Investor behavior, stock returns and CDS spreads: evidence from foreign and domestic investors in Korea

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Abstract

Purpose – This study investigates the dynamic relationships among trading behaviors of different investor groups (foreigners, domestic institutions and domestic individuals), stock returns and sovereign CDS (Credit Default Swap) spreads in Korea.

Design/methodology/approach – We employ the VAR (Vector autoregression) model to examine the dynamic relationships between CDS spread changes, stock returns and investors' behavior in the stock market.

Findings – The CDS spread change (stock return) declines (rises) in response to shocks to net foreign flows into the stock market on the same day. Foreigners buy stocks more intensely one day after an increase in the stock return, but they do not respond to CDS spread changes. Domestic individuals trade in the opposite direction of foreigners in response to shocks to both stock returns and CDS spread changes on the same day. Positive net stock purchases of domestic institutions (individuals) predict positive (negative) stock returns and negative (positive) CDS spread changes next day.

Originality/value – This study extends prior studies by examining how different investor groups' trading behaviors in the stock market are associated with not only the stock market but also a closely related market (CDS market). Prior empirical studies on the relation between the stock and CDS markets do not pay attention to possible heterogeneity in trading behavior across different types of investors in the stock market.

Keywords Investor behavior, Korean stock market, Sovereign CDS

Paper type Research paper

1. Introduction

The literature provides evidence on the heterogeneity in trading behavior across different investor groups in financial markets. Considerable attention has been paid to foreign investors' trading behavior relative to domestic investors in emerging markets [1]. In the Korean stock market, Bae *et al.* (2011) show that foreign investors outperform domestic investors, and they also find that foreigners' behavior shows positive feedback (i.e. momentum) trading, while domestic individuals are contrarian traders. Oh *et al.* (2008) find evidence that domestic individual investors, who use online trading platforms, underperform other types of investors in the Korean stock market. According to Yoo (2011), foreigners' superior performances are due to their well-established reputation. By contrast, Choe *et al.* (2005) find evidence that domestic investors' informational advantage with domestic stocks enable both domestic individuals and institutions to outperform foreign investors. In addition, the informational role of foreign investors in the Korean stock market has been examined. Kang *et al.* (2016) provide evidence that foreign investors improve the information dissemination in the Korean stock market. The literature also shows differential trading behaviors of institutional and individual investors. A large number of empirical studies find evidence that individual investors less informed than institutional investors

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(e.g. Mudalige *et al.*, 2020). It has been shown that individuals are not sophisticated investors (e.g. Barber and Odean, 2000; Choi and Choi, 2019). Boehmer and Kelly (2009) show that stock price efficiency is positively associated with institutional ownership and trading activities. Numerous studies find evidence that institutional investors can predict future stock returns (e.g. Bennett *et al.*, 2003; Yan and Zhang, 2009). In contrast, in recent years, a few studies have shown evidence against the argument that institutional (individual) investors are informed (uninformed) (e.g. Dahlquist *et al.*, 2017; Kelly and Tetlock, 2017). There is also evidence that individual investors' trades have become more informative (Gao and Huang, 2020).

Prior studies focus only on the relationship between different investor groups' behaviors and stock returns. This study extends prior studies by examining how different investor groups' trading behaviors in the stock market are associated with not only the stock market but also a closely related market (CDS market). Prior empirical studies on the relation between the stock and CDS markets do not pay attention to possible heterogeneity in trading behavior across different types of investors in the stock market [2]. Thus, the direct link between trading behavior of various groups of stock investors and CDS spreads has yet to be investigated in the literature. Given the evidence that investors trade in both stock and sovereign CDS markets in response to macroeconomic news [3], investors' trading activities in the stock market may reveal their impact on the sovereign CDS market. In this paper, we bridge this gap by investigating the dynamic relations between CDS spread changes and the trading behavior of foreigners, domestic individuals, and domestic institutions in the stock market. This study is distinguished from prior studies in that we examine not only the relation between stock returns and CDS spreads but also the impact of stock investors' trading behavior on both stock returns and CDS spreads. Further, we investigate which investor group(s) exhibit(s) similar or opposite behaviors.

We estimate the impact of different investor groups' stock trading behaviors on both stock and sovereign CDS markets by measuring the marginal impact of the net stock purchase of each investor group on both stock returns and sovereign CDS spread changes in Korea using recursive vector autoregressions (VAR). For robustness purposes, we also use the BEKK model of Kroner and Ng (1998) (Asymmetric BEKK model) and the time-varying skewed-*t* GARCH copula model to examine contemporaneous relationships of the variables of interest.

Our results show that stock returns (CDS spread changes) increase (drop) following contemporaneous shocks to net foreign flows into the stock market. Moreover, foreigners buy stocks more intensely one day after an increase in the stock return, whereas their net stock purchases are not sensitive to the variation in the CDS spread change. Next, we find that net stock purchases of foreigners (domestic individuals) are more likely to be positive (negative) when (1) the stock return is higher and (2) the CDS spread change is lower. We also provide evidence that positive net stock purchases of domestic institutions (individuals) are associated with positive (negative) stock returns and negative (positive) CDS spread changes next day. Further, our findings reveal that (1) positive shocks to stock returns are followed by negative net stock purchases of domestic institutions, whereas domestic institutions do not react to CDS spread changes and (2) domestic individuals respond to neither stock returns nor CDS spread changes.

The remainder of this paper is organized as follows. Section 2 reviews related literature and motivates this study. Section 3 presents data and descriptive statistics. Second 4 outlines the empirical methodology. Section 5 presents the empirical results. Section 6 provides the results of robustness tests. Section 7 concludes.

2. Literature review and hypothesis development

This paper is related to studies that examine the economics of price discovery in the CDS market. The literature provides mixed evidence of the informational role of the CDS market, in particular in relation to the stock market. Hilscher *et al.* (2015) find evidence that stock

market returns lead CDS returns at the daily and weekly frequencies. They attribute their results to a separating equilibrium where informed traders trade in the stock market, whereas liquidity traders participate in the CDS market. By contrast, more recent studies show that the informational role of the CDS market varies depending on the nature of the information and market conditions. Forte and Loverta (2019) derive a CDS implied equity volatility index from highly liquid one-year contracts in the Eurozone for the period 2008–2014. They find a stationary long-run equilibrium relationship between volatility indices in which the CDS implied index plays the leading role. Also, Marra *et al.* (2019) find that the magnitude of CDS market information declined after recent reforms that increased the level of post-trade regulatory and market transparency for CDSs. They also state that the ability of this CDS-unique information to predict future stock returns decreased and the CDS market has become less of a hidden trading venue for informed investors. Kryzanowski *et al.* (2017) find that the CDS market makes a greater contribution to price discovery during after-hours OTC trading and for negative earnings surprises, especially in the face of high firm-specific uncertainty. In addition, the CDS market plays a more important role in price discovery in response to unexpected macro announcements. Further, Sharma *et al.* (2019) study the price discovery on the Indonesia stock exchange and find that pricing behavior on the stock exchange is affected by the credit risk market. Lastly, Lee *et al.* (2018) document that the CDS market's contribution to price discovery is significant with respect to firm-specific credit information. They also show that CDS returns predict subsequent stock returns, controlling for systematic stock returns using the panel VAR model.

The literature also provides mixed evidence of the dynamic relationship between sovereign CDS spreads and stock returns. Guidolin *et al.* (2020) analyze time-variation of the price discovery process in sovereign debt markets. In doing so, they test whether the cointegrating relationship tie bond and CDS spreads together. They find that all the peripheral countries but Greece CDS and bond spreads show a long-run equilibrium relationship; however, this is not confirmed for core European countries, the UK and the US. In addition, Sun *et al.* (2020) build a spillover network to investigate the complex interactions within the system of sovereign CDS, stock and commodity markets by adopting the spillover index based on forecast error variance (FEV) decomposition. Their results reveal that emerging countries have larger average spillovers than developed countries with regard to sovereign CDS-to-stock returns spillovers, while the developed countries contribute more average spillovers than the emerging countries in the opposite direction. Moreover, the sovereign CDS market and the commodity market still demonstrate a relatively important role during certain periods although stock markets always occupy the dominant position during every phase. Examining European sovereign CDS contracts and stock indexes, Coronado *et al.* (2012) find that stock returns lead sovereign CDS spreads during 2007–2010, but they demonstrate that sovereign CDS spreads move faster than stock prices when the relationship is examined in the year 2010. Chan *et al.* (2009) investigate sovereign CDS spreads and stock prices for seven Asian countries from January 2001 to February 2007 and find that sovereign CDS markets contribute more to price discovery than stock markets in five out of seven countries. They also show that the stock market plays a more important role in price discovery than the sovereign CDS market only in Korea.

This paper is also closely associated with studies on the differential roles of distinct investor groups in the stock market. The literature provides mixed evidence of the contemporaneous relationship between investor groups (e.g. institutions, foreigners, individuals) and stock returns. Tsai *et al.* (2019) investigate the trading behavior of foreign investors, and how it is related to stock prices under different market conditions in Taiwan. They focus on stock market turnover and return and find that foreign investors facilitate the price discovery function when the market is hot (e.g. high stock market turnover and/or high market return). Pedraza *et al.* (2020) study the trading behavior and performance of foreign

investors by level of active management. Using a Colombian dataset, they find that aggregate underperformance of foreign investors is attributable to passively managed foreign funds. Also, they state that these funds pay higher prices to increase the speed of their trades in order to accommodate daily flows proportionally to their benchmark index. In the Korean stock market, Onishchenko and Ülkü (2019), using a 2004–2015 sample of Korean data, show that these foreigners do not any longer trade after prices have moved against them and are no longer disadvantaged; they trade at more favorable prices compared with domestic institutions. Yang and Segara (2020) examine foreign investors' trading behaviors around merger and acquisition (M&A) announcements in the Korean stock market. They find that foreign investors are more likely to buy target stocks with larger wealth effects on the KOSPI market. Park *et al.* (2019) using the account-level data of a major Korean securities firm between 1999 and 2005, examine whether the strength of domestic individual traders' disposition effect is affected by the inflow of foreign investors. They find that individual investors are more likely to realize paper gains on stocks with large recent foreign investor purchases, which appears to be behaviorally motivated. These individual investors are also less likely to trade stocks with large foreign ownership in the first place, further hinting at their aversion. In the Korean stock market, Bae *et al.* (2011) study trading behavior of foreigners, domestic institutions and domestic individuals from 1996 to 2002. They provide evidence that foreign investors outperform domestic investors, and they also show that foreigners and institutions adopt the momentum strategy, while individuals tend to be contrarians, consistent with the findings in Wermers (1999), Odean (1998), and Barber and Odean (2000). Similarly, by examining investors' trading activities from 2001 to 2005, Oh *et al.* (2008) show that domestic individual investors who trade online underperform other types of investors in the Korean stock market. They also provide evidence that foreigners perform better than institutions. Yoo (2011) attributes these findings to foreign investors' well-established reputation. In contrast, by investigating trading behavior of different investor groups from 1996 to 1998 in the Korean stock market, Choe *et al.* (2005) find that both domestic individuals and institutions outperform foreign investors due to domestic investors' informational advantage with domestic stocks.

Richards (2005) finds that net foreign flows into the stock market have a significant association with the foreign exchange market for three of the five currencies examined in the study. The author attributes this result to the fact that foreign exchange transactions are necessary for the purchase of domestic stocks, implying that foreign investors' trading in one market can reveal the impact of their trading on the prices of multiple related securities.

The sovereign CDS market is another trading venue that can be highly associated with foreign investors' behavior in the stock market. Suppose that foreign investors trade in both the stock and sovereign CDS markets simultaneously in response to macroeconomic news. Given the evidence that (1) net foreign flows into the stock market are positively related to stock returns in Asian emerging stock markets (Richards, 2005) and (2) foreign investors improve the information dissemination in the Korean stock market (Kang *et al.*, 2016) [4], we may see that foreign investors buy stocks and sell sovereign CDS contracts simultaneously using positive macroeconomic information, leading to the following hypothesis:

H1a. Net foreign flows into the stock market have a positive (negative) association with stock returns (sovereign CDS spread changes).

It is also possible that foreign investors prefer a particular market for transactions. If the stock market is preferred by foreign investors in response to macroeconomic news, other investors can infer information from the impact of net foreign flows into the stock market on the stock prices and subsequently trade in the sovereign CDS market. We thus have the following hypothesis:

H2a. Lagged net foreign flows into the stock market have a negative association with sovereign CDS spread changes.

Further, we investigate which domestic investor group(s) (domestic individuals and/or domestic institutions) exhibit(s) similar or opposite behavior to that of foreigners. It has been shown that individuals are not sophisticated investors in most empirical studies (e.g. Barber and Odean, 2000; Choi and Choi, 2019) [5]. By contrast, a large body of scholarly work provides evidence that institutions are informed and/or skilled (e.g. Henry *et al.*, 2017; Henry and Koski, 2017; Mudalige *et al.*, 2020). Given the extensive evidence that institutions (individuals) are informed (uninformed) and skilled (unsophisticated) in most empirical studies, we expect that domestic institutions (individuals) exhibit trading behavior similar (opposite) to that of foreigners (see Hypothesis 1a and H2a). Thus, we test the following hypotheses:

H1b. The net stock purchase of domestic institutions has a positive (negative) association with stock returns (sovereign CDS spread changes).

H 1c. The net stock purchase of domestic individuals has a negative (positive) association with stock returns (sovereign CDS spread changes).

H2b. Lagged net purchase of domestic institutions has a negative association with sovereign CDS spread changes.

H2c. Lagged net purchase of domestic individuals has a positive association with sovereign CDS spread changes.

Note that Hypothesis 1b and Hypothesis 1c (Hypothesis 2b and Hypothesis 2c) are related to Hypothesis 1a (Hypothesis 2a).

3. Data and summary statistics

The data for the Korean sovereign CDS contract and the MSCI Korea Index (USD) are sourced from Thomson Reuters through Datastream. For the Korean sovereign CDS contract, the US dollar denominated five-year CDS contract with full restructuring (CR) clauses written on senior unsecure debt is chosen on each trading day and daily CDS spread midpoint (in USD) is used [6]. To measure the performance of the entire Korean stock market, the daily price index on the MSCI Korea Index (USD) is selected. The MSCI Korea Index (USD) is designed to measure (in USD) the performance of the large and mid-cap segments of the South Korean stock market. The index accounts for approximately 85% of the Korean stock universe. The data for stock investor behavior are collected from FnGuide through DataGuide. FnGuide distributes transaction data by each group of stock investors sourced from the KRX (Korea Exchange). Our data set includes the daily aggregate buy and sell values of all KRX-listed operating companies' common stocks by each investor group [7]. In this study, we classify investor groups as foreigners, domestic institutions and domestic individuals. The daily aggregate market capitalization of all Korean companies' common stocks is also sourced from FnGuide. The sample period is from January 1, 2009 to December 31, 2014.

The net stock purchase is the difference between the daily buy value and daily sell value of stocks for a particular investor group divided by the market capitalization, following Richards (2005). The net stock purchase of foreigners (NET_BUY_FOREIGN) is the difference between the daily buy value and daily sell value of stocks for foreigners divided by the market capitalization, the net stock purchase of domestic institutions (NET_BUY_D_INSTITUTION) for domestic institutions and the net stock purchase of domestic individuals (NET_BUY_D_INDIVIDUAL) for domestic individuals. The sovereign CDS spread change (CDS_SPREAD_CHANGE) is the daily change in the

Korean sovereign CDS spread. The stock return (STOCK_RETURN) is the daily stock return on the MSCI Korea Price Index (USD) [8]. To mitigate the influence of extreme values, all variables are winsorized at the 1 and 99% levels.

Table 1 presents the number of observations, mean, standard deviation, minimum, maximum, skewness, kurtosis and Jarque–Bera probability for each variable used in this study. Three variables are negatively skewed (STOCK_RETURN, NET_BUY_D_INSTITUTION and NET_BUY_D_INDIVIDUAL). NET_BUY_D_INDIVIDUAL is found to be the most negatively skewed (−0.4509). All variables have kurtosis values above zero, indicating that the distributions have heavier tails than the normal distribution. CDS_SPREAD_CHANGE has the highest level of kurtosis (6.3984), indicating that extreme changes tend to occur more frequently than the other variables. Jarque–Bera statistics indicate that none of the variables are normally distributed. Figure 1 depicts the time-series of variables of interest. In Figure 1, none of the variables exhibit highly persistent behavior, suggesting that they are likely to be stationary. The results of the Dickey–Fuller test reveal that all variables are stationary at the 1% level.

4. Empirical methodology

We employ the VAR model to examine the dynamic relationships between CDS spread changes, stock returns and investors' behavior in the stock market. The VAR model is commonly used by studies that investigate the relationship between investors' trading behavior and security prices (e.g. Richards, 2005; Vo, 2017). The following VAR model is estimated:

$$y_t = A_0 + A_1 y_{t-1} + \ldots + A_p y_{t-p} + \varepsilon_t \tag{1}$$

where y_t is a vector of variables of interest on trading day t, the VAR disturbance vector ε_t is assumed to be serially uncorrelated. The lag length p is determined based on the Schwarz Bayesian criterion (SBC).

The ordering of variables in the recursive form determines how the variables interact contemporaneously with each other. The impact of shocks is identified in the following recursive form [similar to the model specification used in Bruno and Shin (2015)]:

$$B(L)y_t = u_t \tag{2}$$

where $B(L)$ is a matrix of polynomial in the lag operator L, y_t is a vector of variables of interest and u_t is a vector of orthogonalized disturbances. The following exclusion restrictions on contemporaneous responses in the matrix B result from the Cholesky restrictions for the three-variable VAR:

$$B = \begin{bmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \tag{3}$$

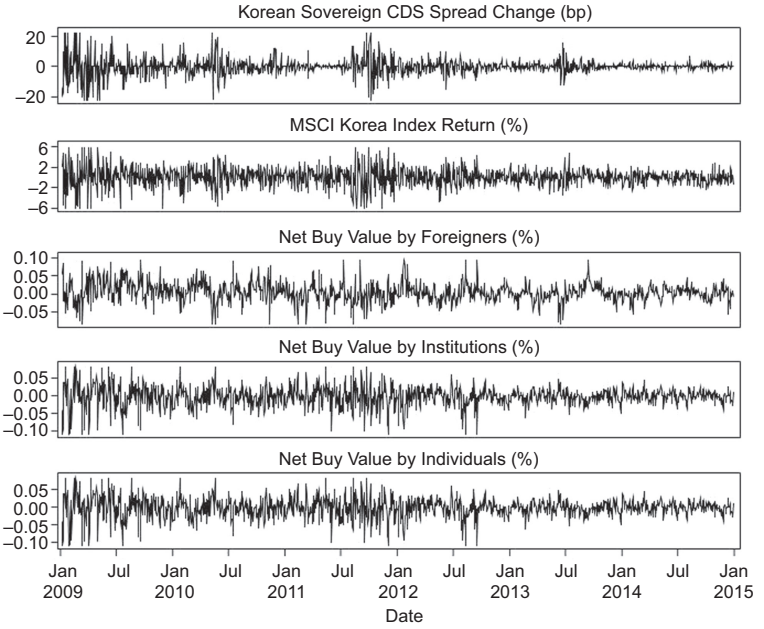
In a three-variable VAR, the last variable (i.e. the variable ordered last) is affected by the contemporaneous shocks to both the first and second variables, the second variable is affected by only the contemporaneous shocks to the first variable, but the first variable is not affected by the contemporaneous shocks to the other two variables.

In this study, the VAR model is estimated for each investor group. With respect to foreigners, the ordering of the three variables is (1) NET_BUY_FOREIGN, (2) STOCK_RETURN and (3) CDS_SPREAD_CHANGE. This ordering implies that (a) CDS_SPREAD_CHANGE is affected by contemporaneous shocks to the other two variables (NET_BUY_FOREIGN and STOCK_RETURN), (b) STOCK_RETURN is affected by contemporaneous shocks to one variable (NET_BUY_FOREIGN) and

Table 1. Descriptive statistics

	N	Mean	Std Dev	Min	Max	Skewness	Kurtosis	Jarque–Bera probability
CDS_SPREAD_CHANGE	1,491	−0.1723	5.1341	−22.5000	22.5000	0.0497	6.3984	0.0000
STOCK_RETURN	1,491	0.0490	1.6848	−5.9936	5.7162	−0.2210	1.9121	0.0000
NET_BUY_FOREIGN	1,491	0.0045	0.0257	−0.0827	0.0943	0.1372	1.5731	0.0000
NET_BUY_D_INSTITUTION	1,491	−0.0018	0.0199	−0.0682	0.0614	−0.2627	1.4468	0.0000
NET_BUY_D_INDIVIDUAL	1,491	−0.0014	0.0272	−0.1097	0.0833	−0.4509	2.3094	0.0000

Note(s): This table presents summary statistics of variables used in the empirical analysis. NET_BUY_FOREIGN is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by foreigners, NET_BUY_D_INSTITUTION by domestic institutions, and NET_BUY_D_INDIVIDUAL by domestic individuals. CDS_SPREAD_CHANGE is the daily change in the CDS spread for the Korean sovereign CDS contract. STOCK_RETURN is the daily stock return: the MSCI Korea Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1 and 99% levels



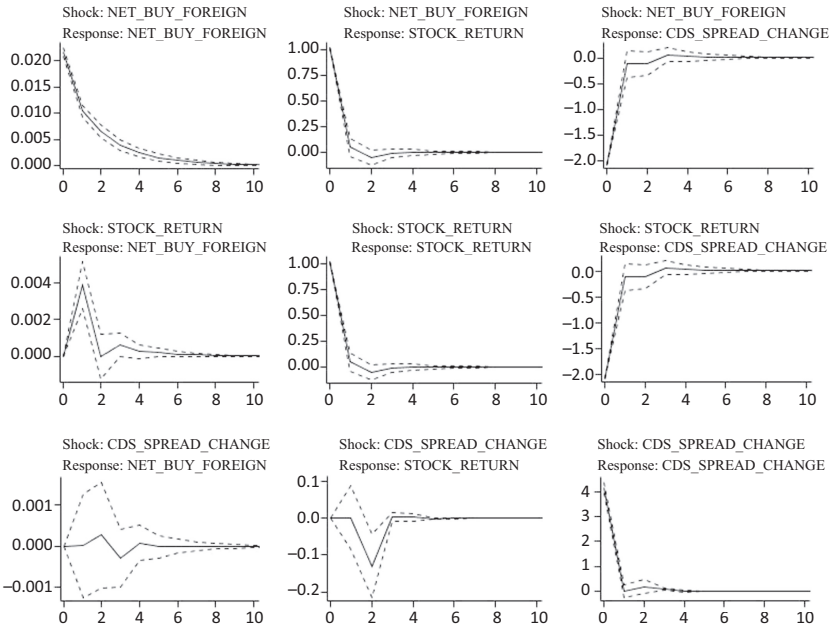
Note(s): This figure presents the time series of variables used for the empirical analysis. Net Buy Value by Foreigners (%) (NET_BUY_FOREIGN) is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by foreigners, Net Buy Value by Institutions (%) (NET_BUY_D_INSTITUTION) by domestic institutions, and Net Buy Value by Individuals (%) (NET_BUY_D_INDIVIDUAL) by domestic individuals. Korean Sovereign CDS Spread Change (bp) (CDS_SPREAD_CHANGE) is the daily change in the CDS spread for the Korean sovereign CDS contract. MSCI Korea Index Return (%) (STOCK_RETURN) is the daily stock return: the MSCI Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1% and 99% levels

Figure 1.
Time series of variables for VAR models

(c) NET_BUY_FOREIGN is affected by contemporaneous shocks to none of the other variables. For the other investor groups, NET_BUY_FOREIGN is replaced with NET_BUY_D_INSTITUTION for domestic institutions and NET_BUY_D INDIVIDUAL for domestic individuals. We select two lags for the models with NET_BUY_FOREIGN or NET_BUY_D_INSTITUTION and one lag for the model including NET_BUY_D_INDIVIDUAL as the Schwarz Bayesian criterion (SBC) suggests.

5. Empirical results

Figure 2 presents estimated impulse-response functions for the three-variable recursive VAR (including NET_BUY_FOREIGN) with two lags and ±2 standard error bands. The ordering of the three variables is (1) NET_BUY_FOREIGN, (2) STOCK_RETURN and (3) CDS_SPREAD_CHANGE. Each graph shows estimated impulse responses of one variable over 12 trading days to a one-standard deviation shock to another variable. The first row of Figure 2 presents estimated impulse responses to a shock to net foreign flows into the stock market. We find that a positive shock to net foreign flows into the stock market increases (decreases) the stock return (CDS spread change) contemporaneously. We observe



Note(s): This figure presents estimated impulse-response functions for the three-variable recursive VAR with two lags and ±2 standard error bands. The VAR model is estimated using the following ordering of the three variables: (1) NET_BUY_FOREIGN, (2) STOCK_RETURN, and (3) CDS_SPREAD_CHANGE. This ordering implies that (a) CDS_SPREAD_CHANGE is affected by contemporaneous shocks to the other two variables (NET_BUY_FOREIGN and STOCK_RETURN), (b) STOCK_RETURN is affected by contemporaneous shocks to one variable (NET_BUY_FOREIGN), and (c) NET_BUY_FOREIGN is affected by contemporaneous shocks to none of the other variables. NET_BUY_FOREIGN is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by foreigners. CDS_SPREAD_CHANGE is the daily change in the CDS spread for the Korean sovereign CDS contract. STOCK_RETURN is the daily stock return: the MSCI Korea Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1% and 99% levels

Figure 2.
Impulse-response functions in recursive VAR model: model with net stock purchase of foreigners

no significant impact of net foreign flows into the stock market on future stock returns and future CDS spread changes.

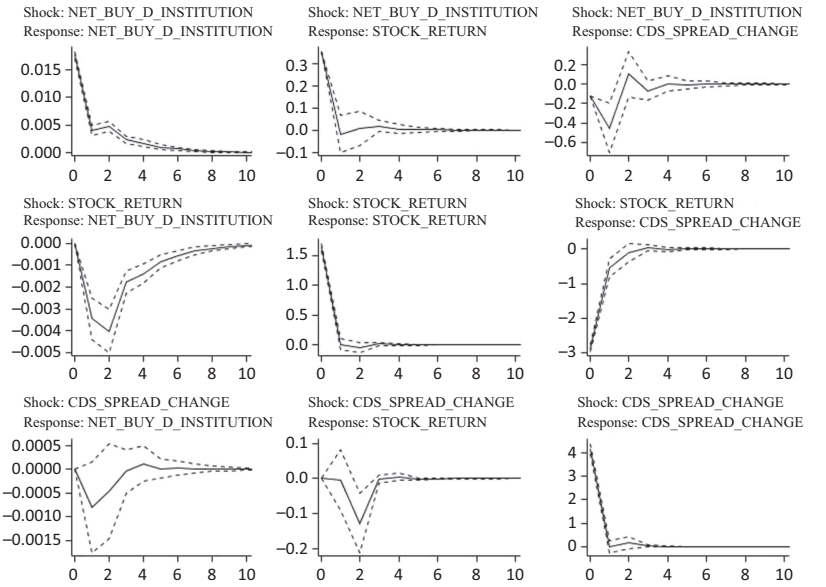
Our results indicate that foreign investors buy stocks more intensely when (1) the stock price rises more rapidly and (2) the CDS spread declines faster. We also find that net stock purchases of foreigners forecast neither future stock returns nor future CDS spread changes. Consider a situation where net foreign flows into the stock market are large, but there is no change in the stock price. Our findings imply that even in this situation, the CDS spread change declines simultaneously. One possible explanation is that foreigners trade in both stock and CDS markets concurrently. Our evidence also suggests that using the information on net stock purchases of foreigners is not helpful in predicting future stock returns and future CDS spread changes.

The second row of Figure 2 shows estimated impulse responses to shocks to the stock return. Following a shock to the stock return, net foreign flows into the stock market rise next day: the impact is significant only for the next day. The CDS spread change declines in

response to a shock to the stock return contemporaneously and next trading day. Figure 2 also reveals that (1) net stock purchases of foreigners do not respond to shocks to CDS spread changes and (2) a shock to the CDS spread change leads to a decline in the stock return at day 2. Our results show that foreign investors buy stocks more intensely one day after an increase in the stock return, indicating that foreign investors are short-term (one day) momentum traders. In contrast, foreign investors do not respond to the variation in the CDS spread change.

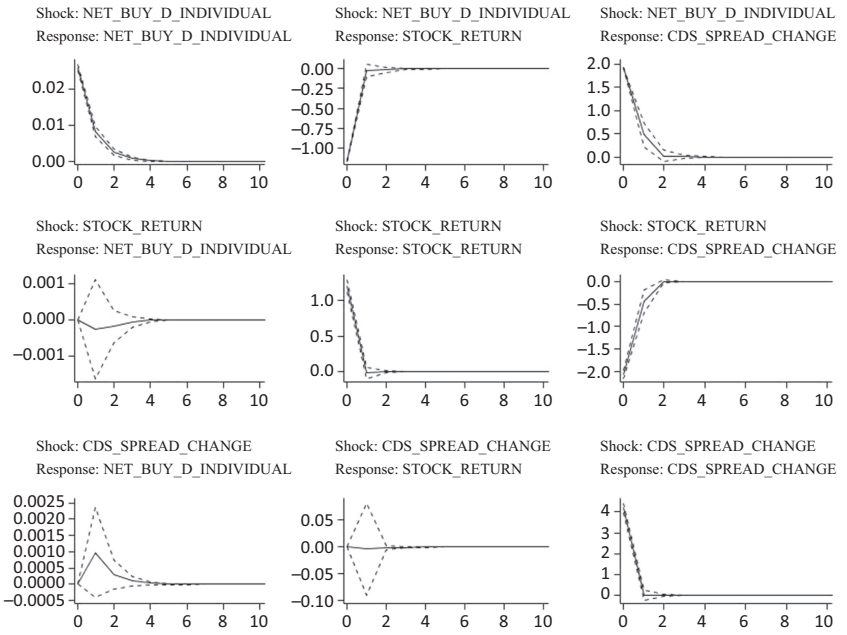
Next, we investigate the dynamic relationships among domestic investors (domestic institutions and domestic individuals separately), stock returns and CDS spread changes. The results of this analysis will reveal, among domestic investors, whether domestic individuals and/or domestic institutions systematically provide liquidity to foreign investors.

Figures 3 and 4 shows estimated impulse-response functions for the three-variable recursive VAR, including NET_BUY_D_INSTITUTION (NET_BUY_D_INDIVIDUAL) with two lags (one lag) and ±2 standard error bands. For Figures 3 and 4, the three variables are ordered as follows: (1) NET_BUY_D_INSTITUTION (NET_BUY_D_INDIVIDUAL),



Note(s): This figure presents estimated impulse-response functions for the three-variable recursive VAR with two lags and ±2 standard error bands. The VAR model is estimated using the following ordering of the three variables: (1) NET_BUY_D_INSTITUTION, (2) STOCK_RETURN, and (3) CDS_SPREAD_CHANGE. This ordering implies that (a) CDS_SPREAD_CHANGE is affected by contemporaneous shocks to the other two variables (NET_BUY_D_INSTITUTION and STOCK_RETURN), (b) STOCK_RETURN is affected by contemporaneous shocks to one variable (NET_BUY_D_INSTITUTION), and (c) NET_BUY_D_INSTITUTION is affected by contemporaneous shocks to none of the other variables. NET_BUY_D_INSTITUTION is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by domestic institutions. CDS_SPREAD_CHANGE is the daily change in the CDS spread for the Korean sovereign CDS contract. STOCK_RETURN is the daily stock return: the MSCI Korea Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1% and 99% levels

Figure 3.
Impulse-response functions in recursive VAR model: model with net stock purchase of domestic institutions



Note(s): This figure presents estimated impulse-response functions for the three-variable recursive VAR with one lag and ±2 standard error bands. The VAR model is estimated using the following ordering of the three variables: (1) NET_BUY_D_INDIVIDUAL, (2) STOCK_RETURN, and (3) CDS_SPREAD_CHANGE. This ordering implies that (a) CDS_SPREAD_CHANGE is affected by contemporaneous shocks to the other two variables (NET_BUY_D_INDIVIDUAL and STOCK_RETURN), (b) STOCK_RETURN is affected by contemporaneous shocks to one variable (NET_BUY_D_INDIVIDUAL), and (c) NET_BUY_D_INDIVIDUAL is affected by contemporaneous shocks to none of the other variables. NET_BUY_D_INDIVIDUAL is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by domestic individuals. CDS_SPREAD_CHANGE is the daily change in the CDS spread for the Korean sovereign CDS contract. STOCK_RETURN is the daily stock return: the MSCI Korea Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1% and 99% levels

Figure 4.
Impulse-response functions in recursive VAR model: model with net stock purchase of domestic individuals

(2) STOCK_RETURN and (3) CDS_SPREAD_CHANGE. Figure 3 reveals that following shocks to net stock purchases of domestic institutions, (1) the stock return rises on the same day only and (2) the CDS spread change drops on the same day and next day. Figure 4 shows that in response to shocks to net stock purchases of domestic individuals (1) only the same-day stock return declines and (2) the CDS spread change rises for 2 trading days (from day 0).

The results for domestic institutions are similar to those for foreigners. Both foreigners and domestic institutions buy (sell) stocks more intensely when the stock price (CDS spread) rises at a faster rate. However, only net stock purchases of domestic institutions predict CDS spread changes next day. By contrast, domestic individuals are more likely to be net sellers when the stock return (CDS spread change) is higher (lower). We also find that positive net stock purchases of domestic individuals (one day prior) predict positive CDS spread changes. Overall, our results reveal that foreigners and domestic institutions (domestic individuals) are more likely to be net buyers (sellers) in the stock market when (1) the stock return is higher

and (2) the CDS spread change is lower. Further, positive net stock purchases of domestic institutions (domestic individuals) predict positive (negative) stock returns and negative (positive) CDS spread changes next day, showing that domestic individuals effectively provide liquidity to domestic institutions for profitable stock purchases one day prior to positive (negative) stock returns (CDS spread changes).

Figures 3 and 4 also show estimated impulse responses of net stock purchases of domestic investors (domestic institutions and domestic individuals) to shocks to the stock market return and CDS spread change. A shock to the stock return decreases net stock purchases of domestic institutions next day and the impact is statistically significant over trading 12 days. The impact reaches a maximum response of −0.004 at day 2. On the contrary, net stock purchases of domestic institutions do not respond to shocks to CDS spread changes. As shown in Figure 4, net stock purchases of domestic individuals are affected by neither stock returns nor CDS spread changes. Our findings indicate that one day after a shock to the stock return, domestic institutions tend to take opposite positions to those of foreigners.

Taken together, our results show how different groups of investors react to shocks to stock returns and CDS spread changes. One possible explanation for our findings is that (1) foreigners (domestic institutions) assume that positive shocks to stock returns, controlling for their own net stock purchases and CDS spread changes, are followed by further stock price increases (decreases) and (2) domestic individuals do not use the information from the stock market systematically. In contrast, none of the investor groups respond to CDS spread changes, possibly because all three groups of investors do not rely on the information from the CDS market when considering transactions in the stock market.

As for the dynamic relation between the stock return and CDS spread change, Figures 2–4 reveal that the CDS spread change declines immediately following a shock to the stock return and the impact remains significant until the next day; in contrast, the CDS spread change has no immediate impact on the stock return. After controlling for the net stock purchases of foreigners or domestic institutions, the stock return drops at day 2 following an appreciation of the CDS spread change. On the other hand, the stock return does not respond to lagged CDS spread changes unrelated to net stock purchases of domestic individuals.

The literature offers evidence that there is heterogeneity in trading behavior across different investor groups. A large literature has been devoted to assessing whether foreign investors destabilize host markets, specifically because they appear to chase returns. Within this framework, we find that the foreigners' behavior observed on detailed Korean data is pervasive. A finding worthy of special note is that foreign stock investors increase their purchases of shares after noticing an increase in the stock market return, but they do not respond to CDS spread changes, indicating that foreign stock investors react differently to the stock and CDS markets. In contrast, foreign stock investors' trading activities have an immediate impact on both the stock and CDS markets. Given the immediate impact of foreign stock investors' trades on not only the stock market but also the CDS market without subsequent reversals of stock returns and CDS spreads, our findings may suggest that foreign stock investors tend to interact with both markets so as to facilitate price discovery and therefore enhance market efficiency. We also show how domestic (both institutional and individual) investors behave compared to foreigners. We provide evidence that domestic individuals provide liquidity to foreigners following shocks to both stock returns and CDS spread changes on the same day. Our results also indicate that only domestic institutions can predict stock returns and CDS spread changes next day.

Our results uncover different investor groups' trading behaviors and their impact on multiple related markets and hence have implications for practitioners and regulators. Practitioners can make use of net stock purchases of foreigners (domestic institutions) as a signal for contemporaneous (future) changes in both stock returns and CDS spreads. These signals can be valuable for those who are able to detect them earlier and react to them faster

than the other market participants. In addition, our findings will extend regulators' understanding of the key roles of different investor groups (foreigners, domestic institutions and domestic individuals) in multiple related markets and hence help them make coherent regulations across markets.

6. Robustness tests

For robustness purposes, we use (1) the BEKK model of Kroner and Ng (1998) (Asymmetric BEKK model) and (2) the time-varying skewed-*t* GARCH copula model [9]. Table 2 presents the asymmetric BEKK model estimation results. Figure 5 represents the time-varying conditional correlations for pairs of the variables of interest. Our results reveal that the CDS spread change is negatively associated with the contemporaneous net foreign flows into the stock market (with an average correlation of −0.3059) but has a positive contemporaneous relationship with the net stock purchase of domestic individuals (with an average correlation of 0.2910). The contemporaneous correlation between the CDS spread change and net stock purchases of domestic institutions is close to zero (with an average correlation of 0.0153). The stock return is positively and contemporaneously related to net foreign flows into the stock market (with an average correlation of 0.5765) and net stock purchases of domestic institutions (with an average correlation of 0.1663); by contrast, it has a contemporaneous negative relation with net stock purchases of domestic individuals (with an average correlation of −0.6861). Turning next to the dynamics of the market prices, we find a contemporaneous negative relationship between the CDS spread change and the stock return (with an average correlation of −0.4616).

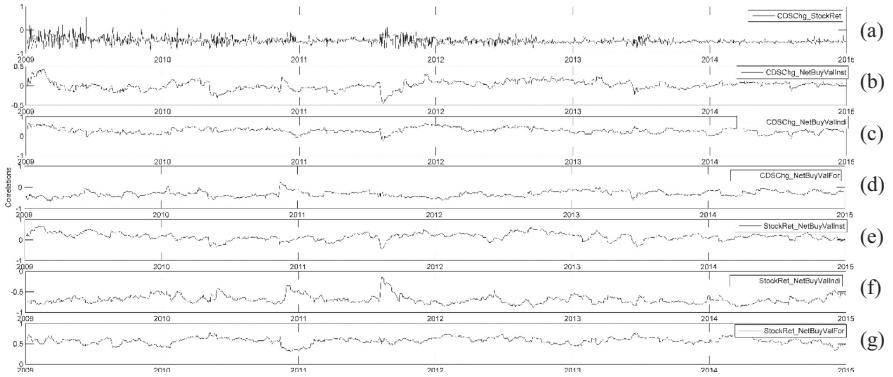
Table 3 presents the AR(1)-GJR(1,1) model estimation results. The majority of the parameters of the model are statistically significant, which confirms the effectiveness of using AR(1)-GJR(1, 1) model in the first stage to estimate the time-varying copula. Table 4 presents the time–varying skewed-*t* GARCH copula estimation results. We find that the CDS spread change is negatively and contemporaneously associated with net foreign flows into the stock market (with an average correlation of −0.3924), while it has a positive contemporaneous association with the net stock purchases of domestic individuals (with an average correlation of 0.3962). The contemporaneous correlation between the CDS spread change and net stock purchases of domestic institutions is close to zero (with an average correlation of 0.0062). The stock return is positively and contemporaneously related to net foreign flows into the stock market (with an average correlation of 0.5965) and net stock purchases of domestic institutions (with an average correlation of 0.1775). By contrast, the contemporaneous correlation between the stock return and net stock purchases of domestic individuals is negative (with an average correlation of −0.7072). We also observe a contemporaneous negative relationship between the CDS spread change and stock return (with an average correlation of −0.4914).

The results of the asymmetric BEKK model are consistent with those of the time–varying skewed-*t* GARCH copula. With respect to the contemporaneous relationships between variables of interest, the results of the VAR models are consistent with those of the asymmetric BEKK model and time–varying skewed-*t* GARCH copula model except for the contemporaneous relation between CDS spread changes and net stock purchases of domestic institutions. In sum, the results of all three models indicate that (1) net stock purchases of foreigners (domestic individuals) are negatively (positively) and contemporaneously related to the CDS spread change, (2) net stock purchases of foreigners and domestic institutions (individuals) have a contemporaneous positive (negative) association with stock returns and (3) the CDS spread change and stock return have a contemporaneous negative relationship.

Table 2.
Asymmetric BEKK model estimation

Parameter	CDS spread and Stock return		CDS spread and Domestic institutions		CDS spread and Domestic individuals		CDS spread and Foreigners		Stock return and Domestic institutions		Stock return and Domestic individuals		Stock return and Foreigners	
C_{11}	2.7656	***	−38.0953	***	0.3199	***	0.1641		0.2622		0.4491	*	0.4494	***
C_{12}	−0.1939	***	0.0943	***	0.0215	***	−0.0019		−0.0017	***	−0.0016		0.0024	**
C_{22}	−1.6408	***	−0.0862	***	0.0009	**	−0.0008		−0.0020	*	0.0047		0.0028	
A_{11}	0.0374		−0.0191	***	−0.0485	***	0.0751	***	0.2408		0.1822		−0.0029	
A_{21}	−0.2037	***	0.0137	*	−0.0065		−0.0589		−0.0636		0.0001		0.1188	
A_{12}	0.0564	***	−0.0514	***	−0.0032	**	−0.0674	***	−0.0020	***	−0.0026		−0.0020	*
A_{22}	−0.0610	***	0.2004		0.0346		0.0565		0.1829	***	0.0820		−0.0985	
G_{11}	0.0391	*	−0.0775	*	−0.0027	**	0.1263	***	0.2472	**	0.1715	***	0.1113	**
G_{21}	0.0668		0.3025		0.0788		−0.1285		−0.3713		0.0048		0.0692	
G_{12}	0.0297	***	−0.1424	***	0.0452	***	0.1295	***	−0.0008		0.0124		−0.0004	
G_{22}	0.0482	***	0.0374		0.0592		−0.0205		0.0793		0.0834		−0.0089	
B_{11}	0.9299	***	0.9376	***	0.9574	***	0.9520	***	0.9377	***	0.9369	***	0.9533	***
B_{21}	0.0441	***	−0.1573	***	0.0389	***	0.0018		−0.0002		0.0095		−0.0464	
B_{12}	−0.0164	***	−0.0255	***	−0.0067	***	0.0099	*	0.0009	*	0.0038	*	0.0003	
B_{22}	0.9628	***	0.9019	***	0.9523	***	0.9526	***	0.9468	***	0.9150	***	0.9582	***
Average correlation	−0.4616		0.0153		0.2910		−0.3059		0.1663		−0.6861		0.5765	

Note(s): This table presents the asymmetric BEKK model estimation results. Each column shows parameter estimates of the asymmetric BEKK model for a given pair of variables. *Average correlation* is the time-series average contemporaneous correlation based on the asymmetric BEKK model. *Foreigners* (NET_BUY_FOREIGN) is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by foreigners, *Domestic Institutions* (NET_BUY_D_INSTITUTION) by domestic institutions, and *Domestic Individuals* (NET_BUY_D_INDIVIDUAL) by domestic individuals. *CDS Spread* (CDS_SPREAD_CHANGE) is the daily change in the CDS spread for the Korean sovereign CDS contract. *Stock Return* (STOCK_RETURN) is the daily stock return: the MSCI Korea Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1 and 99% levels. ***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively



Note(s): This figure presents time-varying conditional correlations from the asymmetric BEKK model. (a) CDSChg and StockRet; (b) CDSChg and NetBuyValInst; (c) CDSChg and NetBuyValIndi; (d) CDSChg and NetBuyValFor; (e) StockRet and NetBuyValInst; (f) StockRet and NetBuyValIndi; (g) StockRet_NetBuyValFor. Each subfigure shows correlations for a given pair of variables based on the asymmetric BEKK model. *NetBuy ValFor* (NET_BUY_FOREIGN) is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by foreigners, *NetBuyValInst* (NET_BUY_D_INSTITUTION) by domestic institutions, and *NetBuyValIndi* (NET_BUY _D_INDIVIDUAL) by domestic individuals. *CDSChg* (CDS_SPREAD_CHANGE) is the daily change in the CDS spread for the Korean sovereign CDS contract. *StockRet* (STOCK_ RETURN) is the daily stock return: the MSCI Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1% and 99% levels

Figure 5. Time-varying conditional correlations – Asymmetric BEKK model

7. Conclusions

In this paper, we investigate the heterogeneity in the impact of stock trading behavior on both stock and CDS markets across different investor groups by estimating the marginal impact of distinct investor groups (foreigners, domestic institutions and domestic individuals) on both stock returns and sovereign CDS spread changes in Korea. We find that the stock return (CDS spread change) rises (declines) in response to shocks to net foreign flows into the stock market on the same day. In contrast, our findings suggest that the use of the information on the net stock purchases of foreigners does not help predict future stock returns and CDS spread changes. Further, we show that foreigners' net buying pressure becomes stronger in the stock market one day after an increase in the stock return.

Considering both foreign and domestic investors, our evidence indicates that foreigners (domestic individuals) are more likely to be net buyers (sellers) when (1) the stock return is higher and (2) the CDS spread change is lower. Furthermore, positive net stock purchases of domestic institutions (domestic individuals) are followed by positive (negative) stock returns and negative (positive) CDS spread changes next day. We also find evidence that domestic institutions buy stocks more intensely following an increase in the stock return on the previous trading day. Turing next to domestic individuals, we show that they respond to neither stock returns nor CDS spread changes on the previous trading day.

We provide further evidence of the dynamic relationship between the stock and CDS markets. Our results show that a shock to the stock return decreases the CDS spread change for two days. By contrast, the CDS spread change has no immediate impact on the stock return. After controlling for the net stock purchases of foreigners or domestic institutions, the

Table 3.
AR(1)-GJR(1,1) model estimation

Parameter	CDS spread		Stock return		Domestic institutions		Domestic individuals		Foreigners	
c_0	0.1619	***	−0.0530	**	0.0011	***	−0.0001		−0.0005	**
c_1	0.0087		−0.0212		0.3566	***	0.2992	***	0.4994	***
ω	0.0369	**	0.0161	**	0.0000	**	0.0000		0.0000	
α	0.2262	***	0.0000		0.0275	***	0.0441	***	0.0152	**
β	0.8733	***	0.9445	***	0.9623	***	0.9695	***	0.9801	***
γ	−0.0764	**	0.0976	***	0.0123		−0.0289	***	0.0067	
υ	3.0099	***	19.1265	***	6.1401	***	7.6925	***	5.5013	***
λ	0.0531	***	−0.1597	***	0.0680	**	−0.1139	***	−0.0038	
LL	−3,797.46		−2,675.36		3,973.84		3,552.45		3,699.98	
AIC	7,610.92		5,366.72		−7,931.68		−7,088.90		−7,383.95	
BIC	7,653.37		5,409.18		−7,889.23		−7,046.45		−7,341.50	

Note(s): This table presents the AR(1)-GJR(1,1) model estimation results. *Foreigners* (NET_BUY_FOREIGN) is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by foreigners, *Domestic Institutions* (NET_BUY_D_INSTITUTION) by domestic institutions, and *Domestic Individuals* (NET_BUY_D_INDIVIDUAL) by domestic individuals. *CDS Spread* (CDS_SPREAD_CHANGE) is the daily change in the CDS spread for the Korean sovereign CDS contract. *Stock Return* (STOCK_RETURN) is the daily stock return: the MSCI Korea Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1 and 99% levels. LL is the optimal value of the log-likelihood function. AIC is the Akaike criteria. BIC is the Schwarz criteria. ***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively

Table 4. Time–varying Skewed-T GARCH copula estimation

Parameter	CDS spread and Stock return		CDS spread and Domestic institutions		CDS spread and Domestic individuals		CDS spread and Foreigners		Stock return and Domestic institutions		Stock return and Domestic individuals		Stock return and Foreigners	
U	29.1125		30.3192	**	3.8420	***	4.9736	***	15.4410	***	7.0329	***	11.5530	***
A	0.0265	***	0.0099	**	0.0000		0.0000	**	0.0627	***	0.0190	**	0.0073	**
B	0.9596	***	0.9770	***	0.8785	**	0.8083	***	0.7953	***	0.9573	***	0.9746	***
LL	221.48		4.02		152.04		142.21		42.65		551.48		335.12	
AIC	−436.96		−2.05		−298.08		−278.41		−79.30		−1,096.96		−664.25	
BIC	−421.04		13.87		−282.15		−262.49		−63.38		−1,081.04		−648.32	
Average correlation	−0.4914		0.0062		0.3962		−0.3924		0.1775		−0.7072		0.5965	
Convergence rate (%) (vs Asymmetric BEKK model)	0.9703		0.9908		0.8948		0.9135		0.9889		0.9788		0.9800	

Note(s): This table presents the time–varying skewed-t GARCH copula estimation results. The parameters α and β correspond to those of the DCC model of Engle (2002) and υ is the degree of freedom parameter of the copula. *Foreigners* (NET_BUY_FOREIGN) is the difference between the buy value and sell value (divided by the market capitalization) on a given trading day by foreigners, *Domestic Institutions* (NET_BUY_D_INSTITUTION) by domestic institutions, and *Domestic Individuals* (NET_BUY_D_INDIVIDUAL) *by domestic individuals*. *CDS Spread* (CDS_SPREAD_CHANGE) is the daily change in the CDS spread for the Korean sovereign CDS contract. *Stock Return* (STOCK_RETURN) is the daily stock return: the MSCI Korea Price Index (USD) is used. To mitigate the influence of extreme values, all variables are winsorized at the 1 and 99% levels. LL is the optimal value of the log-likelihood function. AIC is the Akaike criteria. BIC is the Schwarz criteria. *Average correlation* is the time-series average contemporaneous correlation based on the copula DCC-GARCH model. *Convergence Rate (%) (vs. asymmetric BEKK model)* represents the convergence rate between the time–varying skewed-t GARCH copula and the asymmetric BEKK model. ***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively

stock return drops two days after an increase in the CDS spread change. On the other hand, the stock return is not affected by lagged CDS spread changes, controlling for the net stock purchases of domestic individuals.

There are several ways to extend our study to gain further insight into the heterogeneity in the effect of trading behaviors on financial markets across various investor groups. Due to our limited access to the trading data by investor group, we are unable to address our research questions for a longer period including recent years. Given the evidence that trades by individuals have become more informative (Gao and Huang, 2020), an investigation of a more recent period will likely to offer additional insight. Another possibility is to examine heterogeneity in trading behavior within each investor group if data are available. In addition, researchers will be able to extend understanding of differential trading behaviors of various investor groups by further analyzing the individual stock-level data.

Notes

1. Refer to the following studies related to the impact of foreigners on various aspects of corporations and financial markets: investment (Mitton, 2006; Chari and Henry, 2008); cost of capital (Henry, 2000; Bekaert and Harvey, 2000); economic growth (Bekaert *et al.*, 2005); trading patterns (Onishchenko and Ülkü, 2019; Vo, 2017).
2. Prior studies focus on the relation between stock returns and CDS spreads. The literature provides mixed evidence on the dynamic relationship between the CDS and stock markets. Hilscher *et al.* (2015) show that new information is incorporated into stock prices first, and the CDS market reacts to the stock market. Using CDSs with US reference entities (US-listed firms) from 2001 to 2007, they provide evidence that informed traders prefer the stock market and this preference is partially due to transaction cost differentials. In contrast, there is evidence that the CDS market plays a significant role in price discovery. Lee *et al.* (2018) find evidence that the CDS market makes a significant contribution to price discovery in the presence of prominent firm-specific credit information.
3. Kim *et al.* (2015) find that better-than-expected (worse-than-expected) macroeconomic news tends to reduce (increase) sovereign CDS spreads.
4. Syamala and Wadhwa (2019) show similar results in the Indian stock market. By examining the Malaysian stock market, Lim *et al.* (2016) find evidence that foreigners improve the global information dissemination up to a certain level of foreign ownership.
5. As discussed earlier, there are a few recent studies that demonstrate superior abilities of some individual investors (e.g. Dahlquist *et al.*, 2017; Kelly and Tetlock, 2017).
6. According to the International Monetary Fund (2013), Korea ranked 9th in terms of the gross notional amount outstanding, with $85 billion (USD) among all CDS reference entities examined at the end of 2012. Note that Italy was the largest CDS reference entity with $388 billion (USD) and the United States ranked 124th with $23 billion (USD).
7. REITs, infrastructure funds, investment companies, ship investment companies, ETFs, ETNs, foreign companies, Special Purpose Acquisition Companies (SPACs), KDRs (Korean Depositary Receipts) and KONEX (Korea New Exchange)-listed companies are excluded.
8. The descriptions of the variables (including data sources and related studies) for our empirical analysis are presented in Table A1 in the appendix (Appendix 1).
9. Detailed descriptions of these models are provided in the appendix (Appendix 2).
10. Copula functions are introduced in Sklar (1959).
11. See Patton (2006) for this class of models.
12. For all estimations, Dynamic Copula Toolbox 3.0 (University of Macedonia, Thessaloniki, Greece) is used.

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Appendix 1

Table A1. Variable descriptions

Variable	Definition	Data source
NET_BUY_FOREIGN	Difference between the daily buy value and daily sell value of stocks for foreigners divided by the market capitalization, following Richards (2005)	FnGuide
NET_BUY_D_INSTITUTION	Difference between the daily buy value and daily sell value of stocks for domestic institutions divided by the market capitalization, following Richards (2005)	FnGuide
NET_BUY_D_INDIVIDUAL	Difference between the daily buy value and daily sell value of stocks for domestic individuals divided by the market capitalization, following Richards (2005)	FnGuide
CDS_SPREAD_CHANGE	Daily change in the Korean sovereign CDS spread	Datastream
STOCK_RETURN	Daily stock return on the MSCI Korea Price Index (USD)	Datastream

Appendix 2

The BEKK model is designed to ensure the positive definiteness of the variance covariance matrix H_t. The basic form of BEKK presentation is proposed by Engle and Kroner (1995) as follows:

$$H_t = CC' + \sum_{j=1}^{q} A_j e_{t-j} e'_{t-j} A'_j + \sum_{i=1}^{p} B_i H_{t-i} B'_i \tag{4}$$

where A_j, B_i, and C (a lower triangular matrix) are $N \times N$ parameter matrices. The decomposition of the constant term into a product of two triangular matrices ensures the positive definiteness of H_t. A_j is a matrix of ARCH coefficients, which captures the ARCH effects, and B_i is a matrix of GARCH coefficients capturing the GARCH effects.

Kroner and Ng (1998) introduce the asymmetric version of the BEKK model (Asymmetric BEKK model):

$$H_t = CC' + \sum_{j=1}^{q} A_j e_{t-j} e'_{t-j} A'_j + \sum_{i=1}^{p} B_i H_{t-i} B'_i + \sum_{k=1}^{o} G_k h_{t-k} h'_{t-k} G'_k \tag{5}$$

where

$$C = \begin{bmatrix} C_{11} & 0 \\ C_{21} & C_{22} \end{bmatrix}; A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}; B = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}; G = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix}$$

G_k matrix captures the asymmetries in the conditional variance-covariance matrix. The diagonal elements in A represent the impact of past shocks on the current conditional variances and the diagonal elements in B represent the impact of past volatilities on the current conditional variance. The off-diagonal parameters represent the impact of volatility spillovers. The parameter A_{12} (A_{21}) is the volatility spillover from variable 1 (2) to variable 2 (1). Hence, the statistical significance of these parameters indicates the presence of the volatility spillover. Note that the BEKK model becomes symmetric if asymmetric coefficients are statistically jointly equal to zero.

We also employ the time-varying skewed-t GARCH copula model for an additional robustness test. Copula functions are appropriate in measuring interactions between time series and spillover effects [10]. Copulas are restricted to $[0, 1]^2$ of a bivariate distribution function where margins are uniform in $[0, 1]$. H is a bivariate distribution function with margins $F(x)$ and $G(y)$ and there exists a copula function such that:

$$H(x, y) = C(F(x), G(y)) \tag{6}$$

For continuous conditional distributions, in Patton (2006), Sklar's theorem is stated as follows. Let F be the conditional distribution of $X|Z$, G be the conditional distribution of $Y|Z$, and H be the joint conditional distribution of $X|Y$, Z. Assume that F and G are continuous in x and y, and let $\mathcal{Z}$ be the support of Z. Then, there exists a unique conditional copula C such that:

$$H(x|y,z) = C(F(x|z), G(y|z)|z), \ \forall(x, \ y) \in \mathbb{R}x\mathbb{R} \quad \text{and each } z \in \mathcal{Z} \tag{7}$$

According to Sklar's theorem, for every p-dimensional distribution F, with marginal distributions F_i, $i = 1, \ldots, p$, there exists a copula C, such that:

$$F(x_1, \ldots, x_p) = C(F_1(x_1), \ldots, F_p(X_p)) \tag{8}$$

The above copula is unique if all marginal distributions are continuous. From this equation, the copula can be obtained using the following formula:

$$C(u_1, \ldots, u_p) = F\left(F_1^{-1}(u_1), \ldots, F_p^{-1}(u_p)\right) \tag{9}$$

where

$$u_1 = F_1(x_i), i = 1, \ldots, p$$

If F is p-times differentiable, the joint density can be extracted as:

$$\begin{aligned} f(x) &= \frac{\partial^p}{\partial x_1 \partial x_2 \ldots \partial x_p} F(x) \\ &= \prod_{i=1}^{p} f_i(x_i) \, \frac{\partial^p}{\partial u_1 \partial u_2 \ldots \partial u_p} C(F_1(x_1), \ldots, F_p(x_p)) \\ &= \prod_{i=1}^{p} f_i(x_i) c(F_1(x_1), \ldots, F_p(x_p)) \end{aligned} \tag{10}$$

and the corresponding copula density is:

$$c(u_1, \ldots, u_p) = \frac{f\left(F_1^{-1}(u_1), \ldots, F_p^{-1}(u_p)\right)}{\prod_{i=1}^{p} f_i\left(F_i^{-1}(u_1)\right)} \tag{11}$$

where $x = (x_1, \ldots, x_p)$ and c is the copula density.

The most common way to estimate the copula parameters is to optimize the log likelihood function:

$$L(\xi; x) = \sum_{j=1}^{T} \left(\sum_{i=1}^{p} \log(f_i(x_{i,t}; \varphi_i)) + \log(c(F_1(x_{1,t}), \ldots, F_p(x_{p,t}); \theta)) \right) \tag{12}$$

where $\xi = (\varphi, \ \theta)$ is the vector that contains the marginal parameters $\varphi = (\varphi_1, \ldots, \varphi_p)$ and the copula parameters θ. The last function can be decomposed into two components: (1) the marginal log likelihood:

$$mL(\varphi; x) = \sum_{i=1}^{p} mll_i = \sum_{i=1}^{p} \sum_{j=1}^{T} \log(f_i(x_{i,t}; \varphi_i)) \tag{13}$$

and (2) the copula log likelihood:

$$cL(\theta; u, \varphi) = \log(c(F_1(x_{1,t}), \ldots, F_p(x_{p,t}); \theta)) \tag{14}$$

where $u = (F_1(x_1), \ldots, F_p(x_p))$. Due to a large number of parameters in most cases, a two-step method is used. The first step is to estimate the marginal parameters by optimizing the marginal log likelihoods mll_i and the copula parameters are estimated in the second stage by optimizing the copula log likelihood $cL(\theta; u, \varphi)$, conditional upon the results from the first stage.

Copula functions have become a standard tool in modeling multivariate dependence over the last decade; see copula-GARCH models (Jondeau and Rockinger, 2006). Copula-GARCH models have parameters that are potentially time varying, in an autoregressive way, conditional on particular past information [11]. Applications of copula-GARCH models in finance can be found, for example, in Panchenko (2006), Serban *et al.* (2007), Huang *et al.* (2009), and Wang *et al.* (2009). In this study, we use the skewed student-t GARCH copula model. We observe from the data that most of the variables of interest exhibit the characteristic features of financial time series such as excess kurtosis and non-positive skewness. The normality hypothesis is rejected for all cases, at every confidence level, according to the Jarque–Bera test. In the two-step procedure, the marginal parameters are estimated in the first step. An AR(1)-GJR(1,1) GARCH with skewed-*t* residuals is estimated for each variable. We choose the skewed-t distribution given our finding that three out of the five series exhibit negative skewness. The AR(1)–GJR(1,1) model can be described as follows:

$$\begin{aligned} r_{i,t} &= c_0 + c_1 r_{i,t-1} + e_{i,t} \\ e_{i,t} &= h_{i,t} e_{i,t}, e_{i,t} \sim SkT(\upsilon, \lambda) \\ h_{i,t} &= \omega_{i,t} + a e_{i,t-1}^2 + \beta h_{i,t} + \gamma e_{i,t-1}^2 1(e_{i,t-1} < 0) \end{aligned} \tag{15}$$

Each marginal model has eight parameters: two parameters (c_0, c_1) in the mean equation, four parameters (ω, α, β, γ) in the variance equation and two distributional parameters (υ, λ). The log likelihood of the skewed-t copula takes the following form:

$$\begin{aligned} L_{St}(R, d, u_t) = &-T\log \frac{\Gamma\left(\frac{d+p}{2}\right)}{\left(\frac{d}{2}\right)} - pT\log \frac{\Gamma\left(\frac{d+p}{2}\right)}{\left(\frac{d}{2}\right)} - \frac{d+p}{2}\sum_{t=1}^{T}\log\left(1 + \frac{\varepsilon_t' R^{-1}\varepsilon_t}{d}\right) \\ &- \sum_{t=1}^{T}\log|R| + \frac{d+1}{2}\sum_{t=1}^{T}\sum_{i=1}^{P}\log\left(1 + \frac{\varepsilon_{it}^2}{d}\right) \end{aligned} \tag{16}$$

where ε_t is the vector of the transformed standardized residuals, which depends on the copula specification.

The Gaussian copula is:

$$\varepsilon_t = \left(t_d^{-1}(u_{1,t}), \ldots, t_d^{-1}(u_{p,t})\right) \tag{17}$$

t_d^{-1} denotes the inverse student's *t* distribution with *d* degrees of freedom and *R* is the correlation matrix of ε_t. Copula parameters evolve through time with DCC(1,1) model of Engle (2002). In the second stage, the copula DCC-GARCH model is estimated. In most cases, the DCC model is appropriate because it captures time varying conditional correlations. The DCC model reflects dynamic conditional correlations and accounts for heteroskedasticity directly by estimating correlation parameters using the standardized residuals from the first stage estimation. The correlation matrix R_t along with the variance covariance matrix H_t are time varying and have the following decomposition:

$$H_t = D_t R_t D_t \tag{18}$$

where $D_t = \text{diag}\{\sqrt{h_{i,t}}\}$ is the diagonal matrix of the conditional standard deviations and $R_t = \{\rho_{ij,t}\}$ is the correlation matrix, which is time-varying. The correlation matrix can also be defined as:

$$\begin{aligned} R_t &= \left(Q_t^*\right)^{-1} Q_t \left(Q_t^*\right)^{-1}, \\ Q_t &= [1 - \alpha(1) - \beta(1)]\Gamma + \alpha(L)\eta_{t-1}\eta_{t-1}' + \beta(L)Q_{t-1} \end{aligned} \tag{19}$$

Q_t^* is a diagonal matrix with a square root of the ith diagonal of Q_t on its ith diagonal position. The parameter constraints for the DCC are the same as for the univariate GARCH(1,1) models:

$$\alpha + \beta < 1, \alpha, \beta \in (0, 1) \tag{20}$$

After the estimation of the marginal parameters, we proceed with the specification of the copula [12].

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