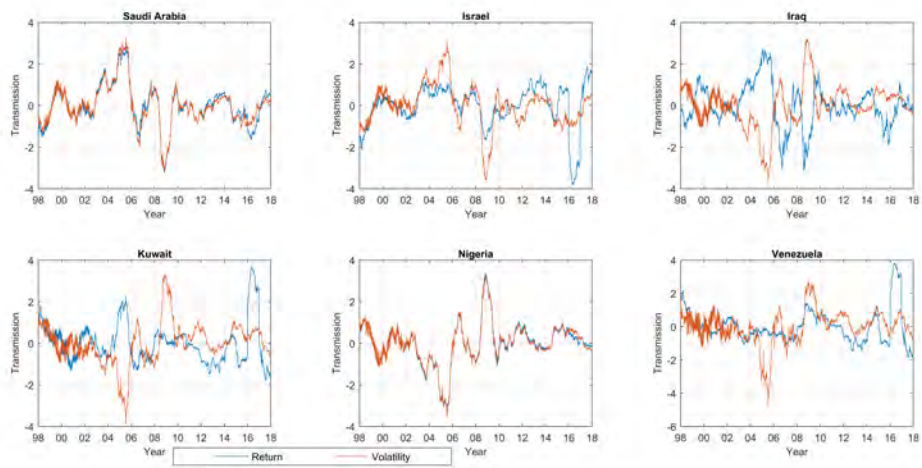


Figure 25: MHD and SVD transmission: oil exporting emerging countries' markets

Note: This figure shows the effects of out-shocks sourced from oil Exporting emerging countries' markets to recipients listed in the OEE cluster gauged in signed spillover index and the signed volatility index .

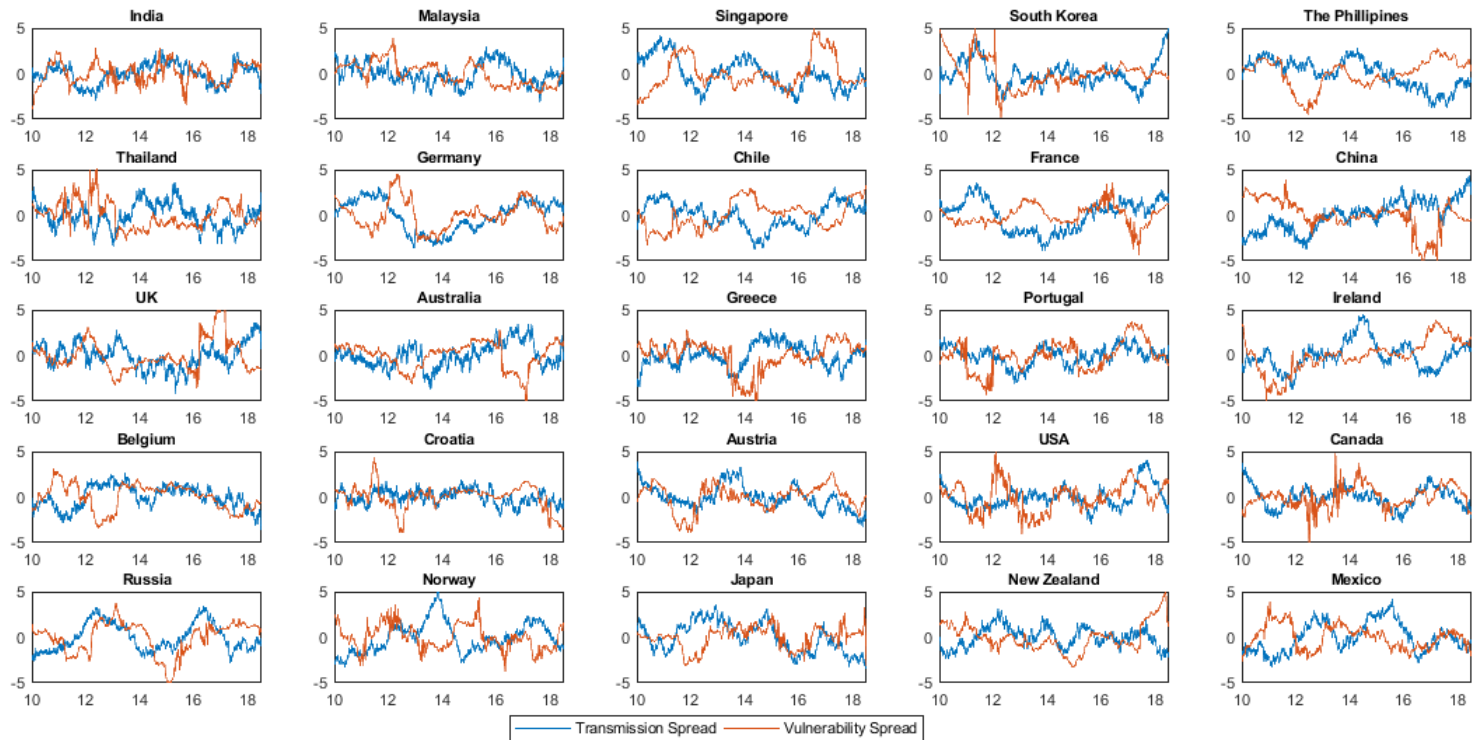


Figure 26: The SVD-MHD spread: This SVD-MHD spread figure focuses out contagious markets from non-contagious markets by drawing on estimated differences between the MHD and SVD gauges.

Table 1: Empirical Analysis comparing DY, MHD, SVD

Blocks	Vulnerability		
	DY	MHD	MHD-SVD
AC	<p>1. India, Malaysia and Thailand show consistently slow increase in vulnerability across the years.</p> <p>2. We see dramatic resilience building for Singapore, South Korea and the Philippines, corresponding to that of the USA with the arrival of the Iraq invasion while the USA recovery from dotcom bubble also remains a more conspicuous factor. The general buoyance in the Asian markets resonates with the recoupling in the USA market coupled with expectations soaring with the invasion. Soon after, vulnerability starts rising for the aforementioned countries' markets.</p>	<p>1. India, Malaysia and Thailand show lasting resilience across the years spanned by our sample, except for pronounced rises only for India and Thailand in the GFC. Moreover, sheer resilience for India is depicted in Figure 6 in the period following the GFC. Among others, Thailand remains somewhat vulnerable, with little spikes in vulnerability corresponding to major events such as the GFC and eurozone crisis.</p> <p>2. In contrast to the findings with DY, we do not see resilience building up dramatically for South Korea, the Philippines and Singapore. Indeed, profound amplifications and dampening are depicted in the South Korean and Philippines markets, adding up to what seems like big jumps in the absolute representation of DY. Rather, we find vulnerability to be the more conspicuous factor attributable to South Korea and the Philippines markets. Attributed with a high degree of systemic risk, both these markets' vulnerabilities amplify in response to almost all the major events presented in our sample period. Despite remaining mostly vulnerable, the degree of vulnerability and resilience reverts to the mean degree for Singapore following the post-Asian financial crisis period.</p>	<p>Coming to the identification of small contemporaneous shocks spawning from volatility characteristics of a market, out of mutually reinforcing long-lived correlations, we find India, Singapore and the Philippines are predominantly volatile. Strong inter-temporal volatility contributing mostly to vulnerability predominates for India, Singapore and the Philippines. While sheer resilience for the Philippines during the eurozone crisis is depicted in Figure 16, this cannot be held true for the others. However, vulnerability for Malaysia, Thailand and, more recently, for South Korea is coming from far less volatility than are Singapore and the Philippines. This suggests that the former countries are more susceptible to international contagion than to local shocks.</p>

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Table 1: Empirical Analysis comparing DY, MHD, SVD

Blocks	Vulnerability		
	DY	MHD	MHD-SVD
EC	<p>1. A strong resilience building up for Germany in late 2002 is consistent with the USA, Singapore, South Korea and Japan. This period marks the recovery of the USA and Japanese markets from economic downturns. This period also marks the advent of the Iraq invasion, which rekindled confidence in the energy stocks. For Germany, the sheer resilience is followed by a pronounced drop following the Iraq invasion. Aggregate vulnerability increases with exogenous shocks coming from oil and commodity indices. This observation holds true for other EC markets such as the UK, France, Chile and China. Australian resilience starts to pick up in the Iraq Invasion period. Predominantly a major exporter of energy resources, Australian resilience build-up can arguably be attributable to the tightening of oil supply from the OPEC countries following the Iraq invasion, boosting confidence in Australian commodities market.</p> <p>2. Germany, the UK and France are conceivable as potent crisis spreaders as the eurozone crisis unfolds. Consequently, they show strong resilience build-up during the same period. Among others, with the announcement of Brexit, the UK sees resilience picking up again. Resilience also picks up strongly for China as the market recovers, followed by a strong recoupling phase.</p> <p>3. Chile remains vulnerable, with vulnerability accelerating more in recent periods corresponding to oil and commodity inclusion, than previously.</p>	<p>1. Resilience amplifications are mounting for Germany with DY, but less so with MHD. However, unlike DY, MHD captures the German market remaining vulnerable across most of the sample period, with occasional resilience build-up phases around the GFC and eurozone crisis. Hence, more phases of resilience are identifiable with MHD for Germany. Similar observations accord well with the France vulnerability pattern. The UK market remains strongly resilient, spanning across the entire sample period. In accordance with DY findings, the MHD plot for the UK in Figure 12 depicts strong resilience in the post-GFC and during the eurozone crisis. While remaining a strong spreader and being susceptible to shocks during the GFC as held by the global literature, it is indeed promising that the degree of rebounding in the UK market complements recoupling.</p> <p>2. Chinese market remains largely vulnerable as depicted in Figure 12. A short-lived resilience during the recent Russian crisis is followed only by more periods of vulnerability for China, with the onset of the Chinese stock market crash. MHD finds Chinese vulnerability is repeated across major global events, providing a better rationalisation for the Chinese market mechanism than for DY. Mostly, DY could not detect the cycles of amplification and dampening corresponding to many past events.</p> <p>3. Similar to the DY vulnerability pattern for Australia, MHD also suggests Australia remains vulnerable in the years spanned by our sample. This holds true also for Chile.</p>	<p>Contemporaneous small shocks that builds up temporal interdependence corresponding to unprecedented local events rather than long-term interdependence is prevalent in Germany, Chile and France. In other words, the market vulnerabilities of Germany, Chile and the UK are less determined by contagion as outlined in the work of Dungey and Renault (2018). Moreover, we concur with Dungey and Renault (2018) in regards to Germany not suffering from the same market reassessment of default risk as the others. Such can be also be held true for France. Although we find strong volatility spikes contributing to aggregate vulnerability for Germany and China during the eurozone crisis and for the UK in the export crisis (see Table 4), return spillovers prevailing for France, Australia and China since the export crisis indicate that these markets' degree of susceptibility increases with contagion within the network itself. Therefore, little decoupling can be expected for these markets and as an economic prior only strong shifts in the network structure may drift the markets away from their current degree of impulses into vulnerability.</p>

Table 1: Empirical Analysis comparing DY, MHD, SVD

Blocks	Vulnerability		
	DY	MHD	MHD-SVD
GC	<p>1. Greece, Portugal and Austria remain highly vulnerable across the sample period. Market resilience starts to pick up slowly in the post-GFC period. Figure 8 depicts an increase in resilience for the Austrian market that coincides with commencement of Greek's new austerity measures. Resilience starts to build in the periods that follow for Greece and Portugal up until the new austerity measure is adopted as the eurozone crisis slows down. Vulnerability amplifies for Greece and Portugal with new Greek austerity measures in place. We conjecture from DY that Greece is more at the receiving end of shocks from its peripheries than transmitting the shocks to others.</p> <p>2. Gyration in the vulnerability of Croatia is more pronounced than for Ireland and Belgium. While the amplification in vulnerability levels off for Ireland and Belgium, as the eurozone crisis becomes full-fledged, the Croatian pattern remains volatile. Facing the dampening of exports, vulnerability for Belgium and Croatia amplifies. .</p>	<p>1. Preceded by a strong amplification in vulnerability facing the eurozone crisis, the Austrian market's vulnerability begins to drop with Greece adopting new austerity measures. The Austrian pattern resonates well with DY, and also holds for Portugal. Moreover, MHD captures that in the most recent periods, with the eurozone crisis subsiding, Greek resilience building accelerates, while vulnerability dominates the risk curve of Portugal.</p> <p>2. MHD provides better information concerning Croatian swings in the systemic risks compared to DY. In contrast with the information produced with DY, MHD supports that Croatian systemic risk swings lie well within the boundary outside the vulnerability region. Croatian market remains rather resilient to shocks across the sample periods. As opposed to the DY pattern, the Belgium systemic risk pattern depicts rapid deceleration in vulnerability, moving the curve towards neutrality in the post-GFC period, and also holds for Ireland. Albeit smaller spikes in vulnerability are discernible for Belgium and Ireland during the eurozone crisis compared to the spikes observable during the GFC, the markets are becoming more resilient.</p>	<p>1. 1. Contemporaneous small surges in volatility due to shocks inherent to local factors have little effect on the GC markets, except for very recently. This suggests contagion influences the GC markets since the onset of the eurozone crisis. During the eurozone crisis and with the phases of Greek austerity measures, Figure 18 shows that positive in-shocks from return spillovers for Portugal, Ireland, Croatia, Austria, Belgium and, especially, Greece far exceeds any localised volatility risk.</p> <p>2. In the period following the eurozone crisis, Portugal, Greece and Ireland become more susceptible to volatility interconnections than to contagion. This indicates that these markets have less risks due to contemporaneous associations with peripheries. This does not hold for the vulnerability patterns of Belgium and Croatia, and Croatia also remains strongly correlated to the peripheries.</p>

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Table 1: Empirical Analysis comparing DY, MHD, SVD

Blocks	Vulnerability		
	DY	MHD	MHD-SVD
OED	<p>As the USA market recovers from debacles following the dotcom bubble and the Japanese market rebounds from the long-lasting debt crisis, resilience in both the markets peaks profoundly. These two major economies recover results with similar outcomes for other deeply connected markets such as Germany, South Korea and Singapore. Canada, New Zealand and Norway's vulnerabilities slowly grow since the GFC unfolds. The Canadian curve shows several episodes of short-term resilience building along the way. However, Canada and New Zealand's vulnerability curve shifts up with the inclusion of oil and commodity indices, but less so for Norway. The strongest resilience build-up for Russia is depicted during the USA embargo on Russia. It emerges that with the embargo, the limited node connections cast out risks for Russia.</p>	<p>Consistent with DY, the MHD plots for the USA and Japan show the strengthening of resilience in early 2000. While vulnerability for the USA and Canada remains positive all along, Japanese resilience peaks correspond to the phases of confidence building in the markets and preceded by recovery periods associated with all major global events. This holds to a much less extent for Norway, and to a moderate extent for New Zealand. From MHD, what re-emerges is that these three countries' markets suffer from the same market assessment of default risk. Unlike what DY depicts, the Russian market remains resilient for the sample period with MHD.</p>	<p>Strong local volatility factors casting off risks are attributable to the USA, Canada, Russia and Norway in the eurozone crisis. This is not so for Japan, which highlights Japanese vulnerability to conditional correlations with the other peripheral markets as depicted in Figure 19. We find that in the post-eurozone crisis and with the onset of export drag, Russia, Norway and Japan become highly susceptible to contagion followed by some degree of decoupling.</p>

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Table 1: Empirical Analysis comparing DY, MHD, SVD

Blocks	Vulnerability		
	DY	MHD	MHD-SVD
OEE	<p>In line with the global literature, Figure 10 depicts the heightening of resilience for large exporters of oil such as Saudi Arabia, Iraq and Nigeria. This is explained global investors' move towards energy securities and away from MBS in the advent of GFC. The increasing resilience for Kuwait and Israel is better explained by boosted investors' confidence as the Iraq invasion is happening. This is due to the conflict between Iraq and Kuwait and Israel in the regime. However, Venezuelan resilience building in the most recent periods can only be attributed to its disentangling of connections, as the whole economy is at a worsening spiral. The vulnerabilities for Israel and Nigeria significantly increase when adding oil and commodity shocks to the system.</p>	<p>MHD perfectly captures the resilience building for Saudi Arabia in DY. However, what DY fails to capture is the strong jump in vulnerability that follows. MHD further captures the neutralising of systemic risks emitting from Iraq. This finding can be better conceived as providing a better rationalisation for the cessation of Iraqi market activities with the invasion. Hence, DY is more misleading for the Iraq case. Despite Kuwait and Israel's resilience building given by both DY and MHD, MHD identifies that this is not as strong for both the markets in comparison to what is drawn from DY. In contrast, DY does not emphasise the peaks in Israeli vulnerability with the GFC. With the fall of Iraq, weakening of OPEC and increasing USA support for Israel in the regime, it is conceivable that Western investors' interest in the Israeli market spikes as barriers drop. This explains the spike in vulnerability for Israel during the GFC with the deepening of interconnections with the USA. Conspicuously in the MHD of Venezuela, which is unlike the results of DY, the economic collapse of Venezuela only fuels its vulnerability in the most recent periods. Nigeria remains vulnerable across the sample period with DY and holds for MHD.</p>	<p>We replace the Middle Eastern markets with New Zealand and Mexico as major oil exporting countries. We find the vulnerabilities in both these markets are coming more from contagion and less from local volatility factors.</p>

Table 2: Empirical analysis comparing DY, MHD, SVD

Blocks	Transmission		
	DY	MHD	MHD-SVD
AC	<ol style="list-style-type: none"> 1. Transmission mounts for India, Singapore and Thailand during the GFC. 2. South Korean transmissions amplify during 2002–2004 when the global economy was riddled with many crises. 3. The Malaysian and Philippines markets demonstrate neutral to dampening transmissions overall. 4. Inclusion of oil and commodity indices amplifies transmission during crisis, but only for India and South Korea. 5. Little amplification in transmission is observed for all participants facing the GFC. 	<ol style="list-style-type: none"> 1. Patterns accord well with DY results for India, Singapore and Thailand during the 2006–2008 GFC period. 2. As opposed to DY depiction, the South Korean transmission bears a negative sign, suggesting the dampening of transmission is dominant during 2002–2004. 3. The Philippines and South Korea portray negative transmissions, the only exception of which was during the GFC event. This supports the DY argument. 4. Positive transmissions are plotted for all markets during the GFC, similar to the DY observations. 	<p>Transmissions in the AC cluster shows India, Malaysia and the Philippines are becoming more epidemic in nature. Strong volatility amplifications in Thailand and Singapore suggest transmissions of crisis from these markets are more endemic in nature.</p>
50 EC	<ol style="list-style-type: none"> 1. We find a resurgence in transmission for Germany during 2002–2004 similar to that of South Korea mentioned earlier. 2. France and UK transmissions amplify in the advent of the eurozone crisis, while remaining neutral in earlier crises. 3. Australian transmissions slightly amplify during the GFC and export crisis. Dampening prevails in the transitions between crises. 4. Chinese transmissions amplify mostly with the recent Chinese crisis. Earlier, Chinese transmissions amplify only during the GFC. 	<ol style="list-style-type: none"> 1. With Germany we again find negative transmissions across 2002–2004, rejecting DY depiction. This is similar to South Korean transmissions mentioned in the earlier cluster. 2. Consistent with DY, MHD shows positive transmission across the eurozone crisis preceded by a negative dampening during the GFC for both France and the UK. 3. MHD is consistent with DY for Australia. 4. The findings are similar to DY. 	<ol style="list-style-type: none"> 1. Most in this cluster turn more epidemic, especially following the onset of Eurozone crisis. In contrast, short-lived volatility rises profoundly for China and Australia, corresponding to the Chinese crash. 2. Importantly, the patterns in Figure 22 outline that the transmissions from this cluster are, on average, epidemic in the cooling-off period from the eurozone crisis. Soon after, markets revert to being endemic to varying degrees.

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Table 2: Empirical Analysis comparing DY, MHD, SVD

Blocks	Transmission		
	DY	MHD	MHD-SVD
GC	<ol style="list-style-type: none"> 1. Transmissions amplify for Greece, Portugal and Ireland with the eurozone and Greek crises. Recently, Ireland transmissions ascend following a descend. 2. Belgium shows escalating transmissions facing the recent export shrinkage. 	<ol style="list-style-type: none"> 1. Greek transmission shows small surges in the positive direction, followed by strong negative dampening, mostly during the eurozone. In contradiction to DY, the strongest surges for Portugal and Ireland are found during the GFC. 2. Belgium transmissions remain neutral to dampening. Unlike DY, the positive and negative estimates offset strong amplifications for Belgium. 3. As the Greek crisis unfolds, positive transmissions resurge for Croatia. This is not identified with DY. 	<ol style="list-style-type: none"> 1. Risk transmissions from this cluster appear not highly epidemic. Strong volatility sways simultaneously over Ireland and Greece following on from when the first Greek austerity measures are adopted. 2. Figure 23 highlights that in the most recent periods, Belgium and Austria cast off some risks at an epidemic level.

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Table 2: Empirical Analysis comparing DY, MHD, SVD

Blocks	Transmission		
	DY	MHD	MHD-SVD
OED	<p>1. We find the strongest transmissions for the USA and Japan during the dotcom bubble. Transmissions resurge during the GFC and GC for the USA. Japanese transmissions decelerate during this period only to amplify in the post-GC period, possibly corresponding to global export shrinkage coupled with oil flat. Crucially, transmissions are reduced with the inclusion of oil and commodity indices.</p> <p>2. Russian transmissions amplify in all major events across the sampling periods, leading to a phenomenal jump facing the recent Russian financial crisis of 2014–2015. Inclusion of oil and commodity indices slightly dampen the transmissions.</p> <p>3. The transmissions for both Canada and Norway sharply descend, corresponding to a dramatic decline in global oil prices immediately after climbing to an apex in the post-GFC period. For both these markets, oil and commodity inclusion reduces transmission levels.</p> <p>4. Gyration in the transmissions of New Zealand do not show sharp oscillations.</p>	<p>1. The anticipated ‘conduit effect’ of the USA and Japan (BIS, 1998), which drives transmissions up from the USA, Japan to other countries and is supported in earlier studies, is dismissed with MHD. We identify dampening for the USA market during the dotcom bubble. Conversely, dampening in transmissions from the Japanese markets is preceded by a strong amplification during the dotcom bubble, suggesting the ‘conduit effect’ may still hold for Japan. The dampening for Japan is attributable to the debt crisis predominating during that period.</p> <p>2. Risk transmission from Russia remains strongly positive for the most part, with exceptions only during the advent of the GFC and Russian crisis of 2014–2015.</p> <p>3. The patterns accord well with the DY findings for both Canada and Norway. Additionally, the Norwegian market shows neither a dramatic dampening nor sharp amplification in its transmissions across the sample period, and the DY estimates may have misrepresented the degree of transmissions for Norway.</p> <p>4. The transmissions that New Zealand emit are predominantly near its mean. Except for a few spikes following the GFC and GC, New Zealand transmissions remain neutral to other major crises or volatility shocks.</p>	<p>1. Risk transmission stemming from locally induced volatility can be attributable to the USA, Russia, Mexico and Norway, especially following the recent Russian economic crisis and oil supply shock. In contrast, Japan, New Zealand and Canada are passing risks on to others in the network, without inflicting locally induced volatility in the process. Hence, we can refer more to these markets as ‘conduits’ than to others in recent years.</p> <p>2. In the post-Chinese crisis, Japanese and New Zealand transmissions might become more pandemic than endemic.</p>

Table 2: Empirical Analysis comparing DY, MHD, SVD

Blocks	Transmission		
	DY	MHD	MHD-SVD
OEE	<p>1. Transmissions peak during the GFC and export shrinkage for the Saudi Arabian market. Oil inclusion causes an overall drop in the transmission curve for this market.</p> <p>2. We identify transmissions amplifying with the onset of Iraq invasion for Israel. Transmissions from this market resurge again as the Greek debt crisis rolls into a full-fledged eurozone crisis.</p> <p>3. While Iraq's invasion of Kuwait does not decelerate the transmissions emitting from Iraq, this leads to the complete nullification of transmissions from Kuwait. A substantial amplification of transmission from Iraq in the ensuing GFC is identified with DY.</p> <p>4. Among the non-Middle Eastern OEE countries' markets, the Nigerian market shows sufficiently proximate contemporaneous small surges in transmission across the years spanned by our samples, and Venezuelan transmissions soar facing the export shrinkage.</p>	<p>1. Despite positive transmissions during the GFC complementing the findings of DY for Saudi Arabia, the transmissions are predominantly negative except for the GFC.</p> <p>2. Neutral to positive Israeli transmissions span the entire sample period, with small surges in the ensuing export shrinkage and stronger surges during Iraq invasion.</p> <p>3. DY fails to capture the strong amplifications in the Kuwait market with the Iraq invasion and export shrinkage. This suggests the Kuwait market is on the rebound as the Iraqi dominance subdues, becoming a central oil exporting partner in the periods that follow.</p> <p>4. DY patterns do not accord well with MHD for Nigeria, and is not conducive to explaining fundamentals driving Nigerian market risk. DY fails to capture the dampening of Nigerian markets during the oil crisis following the Iraq invasion and also transmissions surging with the USA bubble. However, DY and MHD both identify the build-up of Venezuelan hyperinflation in the most recent period, as both show the unprecedented rise in transmissions from Venezuela.</p>	

Table 3: Countries by Analytical Group

Exporters	Commodity Exporters	Oil Exporters	Greek Crisis	Asian Crisis	Conduit Countries
EC	CE	OE	GRC	AC	CC
Australia	Australia	Canada	Austria	Australia	Japan
China	Canada	Ecuador	Belgium	China	USA
Chile	France	Iraq ⁵	Croatia	India	
Germany	Japan	Israel	Greece	Malaysia	
Nigeria	New Zealand	Kuwait	Ireland	Philippines	
Norway	UK	Nigeria	Portugal	Singapore	
Russia		Saudi Arabia		South Korea	
Saudi Arabia		Venezuela		Sri Lanka	
South Korea		USA		Thailand	

Table 4: Financial Crises in the sample period

Crisis events		
Period		Description
1997-1998	Asian Financial Crisis	Collapse of Thai baht, resulting in Thailand becoming effectively bankrupt
1998-2000	Russian Financial Crisis	Devaluation of the ruble followed by Russian Central Bank defaulting on its debt
2000-2002	Dot-Com bubble	Stock market crash in 2002 followed by excessive speculations prevalent in 1997-2000 together with the September 2011 terrorist attack on US.
2003-2008	Global Energy Crisis	Increasing tensions in Middle East together with rising concerns over oil price speculations followed by a significant fall of US dollar; resulted in oil prices rise abruptly, exceeding three time the price at the beginning
2003	The SARS outbreak	First identified in Guangdong province in China, rapidly took an epidemic form worldwide, slowing down economic interactions with China to many markets
2006	Gaza Conflict	Israel-Lebanon war breaks out
2007-2009	Global Financial Crisis	Subprime mortgage crisis followed by 2005 housing bubble burst
2009-2012	Eurozone Crisis	In the wake of Great recession in the late 2009 , several Eurozone members (Greece, Portugal, Ireland, Spain, Cyprus) failed to bailout over-indebted banks and repay foreign debt
2014-2017	Russian Crisis	Collapse of Russian ruble, followed by economic sanctions imposed on Russia and the collapse of Russian stock markets
2016	Export Crisis	Germany, Chile, France, China, UK, Australia among others experience historic decline in total exports to others, followed by the so-called 'oil-glut'

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Table 4: Empirical Analysis comparing DY, MHD, SVD

Crisis events		
Period		Description
2015-2016	Chinese crisis	A massive drop in Chinese stock markets results in markets terminating transactions in the wake of concerns over a Chinese Crisis
2013-present	Venezuelan Crisis	Termed as the Great depression of Venezuela, the deterioration of major macro economic indicators in Venezuela since 2013, resulted in significant social and political degradation. The extent of this deterioration is such, that Venezuela topped the misery index 2013, and ranked lowest by the IFC in investing country index.

Table 5: Descriptive Statistics

Descriptive Statistics	USA	AUS	IND	JAP	MYS	NZL	SGP
Min	-6.629	-8.364	-9.852	-8.239	-19.017	-5.406	-8.848
Max	6.202	8.107	10.783	6.618	17.587	5.138	8.071
Median	0.049	0.069	0.106	0.037	0.022	0.062	0.047
Mean	0.018	0.021	0.038	0.009	0.019	0.017	0.026
Standard Deviation	0.817	1.026	1.244	0.965	1.105	0.832	0.993
JB test p Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Critical Value	5.951	6.008	6.043	6.015	5.986	5.992	5.983
	PHL	KOR	SLK	THA	NIG	VEN	KWT
Min	-8.23	-12.50	-9.95	-10.25	-17.09	-145.75	-62.81
Max	13.890	12.320	11.797	15.888	6.777	20.320	62.554
Median	0.044	0.000	0.000	0.029	0.000	0.008	0.0043
Mean	0.024	0.044	0.025	0.034	0.007	-0.003	0.012
Standard Deviation	1.181	1.514	0.858	1.321	1.129	3.557	1.871
JB test p Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Critical Value	6.019	5.975	5.987	5.988	6.005	5.995	5.996
	IRQ	SAU	CHN	ISR	CAD	GRC	PRT
Min	-41.219	-10.573	-7.863	-6.253	-9.432	-10.350	-7.060
Max	40.780	7.914	6.493	6.506	7.828	8.331	7.494
Median	0.000	0.008	0.020	0.063	0.084	0.064	0.039
Mean	0.027	0.022	0.036	0.028	0.019	-0.012	-0.008
Standard Deviation	2.508	1.013	1.243	0.986	0.985	1.523	1.041
JB test p Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Critical Value	6.003	5.948	6.010	5.996	6.012	5.964	5.986

Table 6: Descriptive Statistics

Descriptive Statistics	IRL	BEL	CRT	AUT	RUS	NOR	GER	CHL	UK	FRA
Min	-11.5	-6.9	-11.2	-7.5	-16.8	-10.8	-6.7	-6.2	-9.7	-6.9
Max	5.9	5.8	11.6	8.19	13.8	7.3	7.1	8.3	7.1	6.7
Median	0.07	0.05	0.03	0.07	0.06	0.07	0.07	0.05	0.04	0.07
Mean	0.01	0.02	0.01	0.02	0.021	0.016	0.02	0.03	0.01	0.02
Standard Deviation	1.06	0.95	1.16	1.01	1.809	1.258	1.14	0.82	0.94	1.02
JB test p Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Critical Value	5.98	6.02	5.96	5.97	5.97	6.03	6.03	5.94	5.95	6.0