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DO S&P 500 AND KOSPI MOVE TOGETHER?: A FUNCTIONAL REGRESSION APPROACH

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This paper explores the return comovement between Korean and U.S. stock markets by investigating the existence of a possible spillover effect using high frequency data. We employ a functional regression methodology to scrutinize the moment dependence and the components of possible spillover effects. We find that the mean, volatility, skewness, and kurtosis spillover effects exist and the components of those effects have not changed over time in 2002-2006. In sum, we conclude that the KOSPI and S&P 500 move together during the sample period. The conclusion, however, is weakened once we modified the data by excluding the opening price of KOSPI since we only find the volatility spillover effect during the same period. Therefore, we can conclude that the opening price of Korean stock market may reflect new information that occurred overnight in foreign markets so that moment dependencies or moment spillover effects are weakened between Korean and U.S. stock market.

JEL Classification: F30, G14, C12, C22
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I. INTRODUCTION

During the financial crisis in late 1997, the Korean economy experienced a restricted growth in the money supply and restricted government expenditure, as well as regulatory reforms in the corporate and financial sectors. In particular Korea opened up its stock market to foreign investors, and opened the possibility that Korean stock market returns would be more closely associated with the returns in foreign stock markets. There has been a huge amount of research to analyze the return comovement in international equity markets, with many different methodologies including correlation coefficients, VAR, conditional heteroskedasticity models, and cointegration techniques among others.[1]

A spillover effect in this paper is defined as the return comovement in international equity markets for the first two moments, i.e., the mean and the variance. The mean represents the value of information transmitted between two markets and the variance represents the noise or volatility of that information. Most of the previous literature has paid attention to the mean, and some recent research has also focused on the comovement of volatility. Previous findings report several empirical regularities: (i) the volatility of stock prices is time-varying; (ii) when volatility is high, the price changes in major markets tend to become highly correlated; and (iii) significant mean and volatility spillovers are found from the U.S. market to other national stock markets.

However, the comovement of the first two moments may not be enough to analyze the spillover effect completely. In this paper, we will investigate the comovement in a very different way. Recently, Park and Qian (2010) propose a regression model that addresses the problem of distributional relationship between two economic variables, and we use this functional regression approach to predict economic variables conditional on a distribution. This approach is useful because the distributions of returns, whether of one stock/index across a time span or

[1] See, for example, Karolyi and Stulz (1996), Becker et al. (1990), Jang and Yi (2004), Shin and Ham (2001), Eun and Shim (1989), Kim and Kim (2001), Lin et al. (1994), Susmel and Engle (1994), Liu and Pan (1997), Arshanapalli et al. (1995), and Park and Chung (2003) for these four approaches. In addition, other approaches to test the comovements have also been proposed in the literature. See, for example, Craig et al. (1995), Gagnon and Karolyi (1997), Forbes and Rigobon (2002), Bae et al. (2003), and Connolly and Wang (2003).

of different stocks in the market or a cohort, carries important information that is relevant to pricing and risk control. The traditional regressions like linear regressions, quantile regressions, and cointegration models have independent economic variables, but the density function itself can be used as an independent variable in the functional regression model. More discussions on the functional analysis are given in Chang et al. (2010).

Once we analyze the density relationships between two stock markets, the spillover effects of the first two moments can be obtained using the density regressions, and persistent higher moment dependence can also be easily analyzed. Therefore, the moments of one distribution should be dependent on the moments of the counterpart distribution over time. By focusing on the full distribution itself and extracting each moment from the density, it is even possible to address the "nonsynchronous trading problem" which comes from inappropriate proxies for opening quotes, and it is known that those problems may induce spurious lagged spillovers. Moreover, it is widely believed that the distribution of stock return is fat-tailed, and therefore characterizing the tail behavior can also be explored between two stock distributions.

Furthermore, most of literature focus on the existence of spillover effect that can be examined only by the counterpart moment, and thus the role of other moments are ignored. For example, the volatility spillover effect may result from not only the variance of the return in foreign markets but also its mean. The functional regression approach deals with the density relationship, and hence is different from the previous analysis. Therefore, our approach can possibly identify the different role of moment relationships affecting the spillover effect as well as the existence of the spillover effect itself.

In this paper, we investigate whether intraday 5-minute return on Korea stock index KOSPI moves together with its counterpart on the S&P 500 index between 1995 and 2006 by testing the moment dependence relationships among them using functional regression analysis. The model is essentially a nonparametric approach for estimating time-varying densities of the underlying stock market returns. As the dependence of densities is modeled nonparametrically, we do not impose any assumptions on the class or structure of the density functions themselves, or the number of dimensions in which the densities may vary.

Based on the definition of comovement above and analysis of the time-varying moments dependence relationships, we find that after the financial crisis the, KOSPI, moved together with the, S&P 500. In particular, the results between 2002 and 2006 indicate that the second moment as well as the first moment of 5-minute return on KOSPI depends on the first and the second moment of S&P 500 return, respectively. That is, the mean spillover effect is originated from the mean of the return whereas the volatility spillover effect is derived from both the variance of return and the mean of return. Moreover, the third and the fourth moment of the KOSPI return depend on moments of S&P 500 return as well. According to the definition of this paper, this can be interpreted as a strong evidence that comovement did occur during the period.

In addition, we test the moment dependence relationships again with the sample where the opening stock returns are excluded. If the market is efficient, information from U.S. should be fully reflected in the opening price of the domestic market and not affect the rest of the distribution. Thus, once this effect is fully accounted, no moment dependence or no moment spillover effects should occur if the market is efficient. Testing on the time-varying moment dependency indicates that the first moment of KOSPI does not depend on the moments of the S&P 500 for consecutive years, and the second moment of KOSPI only depends on the second moment of S&P 500. In other words, there is relatively weak evidence of mean spillover effect, and it does not last for consecutive years, which cannot support the evidence of comovement in the modified data.

The remainder of this paper is as follows. We present some basic tools and notions of functional regression in Section 2, and Section 3 and 4 provide function regression analysis using intraday 5-minute returns on the KOSPI and the S&P 500 during 1995-2006. Section 5 offers some concluding remarks.

II. FUNCTIONAL REGRESSION

We first specify the comovement in two different stock markets as a spillover effect in the first two moments and, in addition, as a persistent moment dependence relationship between the distributions of returns from two indexes. In this section, we introduce the concept of functional regression model and tests on the moment dependence structure between the two distributions. Since the theory of functional regression is fully developed in Park and Qian (2010), we will skip the detailed explanations for the estimation and testings, but briefly mention the key concepts of the methodology.

2.1. The Model

Let g_t and f_t be the densities of 5-min returns on each business day t in two stock markets. We consider these densities as random elements in H_1 and H_2 that denote the Hilbert spaces of square integrable functions on a compact subset. The functional regression model has the following form:

$$g_t = c + Af_t + \varepsilon_t, \quad t = 1,2,\ldots,T, \tag{1}$$

where c is a nonrandom element in H_1, A is an operator from H_2 to H_1, ε_t is a H_1-valued functional white noise process. The model has the same form as a linear regression except that the dependent and independent variables are random density functions of variables instead of random variables.

This model shows not only the functional relationships but moments relationships of the two sequences and hence the linear operator carries all the information on the dependence of the regressand distribution on the regressor. For fixed $v \in H_1$, we consider

$$\langle v, g_t \rangle = \langle v, c \rangle + \langle A^* v, f_t \rangle + \eta_t \tag{2}$$

where A^* is the adjoint operator of A and $\eta_t = \langle v, \varepsilon_t \rangle$ for all t. Here, $\langle \cdot\,, \cdot \rangle$ denotes the inner product in Hilbert space. Let $p_k(x) = x^k$ and $v = p_1$. Then the regressand in (2) becomes

$$\int x g_t(x) dx,$$

i.e., the mean of the distribution represented by g_t. Furthermore, if we write $A^* v = A^* p_1 = \sum_{k=1}^{\infty} = c_k p_k$ with some numerical sequence (c_k), then the regressor reduces to a linear combination of all moments of the distribution represented by f_t. This clearly implies that we can analyze the distribution or the moments of one variable as a function of moments for the other variables.

A linear operator A from H_2 to H_1 is assumed to be written as

$$A = \sum_{k=1}^{\infty} \lambda_k (u_k \otimes v_k) \tag{3}$$

where (u_k) and (v_k) are some orthonormal bases of H_1 and H_2 respectively, (λ_k) are a sequence of numbers tending to zero, and $\otimes$ denotes the tensor product defined as $u \otimes v(\cdot) = \langle v, \cdot \rangle u$. If H_1 and H_2 are finite dimensional, A becomes a finite matrix and the representation in (3) would be a singular valued decomposition. Under regularity conditions (see Park and Qian (2010)), (1) can be formulated to mean-correction form

$$m_t = A w_t + \varepsilon_t$$

where

$$m_t = g_t - \mathbb{E} g, \quad w_t = f_t - \mathbb{E} f. \tag{4}$$

Consider the variance and covariance operators of two random elements *m* and *w*

$$Q = \mathbb{E}(w_t \otimes w_t), \quad P = \mathbb{E}(m_t \otimes w_t), \text{ and } W = \mathbb{E}(m_t \otimes m_t). \tag{5}$$

Then *Q* and *W* allow for the following spectral representations (see, for example, Bosq (2000)),

$$Q=\sum_{k=1}^{\infty}\lambda_k(v_k\otimes v_k) \quad \text{and} \quad W=\sum_{k=1}^{\infty}\gamma_k(u_k\otimes u_k)$$

where (λ_k, v_k) and (γ_k, u_k) are the pairs of eigenvalue and eigenvector of Q and W, respectively. Furthermore, it is clear that

$$P = AQ.$$

To obtain the linear operator of interest, A, we need to get inverse operator of Q, but there is an ill-posed inverse problem for Q as shown in Bosq (2000). To avoid this problem, we restrict the definition of A in a finite subset of H_2. Define V_K to the subspace of H_2 spanned by the K-eigenvectors $v_1,\ldots,v_K$ associated with the eigenvalues $\lambda_1,\ldots,\lambda_K$, which sequentially decrease to zero. Now let

$$A_K = PQ_K^+$$

where

$$Q_K^+=\sum_{k=1}^{K}\lambda_k^{-1}(v_k\otimes v_k).$$

Since (λ_k) decreases to zero, A_K approximates to A well as K of V_K increases. Simply, it can be shown that the ill-posed inverse problem can be dealt with the finite dimensional approach under some regularity condition.

In most applications, densities are not directly observed and should therefore be estimated before looking at the functional regression model. Suppose N observations from g_t or f_t are available and define $(\hat{g}_t)$ and $(\hat{f}_t)$ the consistent estimator for (g_t) and (f_t), respectively. Let $\overline{f}=\frac{1}{T}\sum_{t=1}^{T}\hat{f}_t$ and then $\hat{m}_t=\hat{g}_t-\overline{g}$ and $\hat{w}_t=\hat{f}_t-\overline{f}$. As shown in Park and Qian (2010), the replacement of (m_t, w_t) with $(\hat{m}_t, \hat{w}_t)$ does not affect asymptotic theory as long as the number of cross-sectional observations that we use to estimate $(\hat{f}_t)$ is large enough relative to the number T of time series observations. The reader is referred to Park and Qian (2010) for details.

2.2. Testable Hypotheses for Market Comovements

The functional regression of density allows a complicated dependence structure of regressand density on regressor density, and hence extracting such information from the estimation for the regressive operator *A* will be a crucial part of our analysis. One way to do this is to test hypothesis on *A* or its Hilbert adjoint A^*.

The null hypothesis is

$$H_0 : A^* v \in U, \tag{6}$$

where *U* is a subspace of H_2. Let U be a L-dimensional and spanned by $u_1, \ldots, u_L$, thus orthogonal to the last $K-L$ vectors, so that

$$A^* v = \sum_{k=1}^{L} c_k u_k$$

with some coefficients (c_k). Then

$$\langle v, g_t \rangle = \sum_{k=1}^{L} \langle A^* v, f_t \rangle + \eta_t = \sum_{k=1}^{L} c_k \langle u_k, f_t \rangle + \eta_t \tag{7}$$

If $u_k = p_k = x^k$, then the null hypothesis implies that the *v*-moments of (g_t) only depends on the first *L* moments of (f_t).

The consistent estimators $\hat{Q}_K, \hat{\Sigma}, \hat{A}_K^*$, and ($\hat{u}_k$) give us the test statistics *Z*, which is defined by

$$Z = \frac{1}{\sqrt{2(K-L)}} \sum_{k=L+1}^{K} \left[\frac{T \langle \hat{u}_k, Q_K^{1/2} \hat{A}_K^* v \rangle^2}{\langle v, \hat{\Sigma} v \rangle} - 1 \right] \tag{8}$$

Under the null hypothesis $Z \to_d \mathbb{N}(0,1)$ as $T \to \infty$ as shown in Park and Qian (2010). On the other hand, if H_0 does not hold, *Z* diverges, and therefore the test based on *Z* is consistent as long as $K = o(T^2)$. If *v* and (u_k) are polynomials, the test concerns how the moment of the distribution represented by g_t depends on the distribution represented by

f_t, namely the spillover effect that we will analyze in the following section.

III. DATA AND DESCRIPTIVE STATISTICS

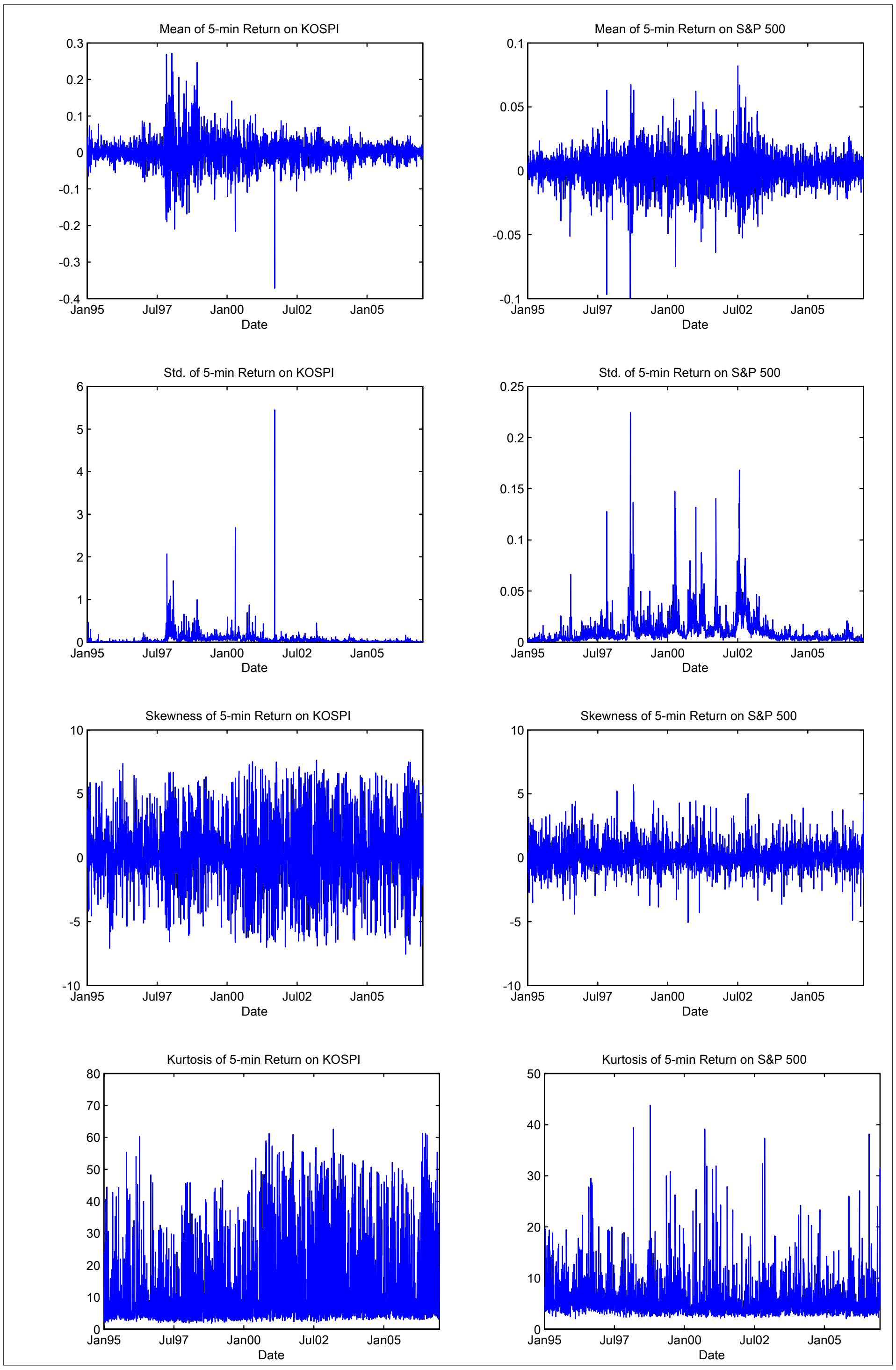
In the paper, the density function for intraday 5-min returns on the KOSPI (Korea) is represented by g_t and that of the S&P 500 (U.S.) by f_t. As the regression aims to clarify the moment dependent relationships between the stock markets in Korea and U.S., one probable result will be stated as the following: the first moment of intraday 5-min return of Korea is dependent on the first and the second moment of that of U.S.. Relating the graph of the first four moments of both returns in Figure 1 with the previous sense, for example, the movement in the first moment of KOSPI can be explained by the movements in the first and the second moment of S&P 500.

For our analysis of the moment dependence structure between the two entire distributions, Korea and the United States, we study the KOSPI index and S&P 500 index. The KOSPI is the index of all common stocks traded on the Stock Market Division of the Korea Exchange, and it is the representative stock market index of Korea. As KOSPI represents all common stocks traded on stock market of Korea, we choose the S&P 500 for U.S. data. The S&P 500 is a market weighted index of 500 large-cap common stocks actively traded in the United States.

There is or 8 and 1/2 hour difference between the close of the Korean stock market and open of the New York Stock Exchange. Since there is no overlapping hours between the two markets, intuitively, traders in Seoul will use any information revealed overnight which may be relevant to their pricing of stocks in Seoul as soon as the opening bell rings. In other words, traders or technical analysts may look at the S&P 500 as a predictor of market movement on the KOSPI and/or examine the previous changes in the U.S. market as indicators of KOSPI performance.

Lin et al. (1994) document that the stock return in Japan is influenced by the return of previous trading day in the U.S. stock market, and Shin and Ham (2001) find the correlation between the stock return for U.S. in the previous trading day and that for Korean stock market in the next day. In this paper, we focus on the functional relationship between U.S. stock

[Figure 1] Moments of 5-min return on KOSPI and S&P 500



return in the previous trading day and Korean stock return in the following day using high frequency data. For better analysis, the trading date of each market is matched. When one market is open and the other is not, then the latter is dropped.

Since the distribution of return is widely believed to be fat-tailed, instead of focusing on the central location of the distribution, we characterize the distribution by looking at the degree of dispersion and the behavior of the tails. The high-frequency data have opened great possibilities to test the detailed structure of markets, especially suited in analyzing the fat-tail property, while traditionally low-frequency data are used for testing macroeconomic models. Moreover, the return is usually a more suitable variable of analysis than the price level for several reasons. It is the variable of interest for traders who use it as a direct measure of the success of an investment, and the distribution of returns is more symmetric and stable over time than the distribution of prices. Obviously, the return process is close to stationary whereas the price process may not be.

In this paper, 5-minute log returns (5-min return hereafter) on each index on each business day are employed to specify the behavior of stock market such as trading mechanism. 5-min returns from the S&P 500 index are defined in the standard way by the natural logarithm of the ratio of consecutive closing levels. Table 1 gives some of descriptive statistics of the calculated return. All figures are in percentage units. In Korea, the stock market opened 6 days a week until 7th December 1998 and then opened 5 weekdays a week as in the United States. The existence of skewness and the high excess kurtosis in these markets suggest that their daily return series have a fat-tailed distribution and the time-varying volatility, which shows the properties far from the normal distribution. It is also easily observed that the standard deviation, skewness, and kurtosis of 5-min return of KOSPI are bigger than those of S&P 500, which implies that KOSPI has more volatile movements than S&P 500.

The choice of an appropriate proxy for opening quotes was an important issue with daily data in the previous studies. Stoll and Whaley (1990) find that it takes an average of 5 minutes for large stocks and 67.4 minutes for small stocks on the New York Stock Exchange (NYSE) for the first transaction to occur after the market opens. Because of the delay in trading, the measured opening price index does not accurately reflect the true underlying price value. This may induce spurious lagged spillovers. To address this question, we focus on the full distributions and treat each estimated daily distribution as a single observation where the choice of opening price is not required.

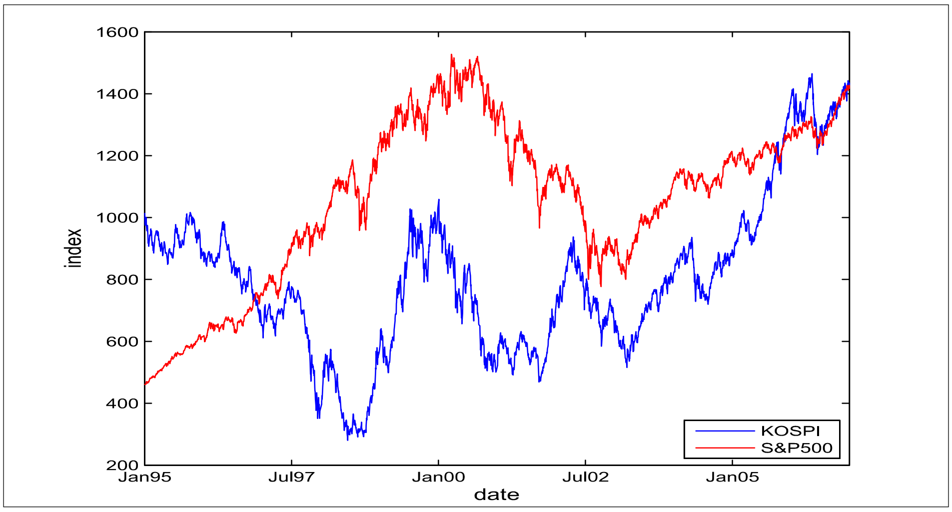
[Table 1] Descriptive Statistics on Intraday 5-min Returns

	Year	*n*	Business Days	Mean	STD	Skew	Kurt	Min	Median	Max
KOSPI	1995	17317	293	-0.0009	0.096	1.03	125.53	-2.27	0.000	2.87
	1996	17810	293	-0.0017	0.094	3.08	71.37	-1.31	0.000	2.37
	1997	12954	292	-0.0043	0.302	-0.84	169.58	-6.85	-0.005	7.18
	1998	13052	292	0.0032	0.381	2.00	46.71	-5.56	-0.005	7.15
	1999	15046	249	0.0039	0.304	0.81	14.47	-3.02	0.004	3.14
	2000	16082	241	-0.0044	0.363	-1.54	147.89	-12.22	-0.003	7.97
	2001	17419	246	0.0018	0.251	-6.76	493.76	-13.16	0.002	6.29
	2002	17244	243	-0.0006	0.226	0.35	51.55	-3.82	0.000	3.79
	2003	17525	247	0.0014	0.196	1.59	81.23	-3.12	0.002	5.46
	2004	17668	249	0.0006	0.166	0.02	31.21	-2.37	0.000	2.23
	2005	17667	249	0.0024	0.127	-0.44	35.93	-2.09	0.002	1.58
	2006	17526	247	0.0002	0.136	-0.69	66.99	-3.20	0.001	2.58
S&P 500	1995	19803	252	0.0015	0.046	-0.07	9.01	-0.41	0.000	0.47
	1996	19915	254	0.0009	0.069	-0.42	12.09	-0.79	0.001	0.62
	1997	19895	253	0.0014	0.099	0.19	11.15	-0.92	0.000	1.73
	1998	19440	252	0.0012	0.122	0.65	22.41	-1.31	0.001	2.06
	1999	19840	252	0.0009	0.110	-0.18	8.17	-1.52	0.001	1.19
	2000	19871	252	-0.0005	0.137	-0.11	7.36	-1.68	-0.001	1.41
	2001	19541	248	-0.0007	0.133	0.36	16.16	-1.28	0.001	2.60
	2002	19820	252	-0.0013	0.155	0.28	7.35	-1.38	-0.001	1.80
	2003	19505	252	0.0012	0.106	0.15	7.14	-1.06	0.002	1.22
	2004	19607	252	0.0004	0.071	0.12	5.76	-0.70	0.000	0.82
	2005	19609	252	0.0002	0.065	0.26	4.25	-0.58	-0.001	0.57
	2006	19502	251	0.0007	0.065	0.04	6.49	-0.88	0.001	0.60

The data are collected from January 1, 1995 to December 31, 2006. During this period, Korea experienced a financial crisis in late 1997 and both countries had a “dot-com bubble” covering roughly between 1998 and 2000, and the dot-com bubble crash from March 2000 to October

2002. Figure 2 shows the movement of each index during the period. From the graph it is not difficult to identify that both indices move in a similar way after year of 1998. As we define the comovement as spillover effects with persistent moment dependence relationship, in next section we will examine whether both stock markets move together after 1998.

[Figure 2] KOSPI and S&P 500 (1995-2006)



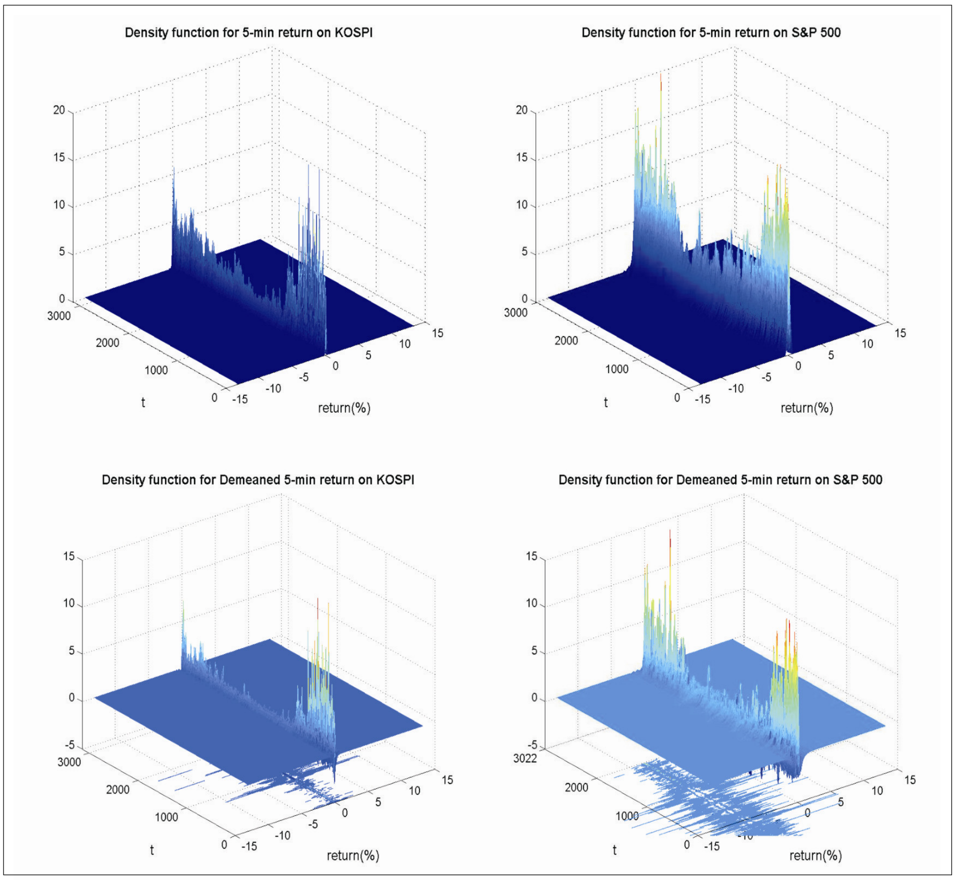
IV. EMPIRICAL RESULTS

4.1. Estimation

We estimate the density of 5-min return on each day using kernel smoothing. The implicit assumption here is that on each day, the 5-min returns on an index is strictly stationary. Under this assumption, the spectral analysis, which is invented for stationary processes, can be applied to nonstationary signals. It is well known that the spectral theory in finite dimensional vector spaces is essentially matrix eigenvalue theory. It is also well known that other estimates of densities are almost invariable created with kernel and the choice of kernel is a minor issue, so we estimate the densities with Gaussian kernel.[2]

[2] The choice of the optimal bandwidth and the kernel function can be determined by well-known

[Figure 3] Estimated Time Varying Density



According to the simulation results by Park and Qian (2007, 2010) the choice of the density support is important for the behavior of the test statistic Z, and asymmetric support has even an negative influence on the performance of the statistic. Thus, we choose the centered support that is wide enough to cover most of the total probability mass of the average of f_t and g_t and the density support is presented in Table 1. For the estimation of the densities, 1024 evenly spaced sample points of the interval are used. This number, which is a power of 2, is chosen to facilitate calculations of Fourier coefficients by the Fast Fourier Transform algorithm.

The estimated demeaned densities for both indices are presented in

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methods in standard kernel density estimations. In our subsequent analysis, Gaussian kernel will be used and the optimal bandwidth is selected as $h = 1:06\sigma n^{-1/5}$ following Silverman (1986).

Figure 3. In Figure 3, it is obvious that each density on each business day varies over time. Since the main purpose of this study is to investigate the relationship between those densities, it is advisable to implement the functional regression method which requires no specific functional form where both regressand and regressor are time-varying density functions. The demeaned density in Figure 3, m_t and w_t in our model, represents the time series fluctuations of the densities, (g_t) and (f_t), respectively.

The definition and notation of mean-correction form equation and the covariance operators are derived from (4) and (5) demonstrated in the previous section. The eigenvalues and eigenvectors of Q are estimated by those of $\hat{Q}$, $(\hat{\lambda}_k, \hat{v}_k)$. Then the condition $\hat{Q}v = \lambda v$ holds, i.e.,

$$\int_C \hat{V}(x,y)v(x)dx = \lambda v(y) \tag{9}$$

where $\hat{V}(x,y) = \frac{1}{T}\sum_{t=1}^{T} \hat{w}_t(x)\hat{w}_t(y)$. Note that equation (9) is the first order condition for the maximization problem in the functional principal component analysis (FPCA). In fact, for reminder, the principal component analysis (PCA) finds a set of a optimal dimensions that explain maximum amount of variation in a minimum number of dimensions. If the basis is orthonormal, FPCA problem reduces to the standard multivariate PCA which is equivalent to numerical problem of finding eigenvalues and eigenvectors of the covariance matrix. Then the original problem is transformed into the problem of computing eigenvalues and eigenvectors of a matrix.

To avoid the ill-posed problem which results from the infinite dimension property and makes the inverse operation impossible, it is recommended to restrict the definition of A in a finite subset of H_2. Now A_K becomes an autoregressive operator of A restricted to subspace V_K of H_2. V_K is generated by K-principal component of (w_t), i.e., K-largest variation in (w_t). In practice, the choice of K is guided by applying a functional principal component analysis (FPCA) and a cross validation (CV) method. In our analysis, value of K is chosen by CV method to minimize the distances between the estimated process and restricted process.

4.2. Hypotheses Testing

Now we conduct tests on the moment dependence structure between two density functions for intraday 5-min returns on KOSPI and S&P 500. Recall that we denote k -th polynomial as p_k. We conduct the following tests. Only the null hypotheses are listed and the alternatives are the opposites of the nulls.

[Table 2] List of Null Hypotheses

(T.1)	$H_0 : A^* p_1 \in \{0\}$	(T.5)	$H_0 : A^* p_2 \in \{0\}$
(T.2)	$H_0 : A^* p_1 \in \text{span}\{p_1\}$	(T.6)	$H_0 : A^* p_2 \in \text{span}\{p_2\}$
(T.3)	$H_0 : A^* p_1 \in \text{span}\{p_1, p_2\}$	(T.7)	$H_0 : A^* p_2 \in \text{span}\{p_2, p_1\}$
(T.4)	$H_0 : A^* p_1 \in \text{span}\{p_1, p_2, p_3\}$	(T.8)	$H_0 : A^* p_2 \in \text{span}\{p_2, p_1, p_3\}$
(T.9)	$H_0 : A^* p_3 \in \{0\}$	(T.13)	$H_0 : A^* p_4 \in \{0\}$
(T.10)	$H_0 : A^* p_3 \in \text{span}\{p_3\}$	(T.14)	$H_0 : A^* p_4 \in \text{span}\{p_4\}$
(T.11)	$H_0 : A^* p_3 \in \text{span}\{p_3, p_1, p_2\}$	(T.15)	$H_0 : A^* p_4 \in \text{span}\{p_4, p_1, p_2, p_3\}$
(T.12)	$H_0 : A^* p_3 \in \text{span}\{p_3, p_1, p_2, p_4\}$	(T.16)	$H_0 : A^* p_4 \in \text{span}\{p_4, p_1, p_2, p_3, p_5\}$

The first four tests in Table 2 concern how the mean of the 5-min return on KOSPI depends on the distribution of the 5-min returns on S&P 500, namely the mean spillover effect. The next four hypotheses test whether the second moment of 5-min return on KOSPI depends on the first four moments of 5-min returns on S&P 500, the volatility spillover effect. T.9 through T.12 is a test on the third moment and T.13 through T.16 is on the fourth moment in a similar way. The hypothesis T.1 means that the mean of the 5-min return on KOSPI does not depend on any moments of 5-min returns on S&P 500. In other words, the mean of the 5-min return on KOSPI is not explained by any moments of S&P 500. If T.1 is not rejected, then we can conclude that there is no relationship between the mean of 5-min return on KOSPI and any moments of 5-min return of S&P 500. Otherwise there are rooms for the first moment of 5-min return on KOSPI depending on some moments of 5-min return on S&P 500. The T.2 means that the mean of the 5-min return depends only on that of S&P 500. If the null hypothesis T.1 is rejected and T.2 is not rejected, it implies that the mean of intraday 5-min return on KOSPI depends only on the first moment of 5-min return on S&P 500. Similarly if T.1 and T.2 are rejected and T.3 is not rejected, we can conclude that the first moment of 5-min return on KOSPI depends on the first two moments of 5-min return on S&P 500.

Before testing the null hypotheses, we briefly introduce the test statistics. An intuitive explanation of the test statistics Z in (8) is as follows. Equation (7) can be reformulated as

$$\begin{aligned}\langle v, g_t\rangle &= \sum_{k=1}^{L} c_k \langle u_k, f_t\rangle + \eta_t \\ &= \sum_{k=1}^{L} c_k \langle u_k, f_t\rangle + \eta_t + \sum_{k=L+1}^{K} c_k \langle u_k, f_t\rangle + o_p(1).\end{aligned}$$

Then dividing each side by $\langle v, g_t\rangle$ we have

$$-\sum_{k=1}^{L} c_k \frac{\langle u_k, f_t\rangle}{\langle v, g_t\rangle} = \sum_{k=L+1}^{K} c_k \frac{\langle u_k, f_t\rangle}{\langle v, g_t\rangle} - 1 .$$

The expression in the right side has similar form to the test statistics Z. In other words, instead of evaluating the left side of the equation, which tests on the first L dimension, Z is a test statistics which examines the behaviors in the last $K-L$ dimension.

As Park and Qian (2010) proposed in their paper, we pretend the integer $K-L$ as a parameter (degree of freedom) of distribution of Z and obtain approximate quantiles of Z using the X^2 quantile table. We also follow the suggested choice of $K-L$ which is the integer part of $-11.96+1.82\sqrt{T}$ where T indicates the number of business day in the sample year, and the calculated $K-L$ value is 15 or 16 since the trading days are between 233 and 241 during 1995-2006. Table 4 to 5 presents the results of hypotheses tests on moment dependence of 5-min returns of KOSPI on that of S&P 500 during sample period. K_0 in the table indicates the $K-L$ and each null hypothesis is equivalent to that in Table 2.

Before we start to investigate whether the stock market comovement between Korea and U.S. exists based on our definition, it is worth testing with the whole data span and compare the result with other approaches. If our test results are consistent with other approaches, it provides an incentive to conduct a in-depth study whether the phenomenon appears every year and what it is consist of. Table 3 shows test statistics with entire data. Referring to the interpretation of Table 2, it is easily found that the mean and the volatility spillover effects as well as the skewness and the kurtosis spillover effects are observed during sample period and all of them are composed of higher-order moments. Thus we can conclude that both international equity market move together during 1995-2006 period and the result corresponds to those of previous literature on comovement between Korean and U.S. equity return, namely Jang and Yi (2004), Jun and Choi (2003), and Park and Chung (2003). This implies that our methodology, functional regression, has the same power of detecting stock market comovement and therefore provides a ground to scrutinize whether spillover effects exist in each year and what their components are, and whether results coincides with the definition of comovement in our context.

[Table 3] Tests on Moment Dependence in Whole Sample

Year	1995-2006	
K_0	88	90
(T.1)	26.3460***	24.1473***
(T.2)	5.8502***	6.5559***
(T.3)	10.2480***	11.:0411***
(T.4)	7.4610***	5.1848***
(T.5)	25.6710***	24.9770***
(T.6)	18.8760***	11.7019***
(T.7)	19.2260***	19.1619***
(T.8)	15.0374***	17.2290***
(T.9)	48.4337***	46.2955***
(T.10)	42.3852***	43.4998***
(T.11)	39.2340***	36.8689***
(T.12)	30.9439***	34.6499***
(T.13)	37.9587***	35.8289***
(T.14)	33.9693***	32.7993***
(T.15)	30.5620***	30.6533***
(T.16)	25.2771***	24.2851***

Note. * denotes rejection at 10% significance level, ** denotes rejection at 5% significance level, and *** denotes rejection at 1% significance level.

[Table 4] Tests on Moment Dependence

Panel A: 1995-1997						
Year	1995		1996		1997	
K_0	15	16	15	16	15	16
(T.1)	0.2962	0.1110	3.5588***	3.2762***	1.3217	1.5401
(T.2)	-0.1366	-0.3040	3.4882***	3.2434***	-0.3928	-0.5263
(T.3)	-0.7768	-0.1521	3.5279***	3.2673***	-0.4443	-0.4776
(T.4)	0.0233	-0.1044	3.5027***	3.2792***	-0.3116	0.0446
(T.5)	-0.6335	-0.7755	-2.0991***	-2.0927***	3.4532***	3.2488***
(T.6)	-0.6450	-0.7806	-1.9897***	-1.8853**	1.1246	0.9144
(T.7)	-0.8598	-0.3562	-1.7699**	-1.8189**	0.9250	0.7662
(T.8)	-0.1935	-0.3636	-2.0255***	-2.1199***	0.9413	0.8813
(T.9)	-0.9476	-1.0557	-0.0533	-0.1732	-0.3628	-0.5236
(T.10)	-0.9078	-1.0469	-0.0877	-0.1915	-0.4184	-0.5653
(T.11)	-1.0676	0.4050	-0.5502	-0.7003	-1.0436	-1.1674
(T.12)	0.4835	0.2927	-0.5475	-0.6637	-1.6198	-1.1295
(T.13)	-0.0929	-0.2656	-0.9742	-1.0927	0.0778	-0.0354
(T.14)	-0.0981	-0.2484	-0.9495	-0.7245	0.0463	-0.0843
(T.15)	-0.2738	0.0145	-0.6052	-0.4998	-0.3892	-0.5000
(T.16)	-0.2663	-0.3293	-0.5721	-0.2256	-0.4644	-0.4563
Panel B: 1998 - 2000						
Year	1998		1999		2000	
K_0	15	16	15	16	15	16
(T.1)	2.6756**	2.6481**	5.9528***	6.1548***	11.5590***	11.0176***
(T.2)	1.3091	1.2343	4.1285***	3.8642***	-0.2672	-0.0784
(T.3)	1.2931	1.0966	3.5082***	3.2441***	0.0658	-0.0202
(T.4)	1.3025	1.2287	3.2850***	3.0087**	0.1465	-0.0228
(T.5)	-0.1167	-0.2869	3.0579**	2.7844**	16.5623***	17.4938***
(T.6)	-0.4988	-0.5572	3.0469**	2.7783**	4.1712***	3.8747***
(T.7)	-0.5986	-0.7533	2.1288**	1.8929**	4.1827***	4.1680***
(T.8)	-0.6023	-0.2497	1.1606	0.9829	4.3123***	4.0486***
(T.9)	-0.3303	-0.4664	4.3018***	4.2635***	13.6245***	13.3359***
(T.10)	-1.1461	-0.1668	3.7124***	3.4807***	7.7923***	7.4204***
(T.11)	-0.7687	-0.9174	1.9790**	1.7459	4.7889***	5.1882***
(T.12)	-0.7791	-0.9211	0.9561	1.0185	4.8656***	5.3220***
(T.13)	-0.7172	-0.7085	3.8597***	3.5646***	23.5285***	27.6821***
(T.14)	-0.5541	-0.6892	2.0824*	1.8708*	9.1452***	9.5736***
(T.15)	-0.6890	-0.7971	0.9295	1.1273	9.4114***	9.2037***
(T.16)	-0.6416	-0.6989	1.0729	1.9646	9.6879***	10.4326***

Note: * denotes rejection at 10% significance level, ** denotes rejection at 5% significance level, and *** denotes rejection at 1% significance level.

[Table 5] Tests on Moment Dependence (Continued)

Panel C: 2001 - 2003						
Year	2001		2002		2003	
K_0	15	16	15	16	15	16
(T.1)	8.9524***	8.6231***	4.9331***	5.7497***	5.7188***	5.3826***
(T.2)	1.1656	3.6023***	0.7588	0.5697	-0.9620	-0.5657
(T.3)	2.8052**	2.9448**	0.0865	-0.0429	-0.4277	-0.4755
(T.4)	1.7689	1.7783	0.1149	0.0672	-0.7360	-0.8274
(T.5)	3.8860***	5.7837***	4.8974***	5.0114***	7.9439***	7.5961***
(T.6)	-0.1668	0.7820	0.3919	0.4312	2.1354*	2.4592**
(T.7)	0.6381	1.4375	0.1491	0.0213	0.8079	0.6621
(T.8)	0.9114	0.7763	-1.8928**	-1.8393**	-0.3006	0.6490
(T.9)	0.7701	0.6299	25.3900***	25.6560***	19.9803***	19.3219***
(T.10)	-0.3971	-0.4234	6.5609***	6.4852***	3.3241***	5.3434***
(T.11)	-0.3839	-0.3336	-1.0853	-1.1768	0.9282	0.7700
(T.12)	-0.1976	-0.3391	-1.2674	-1.3000	-0.3534	-0.3705
(T.13)	2.4054**	2.6678**	4.4303***	4.8856***	4.1452***	4.5908***
(T.14)	-0.1954	-0.3299	0.5147	1.0362	1.9686*	2.4958**
(T.15)	-0.8221	-0.9505	0.6503	0.5158	-0.2740	-0.3960
(T.16)	-0.8016	-0.4007	0.1423	-0.0009	-0.2921	2.3584**
Panel D. 2004 - 2006						
Year	2004		2005		2006	
K_0	15	16	15	16	15	16
(T.1)	4.9533***	5.5914***	6.6038***	6.4357***	11.4517***	11.6079***
(T.2)	1.4231	2.6783**	0.0896	-0.0792	3.5631***	3.3771***
(T.3)	2.1901*	2.0055*	-0.2587	-0.4258	2.7833**	2.5349**
(T.4)	2.2054*	1.9613*	-0.2633	-0.3941	2.3324**	2.1944**
(T.5)	5.6074***	5.6411***	6.3150***	5.9387***	11.4494***	10.9692***
(T.6)	-0.4950	-0.4833	0.4479	0.2795	2.5207**	2.2840**
(T.7)	-0.3328	-0.2541	-0.0399	0.0083	2.1758	2.3714**
(T.8)	-0.0849	-0.1489	0.1188	0.1007	2.6291**	2.5161**
(T.9)	21.3728***	20.6551***	37.3493***	36.4107***	23.0426***	22.5733***
(T.10)	12.6463***	13.5597***	15.6951***	15.8726***	7.6605***	7.8680***
(T.11)	0.8570	0.7333	0.2481	0.0797	1.3228	1.7802
(T.12)	0.8644	0.7260	0.1450	0.1793	2.0089*	2.2450*
(T.13)	2.2888**	2.6246**	3.2504**	2.9860**	3.6744***	3.3860***
(T.14)	1.5202	1.3088	1.6804	1.4508	0.9843	1.0348
(T.15)	1.1505	1.1692	0.3982	0.4645	1.1974	1.1300
(T.16)	1.2365	1.3205	-0.3470	-0.0801	1.0653	0.9335

Note: * denotes rejection at 10% significance level, ** denotes rejection at 5% significance level, and *** denotes rejection at 1% significance level.

[Table 6] Tests on Moment Dependence with Modified Sample (2001-2006)

Year	2001	2002	2003	2004	2005	2006
K_0	K=15	K=15	K=15	K=15	K=15	K=15
(T.1)	0.7245	3.1035**	0.9453	1.6696	1.9125*	3.0765**
(T.2)	-0.2237	1.4634	-1.3270	1.3223	0.0038	1.8512*
(T.3)	1.3100	0.3922	-1.0589	1.3054	-0.3635	1.5708
(T.4)	0.6608	0.3908	-0.9923	1.1516	-0.2073	1.2027
(T.5)	-0.2629	4.0512***	5.6818***	8.8786***	4.0082***	5.9087***
(T.6)	0.7703	2.2146*	1.6977	1.1139	1.5574	1.2907
(T.7)	2.0206*	1.3261	2.2026*	0.9738	0.5459	0.8109
(T.8)	1.7978	1.3188	3.4788***	0.5246	0.4743	0.4634
(T.9)	2.6167**	1.4222	0.5364	-0.3117	-0.5704	1.1101
(T.10)	2.7517**	1.0766	-0.2720	-0.2422	-0.8820	2.1986
(T.11)	1.6460	0.9672	0.2932	-0.4489	-0.8413	1.7223
(T.12)	1.4131	-0.8148	0.2564	-0.9953	-0.7320	1.3007
(T.13)	-0.0914	3.1414**	-0.1057	7.3521***	1.5845	1.4623
(T.14)	1.3039	1.5425	1.1752	0.2657	1.1490	1.0068
(T.15)	1.8775*	0.4766	1.6508	1.2286	0.7355	0.6872
(T.16)	1.9319*	0.5045	-1.3856	0.7574	0.0384	0.1691

Note: * denotes rejection at 10% significance level, ** denotes rejection at 5% significance level, and *** denotes rejection at 1% significance level.

4.2.1. Testing the Mean Spillover Effect

As explained in the previous section, tests from T.1 to T.4 examines whether the mean spillover effect exists and if it does, they find what kinds of moments generate the effect. In 1995 and 1997, all of the null hypotheses are not rejected. It indicates that there exist no moment relationships between the mean of KOSPI and S&P 500 5-min return in 1995 and 1997. In other words, the mean spillover effect does not exist in 1995 and 1997. In 1996, however, all tests from T.1 to T.4 are rejected. It implies that the first moment of the 5-min return on KOSPI depends on the higher-order moments of S&P 500 5-min return. That is, the mean spillover effect does exist in 1996 and the effect is composed of mean, volatility, skewness, kurtosis, and even higher-order moments of S&P 500 5-min return. The result is different from the many previous findings in the literature where the spillover effect is examined only by the counterpart moment and ignored the role of other moments. As the moment dependence relationships have changed along the time, we cannot make a solid conclusion whether the KOSPI and S&P 500 move together during 1995-1997.

In 1998 and 2000, only the T.1 is rejected at 5% significance level and 1% significance level, respectively, and it implies that the mean of the intraday 5-min return on KOSPI depends only on the mean of S&P 500 5-min return. It means that the mean changes of S&P 500 have influence on the mean of the 5-min return on KOSPI. That is, the mean spillover effect exists and it is comprised only of the mean of 5-min return in U.S. stock market.

In 1999 and 2000, when so called "dot-com bubble" occurred, Korea and U.S. both experienced sharp increase in stock prices. As a result, in 1999 the mean of the 5-min return on KOSPI depends on more higher-order than fourth moments of S&P 500 return. The very same results hold as in 1996 and the mean spillover effect consists of higher-order moments of S&P 500 5-min return. The component of the mean spillover effect has changed over time which violates our definition on comovements, and thus we cannot conclude that the KOSPI and S&P 500 move together between 1998 and 2000.

In 2001, the moment dependence relationships are rather weakened compared to those in 1999. Only the tests T.1 and T.2 at 1% significance level with $K_0 = 16$ are rejected. It implies that the first moment of the 5-min return on KOSPI depends on the first two moments of S&P 500 return. The mean spillover effect exists and it is composed of the mean and the volatility of S&P 500 5-min return.

As the moment dependence relationship has changed over 1998-2001, we cannot find stock market comovement during that period based on our definition whereas both indices move in a similar way after year of 1998 in Figure 2. However, looking at the test results between 2002 and 2006 closely, a monotone and persistent, yet interesting moment dependence structure can be easily found. At 1% significance level, test of T.1 is rejected for every year. It implies that during that period the mean of the 5-min return on KOSPI depends only on the first moment of S&P 500 return. In 2006, the dependency of the first moment of 5-min return of KOSPI on moments of S&P 500 return is even strengthened. It is noteworthy that mean of 5-min return on KOSPI depends only on the mean of S&P 500 return and their relations are persistently observed during a specific time period. In other words, the mean spillover effect does exist for the sample period and the components of the effect do not change over time, which is consistent with previous results where the mean spillover effect results from the mean of counterpart's stock return.

Therefore, we can conclude that KOSPI and S&P 500 move together after 2002 considering the test results that the mean spillover effect exists and the element of effect does not change over time.

4.2.2. Testing the Volatility Spillover Effect

To investigate the existence of volatility spillover effect and its elements, the tests from T.5 to T.8 are examined. The volatility spillover effect shows very similar patterns as the mean spillover effect is shown in the previous section. In 1995 all of null hypotheses from T.5 through T.8 are not rejected. In other words, there exist no moment relationships between the volatility of KOSPI and S&P 500 5-min return in 1995 and the volatility spillover effect is not observable. In 1996, however, all tests from T.5 to T.8 are rejected. It indicates that the second moment of the 5-min return on KOSPI depends on the first and the higher-order moment of S&P 500 5-min return. Just like the analysis in the mean spillover effect, this result is also different from the previous researches where the spillover effect is examined only by the counterpart moment and underestimated role of other moments. It can be interpreted that with the powerful analysis based on the functional regression, verifying exactly what kinds of moments constitutes the spillover effect become possible.

Similarly, since the moment dependence structure has changed along the time, we cannot make a solid conclusion whether the KOSPI and S&P 500 move together during 1995-1997. In 1999 and 2000, most of the second moments of the 5-min return on KOSPI are affected by several moments of S&P 500 return. For instance, in 1999 with 5% significance level the second moment of 5-min return on KOSPI depends on the first three moments of S&P 500 return. It implies that the volatility spillover effect exists and it is composed of the first three moments the 5-min return, namely the mean, the volatility, and the skewness. Since the elements of the volatility spillover effect have changed over time which does not match our definition on comovements, and thus we cannot conclude for certain that the KOSPI and S&P 500 move together between 1998 and 2000. Similarly, the second moment of 5-min return on KOSPI, which captures at least part of the intraday risk and volatility, depends only on that moment of S&P 500 return, and their relations are persistently observed during 2001-2006.

Following the definition of comovements set up in this paper, we can draw a solid conclusion that KOSPI and S&P 500 move together after 2002 considering the test results that the second moment of 5-min return on KOSPI only depends on the second moment of S&P 500 return. It means that the volatility spillover effect does exist and the component of the effect remains the very same. Again, with the concept of the volatility spillover effect, it can be interpreted as an evidence that the comovements exist between two national stock markets.

4.2.3. Testing the Spillover Effect of Higher-Order Moments

There have been lots of literature studying the departures from normality of asset return distributions. It is well known that stock return distributions exhibit negative skewness and excess kurtosis (see, for example, Harvey & Siddique, 1999; Peiro, 1999). Table 1 shows these typical behaviors of KOSPI and S&P 500, and both exhibit negative skewness and excess kurtosis. In particular, this phenomenon seems severe in KOSPI index. Excess kurtosis (the fourth moment of the distribution) makes extreme observations more likely, which means that the market return can be very extreme than in normal return distribution. However, the presence of negative skewness (the third moment of the distribution) has the effect of accentuating the left-hand side of the distribution, which implies higher probability of the negative outliers than the positive outliers in the return distribution.

The notion of spillover effect, however, has been restricted to only two moments, mean and volatility, and thus the importance of accounting for higher-order moments seemed neglected in most of the previous literature. Recently, many studies on the role of higher-order moments in the financial data analysis are actively conducted as in Jondeau and Rockinger (2003), however, there are disagreements about what those terms entail and what their roles are in the financial market.

The higher-order moment dependence relationships are briefly reviewed in this section, and we introduce the skewness spillover and kurtosis spillover in a similar way as the first two moments spillover effect. This will allows us to examine components of each effect and its relevance to the comovements behavior.

From 1995 to 1998, all hypotheses on the third moment and the fourth moment are not rejected and it means there seems no moment relationships between the skewness and kurtosis of KOSPI and any moments of S&P 500 5-min return. In 1999 and 2000, however, the third and the fourth moments of the 5-min return on KOSPI are dependent on several moments of S&P 500 return, however, component of each spillover effects are changed over time.

During 2002-2006 period, similar analysis as the mean spillover effect and the volatility spillover effect applies to the skewness and the kurtosis spillover effect. In the sample period, at 5% significance level, only the hypotheses of T.9, T.10, and T.13 are rejected and it indicates that the third moment of the intraday 5-min return on KOSPI depends only on the first three moments of S&P 500 5-min return. In other words, the components of the skewness spillover effect are the mean, the volatility, and the skewness. It also shows that the fourth moment of the 5-min return on KOSPI depends only on the fourth moment of S&P 500 5-min return. The fact that higher-order spillover effect are observed persistently with the very same components shows the comovements and hence we can draw a conclusion that KOSPI and S&P 500 move together between 2002 and 2006 even in terms of higher order moments.

4.3. Testing Market Efficiency Hypotheses with Modified Sample

If the market is efficient, financial information released during U.S. trading hours, such as changes in the level of the S&P index, should have no marginal explanatory power for the change in the overnight level of the KOSPI index, and one would not expect such mean and volatility spillover effects from intraday returns in one stock market (S&P 500) to intraday returns in the other market (KOSPI). Therefore, information about the intraday return performance in one market (S&P 500) should be reflected in the opening price of the other market (KOSPI) under market efficiency assumption. Moreover, those price movements in foreign markets are most likely to reflect news on fundamentals of foreign economies and noise caused by foreign traders. Therefore, if the opening stock price had incorporated all sample information from the previous trading in the other market, the moment dependence relationships would have been generally insignificant.

However, it is known that changes in the S&P index will still be an important determinant of overnight variation in Korean stock returns, representing the overreaction of investors to information. Thus, in pricing the KOSPI index, foreign investors will look beyond KOSPI fundamentals and, for whatever reason, react to S&P stock price movements.

Therefore, we test for the moment dependence relationships again with the sample where the opening stock returns in Korean stock market are excluded. If the market is efficient, foreign news should be fully reflected in the opening price of the domestic market and thus the rest of KOSPI return distribution should not have significant relationship with S&P 500 movements. With the modified data in our case, no persistent moment dependence relationships or moment spillover effects should occur if the market is efficient. Since we have found strong comovements after 2000, we narrow our focus on testing the mean spillover effect and the volatility effect between 2002 and 2006 instead of examining the whole period.

The test results on moment dependence of 5-min returns of KOSPI on that of S&P 500 with modified data are presented in Table 6. In 2002 and 2006, only the null hypothesis T.1 is rejected at 5% significance level, which indicates that the first moment of the 5-min return on KOSPI depends only on the first moment of S&P 500 5-min return. It implies the existence of the mean spillover effect in 2002 and 2006. Allowing the significance level up to 10%, the same interpretation is possible for 2005 and the source of the effect in 2006 includes volatility as well. In 2003 and 2004, however, none of the null hypotheses are rejected and it indicates the absence of the mean spillover effect. That is, the mean spillover effect is not supported for consecutive years, and even the component of the effect is different in 2006. These results do not match the results in the previous section where we find very strong persistent mean spillover effect. We cannot find any strong evidence that KOSPI and S&P 500 do not move together during 2002-2006 period with this modified sample.

However, the test T.5 is rejected at 1% significance level for every year between 2002 and 2006, which is the same result that we have in the previous section. It means that the second moment of the 5-min return on KOSPI depends only on the second moment of S&P 500 5-min return and implies the existence of volatility spillover effect during the sample period. In addition, the test results between 2002 and 2006 show that the skewness spillover effect never happened, and the kurtosis spillover effect is observed only in 2002 and 2004 at 5% significance level. Therefore, the results show that the higher moments dependencies are not consistently observed in 2002-2006 period.

In sum, we find that only the volatility spillover effect is found to be significant, and all other three kinds of effects do not consistently exist. Thus, testing on the time-varying moments dependence relationships with the modified sample indicates only weak evidence of the volatility spillover effect and it is not sufficient to conclude that KOSPI and S&P 500 move together. Moreover, if the market is efficient, the foreign news should be fully reflected in the opening price of the domestic market and thus no consistent spillover effect should be detected with the modified data in our case. Our findings show that it is difficult to conclude that Korean stock market in Korea is inefficient in a very limited sense since U.S. stock market information are fully reflected in the opening price of Korean stock market.

V. SUMMARY AND CONCLUSIONS

In this paper, we examine whether intraday 5-min return on the Korea stock index KOSPI moves together with the S&P 500 between 1995 and 2006 by investigating the moment dependence relationships between the two indexes. We employ the functional regression method to identify the spillover effect and its component if the effect exists. The functional regression analysis is quite useful in explaining economic variables conditioning on a distribution, and it makes possible to explain whether one distribution of returns carries important information that are relevant to pricing and risk to the other distribution of return. Moreover, by allowing time varying densities of returns, we are able to conduct the hypothesis testings on whether the first four moments of intraday 5-min returns on KOSPI depend on the first four moments of S&P 500 return.

The results of hypotheses test show that until 2002, the mean spillover effect and the volatility spillover effect did not exist for consecutive years, and even the component of each effect changes over time. Between 2002 and 2006, the mean and the volatility spillover effects as well as the skewness and the kurtosis spillover effects are observed for every year, and the element of each effect does not change, we therefore conclude conclusion that the KOSPI and the S&P 500 move together during 2002-2006. We also try to find the evidence whether the opening price of the Korean stock market fully reflects all the available information, and conclude that the Korean stock market is net inefficient in the sense that S&P 500 cannot predict movements for intraday returns on the KOSPI.

References

Arshanapalli, B., J. Doukas and L. H. P. Lang (1995), “Pre and Post-October 1987 Stock Market Linkages between U.S. and Asian Markets,” *Pacific-Basin Finance Journal*, Vol. 3, pp. 57-73.

Bae, K., G. A. Karolyi and R. M. Stulz (2003), “A New Approach to Measuring Financial Contagion,” *The Review of Financial Studies*, Vol. 16, No. 3, pp. 717-763.

Becker, K. G., J. E. Finnerty and M. Gupta (1990), “The Intertemporal Relation Between the U. S. and Japanese Stock Markets,” *The Journal of Finance*, Vol. 45, No. 4, pp. 1297-1306.

Bosq, D. (1998), *Nonparametric Statistics for Stochastic Processes*, *Springer*.

Bosq, D. (2000), *Linear Processes in Function Spaces*, *Springer*.

Connolly, R. A. and F. A. Wang (2003), “International Equity Market Comovements: Economic Fundamentals or Contagion?,” *Pacific-Basin finance Journal*, Vol. 11, pp. 23-43

Chang, Y., C. Kim and J. Y. Park (2010), “Testing for unit roots in Time Series of Cross-Sectional Distributions,” Working Paper.

Craig, A., A. Dravid and M. Richardson (1995), “Market Efficiency Around the Clock Some Supporting Evidence Using Foreign-Based Derivatives,” *Journal of Financial Economics*, Vol. 39, pp. 161-180.

Eun, C. and S. Shim (1989), “International Transmission of Stock Market Movements,” *The Journal of Financial and Quantitative Analysis*, Vol. 24, 2, pp. 241-256.

Forbes, K. J. and R. Rigobon (2002), “No Contagion, Only Interdependence: Measuring Stock Market Co-Movements,” *Journal of Finance*, pp. 2223-2261.

Gagnon, K. and G. A. Karolyi (1997), “Information, Trading Volume and International Stock Market Comovement,” Working Paper.

Goodhart, C. A. E. and M. O’Hara (1997), “High Frequency Data in Financial Markets: Issues and Applications,” *Journal of Empirical Finance*, Vol. 4, No. 2-3, pp. 73-114.

Harvey, C. R. and A. Siddique (1999), “Autoregressive Conditional Skewness,” *Journal of Financial and Quantitative Analysis*, Vol. 34, pp. 465-487.

Jang, H. and K. Yi (2004), “Foreign Investor’s Trading Pattern and the Stock Market Return Co-movement between Korean and U.S.,” *Korean Management Review*, Vol. 33, 2, pp. 531-572.

Jondeau, E. and M. Rockinger (2003), “Conditional Volatility, Skewness, and

Kurtosis: Existence, Persistence, and Comovements," *Journal of Economic Dynamics and Control*, Vol. 27, pp. 1699-1737.

Jun, S. and J. Choi (2003), "Analysis of Investment Behavior: From the Perspective of Capital Market Comovements," *Korean Financial Management Association*, Vol. 20, No. 2, pp. 127-150.

Karolyi, G. A. and R. M. Stulz (1996), "Why Do Markets Move Together? An Investigation of U.S.-Japan Stock Return Comovements," *The Journal of Finance*, Vol. 51, No. 3, pp. 951-986.

King, M. A. and S. Wadhwani (1990), "Transmission of Volatility between Stock Markets," *The Review of Financial Studies*, Vol. 3, Vo. 1, pp. 5-33.

Kim, I. and C. Kim (2001), "International Transmission of Stock Market Movements Among the Kosdaq, Nasdaq, and Jasdap," *Asian-Pacific Journal of Financial Studies*, Vol. 28, pp. 481-511.

Lin, W., R. F. Engle and T. Ito (1994), "Do Bulls and Bears Move Across Borders? International Transmission of Stock Returns and Volatility," *The Review of Financial Studies*, Vol. 7, No. 3, pp. 507-538.

Liu, Y. A. and M. S. Pan (1997), "Mean and Volatility Spillover Effects in the U.S. and Pacific-Basin Stock Markets," *Multinational Finance Journal*, Vol. 1, No. 1, pp. 47-62.

Pagan, A. and A. Ullah (1999), *Nonparametric Econometrics*. *Cambridge University Press*.

Peiro, A. (1999), "Skewness in Financial Returns," *Journal of Banking and Finance*, Vol. 23, pp. 847-862.

Park, J. and K. Chung (2003), "On the Co-movement of Korea and US Stock Markets," *Korea Institute of Finance*, Vol. 9, No. 1, pp. 1-94.

Park, J. and J. Qian (2007), "Autoregressive Modeling of Time-Varying Densities in Functional Space." Working Paper.

Park, J. and J. Qian (2010), "Functional Regression of Continuous Stationary Distributions," forthcoming in *Journal of Econometrics*.

Shin, I. and S. Ham (2002), "A Study of Correlations in Stock Returns and Volatility between the U.S. and Korea," *Korea Development Institute*, Vol. 24, No. 2, pp. 83-199.

Silverman, B. W., (1986), "Density Estimation for Statistics and Data Analysis," *Chapman and Hall*.

Stoll, H. and R. Whaley (1988), "Stock Market Structure and Volatility," *Review of Financial Studies*, Vol. 3, pp. 37-71.

Susmel, R. and R. F. Engle (1994), "Hourly Volatility Spillovers between International Equity Markets," *Journal of International Money and Finance*, Vol. 13, pp. 3-25.