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Quantile Dependence between Foreign Exchange Market and Stock Market: The Case of Korea*

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This paper examines quantile dependence and directional predictability between the foreign exchange market and the stock market in Korea. Instead of adopting a multivariate model such as a vector autoregressive model, a multivariate GARCH model or a combination of both models, we apply the cross-quantilogram recently proposed by Han et al. (2016). Considering various quantile ranges, we investigate various spillover effects between two markets. Our findings show that there exists an asymmetric bi-directional spillover between two markets and the interdependence between two markets implies that one market has significant predictive power on the other.

Keywords: Quantile, Cross-Quantilogram, Spillover, Foreign Exchange Market, Stock Market
JEL classification: C12, C22, G15

I. INTRODUCTION

The interaction between stock market and currency market has been the subject of a long-drawn academic debate with inconclusive results. There are two competing hypotheses to explain these macroeconomic variables; traditional and portfolio approaches. The traditional approach, suggested by Dornbusch et al. (1980) is that exchange rate movements lead change in stock prices since the stock

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prices represent firm's values denominated in foreign currency. In contrast to traditional theory, portfolio approach, first discussed by Branson et al. (1977) postulates that changes in stock prices may have an influence on exchange rate via portfolio adjustments.

Even though the theoretical explanations have attempted to show causal relation between stock market and exchange rate market, the empirical findings are rather mixed for the causal direction. Furthermore, the empirical results of causal relation between two financial markets have been varied by countries and time periods. Table 1 reports the summary of previous empirical studies.

Table 1. Related Review on Relationship between Exchange Rate and Stock Price

Authors	Method	Sample Period	Countries
Traditional Approach: EX → ST			
Abdalla et al.(1997)	GC/VAR, ECM	Jan.1985-Jul.1994	India, Korea, Pakistan
Ajayi et al.(1998)	GC	Dec.1987-Sep.1991	Korea
Granger et al.(2000)	GC/VAR	Jan.1995-Nov.1997	Japan, Thailand
Wu (2000)	ECM	Apr.1991-May.2000	Singapore
Pan et al.(2007)	GC/ECM	Before Asian crisis	Japan, Malaysia, Thailand
Pan et al.(2007)	GC/ECM	During Asian crisis	Hong Kong, Japan, Korea, Singapore, Taiwan, Thailand
Kang et al.(2012)	GC, B-GARCH	Jan.2002-Mar.2011	Korea, Singapore, Taiwan
Portfolio Approach: ST → EX			
Abdalla et al.(1997)	GC/ ECM	Jan.1985-Jul.1994	Philippines
Ajayi et al.(1998)	GC	Apr.1985-Aug.1991	Canada, France, Germany, Italy, Japan, U.K, U.S
Ajayi et al.(1998)	GC	Dec.1987-Sep.1991	Indonesia, Malaysia, Philippines, Taiwan, Thailand
Granger et al.(2000)	GC/VAR	Jan.1995-Nov.1997	Taiwan
Hatemi-J et al.(2002)	GC/VAR	Jan.1993-Dec.1998	Sweden
Pan et al.(2007)	GC/ECM	Before Asian crisis	Korea, Singapore
Lee and Ahn (2010)	GC/VAR	Jan.2006-Dec.2009	Korea
Bi-directional Causality: EX ↔ ST			
Ajayi et al.(1996)	ECM	Apr.1985-Jul.1991	Canada, France, Germany, Italy, Japan, Netherlands, U.K, U.S.
Granger et al.(2000)	GC/VAR	Jan.1995-Nov.1997	Korea, Malaysia, Philippines
Lee (2007)	GMM	Jan.1999-Dec.2006	Korea
Pan et al.(2007)	GC/ECM	Jan 1988-Oct.1992	Hong Kong
Kang et al.(2012)	GC, B-GARCH	Jan.2002-Mar.2011	Hong Kong

Note: GC, ECM and B-GARCH represent Granger causality, error correction model and bivariate GARCH model, respectively.

Abdalla and Murinde (1997) find the supportive evidences in favor of traditional approach using a country's monthly exchange rates. The studies show that there is uni-directional causality from exchange rate to stock return in India, Korea and Pakistan. Similarly, Wu (2000) shows Singapore-dollar exchange rates Granger stock prices. In contrast, Ajayi et al. (1998) find significant linkage between two financial markets by indicating uni-directional causality from the stock market to the currency market for advanced countries including Canada, France, Germany, Italy, Japan, U.K, and U.S from 1985 to 1991. Hatemi-J and Irandoust (2002) confirm that stock market tends to lead exchange rates in favor of the portfolio approach for Sweden. In a similar vein, Pan et al. (2007) find out there is uni-directional causal relationship from stock price to exchange rate for Korea and Singapore before Asian financial crisis.

On the other hand, some of the studies have found bi-directional causality between two financial markets (Ajayi and Mougoue, 1996). In this regard, Pan et al. (2007) also provide evidences to indicate bi-directional causal relationship for Hong Kong before the Asian financial crisis. Granger et al. (2000) investigate causality based on Granger causality tests for nine Asian countries during the Asian financial crisis then obtain fairly differing results by country. They show that exchange rate market tends to lead the stock market in Japan and Thailand, which support traditional approach whereas stock market takes the lead in Taiwan. Furthermore, bi-directional relation is discovered for Korea, Malaysia and the Philippines. In Singapore, there exists no such causal relation.

The ratio of foreign investors in Korean stock market has been high as shown in Table 3. It has been mostly more than thirty percent since 2001 and it reached its peak 40.1% in 2004. In other words, the foreign investment in Korea is a major component in Korean financial market. There have been numerous studies to investigate the relation between two financial markets, however, the existing literature is inconclusive on the relation between stock market and exchange rate.

Korean stock market can be affected by the change in exchange rate of Korean Won via the traditional approach (Abdalla and Murinde, 1997; Kang and Yoon, 2012) while it also can affect the foreign exchange market via the portfolio approach (Lee and Ahn, 2010). On the other hand, Lee (2007) and Granger et al. (2000) provide bi-directional interaction between exchange rates and stock prices in Korea. In addition, Pan et al. (2007) find out that the results are in line with the traditional approach during Asian crisis, while they agree with the portfolio approach before Asian crisis in Korea. Therefore, examining the detailed relationship between foreign exchange market and stock market in Korea is appropriate to study the interaction between two markets and moreover it is very important for investors and policy makers in Korea.

Volatility spillover and co-movement of financial markets have been extensively investigated in the literature. See Baele (2005), I (2015), Karolyi (1995), Kanas (2000), Ng (2000), Yang and Doong (2004), Wu (2005) and references therein. Researchers typically adopted a vector autoregressive model, a multivariate GARCH model or a combination of both models to analyze volatility spillover and co-movement of financial markets (In et al., 2001; Jebran and Iqbal, 2016), among others. The existing methods generally depend on modeling conditional variance and conditional correlation of multivariate financial time series and therefore they cannot provide quantile-based detailed relationship between financial markets.

However, the cross-quantilogram recently proposed by Han et al. (2016) can address this aspect. The cross-quantilogram is a correlation statistic of quantile hit processes and measures dependence between a quantile range of one time series and a quantile range of the other time series. Therefore, it can provide quantile-based dependence between two financial markets. Moreover, it is particularly appropriate in analyzing financial time series because it does not require any moment condition of time series. It is well known that finite fourth moments do not exist for most stock return or exchange rate return series even if commonly used models such as multivariate GARCH models in general assume the existence of finite fourth moments of time series.

We consider the relationship between foreign exchange market and stock market in Korea for the period from 3 January 1997 to 31 October 2014. The main results of the paper are as follows. First, when Korean Won depreciates largely at day t, i.e., the exchange rate return is less than its 0.05 quantile, it is more likely for Korean stock market to have a large loss in the next day but to have a large gain from day $t+2$. This shows that there exists a risk spillover from foreign exchange market to stock market in the next day. Second, when Korean Won appreciates largely at day t, i.e., the exchange rate return is larger than its 0.95 quantile, it is more likely for the stock market to have a large gain for the next two days. Third, the tail dependence is asymmetric. Comparing the magnitude of spillover, the risk spillover (spillover from left tail to left tail) is much stronger than the positive from right tail to right tail.

Fourth, when stock market has a large loss at day t, it is more likely for Korean Won to depreciate largely in the next day. If we consider the dependence in the next day, a risk spillover exists in both directions between the foreign exchange market and the stock market. From day $t+2$, it is more likely for Korean Won to fluctuate largely for some lags. Fifth, when stock market has a large gain at day t, a direction is not conclusive in the next day. The values of the cross-quantilogram for both tails of the exchange rate return are low even if they are significantly positive.

The rest of the paper is organized as follows. Section II explains the cross-quantilogram and related Box-Ljung type test statistic. Section III provides the data description and preliminary results using a vector autoregressive model. Section IV presents the main results of the paper and Section V concludes the paper.

II. ECONOMETRIC TOOL

Linton and Whang (2007) introduce the (auto-) quantilogram to measure predictability in different parts of the distribution of a stationary time series based on the correlogram of quantile hits. Han et al. (2016) develop its multivariate version and consider the cross-quantilogram. To construct confidence intervals of the cross-quantilogram, they propose and investigate the stationary bootstrap procedure and a self-normalized approach.

As explained in Linton and Whang (2007) and Han et al. (2016), the advantages of the cross-quantilogram are 1) it is simple to interpret, 2) no moment condition is required for time series, 3) it captures properties of a joint distribution, 4) it can consider arbitrary lags. In particular, the second part is important for financial time series because it is known that financial time series such as stock return or exchange rate return has heavy tails and does not have a finite fourth moment. The cross-quantilogram can be used 1) to measure quantile dependence between two series, 2) to test directional predictability between two series, 3) to test model specification.

Let $q_{i,t}(\tau_i)$ be either τ_i conditional quantile or unconditional quantile of $y_{i,t}$. To measure dependence between two events $\{y_{1,t} \leq q_{1,t}(\tau_1)\}$ and $\{y_{2,t-k} \leq q_{2,t-k}(\tau_2)\}$ for an arbitrary pair of $\tau = (\tau_1, \tau_2)'$ and a positive integer k, Han et al., (2016) analyze the cross-quantilogram and related Portmanteau tests. In the literature, $\{1[y_{i,t} \leq q_{i,t}(\cdot)]\}$ is called the quantile-hit or quantile-exceedance process for $i = 1, 2$, where $1[\cdot]$ denotes the indicator function. The cross-quantilogram is defined as the cross-correlation of the quantile-hit processes

$$\rho_\tau(k) = \frac{E[\psi_{\tau_1}(y_{1,t}-q_{1,t}(\tau_1))\psi_{\tau_2}(y_{2,t-k}-q_{2,t-k}(\tau_2))]}{\sqrt{E[\psi_{\tau_1}^2](y_{1,t}-q_{1,t}(\tau_1))}\sqrt{E[\psi_{\tau_2}^2(y_{2,t-k}-q_{2,t-k}(\tau_2))]}} \quad (1)$$

for $k = 0, \pm 1, \pm 2, \ldots$, where

$$\psi_{\tau_i}(y_{i,t} - q_{i,t}(\tau_i)) = 1[y_{i,t} < q_{i,t}(\tau_i)] - \tau_i.$$

Its sample counterpart is

$$\hat{\rho}_\tau(k) = \frac{\sum_{t=k+1}^{T}\psi_{\tau_1}(y_{1,t}-\hat{q}_{1,t}(\tau_1))\psi_{\tau_2}(y_{2,t-k}-\hat{q}_{2,t-k}(\tau_2))}{\sqrt{\sum_{t=k+1}^{T}\psi_{\tau_1}^2(y_{1,t}-\hat{q}_{1,t}(\tau_1))}\sqrt{\sum_{t=k+1}^{T}\psi_{\tau_2}^2(y_{2,t-k}-\hat{q}_{2,t-k}(\tau_2))}},$$

where $\hat{q}_{i,t}(\tau_i)$ is the estimate of either τ_i conditional quantile or unconditional quantile of $y_{i,t}$.

If one is interested in measuring dependence between two events $\{q_{1,t}(\tau_1^l) \leq y_{1,t} \leq q_{1,t}(\tau_1^h)\}$ and $\{q_{2,t-k}(\tau_2^l) \leq y_{2,t-k} \leq q_{2,t-k}(\tau_2^h)\}$ for arbitrary quantile ranges $[\tau_1^l, \tau_1^h]$ and $[\tau_2^l, \tau_2^h]$, one can use an alternative version of the cross-quantilogram that is defined by replacing $\psi_{\tau_i}(y_{it} - q_{i,t}(\tau_i))$ in (1) with

$$\psi_{[\tau_i^l,\tau_i^h]}(y_{it} - q_{i,t}([\tau_i^l, \tau_i^h])) = 1[q_{i,t}(\tau_i^l) < y_{it} < q_{i,t}(\tau_i^h)] - (\tau_i^h - \tau_i^l).$$

See footnote 4 in Han et al. (2016). This alternative version could be easier to interpret and therefore we will adopt this alternative version of the cross-quantilogram in this paper. The stationary bootstrap inference procedure is still valid for this alternative version as mentioned in Han et al. (2016) and, therefore, we will use it to construct confidence bands.

If $\rho_\tau(k) = 0$, there is no dependence or directional predictability from an event $\{q_{2,t-k}(\tau_2^l) \leq y_{2,t-k} \leq q_{2,t-k}(\tau_2^h)\}$ to an event $\{q_{1,t}(\tau_1^l) \leq y_{1,k} \leq q_{1,t}(\tau_1^h)\}$. If $\rho_\tau(k) \neq 0$, there exists quantile dependence or directional predictability between two events. If $\rho_\tau(k) > 0$, it means that it is more likely for $y_{1,t}$

to be in a range $[q_{1,t}(\tau_1^l), q_{1,t}(\tau_1^h)]$ when $y_{2,t-k}$ is located in a range $[q_{2,t-k}(\tau_2^l), q_{2,t-k}(\tau_2^h)]$. If $\rho_\tau(k) < 0$, it means that it is less likely for $y_{1,t}$ to be in a range $[q_{1,t}(\tau_1^l), q_{1,t}(\tau_1^h)]$ when $y_{2,t-k}$ is located in a range $[q_{2,t-k}(\tau_2^l), q_{2,t-k}(\tau_2^h)]$.

We use the stationary bootstrap procedure by Politis and Romano (1994) to obtain confidence intervals of the cross-quantilogram and they are based on 10,000 bootstrap replicates in our application. The tuning parameter is chosen by adapting the rule suggested by Politis and White (2004), and later corrected in Patton et al. (2009).

Suppose that $\tau \in \mathrm{T}$ and p are given. One may be interested in testing

$$H_0 \quad : \quad \rho_\tau(1) = \cdot\cdot\cdot = \rho_\tau(p) = 0 \ ,$$

$$H_0 \quad : \quad \rho_\tau(k) \neq 0 \ \text{for some} \ k \in \{1, \ldots, p\}.$$

For this test, the Box-Ljung type test statistic $\hat{Q}_\tau^{(p)} = T\sum_{k=1}^{p}\hat{\rho}_\tau^2(k)$ can be used. We will use the Box-Ljung version $\breve{Q}_\tau^{(p)} = T(T+2)\sum_{k=1}^{p}\hat{\rho}_\tau^2(k)/(T-k)$ because it has a better finite sample performance for a large p and a small sample size.

III. DATA AND PRELIMINARY VAR ANALYSIS

1. Data Description

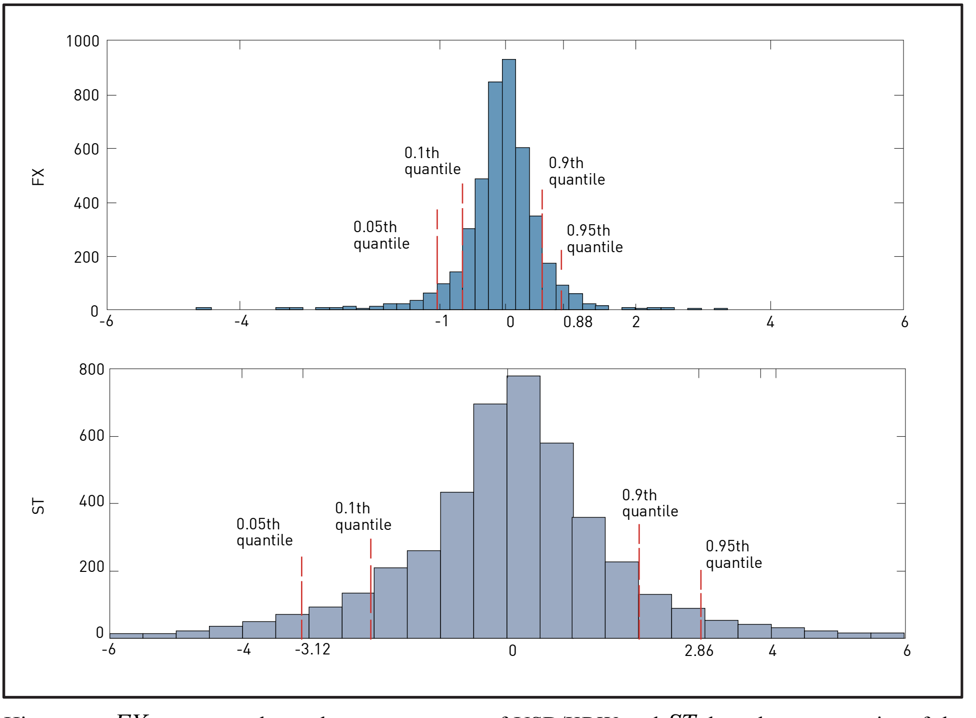
We consider the sample period from 3 January 1997 to 31 October 2014 (4,413 daily observations). The exchange rate is based on USD/KRW and therefore a positive exchange rate return means that Korean Won appreciates. The stock return is the return series of the KOSPI index. Both return series are in percentage form. Table 2 provides descriptive statistics of the time series. While the standard deviation of the stock return is higher than that of the exchange rate return, the sample kurtosis of the exchange rate return is much larger. This is because the exchange rate return has some extreme outliers. Figure 1 provides histograms of both return series. For the exchange rate return series, the 5% and 10% quantiles are located at -1.0026 and -0.6197, respectively. For the stock return series, the 5% and 10% quantiles are located at -3.1245 and -2.0645, respectively.

Table 2. Descriptive Statistics

	Exchange Rate Return	Stock Return
Mean	-0.0054	0.0249
Median	0.0113	0.0788
Maximum	20.346	11.284
Minimum	-13.455	-12.805
Std. Dev.	0.9724	1.8892
Skewness	1.0318	-0.2191
Kurtosis	90.0760	7.6543

Note: The descriptive statistics of the return series of exchange rate USD/KRW and the return series of the KOSPI index for the sample period from 3 January 1997 to 31 October 2014. Both are in percentage form.

Figure 1.



Histogram. FX represents the exchange rate return of USD/KRW and ST does the return series of the KOSPI index. The upper panel of the figure is a histogram of FX. The 5% quantile is located at -1.0026, the 10% quantile at -0.6197, the 90% quantile at 0.6026 and the 95% quantile at 0.8754. The lower panel of the figure is a histogram of ST. The 5% quantile is at -3.1245, the 10% quantile at -2.0645, the 90% quantile at 1.9357 and the 95% quantile at 2.8576.

Table 3 presents changes in shareholdings in terms of market capitalization by shareholder type in the firms listed in the Korean Exchange from 1999 to 2013. It shows that foreign shareholders are one of the main investors in the Korean stock market. Foreign shareholders owned over thirty percent of total market capitalization from 2001 except for 2008. The percentage by foreign shareholders reached highest (40.1%) in 2004 and is 32.9% in 2013. Such a high ratio indirectly implies that the relationship between foreign exchange market and stock market is very important for investors and policy makers in Korea.

Table 3. Shareholding by Shareholder Type in Korean Stock Market

	Government		Institutions		Other corporations		Individuals		Foreigners	
Year	Market Cap	Weight	Market Cap	Weight	Market Cap	Weight	Market Cap	Weight	Market Cap	Weight
1999	78.6	16.6	67.6	14.3	90.0	19.0	150.1	31.7	87.6	18.5
2000	28.5	13.2	35.5	16.4	43.0	19.9	50.7	23.5	58.3	27.0
2001	27.5	8.9	47.3	15.4	52.7	17.1	81.3	26.4	99.1	32.2
2002	19.4	6.6	45.2	15.3	58.7	19.8	75.6	25.6	97.1	32.8
2003	18.0	4.6	61.6	15.7	73.7	18.8	91.5	23.3	147.9	37.7
2004	18.3	4.1	75.5	17.0	79.7	18.0	92.3	20.8	178.0	40.1
2005	26.5	3.7	134.8	18.6	130.9	18.0	164.0	22.6	269.8	37.2
2006	30.5	3.9	161.7	20.8	140.6	18.1	170.7	22.0	273.1	35.2
2007	30.1	2.8	210.1	20.0	220.5	21.0	265.6	25.3	325.4	30.9
2008	17.0	2.8	72.7	11.7	176.2	28.3	186.3	30.0	169.4	27.3
2009	16.7	1.7	117.1	12.0	206.6	21.2	336.2	34.6	296.0	30.4
2010	40.5	3.3	166.3	13.5	346.3	28.0	297.9	24.1	385.4	31.2
2011	27.4	2.4	148.4	13.0	339.3	29.6	279.3	24.4	350.3	30.6
2012	41.4	3.3	200.1	15.8	309.3	24.5	303.1	24.0	409.5	32.4
2013	42.9	3.3	209.9	16.1	314.4	24.1	308.6	23.6	429.5	32.9

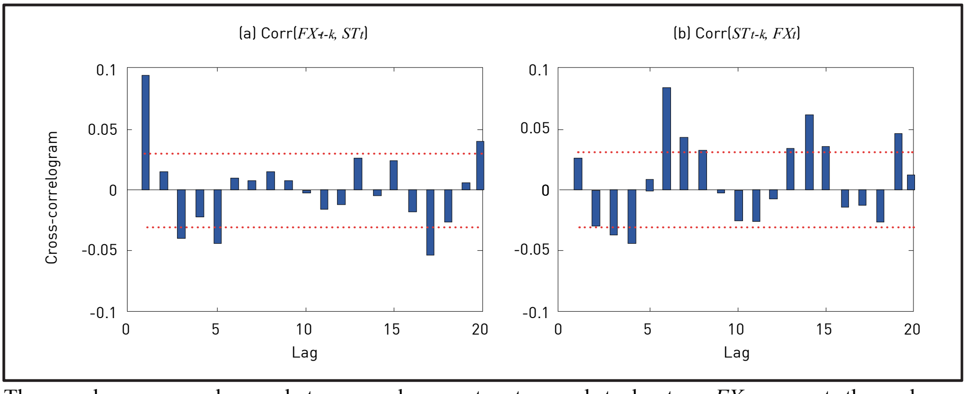
Note: Changes in shareholding in terms of market capitalization by type of shareholders in the firms listed in the Korean Exchange. Weight stands for the percentage of market capitalization and total weight must be 100 percent. The unit of market cap is one trillion Korean Won.

Source: http//www.index.go.kr/potal/main/EachDtlPageDetail.do?idx_cd=2438 (accessed July 21, 2016)

Figure 2 provides the sample cross-correlogram between exchange rate return (FX) and stock return (ST). At the first lag ($k = 1$), the correlation between FX_{t-1} and ST_t is the highest (0.094) while the correlation between ST_{t-1} and

FX_t is insignificant. The correlation between ST_{t-k} and FX_t is the highest (0.085) at the lag $k = 6$.

Figure 2.



The sample cross-correlogram between exchange rate return and stock return. *FX* represents the exchange rate return of USD/KRW and *ST* does the return series of the KOSPI index.

2. Preliminary VAR Analysis

To investigate the relationship between exchange rate return and stock return, one of the most typical model adopted is a vector autoregressive (VAR) model. In this subsection, we briefly show some results that the usual VAR analysis provides. We focus on the impulse response analysis because it is what researchers mostly use.

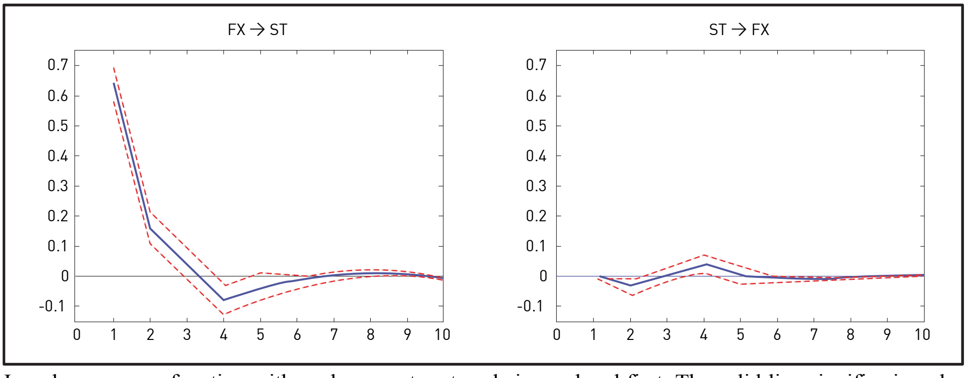
Based on the BIC, the VAR(4) model is selected for the data.[1] The model is identified as in Sims (1980) using a Cholesky decomposition of the error variance-covariance matrix. Impulse response functions measure the effect of a one-standard deviation shock of a variable on the variables in the system. Since a different ordering of the variables might produce different outcomes with respect to the impulse responses, we consider both orderings to analyze the impulse responses as shown in Figures 2-3.

Figure 3 presents impulse response functions when the exchange rate return is ordered first. One standard deviation shock to the exchange rate return at day t

[1] Each return series is the log difference of either exchange rate or stock index. Since they are already first differenced, these return series are obviously not unit root processes. Hence, unit root test and cointegration test are unnecessary.

causes the stock return to peak (0.638) in the next day and the effect becomes negligible from $t+3$. On the other hand, the shock to the stock return does not have any significant effect on the exchange rate return at all.

Figure 3.



Impulse response function with exchange rate return being ordered first. The solid line signifies impulse response functions and the dashed lines represent 95% confidence bands. FX represents the exchange rate return of USD/KRW and ST does the return series of the KOSPI index.

Figure 4 provides the impulse response functions when the stock return is ordered first. The shock to the exchange rate return at day t causes stock return to slightly increase (0.131) at day $t+2$ and fluctuate, but the effect is mostly insubstantial and insignificant. On the other hand, the shock to stock return causes the exchange rate return to increase (0.313) in the next day and the effect becomes mostly insignificant after that.

As it is well known, the results of the impulse response analysis of the VAR model depend on the ordering of the variables and they provide rather limited information on the dependence between two series.[2] Moreover, the Granger

[2] We also applied the generalized impulse response function (GIRF) to avoid problem that results from orthogonal impulse response function (OIRF) are sensitive to variables ordering. That is, GIRF is unaffected by the ordering of variables. We note that the GIRF to an exchange rate shock coincides with the OIRF to an exchange rate return shock when an exchange return is ordered first as shown in the left panel of Figure 2. Also we note that the orthogonal impulse response to an exchange return shock shown in the left panel in Figure 3 is very different from the corresponding GIRF. Likewise, the GIRF to a stock return shock is identical only with the OIRF to a stock return shock when a stock return is ordered first as in the right panel of Figure 3.

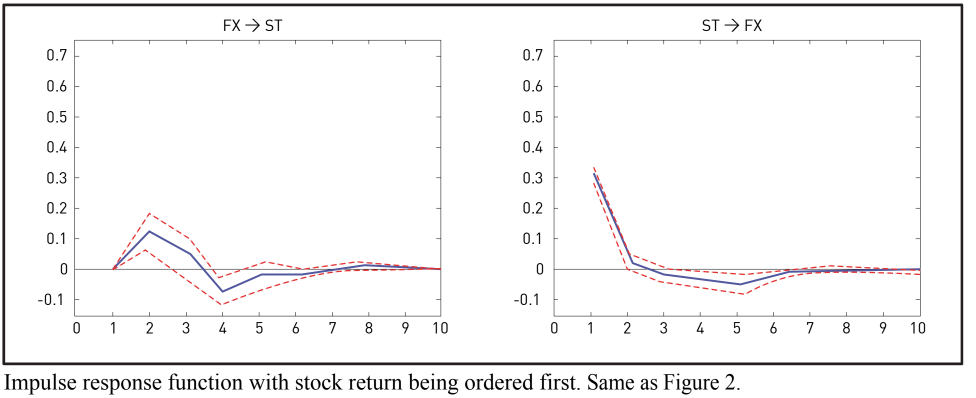
causality test also provides only limited information for dependence between these two series. Table 4 reports the test results, which show that exchange rate return (*FX*) and stock return (*ST*) Granger cause each other. In the next section, we try to provide more complete relationship between exchange rate return and stock return.

Table 4. Granger Causality Test Result

Lag	H_0: FX does not Granger cause ST	H_0: ST does not Granger cause FX
1	27.08**	10.79**
2	13.84**	5.75**
3	10.60**	4.64**
4	8.09**	3.73**

Note: *FX* represents the exchange rate return of USD/KRW and *ST* does the return series of the KOSPI index. ** indicates rejecting H_0 on the 1% significance level.

Figure 4.



Impulse response function with stock return being ordered first. Same as Figure 2.

IV. MAIN RESULTS BASED ON CROSS-QUANTILOGRAM

1. Spillover from Foreign Exchange Market to Stock Market

In this section, we examine a significant impact of change in Korean Won on the stock market. Figure 5-6 show cross-quantilograms and Box-Ljung test statistics from foreign exchange market to stock market. Since the tail dependence of financial markets has been of interest in the literature, we let τ_2 be [0, 0.05] or [0.95, 1], where τ_2 is the quantile range of exchange rate return. The quantile range of stock return τ_1 is set to be [0, 0.05], [0.05, 0.1], [0.1, 0.2], [0.2, 0.4], [0.4, 0.6], [0.6, 0.8], [0.8, 0.9], [0.9, 0.95] and [0.95, 1] for 20 lags.

1) Spillover from Left Tail

In Figures 5(a) and 5(b), we examine quantile dependence and directional predictability from foreign exchange market to stock market when Korean Won has a large loss, $\tau_2 =$ [0, 0.05], i.e., Korean Won depreciates largely. In Figure 5(b), the Box-Ljung test statistic is significant at both tails ($\tau_1 =$ [0, 0.05], [0.95, 1]) and at mid-ranges ($\tau_1 =$ [0.2, 0.4], [0.4, 0.6], [0.6, 0.8]). For both tails, the cross-quantilograms are significantly positive for some lags in Figure 5(a). However, for mid-ranges, the cross-quantilograms are significantly negative for some lags, which means that it is less likely for stock return to be in mid ranges when Korean Won depreciates largely.

For a detailed tail dependence, Table 5 reports the cross-quantilogram for the first five lags at both tails. From $\tau_2 =$ [0, 0.05] to $\tau_1 =$ [0, 0.05] in Table 5, the cross-quantilogram $\hat{\rho}_{[0,0.05]}(k)$ is significantly positive for the first lag, which implies that it is more likely for stock market to have a large loss in the next day when there is a large loss in foreign exchange market. The risk spillover from the exchange market to stock market is insignificant at day $t+2$ then back to be significant from $t+3$. More specifically, a cyclic pattern exists when cross-quantilograms fall and rise, and the duration of these pattern is usually of 4-5 days. Hence every 4 to 5 days, cross-quantilograms reach its peak that is close to 0.1.

Additionally, Table 5 provides the cross-quantilogram for the contemporaneous dependence, i.e., lag $k = 0$. From $\tau_2 =$ [0, 0.05] to $\tau_1 =$ [0, 0.05], the cross-quantilogram $\hat{\rho}_{[0,0.05]}(0)$ is 0.247. Not surprisingly, the contemporaneous dependence for left tail events is stronger than the lagged dependences of $k \geq 1$.[3] Moreover, the contemporaneous dependence for left tail events is stronger than that for the right tail events. From $\tau_2 =$ [0.95, 1] to $\tau_1 =$ [0.95, 1], the cross-quantilogram $\hat{\rho}_{[0,0.05]}(0)$ is 0.205, which is smaller than its counterpart for the left tail events.

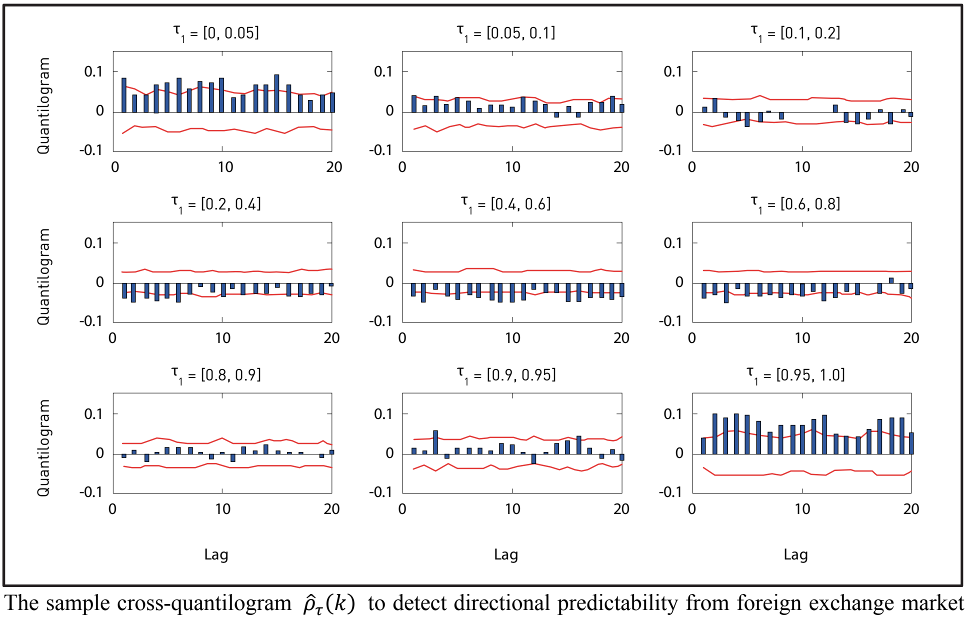
[3] The cross-correlation between FX_{t-1} and ST_t is 0.342 for $k = 0$ while it is 0.094 for $k = 1$ and gets smaller for $k > 1$

Table 5. Cross-quantilogram from Foreign Exchange Market to Stock Market

	From τ_2=[0,0.05]		from τ_2=	[0.95,1]
Lag	To τ_1=[0,0.05]	To τ_1=[0.95,1]	To τ_1= [0,0.05]	To τ_1=[0.95,1]
0	0.247*	-0.010	-0.015	0.205*
1	0.086*	0.038	0.009	0.085*
2	0.043	0.100*	0.024	0.071*
3	0.043*	0.095*	0.067*	0.038
4	0.067*	0.101*	0.067*	0.009
5	0.077*	0.096*	0.057*	0.029

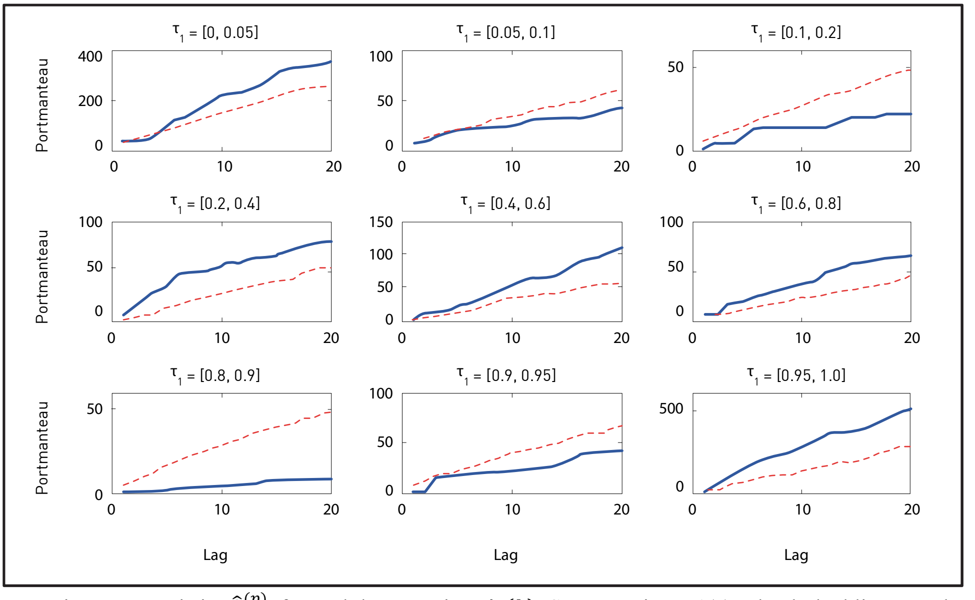
Note: The sample cross-quantilogram $\hat{\rho}_\tau(k)$ to detect directional predictability from foreign exchange market (τ_2) to stock market (τ_1). τ_1 is the quantile range of stock return and τ_2 is the quantile range of exchange rate return. *indicates significance based on the 95% bootstrap confidence intervals.

Figure 5(a).



The sample cross-quantilogram $\hat{\rho}_\tau(k)$ to detect directional predictability from foreign exchange market (τ_2=[0, 0.05]) to stock market (τ_1). τ_1 is the quantile range of stock return and τ_2 is the quantile range of exchange rate return. Bar graphs describe sample cross-quantilograms and lines are the 95% bootstrap confidence intervals.

Figure 5(b).



Box-Ljung test statistic $\hat{Q}_{\tau}^{(p)}$ for each lag p using $\hat{\rho}_{\tau}(k)$. Same as Figure 1(a). The dashed lines are the 95% bootstrap confidence intervals.

The cross-quantilogram is significant at the first lag and insignificant at any higher order lags when $\tau_1 = [0.1, 0.2]$ whereas the cross-quantilogram $\hat{\rho}_{\tau}(k)$ for $\tau_1 = [0.2, 0.4]$, $\tau_1 = [0.4, 0.6]$ and $\tau_1 = [0.6, 0.8]$, are negative and significant for many lags. In case of $\tau_1 = [0.8, 0.9]$, almost all the values at different lags are very close to zero and there is the absence of any significance pattern. That implies a deprecation of Korean Won against US dollar is not helpful in predicting the stock market's path.

From $\tau_2 = [0, 0.05]$ to $\tau_1 = [0.95, 1]$, the cross-quantilogram is insignificant in the next day but significantly positive form day $t + 2$. There appears to be a small swing between significantly positive values of cross-quantilogram. As we see from the Table 5, the fourth lag has the highest value (0.101). This implies that it is more likely for stock market to have a large gain from day $t + 2$ when Korean Won depreciates largely at day t. According to OECD data, exports account for roughly half (50.3% in 2014) of Korea's GDP and this weight is relatively large compared to OECD totals (29% in 2014). A depreciation of Korean Won could be accompanied by an improvement of net export performance by reducing imports and increasing exports. Since Korean firms are heavily dependent on export, a devaluation of currency will lead to a large gain in stock market.

It is interesting to compare the dependence to each tail. The dependence to left tail of stock return is different from the dependence to right tail of stock return when exchange rate return is extremely negative in the previous day. When Korean Won depreciates largely at day t, there is an increased likelihood of having a very large loss of stock market in the next day but having a large gain from day $t+2$. After a large depreciation of Korean Won, there exists a risk spillover to stock market in the next day but is more likely for stock market to rebound sharply from day $t+2$.

The devaluation of Korean currency makes investor shift funds from Korean assets to dollar assets. In a consequence, stock market price declines by favoring dollar assets over domestic stocks. At the day $t+2$, however, it is more likely for stock market to have a large gain. This implies that a devaluation of home currency leads to an increase in export earnings and induces higher capital inflows to Korea. From $t+3$, when Korean Won depreciates, both the large loss and large gain in the stock market are significant. In other words, currency depreciation is negatively related to stock prices for export-dominant industries, at the same time, it is positively associated for import-dominant industries.

2) Spillover from Right Tail

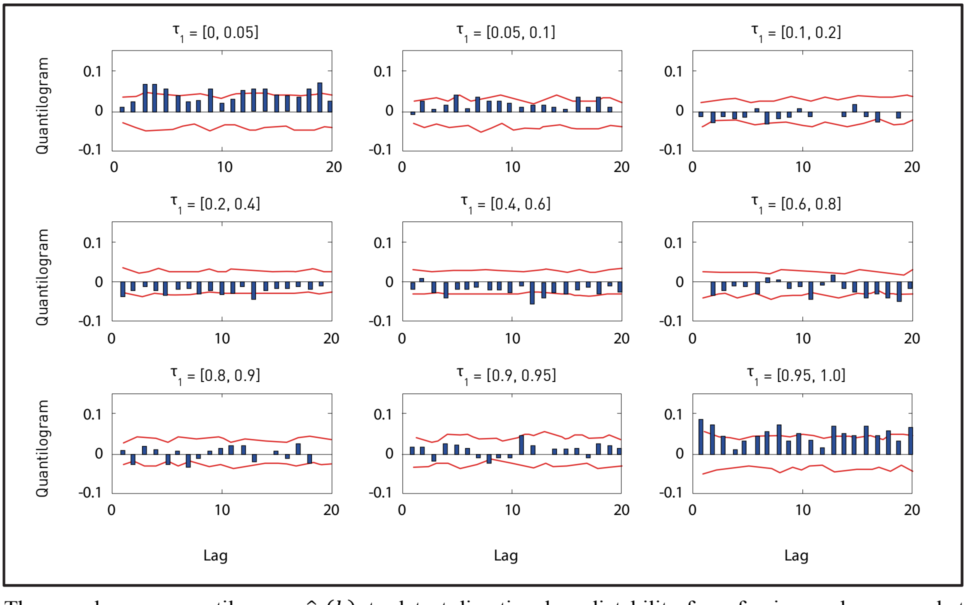
In Figures 6(a) and 6(b), we examine quantile dependence and directional predictability from foreign exchange market to stock market when Korean Won is in the high quantile, $\tau_2 =$ [0.95, 1], i.e., Korean Won appreciates largely. In Figure 6(b), the Box-Ljung test statistic is significant at both tails ($\tau_1 =$ [0, 0.05], [0.95, 1]) but mostly insignificant in the rest quantile ranges. Compared to the previous case of $\tau_2 =$ [0, 0.05], we observe that dependence is generally weaker.

From $\tau_2 =$ [0.95, 1] to $\tau_1 =$ [0, 0.05] in Table 5, when Korean currency appreciates largely at day t, the cross-quantilograms are insignificant for the next two days but significantly positive from $t+3$ to $t+5$. After that, cross-quantilograms are mostly insignificant. That implies that currency appreciation has a negative effect on the domestic market by declining the price competitiveness of exports from $t+3$ to $t+5$.

From $\tau_2 =$ [0.95, 1] to $\tau_1 =$ [0.95, 1], the Figure 6(a) shows statistically significant cross-quantilogram for the first and second lags. The third lag is at the borderline of a statistical significance. As seen Table 5, the first lag has the highest value (0.085) and the second lag is significant then insignificant after that until the 6th lag.

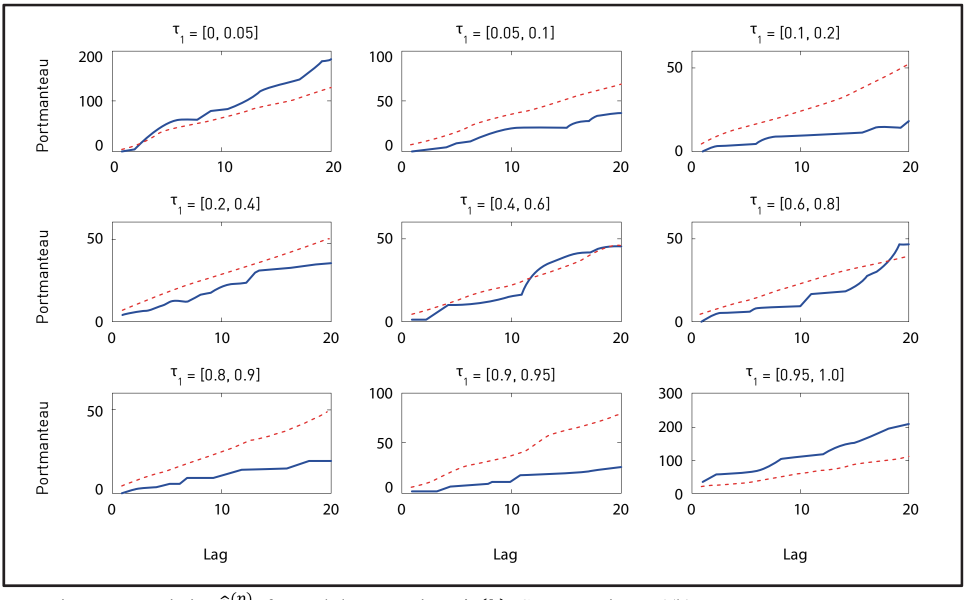
Specifically, when Korean Won appreciates largely at day t, it is more likely for stock market to have a large gain in the next two days and to have a large loss from day $t+3$ to day $t+5$. It is interesting to note that a large appreciation of Korean Won is more likely to have a positive effect on stock market immediately. From the third day, an appreciation of Korean currency leads to a loss in stock market. Since Korea has high dependence on import of raw materials and industrial supplies, an appreciation of Korean currency determines the cost of the output supplied by raising cost of intermediate goods.

Figure 6(a).



The sample cross-quantilogram $\hat{\rho}_{\tau}(k)$ to detect directional predictability from foreign exchange market (τ_2=[0.95, 1]) to stock market (τ_1). τ_1 is the quantile range of stock return and τ_2 is the quantile range of exchange rate return. Same as Figure 4(a).

Figure 6(b).



Box-Ljung test statistic $\hat{Q}_{\tau}^{(p)}$ for each lag p using $\hat{\rho}_{\tau}(k)$. Same as Figure 4(b).

Hence, an appreciation of Korean currency induces a large gain in stock market for next two days. Then the appreciation affects the stock market negatively after the third days since it is found to increase prices of domestic goods subsequently it lowers demand of domestic goods.

If we consider tail dependence between two markets only for the next day, foreign exchange market and stock market move in the same direction in both tails; when Korean Won depreciates (appreciates) largely at day t, it is more likely for stock market to have a large loss (gain) in the next day. If we consider the magnitude of cross-quantilogram for tail-dependence, the dependence is asymmetric because the cross-quantilogram has higher values when Korean Won depreciates largely. Hence, the tail dependence is stronger when there is a negative shock in foreign exchange market than a positive shock.

2. Spillover from Stock Market to Foreign Exchange Market

In this section, we investigate a significant impact of change in Korean stock market on exchange rate market. Figures 7-8 show cross-quantilogram and Box-

Ljung test statistics to identify the causal relationship between two financial markets. Similar to the previous section, we let τ_2 be [0, 0.05] or [0.95, 1], where τ_2 is the quantile range of stock return. The quantile range of exchange rate return τ_1 is defined on [0, 0.05], [0.05, 0.1], [0.1, 0.2], [0.2, 0.4], [0.4, 0.6], [0.6, 0.8], [0.8, 0.9], [0.9, 0.95] and [0.95, 1] for 20 days.

1) Spillover from Left Tail

In Figures 7(a) and 7(b), we examine quantile dependence and directional predictability from stock market to foreign exchange market when a stock market has a large loss, $\tau_2 =$ [0, 0.05]. In Figure 7(b), the Box-Ljung test statistic is significant at both tails ($\tau_1 =$ [0, 0.05], [0.95, 1]). It is mostly insignificant in the rest quantile ranges except for $\tau_1 =$ [0.2, 0.4].

For a detailed tail dependence, Table 6 reports the cross-quantilogram for the first five lags at both tails. Specifically, from $\tau_2 =$ [0, 0.05] to $\tau_1 =$ [0, 0.05] in Table 6, the cross-quantilogram shows a risk spillover from stock market to foreign exchange market. For the first to third lags, cross-quantilograms are significantly positive but not at the fourth lag. After that, it is significant in most cases except at 10th and 11th lags. The cross-quantilogram reaches its peak of 0.109 at the first lag then it drops to 0.052 at the second lag. It seems that a loss in stock market reduces domestic investor's wealth, subsequently, capital outflows occur leading to a currency depreciation.

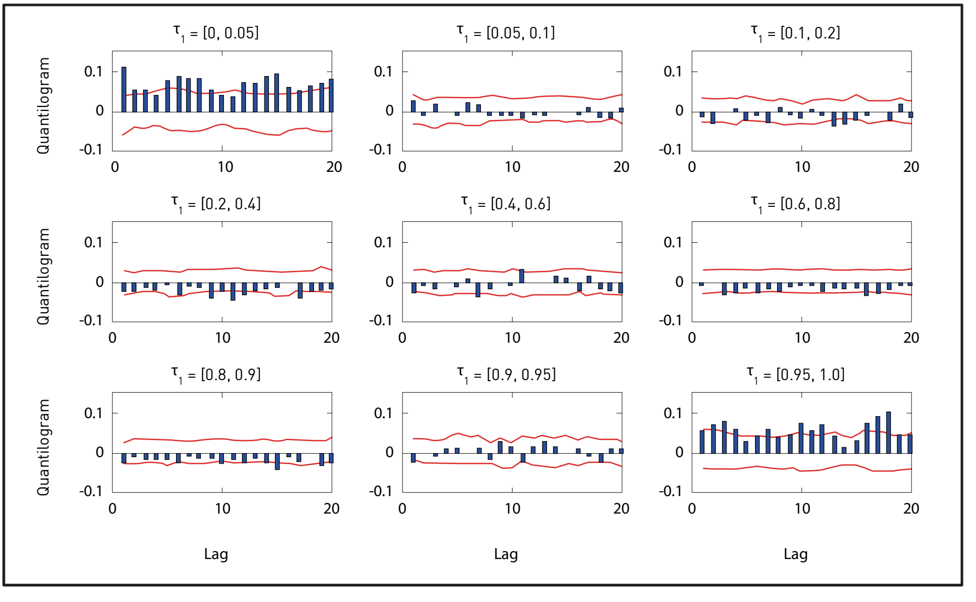
From $\tau_2 =$ [0, 0.05] to $\tau_1 =$ [0.95, 1.0], the cross-quantilogram is insignificant in the first lag then significantly positive after that except for the fifth lag. In Figure 7(a), the cross-quantilogram reaches its highest value which is close to 0.1 at $t + 18$ then declines afterwards. That means, it takes 18 days for the gain from exchange market to reach its peak when stock market crash occurs. When a large negative shock occurs in the stock market, Korean Won depreciates immediately due to the outflows of foreign capital. After then, a depreciation of Korean currency makes exporting goods more competitive relative to other foreign goods, leading to a large gain in stock market.

Table 6. Cross-quantilogram from Stock Market to Foreign Exchange Market

	From τ_2=[0,0.05]		from τ_2= [0.95,1]	
Lag	To τ_1=[0,0.05]	To τ_1=[0.95,1]	To τ_1=[0,0.05]	To τ_1=[0.95,1]
0	0.247*	-0.015	-0.010	0.205*
1	0.109*	0.052	0.057*	0.052*
2	0.052*	0.066*	0.047*	0.043
3	0.052*	0.076*	0.095*	0.033
4	0.043	0.057*	0.100*	0.052*
5	0.076*	0.028	0.023	0.057*

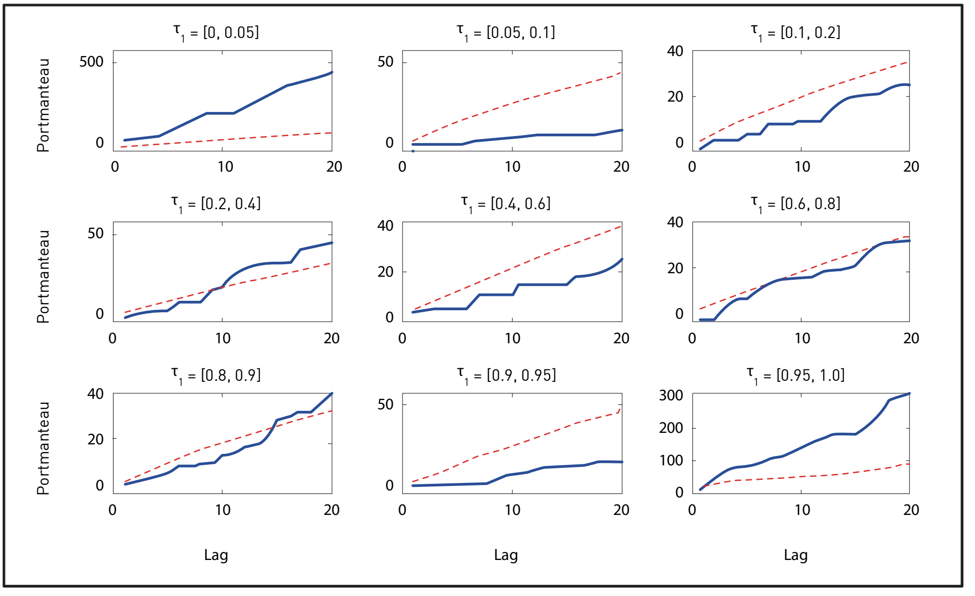
Note: The sample cross-quantilogram $\hat{\rho}_\tau(k)$ to detect directional predictability from stock market (τ_2) to foreign exchange market (τ_1). τ_1 is the quantile range of exchange rate return and τ_2 is the quantile range of stock return. Same as Table 4.

Figure 7(a).



The sample cross-quantilogram $\hat{\rho}_\tau(k)$ to detect directional predictability from stock market (τ_2=[0, 0.05]) to foreign exchange market (τ_1). τ_1 is the quantile range of exchange rate return and τ_2 is the quantile range of stock return. Same as Figure 4(a).

Figure 7(b).



Box-Ljung test statistic $\hat{Q}_{\tau}^{(p)}$ for each lag p using $\hat{\rho}_{\tau}(k)$. Same as Figure 4(b).

2) Spillover from Right Tail

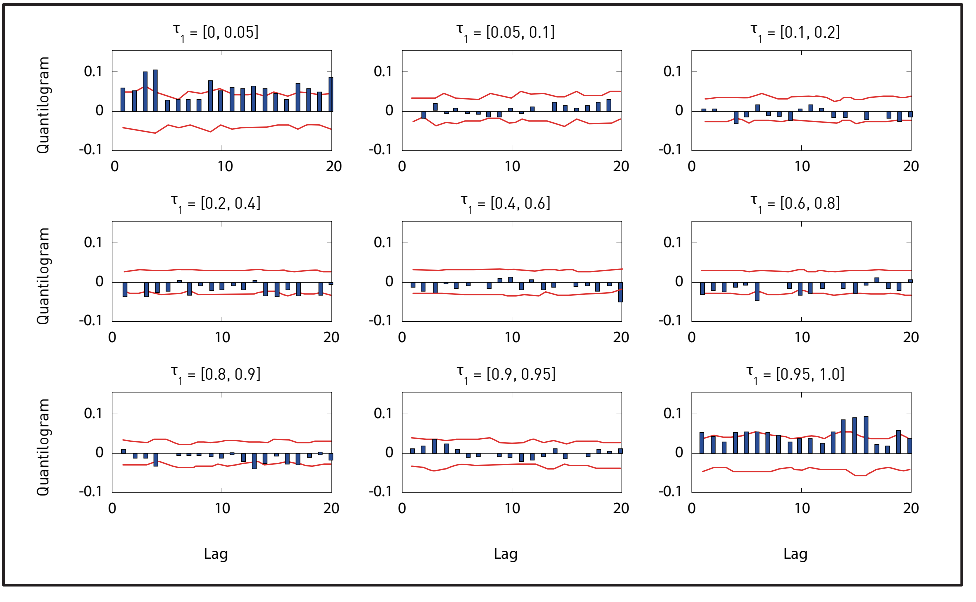
In Figures 8(a) and 8(b), we examine quantile dependence and directional predictability from stock market to foreign exchange market when stock market has a large gain, τ_2 = [0.95, 1]. In Figure 8(b), the Box-Ljung test statistic is significant at both tails (τ_1 = [0, 0.05], [0.95, 1]). It is also significant at τ_1 = [0.2, 0.4] or [0.6, 0.8] because cross-quantilogram is significantly negative for some lags. That implies, it is less likely for exchange rate return to be in [0.2, 0.4] or [0.6, 0.8].

From τ_2 = [0.95, 1] to τ_1 = [0, 0.05], Table 6 shows statistically significant results for the lag 1 to lag 4. Specifically, the value of cross-quantilogram increases steadily from the next day then it reaches its peak (0.100) at the fourth lag. An increase in stock market results in higher inflation expectation since a rising stock market is regarded as an indicator of an expanding economy. Then, investors' demand for Korean currency drops due to the negative perception concerning the higher inflation. Therefore, Korean Won depreciates.

In case of τ_2 = [0.95, 1] and τ_1 = [0.95, 1], Table 6 shows significantly positive cross-quantilogram at the first lag but not at the lag 2 and lag 3 then back to be significantly positive from the fourth lag. In Figure 8(a), the cross-quantilogram is close to 0.1 from $t + 14$ to $t + 16$ and it reaches its highest point at $t + 16$. The upward movements in stock market stimulate money growth leading to an increase in interest rates consequently. The rising in interest rates induces capital inflows then Korean Won appreciates (Pan et al., 2007).

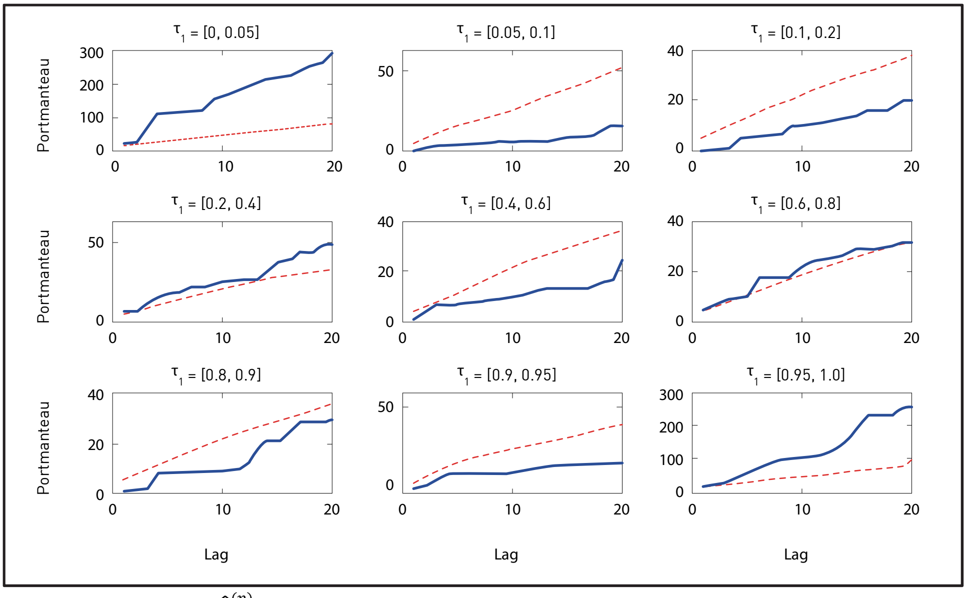
It is interesting to note that, it takes 16 days to reach the highest value of cross-quantilogram for $\tau_1 = [0.95, 1]$ while only 4 days are taken to reach the highest one when $\tau_1 = [0, 0.05]$. After a large gain in stock market, it sees that foreign investment funds move in and out Korean market for a while and therefore exchange rate fluctuates severely.

Figure 8(a).



The sample cross-quantilogram $\hat{\rho}_\tau(k)$ to detect directional predictability from stock market (τ_2=[0.95, 1]) to foreign exchange market (τ_1). τ_1 is the quantile range of exchange rate return and τ_2 is the quantile range of stock return. Same as Figure 4(a).

Figure 8(b).



Box-Ljung test statistic $\hat{Q}_{\tau}^{(p)}$ for each lag p using $\hat{\rho}_{\tau}(k)$. Same as Figure 4(b).

V. CONCLUSION

This study documents the presence of spillover between Korean stock and currency markets using cross-quantilogram that addresses quantile-based dependence between the financial markets. Our results indicate that the tail dependence from foreign exchange market to stock market is different from one from stock market to foreign exchange market. It is more likely for Korean stock market to have a large loss (gain) next day in response to an exchange rate depreciation (appreciation). This effect shows an intriguing asymmetry: the risk spillover from left tail to left tail is much stronger than the positive spillover from right to right tail events. Significantly, we also find large stock market losses could lead to Korean currency depreciation next day. When stock market has a large gain, however, the direction is inconclusive in the next day. The results in this paper support both the traditional approach and the portfolio approach (bi-directional causality) in the literature, but it should be emphasized that the quantile-based analysis in this paper delivers more detailed results that cannot be provided by using existing methods.

The evidence that stock and foreign exchange markets are interrelated in Korea signifies that one market has significant predictive power on the other. Specifically, negative spillovers between stock and currency markets occur instantaneously while positive spillovers from stock to currency markets occur with a time delay. The information of detailed quantile dependence can be used for various purposes such as risk management, modelling univariate or multivariate volatility model, estimating value at risk and asset allocation, etc. We leave it as future work.

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