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Stock Index Autocorrelation and Cross-autocorrelations of Size-sorted Portfolios in the Japanese Market

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Abstract

Following Lo and MacKinlay's work on the U.S. market (1988, 1990), this paper investigates the autocorrelation of the market index and the cross-autocorrelations of size-sorted portfolios in the Japanese market. The structure of the cross-autocorrelations in the Japanese market is very similar to that of the U.S. in the sense that there are lead-lag relations running from larger stocks to smaller stocks, which will create positive autocorrelation in the market index. Although we have found no autocorrelation in the popular Japanese TOPIX market index, it is because TOPIX puts much more weight on larger stocks compared to the CRSP index for the U.S. market. However, such a cross-autocorrelation structure disappeared during the latter half of the 1990s, as the largest stocks in the Japanese market began to exhibit negative autocorrelation. The possibility of a serious financial crisis during this period provides an explanation for negative autocorrelation. Some empirical evidence is provided for this explanation.

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*Main empirical results in Sections 3 and 4 draw heavily on the Japanese version of the author's article (Iwaisako, 2003). However, the analysis in Section 5 is new.

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1 Introduction

The random character of asset returns is the foundation of modern financial economics. The random walk hypothesis remains an important starting point in understanding the nature of asset returns, even though it is neither necessary nor sufficient for market efficiency. Lo and MacKinlay (1988, 1990) provided the seminal empirical test of the random walk hypothesis. They found that the random walk hypothesis has been clearly rejected for U.S. market indexes, and that cross-autocorrelation among size-sorted portfolios is responsible for a substantial proportion of the positive autocorrelations observed for the market index.

The question is whether positive autocorrelation in market index returns and cross-autocorrelation of size portfolios behind them are universal phenomena. This paper investigates Japanese stock market data for autocorrelations and cross-autocorrelations of size-sorted portfolios as a source of index autocorrelations. Among previous studies, Chang, McQueen, and Pinegar (1999) used monthly PACAP data to carefully analyze and find evidence of the lead-and-lag relations among size-sorted portfolios in Asian stock markets, including the Tokyo market. However, they did not investigate the implications for market index autocorrelation. On the other hand, recent evidence, for example in Mitsui (2000) and Kim (2002), suggests there is no significant autocorrelation in popular Japanese market indexes. This paper closely follows Lo and MacKinlay's (1988, 1990) empirical procedure to reconcile previous results and shows, in fact, that the cross-autocorrelation structure of size-sorted portfolios in the Japanese market resembles that in the U.S. market. It is argued that popular Japanese market indexes such as TOPIX and Nikkei 225 put much more weight on large stocks than the CRSP indexes examined by Lo and MacKinlay. Therefore, if the market index equivalent to CRSP is constructed for Japanese market data, the random walk hypothesis will be rejected. However, I also show that such a cross-autocorrelation structure became unstable in the second half of the 1990s, and the fact that the largest stocks began to exhibit negative autocorrelations in the recent period is the major source of this change. I also provide some explanation of the change in the stochastic character of stock returns in recent years.

The data used in this study is weekly data that covers all listed stocks in the first and second sections of the Tokyo stock exchange, which includes six times more individual stocks than the monthly PACAP data used by Chang, McQueen, and Pinegar (1999). Hence this is the first comprehensive study of the random walk hypothesis using Japanese data, conducted in a way directly comparable with recent studies of the U.S. market.

The remainder of this paper is organized as follows. The next section describes the data and discusses definitions of market indexes. Section 3 studies autocorrelation of stock market indexes and size-sorted portfolios in the Japanese market. In Section 4, cross-autocorrelations of size-sorted portfolios are examined. In Section 5, we examine the same issues discussed in Sections 3 and 4, but concentrate on the period after 1995. Section 6 concludes the paper.

2 Stock Market Data and Different Market Indexes

Among the current literature on empirical testing of the random walk hypothesis, Lo and MacKinlay's work (1988) is the seminal benchmark. They found that the random walk hypothesis has been clearly rejected for CRSP market index returns using weekly data. In the update of Lo and MacKinlay's original findings (Campbell, Lo, and MacKinlay 1997, Table 2.4), they reported that the first-order autocorrelation of equal-weighted CRSP return indexes was 17.6% for daily data and 1.5 % for weekly data for the sample period from 1962 to 1994. Similarly, Foster and Nelson (1996) reported the first-order autocorrelation of S&P 500 index returns to be around 6% in the daily sample spans from 1928 to 1990.

On the other hand, recent evidence on Japanese data, reported for example in Mitsui (2000) and Kim (2002), suggests there is no significant autocorrelation in popular Japanese market indexes such as TOPIX and Nikkei 225[1]. These researchers are more interested in applying statistical models of time-varying volatility to the Japanese market. They tested routinely for autocorrelation, and so did not pursue the meaning of their test results. In the next section, I re-examine carefully the random walk hypothesis for Japanese market index returns following the methodology of Lo and MacKinlay (1988, 1999). In Section 4, cross-autocorrelations of size-sorted portfolios and their effects on autocorrelation of market index returns are also investigated.

The Japanese stock market data used in this paper are the market index TOPIX and size-sorted portfolios of the Tokyo stock exchange. TOPIX is the value-weighted index of individual stocks listed in the first section of the Tokyo stock exchange. The size-sorted portfolio data here are the indexes of three size-based portfolios of the first section, which are referred to as *Large*, *Medium*, and *Small,* and the index of the second section, referred to as *Second-section*, all published by the Tokyo Stock Exchange. Throughout this paper, *Second-section* is treated as the smallest size portfolio. Even though second section stocks are on average much smaller than first section stocks, whether an individual stock will belong to the first section or to the second section is, to some extent, decided by the choice of an individual firm. In that sense, the difference between the *Second-section* portfolio and the other three portfolios are not strictly based on constituent firm size alone. However, as will become apparent in the following analysis, this grouping of portfolios seems to be appropriate and mostly consistent with size-based sorting, judging from the patterns of autocorrelation and cross-autocorrelations. There is a quantitatively small, but very persistent, difference between

[1] There are other studies in which the random walk hypothesis is tested, but the main focus is the application of new statistical techniques to detect autocorrelations. Such papers include Kariya and Terui (1997), Kariya et al. (1995), and Kishimoto (1995).

the behaviors of *Small*-size and *Second-section* portfolios. The latter behaves unambiguously like a portfolio smaller than the former. The differences between *Second-section* and the two larger portfolios in the first section are much more significant.

The sample period of original data spans from January 1, 1968 to August 15, 2001. Following Lo and MacKinlay, a weekly return is defined by continuously compounded returns from Wednesday in one week to Wednesday in the following week. If Wednesday data is missing, Tuesday data is used instead. If both Tuesday and Wednesday data are missing, Thursday data is used. If all three days' data are missing, the return from that week is not reported. As a result, we obtained 1,715 weekly returns in the period from the first week of January 1968 to the second week of August 2001. Their basic statistics are summarized in Table 1.

[Table 1 is about here]

In comparing Japanese market index returns to those of the U.S., it is important to take into account the difference in definitions of stock market indexes. Nikkei 225 and TOPIX are the most popular Japanese market indexes and they have also been used in academic studies. As noted above, TOPIX is the value-weighted index of the first section of the Tokyo stock exchange, while Nikkei 225 is the equal-weighted index of selected stocks from the first section. However, Lo and MacKinlay (1988) used CRSP indexes which cover all listed stocks in NYSE, AMEX, and NASDAQ. Therefore CRSP indexes cover a broader range of individual stocks, in particular more small stocks, than Japanese indexes. In other words, both Nikkei 225 and TOPIX are expected to be less sensitive to the behaviors of small stocks than the CRSP index. The difference between TOPIX and Nikkei 225 is not as obvious. While TOPIX puts more weight on larger stocks, Nikkei 225 covers far fewer stocks, and its coverage concentrates on the largest stocks. Hence, we cannot tell which index would be more sensitive to the movements of larger stocks. In this paper, we take TOPIX as representative of the Japanese market index as its criterion for selecting individual stocks is known to be mechanical and more transparent than that of the Nikkei 225.

These differences in the definition of stock market indexes are particularly important as Lo and MacKinlay (1988) argue that the rejection of the random walk hypothesis for CRSP indexes is due to the behaviors of small stocks. They found stronger rejection for the equal-weighted CRSP index than for the value-weighted index. Obviously the equal-weighted index is more sensitive to the behaviors of small stocks than the value-weighted index. The random walk hypothesis is also rejected more strongly for smaller size-sorted portfolios than for larger portfolios. In their subsequent work, Lo and MacKinlay (1990) showed that there exist lead-lag relations running from larger size portfolios to smaller size portfolios, and that such relations generate autocorrelations in market index returns.

Given such findings about the U.S. market, we also use a couple of heuristic market indexes defined as follows, to identify the significance of differences in definitions.

$$\begin{aligned} \textit{First Section} &\equiv \frac{\textit{Small} + \textit{Medium} + \textit{Large}}{3} \\ \textit{Market Average} &\equiv \frac{\textit{Small} + \textit{Medium} + \textit{Large} + \textit{Second Section}}{4} \end{aligned}$$

They are not market indexes in a proper sense, but the behaviors of these "pseudo" market indexes are expected to be more sensitive to small stock returns and would be closer to those of the CRSP indexes. Their basic statistics also are reported in Table 1.

3 Autocorrelations in Stock Market Indexes and Size-sorted Portfolios

First, we tested the random walk hypothesis for the market indexes and size-sorted portfolios of the Japanese market. Table 2 shows the results for market indexes. Panel (A) of Table 2 shows the evidence based on correlation coefficients and Ljung-Box Q statistics.

The first-order autocorrelation of TOPIX reported in Table 2 is only 2.2%. In the corresponding table, Table 2.4, Campbell, Lo, and MacKinlay (1997) report 20.3% first-order autocorrelation for the equal-weighted CRSP index and 1.5% for the value-weighted index for weekly U.S. data from July 1962 to December 1994. TOPIX therefore seems to be behaving more like the value-weighted CRSP index than like the equal-weighted index. At the same time, autocorrelations of *First-section* are higher than those of TOPIX in all lag lengths, while those of *Market Average* are even higher. Test results based on Q statistics suggest the same findings. We found statistically significant autocorrelations in all three stock market indexes, and that the significance of Q statistics gets stronger in order from TOPIX, then *First-section* and *Market Average*. This is consistent with our discussion in the previous section: *First-section* and *Market Average* are supposed to be more sensitive to the behaviors of smaller stocks than TOPIX in that order.

[Table 2 is about here]

Panel B of Table 2 shows the results of a variance ratio test. The $z(q)$ statistics reported in Table 2 and other tables in this paper are Lo and MacKinlay's (1988) heteroscedasticity-consistent test statistics which asymptotically follow the standard normal distribution under the null of random walk. According to the results of the variance ratio test, autocorrelation of TOPIX is not statistically significant, except that the variance ratios are consistent with the values of autocorrelations and Ljung-Box Q statistics. The variance ratio becomes higher and the rejection of random walk becomes stronger in order from TOPIX, then *First Section*, and *Market Average*.

Table 3 reports the test results of Q statistics and the variance ratio test for size-sorted portfolios. The autocorrelation becomes higher in order from *Large*, then *Medium*, *Small*, and *Second-section*. The same pattern is observed for the statistical significance of Q statistics and $z(q)$ statistics. Once again, the results are consistent with the findings of Lo and MacKinlay discussed in the previous section. Also, both Q statistics and the variance ratio test do not reject the random walk for *Large*-size and *Medium*-size portfolios. These findings coincide with the results for market index returns in Table 2.

[Table 3 is about here]

We examined various subsamples to check the robustness of the above empirical results. The variance ratio test never rejects the random walk hypothesis for TOPIX and *Large*-size portfolios. On the other hand, the rejection based on Ljung-Box Q statistics was found to be heavily influenced by the first 300 to 400 observations of the sample. Since the 400th observation corresponds to the last week of August 1975, the observations before and during the first oil crisis strongly affect the rejection of our hypothesis based on Q statistics. This is not surprising as the period from 1968-74 included major economic events such as the collapse of the fixed exchange rate regime, the first oil crisis, and a high inflation period in early 1970s. These events were not specific to Japan, but hit the Japanese economy much harder than they did other developed economies.

We repeated the tests in Tables 2 and 3 using the subsamples starting from 1975. The results reported in Table 4 are the main findings of the analysis in this section. For the sample after the oil crisis, neither Q statistics nor the variance ratio test rejected the random walk for TOPIX and *Large*-size portfolio. Further, the variance ratio test does not reject the random walk hypothesis for the *Medium*-size portfolio either. For the pseudo indexes, *First Section* and *Market Average*, the rejection of the random walk is a little weaker in Table 4. However, both Q statistics and the variance ratio test do reject the random walk for the smaller portfolios. The autocorrelations of *Small*-size and *Second-section* also remained high and were not so different from the full sample values reported in Table 3.

[Table 4 is about here]

In summary, there is only remote evidence for autocorrelation in TOPIX and *Large*-size portfolio returns. This confirms the results reported in Mitsui (2000) and Kim (2002) using more recent data. On the other hand, the random walk hypothesis is rejected for two additional indexes defined in this paper, *First Section* and *Market Average*, which put more weight on small stocks than TOPIX. Finally, strong positive autocorrelations are found and the random walk is rejected for *Medium*-size, *Small*-size, and *Second-section* portfolios. Autocorrelation becomes stronger in that order. These results suggest that if the equal-weight index that covers both the first and the second section of the Tokyo exchange is constructed, such that it is directly comparable with the CRSP equal-weight index, the random walk will be rejected for that index. Given this analysis and the fact that the autocorrelations are stronger for smaller portfolios, the pattern of stock return autocorrelations in the Japanese market is very similar to that of the U.S. market reported in Lo and MacKinlay (1988, 1999).

4 Cross-autocorrelations of Size-sorted Portfolios

Next, we examined cross-autocorrelations and lead-lag relations among size-sorted portfolios of the Tokyo market. For this purpose, let us consider the vector of four size-sorted portfolio returns $X_t \equiv [R_{1t} \;\; R_{2t} \;\; R_{3t} \;\; R_{4t}]'$, where R_{1t} is the return of the *Second-section* portfolio and R_{2t}, R_{3t}, R_{4t} are the returns of *Small*, *Medium*, and *Large*-size portfolios, respectively.

In Table 5, the correlation matrix of weekly size-sorted portfolio returns vector $\widehat{\Upsilon}(0)$ and kth order cross-autocorrelation matrices $\widehat{\Upsilon}(k)$ are shown[2]. In the matrices shown in Table 5, all the entries below the diagonals of $\widehat{\Upsilon}(k)$ are larger than entries above the diagonals, except for $\widehat{\Upsilon}(0)$ which is a symmetric matrix by definition. Let us consider $\widehat{\Upsilon}(1)$ for example: The correlation between *Large*-size portfolio last week (R_{4t-1}) and *Second-section* portfolio this week (R_{1t}) in $\widehat{\Upsilon}(1)$ is 13.3%. However, the correlation between *Second-section* portfolio last week (R_{4t}) and *Large*-size portfolio this week (R_{1t-1}) is only 2.8%. The latter is not statistically significant if multivariate IID returns are assumed for the null hypothesis. Such asymmetry in cross-autocorrelations imply a lead-lag relation running from *Large*-size portfolios to *Second-section* portfolios. This will become more apparent if we calculate the difference between $\widehat{\Upsilon}(k)$ and its transpose. The results are shown in Table 6. For all $\widehat{\Upsilon}(k)$, the entries below the diagonals are positive, even though the values are a little smaller than those reported in Table 2.9 of Campbell, Lo, and MacKinlay (1997). This means that the correlations between smaller portfolios today and larger portfolios in the past are always higher rather than the other way around. The values become smaller as the number of lags k becomes larger. However, the same lead-lag pattern is still observed.

This kind of cross-autocorrelation structure can account for a substantial proportion of observed auto-correlation in the market indexes such as *Market Average* and *First Section* that put more weight on small stocks than TOPIX. Such a mechanism behind index auto-correlation is the same as in the U.S. market, first pointed out by Lo and MacKinlay (1988, 1990).

[2]The results for the subsample after the oil crisis, 1975-2001, are very similar to the full sample results in Table 5.

[Table 5 and Table 6 are about here]

5 Recent Changes in the Autocorrelation Structure of the Japanese Market

Since the early 1990s, the Japanese economy and the Japanese stock market have been trapped in financial turmoil. In this section, we investigate whether or not the patterns of Japanese stock returns discussed in the previous two sections have changed during the recent years of serious financial trouble.

It is not immediately obvious at what point the fragility of the Japanese financial system really became a serious concern. Here, we examine the subsample starting from 1995. However, the points made in the following discussion remain unaffected as long as the subsample begins after January 1995.

In Table 7, autocorrelation is tested for the sample starting from the first week of January 1995. Surprisingly, in Table 7, most autocorrelations of TOPIX and *Large*-size portfolio are negative. This is in sharp contrast to the full sample result in Table 1, in which positive autocorrelations are found for TOPIX and *Large*-size portfolio returns. In particular, the first-order autocorrelations are not only negative, but also four or five times larger than the numbers in Tables 3 and 4 in absolute value. Even though Q statistics are not significant, given the fact that all autocorrelations take a positive sign in the full sample, this finding is difficult to dismiss. For smaller portfolios, on the other hand, we find a similar pattern of autocorrelation as in the full sample results in Tables 3 and 4. Even though the persistence of autocorrelation is lower than in the full sample and is not statistically significant, autocorrelations of *Small*-size and *Second-section* portfolios are still positive. Also, autocorrelations gradually decay as the lag-length becomes higher, as for the full sample results.

[Table 7 is about here]

Since the structure of autocorrelations is unstable for the recent subsample, it is not difficult to imagine that the cross-autocorrelations and lead-lag relations between size portfolios have also become unstable. In Table 8, the cross-autocorrelation matrices of size-sorted portfolios are tabulated for the post-1995 subsample. Comparing Table 8 with Tables 5 and 6, no significant difference is detected for the contemporaneous correlation matrix $\widehat{\Upsilon}(0)$. However, in Table 8, the pattern of lead-lag relations running from larger size portfolios to smaller is no longer clear.

[Table 8 is about here]

To investigate the nature of recent changes in the autocorrelation structure of the market index and *Large*-size portfolios, we estimated a couple of univariate time series models. The first model is the following AR model with a dummy variable.

$$R_t = \alpha + \beta_1 R_{t-1} + \beta_2 R_{t-1} \cdot d_{t-1} + \epsilon_t \tag{1}$$
$$\begin{cases} d_t = 1 & \text{if } R_t \leq 0 \\ d_t = 0 & \text{otherwise} \end{cases}$$

Using such a specification, we wanted to examine whether the sign of the previous week's innovation affects the correlation between the returns in the current week and in the previous week. For example, if β_2 was negative and significant, it implies that a negative shock tends to cause negative correlation, hence a negative innovation tends to be followed by an offsetting positive innovation the following week. If both positive and negative shocks generate negative autocorrelation, β_1 will be negatively significant and β_2 will be insignificant.

Estimation results of AR(1) in equation (1) are shown in Table 9. We report only AR(1) results, but adding more lags did not change the basic results; AR coefficients of the second and higher lags were statistically insignificant. Panel A of Table 9 shows the results of the ordinary AR(1) model without a dummy variable. In these results, no parameter estimates of β_1 are statistically significant, confirming that there is no autocorrelation found for TOPIX and *Large*-size portfolios in the full sample. In the recent subsample, the estimates of β_1 take relatively large negative values, but they remain statistically insignificant.

In the specification that includes a dummy variable, reported in Panel B, the estimated β_1 are all positive in both subsamples, though none are statistically significant. On the other hand, the estimates of β_2 are all negative. They are statistically significant even for the recent subsample, at 5% level for TOPIX and at 10% level for the *Large*-size portfolios. The β_2 estimates for the recent subsample are more than twice as large in absolute value than those for the earlier subsample. In Panel C, the structural break at the end of 1994 is directly tested by the simple Chow test and by the bootstrap test for β_2. Both tests suggest there was a structural change in the autocorrelation structure of stock returns at the end of 1994 and the beginning of 1995. These results imply that since the second half of the 1990s, negative innovations in stock returns have been likely to create negative autocorrelation. This means that when there is a negative shock in the market, we would expect to see a rebound in the following week. However, positive shocks will not create such a tendency.

[Table 9 is about here]

A complete investigation of the source of the recent changes in autocorrelation structure is beyond the scope of this study. However, we can suggest some possible interpretations. First, the empirical results in Tables 7 and 9 can be considered evidence that Japanese investors have become very sensitive to, and overreact to, negative news during a period of serious financial trouble. A slightly different interpretation that we would prefer to the first, is a variation of “the peso problem.”[3] If negative news, such as the consecutive failures of large financial institutions in the winter of 1997, hits the market, it creates fear of a complete meltdown of the financial system. The probability of such a catastrophic event is very small. However, since the potential damage is so large, the stock market drops sharply. Eventually, the fear of immediate crisis will become remote and stock prices will recover. This will create significant negative autocorrelation in the stock returns. Since the price of risk would rise sharply when significant negative news hits the market, observed negative autocorrelation is consistent with the rationality of investors. Unlike the peso problem in the foreign exchange rate literature, the possibility of a catastrophic event arises only occasionally, but arises sharply. This creates temporal negative shocks followed by recovery in the market.

Given the above interpretations, it is straightforward to examine whether negative economic and financial shocks induce negative autocorrelation in stock returns. A typical example of such a negative event is the “March crisis” that has been repeated in Japan year after year since the late 1990s. The popular explanation of the“March crisis” is: The accounting year of the majority of Japanese firms ends in March. Hence, the decline of stock prices toward the end of March creates concern among investors about the balance sheets of Japanese firms that hold many other firms’ shares by cross-holdings. The public’s fear that a stock price decline will trigger the failure of major firms and financial institutions puts even further downward pressure on stock prices. Such a process creates a vicious circle between investors’ expectations and stock prices. As March ends, this negative concern also ends and the downward pressure on stock prices disappears. Stock prices therefore rise as April begins and this creates a negative autocorrelation after negative shocks.

[3]Fankel and Froot (1987, p. 139): “the peso problem arises when there is a small probability of a large change in the exchange rate each period — such as results from a devaluation, a bursting of a speculative bubble, or a big change in fundamentals — and when the sample size is not large enough to invoke the central limit theorem with confidence.”

To examine the effect of the "March crisis," another dummy variable is added to the AR(1) model, corresponding to the last three weeks of March and the first week of April:

$$R_t = \alpha + \beta_1 R_{t-1} + \beta_2 R_{t-1} \cdot d_{t-1} + \beta_3 R_{t-1} \cdot d_{t-1} \cdot q_{t-1} + \epsilon_t \tag{2}$$

$$\begin{cases} d_t = 1 & \text{if } R_t \leq 0 \\ d_t = 0 & \text{otherwise} \end{cases}$$

$$\begin{cases} q_t = 1 & \text{last three weeks of March and the first week of April} \\ q_t = 0 & \text{otherwise} \end{cases}$$

If the "March crisis" is a major source of negative autocorrelation, β_3 will be negative and statistically significant. Table 10 shows the estimation results of equation (3) for TOPIX and *Large*-size portfolio returns. As expected, β_3 estimates take negative values and are highly significant in the post-1995 subsample. In addition, we estimated the same model for the subsample beginning from 1999, because the serious financial trouble that started in the winter of 1997 had come to an end, at least temporarily, by the end of 1998. In the estimates for the later and shorter subsample 1999-2001, β_2 estimates are smaller and β_3 estimates are larger than in the 1995-2001 subsample. Therefore, after the series of financial troubles of individual financial institutions had been contained, the"March crisis" became a dominant source of negative autocorrelation in TOPIX and *Large*-size portfolio returns in recent years.

[Insert Table 10 here]

The empirical results in Table 10 will not completely rule out other potential explanations[4]. Overall, however, the evidence is consistent with "the peso problem" interpretation

[4] A possible explanation worth considering is the combination of the leverage effect and the volatility feed back effect. In ARCH model literature, negative innovations in returns drive up volatility more than positive innovations (*the leverage effect*). It is widely believed that larger conditional volatility should increase expected returns (*volatility feedback* or *GARCH-in-mean* effect), even though there is much less evidence for this than for the leverage effect. Therefore the causality of "negative shock → higher volatility → higher expected return" creates negative autocorrelation, if the negative shocks are concentrated. We examined weekly data used in this paper, but found evidence only for the leverage effect and none for the volatility feedback effect. However, with daily data, we might find evidence for such an explanation.

of observed negative autocorrelation in the recent Japanese stock market, which emphasizes the role of possible serious, but unrealized, financial panics.

6 Conclusions

This paper has re-examined the nature of market index autocorrelations and cross-autocorrelation of size portfolios generating index correlations in the Japanese market. No autocorrelation was found for TOPIX, the value-weighted index of the first-section of the Tokyo stock exchange. However, other evidence suggests that if an index were constructed so as to put more weight on smaller stocks, as for the equal-weighted CRSP index, the random walk hypothesis will be rejected for that index. There are also cross-autocorrelations among size-sorted portfolios which create lead-lag relations running from larger portfolios to smaller ones. In these respects, the structure of the Japanese market is very similar to the U.S. market.

However, such autocorrelation and cross-autocorrelation structures have become unstable since the second half of the 1990s. The largest size portfolio, and TOPIX itself, began to exhibit negative autocorrelations in the recent sample, and lead-lag relations among size portfolios disappeared. We suggest the possibility that financial panic, which occasionally increased very sharply during this period, will explain negative autocorrelation in *Large* portfolio and TOPIX. Some supporting evidence is provided using the so-called "March crisis." Another paper is required to investigate this issue fully. Such an analysis will also open the way to relate empirical findings of this paper to the broader issues of market microstructure[5].

[5]For the studies of market microstructure related to Lo and MacKinlay (1988, 1990), see Badrinath, Kale, and Noe (1995), Boudoukh, Richardson, and Whitelaw (1994), Brennan, Jegadeesh, and Swaminathan (1993), Conrad, Kaul, and Nimalendran (1991), Jegadeesh and Titman (1995), and Mech (1993). For studies of market microstructure of the Japanese market, see Kato (1991), and Bremer and Kato (1996).

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Table 1 Basic Statistics

Summary statistics of continuously compounded weekly returns (in percentages) of market indexes and size-sorted portfolios of the Japanese stock market (Tokyo stock exchange), over the sample period from the first week of January 1968 to the second week of August 2001. The number of observations for each time series is 1,715. The number of stocks reported for size portfolios are as of August 2001. Skewness and excess kurtosis marked with (**) and (*) indicate that they are statistically different from zero at the 1% and 5% levels of significance, respectively. Parentheses under skewness and excess kurtosis are p-values.

$$\textit{First Section} \equiv \frac{\textit{Small} + \textit{Medium} + \textit{Large}}{3}$$

$$\textit{Market Average} \equiv \frac{\textit{Small} + \textit{Medium} + \textit{Large} + \textit{Second Section}}{4}$$

Panel A: Market Indexes

	Mean	Standard Deviation	Skewness	Excess Kurtosis	Minimum	Maximum
TOPIX	0.137	2.31	−0.33**	3.49**	−12.51	13.41
			[0.00]	[0.00]		
First Section	0.137	2.19	−0.50**	4.28**	−13.57	13.11
			[0.00]	[0.00]		
Market Average	0.143	2.15	−0.50**	3.87**	−12.64	12.53
			[0.00]	[0.00]		

Panel B: Size-sorted Portfolios

	Mean	Standard Deviation	Skewness	Excess Kurtosis	Minimum	Maximum	Number of Stocks
First Section							
Large	0.136	2.40	−0.21**	3.23**	−11.77	13.39	613
			[0.00]	[0.00]			
Medium	0.132	2.31	−0.50**	4.56**	−14.60	13.92	515
			[0.00]	[0.00]			
Small	0.144	2.33	−0.42**	4.33**	−14.90	12.27	344
			[0.00]	[0.00]			
Second section							
Second-section	0.165	2.38	−0.12*	2.99**	−12.21	10.91	580
			[0.04]	[0.00]			

Table 2 Testing for Autocorrelation in Market Indexes

Tests of autocorrelation in Japanese market index returns for the sample period from the first week of January 1968 to the second week of August 2001.

Panel A: Autocorrelation coefficients $\widehat{\rho}_i$(in percent) and Ljung-Box Q statistics $\widehat{Q}_i$for $i = 5, 10$. Under the null hypothesis of no autocorrelation up to order i, Ljung-Box $Q_i$statistics follows chi-square distribution, χ_i^2.

Panel B: In calculating variance ratio, we use the following definition:

$$\widehat{M}_r(q) \equiv \sum_{j=1}^{q-1} \frac{2\,(q-j)}{q} \widehat{\rho}_i$$

In parentheses under variance ratios are z statistics, defined by $z(q) = \sqrt{nq}\widehat{M}_r(q)/\sqrt{\widehat{\theta}}$, where nq is the number of observations and $\widehat{\theta}$ is the asymptotic variance of $\widehat{M}_r(q)$ defined by equation (2.1.20) in Lo and MacKinlay (1999). Under the null hypothesis of the random walk, $z(q)$ asymptotically follows the standard normal distribution.

Statistics marked with (**) and (*) indicate that they are statistically significant at 1% and 5% level, respectively, rejecting the null hypothesis of no autocorrelation.

Panel A: Autocorrelation coefficients and Q statistics

	$\widehat{\rho}_1$	$\widehat{\rho}_2$	$\widehat{\rho}_3$	$\widehat{\rho}_4$	$\widehat{Q}_5$	$\widehat{Q}_{10}$
TOPIX	2.2	1.6	7.9	1.0	13.5*	20.6**
First Section	8.0	4.3	9.1	1.7	29.3**	37.0**
Market Average	11.9	6.1	10.7	3.3	54.2**	63.0**

Panel B: Variance ratios

	Number q of base observations aggregated to form variance ratio			
	2	4	8	16
TOPIX	1.02	1.09	1.19	1.30
	[0.45]	[1.06]	[1.54]	[1.75]
First Section	1.08	1.21	1.35	1.46
	[1.58]	[2.40]*	[2.73]**	[2.68]**
Market Average	1.12	1.30	1.50	1.66
	[2.41]*	[3.44]**	[3.94]**	[3.88]**

Table 3 Testing for Autocorrelation in Size-sorted Portfolios

Autocorrelation coefficients, Ljung-Box Q statistics, and variance ratios of size-sorted portfolio returns for the sample period from the first week of January 1968 to the second week of August 2001. See notes in Tables 1 and 2 for definitions of size-sorted portfolios and test statistics. Statistics marked with (**) and (*) indicate that they are statistically significant at 1% and 5% level, respectively.

Panel A: Autocorrelation coefficients and Q statistics

	$\widehat{\rho}_1$	$\widehat{\rho}_2$	$\widehat{\rho}_3$	$\widehat{\rho}_4$	$\widehat{Q}_5$	$\widehat{Q}_{10}$
Large	1.6	1.5	7.7	1.4	13.0*	18.2*
Medium	5.9	2.9	8.9	−0.4	21.2**	28.7**
Small	18.1	9.4	10.0	5.2	93.6**	99.4**
Second-section	17.3	10.8	13.9	5.8	119.3**	132.4**

Panel B: Variance ratios

	Number q of base observations aggregated to form variance ratio			
	2	4	8	16
Large	1.02	1.08	1.18	1.30
	[0.33]	[0.94]	[1.49]	[1.72]
Medium	1.06	1.17	1.25	1.30
	[1.18]	[1.86]	[1.97]*	[1.75]
Small	1.18	1.42	1.66	1.81
	[3.53]**	[4.75]**	[5.09]**	[4.64]**
Second-section	1.17	1.44	1.77	2.06
	[3.58]**	[5.38]**	[6.27]**	[6.20]**

Table 4 Autocorrelations after the Oil Crisis: 1975-2001

Autocorrelation coefficients, Ljung-Box Q statistics, and variance ratios of market indexes and size-sorted portfolios, for the sample period from the first week of January 1975 to the second week of August 2001. The number of observations is 1,347. See notes in Tables 1 and 2 for definitions of the variables and test statistics. Statistics marked with (**) and (*) indicate that they are statistically significant at 1% and 5% level, respectively.

Panel A: Autocorrelation coefficients and Q statistics

	$\widehat{\rho}_1$	$\widehat{\rho}_2$	$\widehat{\rho}_3$	$\widehat{\rho}_4$	$\widehat{Q}_5$	$\widehat{Q}_{10}$
TOPIX	−1.3	4.0	5.5	−2.1	9.0	14.3
First Section	−5.3	7.4	7.0	−1.0	18.9**	23.8**
Market Average	9.6	9.2	8.9	1.2	37.3**	42.4**
Large	−1.8	3.6	5.3	−1.9	8.6	12.9
Medium	3.7	6.4	7.1	−3.0	16.1**	21.2*
Small	17.3	13.1	9.5	3.9	78.3**	81.1**
Second-section	17.1	13.0	13.8	5.7	102.9**	112.9**

Panel B: Variance ratios

	Number q of base observations aggregated to form variance ratio			
	2	4	8	16
TOPIX	0.99	1.05	1.11	1.15
	[−0.24]	[0.49]	[0.76]	[0.79]
First Section	1.05	1.19	1.30	1.35
	[0.92]	[1.88]	[2.01]*	[1.74]*
Market Average	1.10	1.28	1.46	1.58
	[1.75]	[2.89]**	[3.19]**	[2.91]**
Large	0.98	1.04	1.10	1.15
	[−0.33]	[0.38]	[0.70]	[0.76]
Medium	1.04	1.16	1.23	1.24
	[0.65]	[1.53]	[1.53]	[1.17]
Small	1.17	1.44	1.68	1.79
	[2.99]**	[4.38]**	[4.54]**	[3.87]**
Second-section	1.17	1.46	1.81	2.11
	[3.19]**	[4.99]**	[5.75]**	[5.58]**

Table 5 Cross-autocorrelations Matrices for Size-sorted Portfolio Returns

Autocorrelation matrices of the vector of size-sorted portfolio returns, $X_t \equiv [R_{1t} \;\; R_{2t} \;\; R_{3t} \;\; R_{4t}]'$. R_{it}s are simple returns of size-sorted portfolios defined as follows:

R_{1t} = *Second-section* (second section)
R_{2t} = *Small*-size (first section)
R_{3t} = *Medium*-size (first section)
R_{4t} = *Large*-size (first section)

Sample period is from the first week of January 1968 to the second week August 2001. The k-th order autocorrelation matrix is defined by $\Upsilon(k) \equiv D^{-1/2}E[(X_{t-k} - \mu)(X_t - \mu)']D^{-1/2}$ where $D \equiv Diag(\sigma_1^2, ..., \sigma_4^2)$. Hence, the (i,j) element of $\Upsilon(k)$ corresponds to the correlation between R_{it-k} and R_{jt}. Under the null of multivariate IID, asymptotic standard error of the correlation is given by $1/\sqrt{T} = 0.024$.

$$\widehat{\Upsilon}(0) = \begin{array}{c} \\ R_{1t} \\ R_{2t} \\ R_{3t} \\ R_{4t} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 1.000 & 0.854 & 0.784 & 0.604 \\ & 1.000 & 0.916 & 0.693 \\ & & 1.000 & 0.819 \\ & & & 1.000 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(1) = \begin{array}{c} \\ R_{1t-1} \\ R_{2t-1} \\ R_{3t-1} \\ R_{4t-1} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.016 & 0.165 & 0.071 & 0.028 \\ 0.203 & 0.059 & 0.070 & 0.011 \\ 0.192 & 0.164 & 0.181 & 0.018 \\ 0.133 & 0.094 & 0.019 & 0.173 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(2) = \begin{array}{c} \\ R_{1t-2} \\ R_{2t-2} \\ R_{3t-2} \\ R_{4t-2} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.015 & 0.082 & 0.039 & 0.011 \\ 0.109 & 0.029 & 0.053 & 0.028 \\ 0.079 & 0.065 & 0.094 & 0.009 \\ 0.042 & 0.030 & 0.019 & 0.108 \end{pmatrix} \end{array}$$

Table 5 (continued)

$$
\widehat{\Upsilon}(3) = \begin{array}{c} \\ R_{1t-3} \\ R_{2t-3} \\ R_{3t-3} \\ R_{4t-3} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.077 & 0.108 & 0.074 & 0.042 \\ 0.115 & 0.089 & 0.068 & 0.038 \\ 0.121 & 0.112 & 0.100 & 0.066 \\ 0.107 & 0.083 & 0.080 & 0.139 \end{pmatrix} \end{array}
$$

$$
\widehat{\Upsilon}(4) = \begin{array}{c} \\ R_{1t-4} \\ R_{2t-4} \\ R_{3t-4} \\ R_{4t-4} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.014 & 0.045 & 0.014 & -0.006 \\ 0.065 & -0.004 & 0.009 & -0.020 \\ 0.062 & 0.043 & 0.052 & -0.029 \\ 0.064 & 0.051 & 0.022 & 0.058 \end{pmatrix} \end{array}
$$

Table 6 Asymmetry of Cross-autocorrelation Matrices

Differences between autocorrelation matrices and their transposes for the vector of size-sorted portfolio returns. See notes in Table 5 for definitions of variables and the sample period.

$$\widehat{\Upsilon}(1)-\widehat{\Upsilon}'(1) = \begin{array}{c} \\ R_{1t-1} \\ R_{2t-1} \\ R_{3t-1} \\ R_{4t-1} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.000 & -0.038 & -0.121 & -0.105 \\ 0.038 & 0.000 & -0.094 & -0.083 \\ 0.121 & 0.094 & 0.000 & -0.001 \\ 0.105 & 0.083 & 0.001 & 0.000 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(2)-\widehat{\Upsilon}'(2) = \begin{array}{c} \\ R_{1t-2} \\ R_{2t-2} \\ R_{3t-2} \\ R_{4t-2} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.000 & -0.027 & -0.040 & -0.031 \\ 0.027 & 0.000 & -0.012 & -0.002 \\ 0.040 & 0.012 & 0.000 & -0.010 \\ 0.031 & 0.002 & 0.010 & 0.000 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(3)-\widehat{\Upsilon}'(3) = \begin{array}{c} \\ R_{1t-3} \\ R_{2t-3} \\ R_{3t-3} \\ R_{4t-3} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.000 & -0.007 & -0.047 & -0.065 \\ 0.007 & 0.000 & -0.044 & -0.045 \\ 0.047 & 0.044 & 0.000 & -0.014 \\ 0.065 & 0.045 & 0.014 & 0.000 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(4)-\widehat{\Upsilon}'(4) = \begin{array}{c} \\ R_{1t-4} \\ R_{2t-4} \\ R_{3t-4} \\ R_{4t-4} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.000 & -0.020 & -0.048 & -0.070 \\ 0.020 & 0.000 & -0.034 & -0.071 \\ 0.048 & 0.034 & 0.000 & -0.051 \\ 0.070 & 0.071 & 0.051 & 0.000 \end{pmatrix} \end{array}$$

Table 7 Testing Autocorrelations for the Sample after 1995

Autocorrelation coefficients, Ljung-Box Q statistics, and variance ratios of market indexes and size-sorted portfolios for the sample period from the first week of January 1995 to the second week of August 2001. The number of observations is 368. See Tables 2 and 3 for definitions of variables and test statistics. Statistics marked with (**) and (*) indicate that they are statistically significant at 1% and 5% level, respectively.

Panel A: Autocorrelation coefficients and Q statistics

	$\widehat{\rho}_1$	$\widehat{\rho}_2$	$\widehat{\rho}_3$	$\widehat{\rho}_4$	$\widehat{Q}_5$	$\widehat{Q}_{10}$
TOPIX	−8.1	−0.5	4.2	−4.0	9.1	12.1
First Section	−0.6	2.7	8.2	−2.9	7.7	12.7
Market Average	3.7	4.7	9.6	−0.2	10.2	18.5*
Large	−9.2	−0.5	3.3	−3.9	9.2	11.7
Medium	−1.8	−0.3	9.1	−7.3	10.8	15.1
Small	11.6	9.4	10.6	1.4	13.2*	21.2*
Second Section	9.1	8.5	13.3	3.4	16.8**	36.1**

Panel B: Variance ratios

	Number q of base observations aggregated to form variance ratio			
	2	4	8	16
TOPIX	0.92	0.89	0.93	0.94
	[−0.94]	[−0.77]	[−0.35]	[−0.21]
First Section	0.99	1.05	1.15	1.20
	[−0.09]	[0.35]	[0.67]	[0.64]
Market Average	1.03	1.14	1.29	1.44
	[0.38]	[0.97]	[1.32]	[1.39]
Large	0.91	0.87	0.89	0.90
	[−1.05]	[−0.90]	[−0.50]	[−0.34]
Medium	0.98	1.01	1.07	1.10
	[−0.24]	[0.07]	[0.30]	[0.33]
Small	1.11	1.32	1.53	1.67
	[1.06]	[1.92]*	[2.04]*	[1.88]
Second Section	1.09	1.28	1.52	1.87
	[0.91]	[1.74]	[2.07]*	[2.41]*

Table 8 Cross-autocorrelations of Size-sorted Portfolios in the Subsample after 1995

Autocorrelation matrices $\Upsilon(k)$, and differences between $\Upsilon(k)$ and their transposes, $\widehat{\Upsilon}(k) - \widehat{\Upsilon}'(k)$. $\Upsilon(k)$ is autocorrelation matrices of $X_t \equiv [R_{1t} \quad R_{2t} \quad R_{3t} \quad R_{4t}]'$, where R_{it} are simple returns of size-sorted portfolios. Sample period is from the first week of January 1995 to the second week of August 2001 and the number of observations is 368. See Table 5 for detailed definitions of variables. Under the null of multivariate IID, asymptotic standard error of the correlation is given by $1/\sqrt{T} = 0.024$.

$$\widehat{\Upsilon}(0) = \begin{array}{c c} & \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{array}{c} R_{1t} \\ R_{2t} \\ R_{3t} \\ R_{4t} \end{array} & \begin{pmatrix} 1.000 & 0.806 & 0.772 & 0.698 \\ & 1.000 & 0.907 & 0.781 \\ & & 1.000 & 0.896 \\ & & & 1.000 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(1) = \begin{array}{c c} & \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{array}{c} R_{1t-1} \\ R_{2t-1} \\ R_{3t-1} \\ R_{4t-1} \end{array} & \begin{pmatrix} 0.095 & 0.110 & 0.021 & 0.017 \\ 0.107 & 0.117 & 0.009 & -0.071 \\ 0.092 & 0.095 & -0.019 & -0.070 \\ 0.075 & 0.048 & -0.056 & -0.092 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(1) - \widehat{\Upsilon}'(1) = \begin{pmatrix} 0.000 & 0.003 & -0.071 & -0.058 \\ -0.003 & 0.000 & -0.086 & -0.119 \\ 0.071 & 0.086 & 0.000 & -0.014 \\ 0.058 & 0.119 & 0.014 & 0.000 \end{pmatrix}$$

Table 8 (continued)

$$\widehat{\Upsilon}(2) = \begin{array}{c} \\ R_{1t-2} \\ R_{2t-2} \\ R_{3t-2} \\ R_{4t-2} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.086 & 0.080 & 0.004 & -0.016 \\ 0.092 & 0.099 & 0.029 & 0.014 \\ 0.088 & 0.067 & 0.001 & 0.008 \\ 0.067 & 0.030 & -0.024 & -0.003 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(2) - \widehat{\Upsilon}'(2) = \begin{pmatrix} 0.000 & -0.012 & -0.084 & -0.083 \\ 0.012 & 0.000 & -0.038 & -0.016 \\ 0.084 & 0.038 & 0.000 & 0.032 \\ 0.083 & 0.016 & -0.032 & 0.000 \end{pmatrix}$$

$$\widehat{\Upsilon}(3) = \begin{array}{c} \\ R_{1t-3} \\ R_{2t-3} \\ R_{3t-3} \\ R_{4t-3} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.137 & 0.084 & 0.048 & 0.014 \\ 0.105 & 0.107 & 0.073 & 0.013 \\ 0.110 & 0.121 & 0.093 & 0.033 \\ 0.122 & 0.095 & 0.089 & 0.036 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(3) - \widehat{\Upsilon}'(3) = \begin{pmatrix} 0.000 & -0.021 & -0.062 & -0.108 \\ 0.021 & 0.000 & -0.048 & -0.082 \\ 0.062 & 0.048 & 0.000 & -0.056 \\ 0.108 & 0.082 & 0.056 & 0.000 \end{pmatrix}$$

$$\widehat{\Upsilon}(4) = \begin{array}{c} \\ R_{1t-4} \\ R_{2t-4} \\ R_{3t-4} \\ R_{4t-4} \end{array} \begin{array}{c} \begin{array}{cccc} R_{1t} & R_{2t} & R_{3t} & R_{4t} \end{array} \\ \begin{pmatrix} 0.043 & 0.056 & 0.025 & 0.000 \\ 0.003 & 0.019 & -0.028 & -0.061 \\ -0.014 & -0.010 & -0.068 & -0.109 \\ 0.034 & 0.036 & -0.008 & -0.036 \end{pmatrix} \end{array}$$

$$\widehat{\Upsilon}(4) - \widehat{\Upsilon}'(4) = \begin{pmatrix} 0.000 & 0.053 & 0.039 & -0.034 \\ -0.053 & 0.000 & -0.018 & -0.097 \\ -0.039 & 0.018 & 0.000 & -0.101 \\ 0.034 & 0.097 & 0.101 & 0.000 \end{pmatrix}$$

Table 9 Changes in Autocorrelations after 1995

AR(1) models are estimated for continuously compounded weekly returns of TOPIX and *Large*-size portfolio, for the following subsamples:

Jan 75-Dec 94: The 1st week of January 1975 to the last week of December 1994 (992 obs.).

Jan 95-Aug 01: The 1st week of January 1995 to the 2nd week of August 2001 (368 obs.).

We first estimated an ordinary AR(1) model as the benchmark. We also estimated the extended AR(1) model which allows asymmetric responses to past innovations with different signs:

$$R_t = \alpha + \beta_1 R_{t-1} + \beta_2 R_{t-1} \cdot d_{t-1} + \epsilon_t \tag{1}$$
$$\begin{cases} d_t = 1 & \text{if } R_t \leq 0 \\ d_t = 0 & \text{otherwise} \end{cases}$$

In parentheses under parameter estimates, heteroscedasticity-robust standard errors of White (1980) are reported. Estimated coefficients marked with (**), (*) and (†) indicate that they are statistically different from zero at the 1%, 5%, and 10% significance level respectively.

In Panel C, we tested for the structural break at the end of 1994. In addition to the ordinary Chow test, which assumes normal disturbances, we also tested for a structural break by bootstrap: From the Jan 75-Dec 94 subsample, 5,000 replications, each with 368 observations corresponding to the post-1995 sample size, are drawn. The extended AR(1) model was then estimated for each draw. Under the null hypothesis that $\beta_2$in the later subsample (Jan 95-Aug 01) is same as in the earlier subsample (Jan 75-Dec 94), we calculate the probability that the parameter estimate of $\beta_2$will be equal to or smaller than the actual $\widehat{\beta}_2$estimated from the later subsample.

Panel A: Benchmark case, AR(1) with no dummy variable ($\beta_2 = 0$).

TOPIX			*Large*-size Portfolio		
	Jan 75-Dec 94	Jan 95-Aug 01		Jan 75-Dec 94	Jan 95-Aug 01
$\widehat{\beta}_1$	0.023	−0.082	$\widehat{\beta}_1$	0.018	−0.092
[S.E.]	[0.051]	[0.062]	[S.E.]	[0.051]	[0.062]
R^2	0.1	0.7	R^2	0.0	0.9
$\overline{R}^2$	−0.0	0.4	$\overline{R}^2$	−0.1	0.6

Table 9 (continued)

Panel B: Different responses to past innovations of different signs.

TOPIX			*Large*-size Portfolio		
	Jan 75-Dec 94	Jan 95-Aug 01		Jan 75-Dec 94	Jan 95-Aug 01
$\widehat{\beta}_1$	$0.115^{\dagger}$	0.108	$\widehat{\beta}_1$	0.096	0.077
[S.E.]	[0.066]	[0.109]	[S.E.]	[0.064]	[0.109]
$\widehat{\beta}_2$	−0.179	-0.402^{*}	$\widehat{\beta}_2$	−0.158	$-0.358^{\dagger}$
[S.E.]	[0.138]	[0.192]	[S.E.]	[0.138]	[0.197]
R^2	0.5	2.3	R^2	0.4	2.1
$\overline{\mathrm{R}}^2$	0.3	1.7	$\overline{\mathrm{R}}^2$	0.2	1.6

Panel C: Tests of structural break at the end of 1994 in the extended AR(1) model.

	TOPIX	*Large*-size Portfolio
Chow test	$F(3, 1340) = 2.52$ [0.06]	$F(3, 1340) = 2.21$ [0.08]
Bootstrap	$p[\beta_{2,75-94} \leq \widehat{\beta}_{2,94-01}] = 0.04$	$p[\beta_{2,75-94} \leq \widehat{\beta}_{2,94-01}] = 0.05$

$p[\beta_{2,75-94} \leq \beta_{2,94-01}]$ = Probability that the estimated β_2 will be smaller than $\widehat{\beta}_{2,94-01}$ estimated from the later subsample under the null hypothesis that β_2 are the same in both subsamples.

Table 10 Changes in Autocorrelations before and after 1995

We estimate the extended AR(1) model with additional dummy variable $q_t$for the last three weeks of March and the first week of April every year:

$$R_t = \alpha + \beta_1 R_{t-1} + \beta_2 R_{t-1} \cdot d_{t-1} + \beta_3 R_{t-1} \cdot d_{t-1} \cdot q_{t-1} + \epsilon_t \tag{2}$$

$$\begin{cases} d_t = 1 & \text{if } R_t \leq 0 \\ d_t = 0 & \text{otherwise} \end{cases}$$

$$\begin{cases} q_t = 1 & \text{last three weeks of March and the first week of April} \\ q_t = 0 & \text{otherwise} \end{cases}$$

In parentheses under parameter estimates, the heteroscedasticity-robust standard errors of White (1980) are reported. Estimated coefficients marked with (**), (*) and (†) indicate that they are statistically different from zero at the 1%, 5%, and 10% significance level respectively. The above model is estimated for continuously compounded weekly returns of TOPIX and *Large*-size portfolio for the following subsamples:

Jan 75-Dec 94: The 1st week of January 1975 to the last week of December 1994 (992 obs.).

Jan 95-Aug 01: The 1st week of January 1995 to the 2nd week of August 2001 (368 obs.).

Jan 99-Aug 01: The 1st week of January 1999 to the 2nd week of August 2001 (138 obs.).

TOPIX

	Jan 75-Dec 94	Jan 95-Aug 01	Jan 99-Aug 01
$\widehat{\beta}_1$	$0.117^{\dagger}$	0.110	0.140
[S.E.]	[0.066]	[0.109]	[0.194]
$\widehat{\beta}_2$	−0.199	$-0.335^{\dagger}$	−0.219
[S.E.]	[0.139]	[0.184]	[0.296]
$\widehat{\beta}_3$	0.112	-0.773^{**}	-1.119^{**}
[S.E.]	[0.325]	[0.258]	[0.283]
R^2	0.6	4.6	7.7
$\overline{R}^2$	0.3	3.8	5.6

Large-size Portfolio

	Jan 75-Dec 94	Jan 95-Aug 01	Jan 99-Aug 01
$\widehat{\beta}_1$	0.098	0.078	0.132
[S.E.]	[0.064]	[0.109]	[0.192]
$\widehat{\beta}_2$	−0.180	−0.290	−0.189
[S.E.]	[0.138]	[0.189]	[0.294]
$\widehat{\beta}_3$	0.154	−0.784**	−1.119**
[S.E.]	[0.341]	[0.266]	[0.304]
R^2	0.5	4.5	7.5
$\overline{R}^2$	0.2	3.7	5.4