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ALLAN W. KLEIDON and ROBERT E. WHALEY

ABSTRACT

We provide new evidence regarding the degree of integration among markets for stocks, futures and options prior to and during the October 1987 market crash. Where previous analyses have resulted in recommendations for the implementation of circuit breakers, the coordination of margin requirements across markets, and changes in regulatory jurisdiction, our analysis indicates that delinkage between markets during the crash was primarily caused by an antiquated mechanism for processing stock market orders. The results suggest that market integration may be better served by efficient order execution than by further restricting markets.

> To a large extent, the problems of mid-October can be traced to the failure of these market segments [stocks, stock index futures, and stock options] to act as one. (Report of the Presidential Task Force [Brady Report] (1988, Executive Summary, p. vi)).

ON OCTOBER 19, 1987, the December S&P 500 futures contract price fell dramatically below the S&P 500 cash index level. The difference between the futures and cash prices, called the "basis," is normally positive as a result of the short-term interest rate exceeding the dividend yield of the S&P 500 index portfolio and of active index arbitrage between the index futures and stock markets. During the October 1987 crash, however, the basis was frequently negative, which under normal conditions would signal arbitrage opportunities. The negative basis has been the subject of much research and frequent attempts at explanation.[1]

This breakdown of the normal relation between the cash and futures markets has had broad and longlasting effects. Not least is the continuing debate over proposals from the Brady Report. Although the ostensibly separate stock, futures and option markets are in reality only one market

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[1] An incomplete bibliography includes Barrow et al. (1989), Bassett, France and Pliska (1989, 1990), Harris (1989), Kleidon (1992), Kyle (1988), Leland (1988), Metz (1988), Miller et al. (1988), Presidential Task Force (1988) [Brady Report], Santoni (1988), U.S. Commodity Futures Trading Commission (1988), U. S. Securities and Exchange Commission (1988).

given the links among them in normal times, the regulatory structure has historically treated them as separate markets, which the Brady Commission believed exacerbated problems during the crash. Indeed, in the view of the Brady Report, the breakdown between markets was the primary cause of problems induced by the crash. Consequently, the major recommendation of the Brady Report was that regulatory changes were necessary to enhance the "one-market concept." In its view (p. vi):

> Analysis of the October market break demonstrates that one agency must have the authority to coordinate a few critical intermarket issues cutting across market segments and affecting the entire financial system; to monitor activities of all market segments; and to mediate concerns across market-places.

Specific issues that have subsequently arisen include who should take over the role of "superagency" (especially internecine rivalry between the Securities and Exchange Commission (SEC) and the Commodity Futures Trading Commission (CFTC)), coordination across markets of margin requirements, and circuit-breakers.[2] All three issues are raised in the Brady Report.

Clearly society has expended a lot of resources on the premise that the fundamental problem during the crash was a breakdown of the usual linkages among markets. It is important to note, however, that the Brady Report did not detail a mechanism that created the specific market prices that were observed. Nor did it analyze the relations between the futures and option markets to quantify the extent of any breakdown between these markets. The primary focus was on the negative basis between the cash and futures.

This paper analyzes the extent and cause of apparent breakdowns among markets during the crash of October 1987. The principal conclusions are that the futures and option markets operated largely in unison during the crash, but that each of these markets showed breakdowns with the cash market. The paper argues and presents evidence that the primary source of the breakdowns was a mechanical order processing problem on the New York Stock Exchange (NYSE). Given this explanation, we question the basis for the broad regulatory changes proposed in the Brady Report. In particular, an argument that equates regulatory jurisdiction with market integration is challenged by the facts that the cash and option markets were delinked during the crash despite the SEC having jurisdiction over both markets, while the options and futures, regulated by the SEC and CFTC, respectively, were effectively integrated.

The first section sets the stage for our analysis by demonstrating the extent to which the three primary markets addressed in the Brady Report comprised virtually one market prior to October 19, 1987. In particular, for October 13 we present (a) the cash (stock) indexes for both the S&P 500 and S&P 100; (b) the futures contract on the S&P 500; and (c) the underlying cash index

[2] See, for example, Miller (1990).

implied by the option contract on the S&P 100. October 13 represents price behavior on a typical day. The conclusion is that the markets are highly integrated.

Section II then presents corresponding results for October 19. First, as noted by the Brady Commission, the cash indexes are out of line with the futures contract—these markets were delinked. Additional results also emerge. The S&P 500 and 100 indexes are almost identical, which is not surprising given the overlap of composition. However, significantly, the level of the S&P 100 index implied by the option prices is very different from the observed S&P 100 index, in contrast to normal times. In other words, the option market was delinked from the cash market during the crash. Further, the general level of the implied S&P 100 index is consistent with that of the futures contract—that is, the option and futures markets retained much of their usual linkage. It appears as if the primary problem lies with the cash market.

Section III focuses attention on the cash market, and examines different explanations for the behavior of the cash indexes during the crash. One explanation is the liquidity theory, which suggests that the primary cause for the delinkage between markets was market illiquidity in the face of extraordinarily high volume. Blume, MacKinlay, and Terker (1989) advocate this view and document an apparent delinkage within the cash (stock) market between those NYSE stocks in and out of the S&P 500, which they ascribe to liquidity effects. They note, however, that an alternative explanation also consistent with the facts is that the non-S&P stocks may reflect current information more slowly than the S&P stocks.

Kleidon (1992) supports this alternative explanation. More specifically, he argues that the primary cause of market delinkage was a physical order processing problem on the NYSE during the crash. The NYSE order routing systems then in place meant long delays between the submission and execution of limit orders. This greatly exacerbated the potential for stale limit buy orders to be "picked off" as the current-information price fell below the stale limit orders, thus creating stale prices in the cash market. While this is always a potential problem for traders submitting limit orders—it is well known that they provide a free option to those on the other side of the market—the extraordinary volume on October 19, 20, and 21 and the consequent delays in processing of orders, particularly due to queues that developed at physical printers on the NYSE, created a much greater problem with stale prices than normal. Differential degrees of staleness across individual stocks resulted in nonsynchronous prices across stocks, even if they traded more or less continuously given the high volume.

Along with the explanations of the cash market behavior on October 19 that are presented in Section III, we also develop predictions for means and higher order moments of the cash index returns under each explanation. Section IV then presents empirical evidence on the cash, futures and option markets, and evaluates the alternative explanations of the aberrant cash behavior. Our conclusion is that although both liquidity and the stale price models are consistent with observed mean effects, the liquidity models do not explain the observed higher order moments, in contrast to the stale price model. Section V concludes the paper, and discusses the proposed regulatory change in the Brady Report in light of the evidence that such breakdowns as existed were primarily caused by inadequate capacity on the NYSE (which has since been corrected).

I. Stocks, Futures, and Options: One Market

This section demonstrates empirically that during the period prior to the crash, the stock, futures and option markets were closely linked. Our proxies for stock market behavior are the S&P 500 and S&P 100 cash indexes. To demonstrate futures and option price movements, the most actively traded index futures and option contracts are selected. During October 1987, these were the December 1987 S&P 500 index futures and the November 1987 S&P 100 index option contracts.

Before comparing the movements of the four different indexes, two important issues need to be addressed. First, we compare the compositions of the S&P 500 and the S&P 100. Both indexes are market value-weighted indexes of high market capitalization U.S. stocks. The S&P 500 is older, and in October 1987 comprised 462 NYSE stocks, thirty over-the-counter stocks, and eight American Stock Exchange stocks. The S&P 100 index is much more recent in origin. When the Chicago Board Options Exchange (CBOE) contemplated introducing index options in the early 1980s, it chose the one hundred largest stocks from those on which options were traded to create the S&P 100.[3] While membership in both indexes have changed through time, all of the S&P 100 stocks were contained in the S&P 500 in October 1987, and the S&P 100 stocks accounted for about 46% of the S&P 500's total market capitalization.

Second, although the S&P 500 and S&P 100 cash index levels and the S&P 500 futures price correspond to stock portfolio values, the S&P 100 index option prices are leveraged, dynamically-rebalanced stock portfolio values. Direct comparison of index option price movements with index futures price/cash index level movements is difficult since not only does the sensitivity of the option price to the index level change as the index level changes, but also the sensitivity of the option price to the index level changes as the volatility of index returns changes. To circumvent these problems, we equate observed S&P 100 index option prices to their corresponding theoretical values and simultaneously estimate the S&P 100's index level and return volatility. To ensure precise estimation, we use all available intraday bid/ask quotes for the S&P 100 index options during October 1987. The Appendix contains a detailed explanation of the methodology. Below we compare the observed levels of the S&P 500 and S&P 100 cash indexes with the price of

[3] Originally, the name of the index was the "CBOE 100." It later became known as the S&P 100 when Standard & Poors assumed responsibility for tracking the index composition.

the S&P 500 futures and the implied (from the option) level of the S&P 100 index.

Figure 1 presents time series at five-minute intervals on October 13 (a typical trading day) for both the S&P 500 and S&P 100 (cash) indexes, the S&P 500 futures contract, and the S&P 100 index implied by the option prices. At 10:00 A.M. on October 13, the S&P 100 index is normalized to the level of the S&P 500 index; the implied S&P 100 index is normalized proportionately.[4]

Several results are apparent. First, the index levels in Figure 1 show that the price movements of the S&P 100 and the S&P 500 are virtually indistinguishable. In fact, in terms of the subsequent analysis and interpretation in this paper, we view the price movements of the two cash indexes as substitutes. Second, Figure 1 shows that there is very little difference between the observed S&P 100 cash index and the S&P 100 index implied by option

[4] The 10:00 A.M., Eastern Standard Time (EST) starting time is used to ensure that the beginning of day cash index levels are not largely based on the previous day's closing prices.

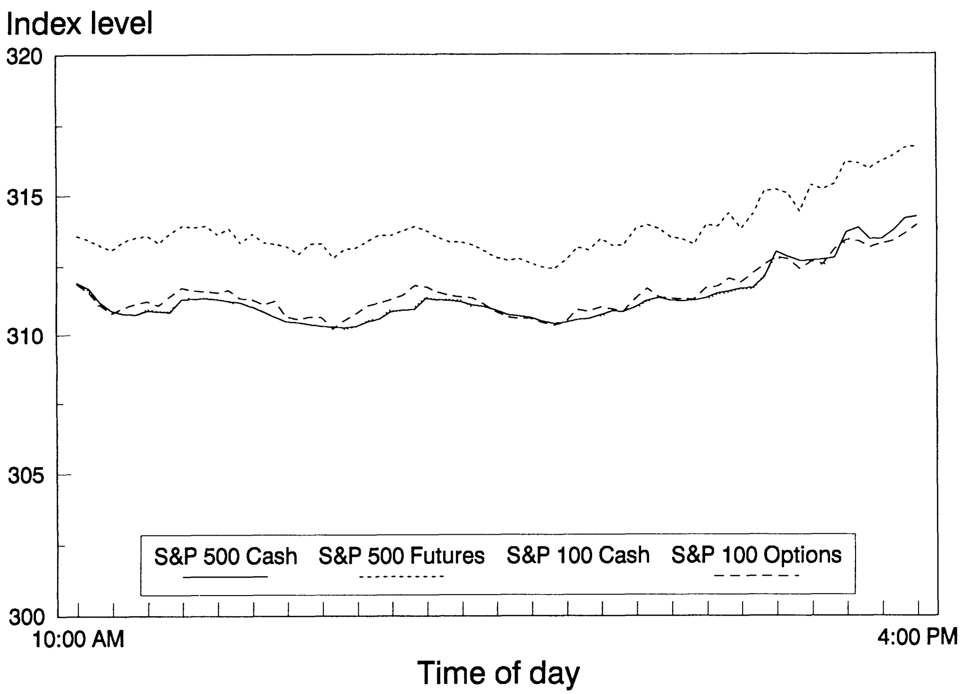

Figure 1. Index levels at five-minute intervals during the trading day, October 13, 1987. The figure contains the levels of the S&P 500 cash index and the December 1987 S&P 500 futures contract. The S&P 100 cash index level is normalized to the S&P 500 cash index level at 10:00 A.M. (EST). The implied S&P 100 index level is computed on the basis of November 1987 S&P 100 index option price quotes during each five-minute interval, and is normalized using the same proportionate adjustment as is used for the S&P 100 cash index.

prices during a typical trading day. The indexes move together throughout the day, with the average index levels appearing approximately the same. This result is consistent with the end-of-day results of Harvey and Whaley (1991), who report virtually no difference between the time series properties of daily closing actual and implied S&P 100 index levels. Third, there is an approximately constant vertical distance between the futures prices and those of the cash indexes during the day. This distance reflects the cost of carry noted earlier. Otherwise the lines appear very similar, although there is slight smoothing of the cash index relative to the futures, which is consistent with some nontrading in the stocks comprising the cash index.

In short, Figure 1 serves to confirm the premise of the Brady Report that under normal trading conditions prior to the crash, the cash, futures and option markets were highly integrated, despite their physical (and regulatory) separation. We now turn to October 19 and the breakdown of the usual integration across markets.

II. Stocks, Futures, and Options: October 19, 1987

Figure 2 provides results corresponding to those of Figure 1, but for October 19 rather than October 13. Again, both stock indexes are normalized to the 10:00 A.M. S&P 500 level. The implied S&P 100 index level does not appear until 12:30 P.M. since the S&P 100 options experienced an unusually long opening rotation.[5]

Figure 2 first provides evidence on the practical significance of the difference between the S&P 500 and S&P 100 indexes. In spite of the fact that the stock market was experiencing an unprecedented decline, the two cash indexes are still very similar, as under normal trading conditions.

When we turn to the relation between the futures and the cash markets, however, the situation on October 19 is dramatically different from normal. First, the notorious negative basis between the futures price and the observed cash indexes (either S&P 500 or S&P 100) is readily apparent, although there are three separate intervals: from open to about 11:00 A.M., during which the basis was negative; a brief period during which the basis was positive; then the period from about 11:00 to close, during which the basis remained negative and in general widened. Second, the observed cash indexes are much more highly smoothed relative to the futures contract than normal.

Figure 2 also presents new evidence on the breakdown between markets during the crash. We see that the implied S&P 100 index given by the options reflects a breakdown of the usual links between the cash and option markets. Although the implied index normally mirrors the observed index, on

[5] To permit an orderly opening for each S&P 100 option series, the CBOE rotates through each option series at the beginning of the day, opening one option at a time. Simultaneous open trading of S&P 100 options does not commence until all options have gone through rotation. On October 19, 1987, this occurred just after 12:30 P.M. (EST).

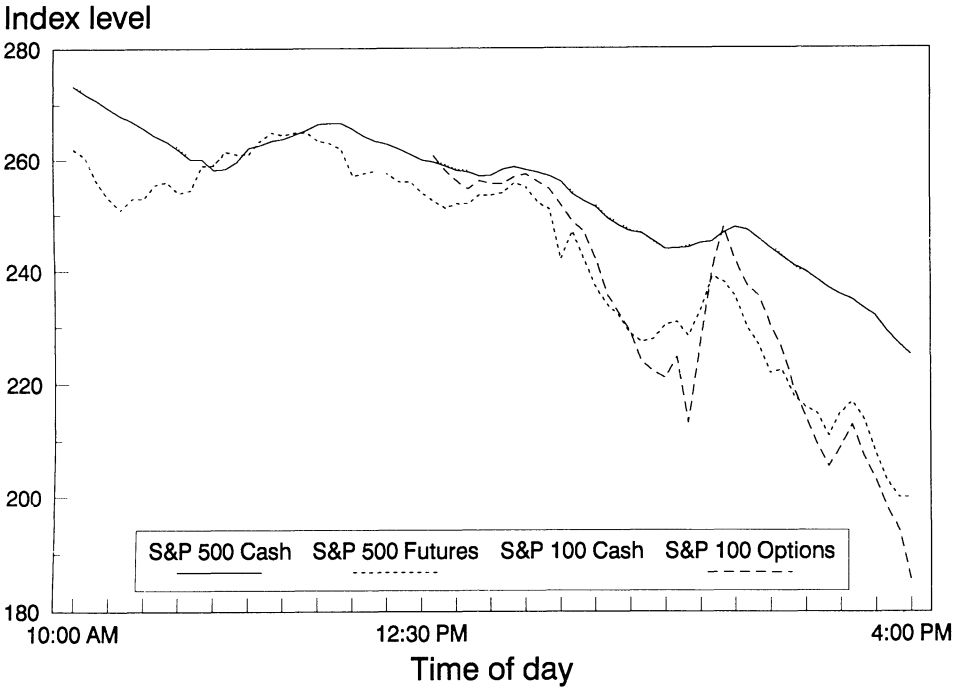

Figure 2. Index levels at five-minute intervals during the trading day, October 19, 1987. The figure contains the levels of the S&P 500 cash index and the December 1987 S&P 500 futures contract. The S&P 100 cash index level is normalized to the S&P 500 cash index level at 10:00 A.M. (EST). The implied S&P 100 index level is computed on the basis of November 1987 S&P 100 index option price quotes during each five-minute interval, and is normalized using the same proportionate adjustment as is used for the S&P 100 cash index.

October 19 there is a large discrepancy between the observed and implied indexes, with the implied index falling much more than the actual index. One interpretation is that the index levels implied by index option prices predict a decline in the index—this is precisely the counterpart to the negative basis between the cash and futures. Further, again as with the futures versus cash, there is much more short-term movement in the implied index than in the actual cash index.

Significantly for our current purposes, the movements of the implied S&P 100 index on October 19 closely match the S&P 500 futures index, but neither of the observed cash indexes. At 12:30 P.M., both S&P 500 futures and implied S&P 100 indexes fall, with the rate of decline being slightly higher for the S&P 100 index. Then, around 2:15 P.M., both indexes reverse and go up, with the rate of ascent slightly higher for the S&P 100 options. After about fifteen minutes, both indexes reverse once again and fall for the remaining part of the trading day. Even for the more minor reversals in the last hour of trading, the two indexes change direction simultaneously and move by about the same amount.

In summary, Figure 2 indicates that relative to normal conditions, both the option and futures markets appeared to be delinked from the cash market on October 19, although they largely retained their own usual integration. In response to the Brady Commission, then, it appears that is would be more accurate to say that the cash market was delinked from the other two markets than to assert a general market breakdown. As we show in the next section, there are good reasons to focus on the trading of stocks on the NYSE as the major cause of the apparent breakdowns between markets.

III. Cash Market: Liquidity and Stale Price Models

The causes of the "delinkage" between the stock and futures/option markets on October 19, 1987 have been the subject of frequent debate, particularly focusing on the effects of the extraordinarily high volume during this period. General liquidity effects tied to the cost of immediacy, such as discussed in Grossman and Miller (1988), were no doubt present during the crash. However, some more structure is necessary to explain the delinkages among markets.

The price pressure hypothesis of Blume, MacKinlay, and Terker (1989), for example, argues that differential price changes across stocks were caused by differential temporary order imbalances. While Blume et al. do not directly address the stock, futures and option markets, they extend arguments regarding the negative basis to differences between the S&P 500 index stocks and those NYSE stocks which are not in the S&P 500. Their rationale is that the negative basis indicated that the cash and futures markets became delinked because of the extreme conditions during the crash; perhaps subsets of NYSE stocks were also delinked. They find that S&P 500 stocks declined about seven percentage points more than non-S&P 500 stocks on October 19, and recovered almost all of this loss in the opening hours of trading on October 20. They conclude (p. 843) that their results "are consistent with, but do not prove, the hypothesis that S&P stocks fell more than warranted on October 19 because the market was unable to absorb the extreme selling pressure on those stocks."

In the International Stock Exchange of Great Britain (henceforth the London market), futures contracts also traded at a discount to the underlying cash index. The Quality of Markets Report discusses why such a discount existed between cash and futures markets. The Report states (Barrow et al., 1989, p. 336): "The question remains, 'Why did the discount occur?' It is too simplistic to say that the heavy selling pressure in the futures market caused the discount without asking why sellers were willing to accept a discount of typically five percent to the quoted index." Two reasons are suggested: first, sellers did not believe that they could sell in the cash market immediately and at the quoted prices, and second, sellers may not have believed that the cash market prices were real and available for trading. While the Report concludes that quoted prices were generally a good indicator of trading prices, it concedes that problems with access to the cash market may have led some investors "to deal in a discounted market because it was more accessible and so provided certainty of execution" (p. 336).

This analysis of the London market explicitly ties the observed discount to reasonable behavior on the part of participants, with an explanation that may well be relevant for at least some of the discount in the U.S. markets. However, it cannot provide the full explanation in the U.S., because such real discounts would not necessarily imply the serial correlation or cross-correlation with lagged futures that is seen in the S&P cash index. Further, the apparent discount between the S&P cash and futures index was considerably greater (about 14%) than in London, while that between non-S&P NYSE stocks and the futures index was more than 20%.

Another possible explanation for the delinkage is differential degrees of nontrading. For example, Blume et al.'s results could be explained by more rapid trading of S&P 500 stocks than non-S&P 500 stocks. More importantly, if this explanation were true, the negative basis on October 19 may have resulted merely from S&P 500 stocks trading less frequently on average than the S&P 500 futures. Official reports and individual studies exhaustively examined this possibility, and demonstrate that nontrading (more precisely, delayed openings) can explain the negative basis in Figure 2 from exchange opening to around 11:00 A.M. on October 19, when the cash and futures came together. The problem is that after about 11:00, when almost all stocks had opened for trading, the extreme order flow meant that virtually none of the negative basis was due to nontrading. This result is consistent across studies that use a variety of estimation procedures to account for nontrading.[6] Similarly, Blume et al. (1989) document that virtually none of the differences after 11:00 A.M. between the S&P cash index and the non-S&P index they construct can be attributed to nontrading.[7]

An alternative explanation is offered in Kleidon (1992). The unprecedented NYSE order flow on October 19, 20, and 21 caused long and variable delays between submission and execution of limit orders for constituent stocks in the cash index. Kleidon argues that these delays led to prices that did not fully reflect information at the time of execution. Across stocks, there were different degrees of nonsynchroneity relative to current information, which is assumed here to be accurately reflected in futures prices since the trading mechanism in the futures market means that buyers meet sellers directly (or at least through human agents) for each transaction. In contrast, electronic handling of orders on the NYSE allowed for delays between submission and execution, particularly for limit orders since the software allowing retrieval of limit orders did not function properly. The primary source of the relevant delays were printers at specialists' posts, which developed queues of up to 75 minutes by noon on October 19. Problems were particularly severe for limit

[6] See, e.g., Bassett, France, and Pliska (1989, 1990), Harris (1989), and SEC (1988).

[7] In particular, see Blume et al. (1989), Figure A1, p. 845, which shows that all adjustments for nontrading result in indexes indistinguishable from the unadjusted index after about 11:00, in contrast to the period from open until 11:00.

orders, which resulted in a succession of limit buy orders at prices which were determined prior to their arrival at the post, and hence based on prior information.

According to NYSE specialists, execution of these stale limit buy orders could result in stale prices that effectively held the price at a higher level than would have existed had there been no execution delays. Two possibilities exist which can lead to differential lags across stocks. First, depending on the timing of buy and sell orders and the degree of participation by the specialist out of inventory, the price could fall below the level set by limit buy orders, which would convert them to market buy orders. In such circumstances, since there would be effectively only market buy and market sell orders (limit sell orders are irrelevant here, since market sell orders would better the stale limit price), the price could lie anywhere in the range bounded above by the limit buy orders and below by the asks of potential sellers in the crowd (which will be based on more current information than the limit buy orders coming off the printers).

Second, differential delays for a stock could develop if the order flow is lumpy, so that limit orders on the specialists' books sometimes display some depth and sometimes are exhausted. Even if the specialist actively took the price down to the level implied by the current futures price when the book was exhausted, subsequent queues could again mean that the stock will trade with a lag. Differential order arrival across stocks will result in differential nonsynchroneity at any given time.

These two arguments imply active involvement on the part of the specialist if the stock is to trade at a price different from that given by stale limit buy orders. While each stock on the NYSE has only one specialist, each specialist can be responsible for many stocks. Stocks are allocated among specialists to give them a mixture of large, high volume stocks and stocks of lesser importance. For a specialist who is responsible for more than one stock—which means virtually every specialist—attention at any given time must be divided among competing stocks.

Given the volume of trade during the 1987 crash, it would not be surprising if more attention were devoted to the relatively more important stocks, which in the current context may well be S&P 500 stocks rather then non-S&P 500 stocks. Assuming that some form of financial triage occurred, we should expect differences in indexes created from those stocks with high priority versus those with lower priority. It seems reasonable to regard inclusion in the S&P 500 index as a good instrument for those stocks of relatively high priority during the crash. If so, then we have identified a specific source of the breakdown of usual linkages between S&P 500 and non-S&P 500 stocks that Blume et al. document.

A. Implications of the Liquidity and Stale Price Models

While price pressure and stale price explanations both predict that on October 19 the non-S&P 500 index will be higher than the S&P 500 (cash) index, the arguments are on opposite sides of the fence. The stale price model implies that the cash index was more current than the non-S&P index, so that the latter was too high given current information. The price pressure hypothesis of Blume et al. says that extreme selling of S&P 500 stocks caused that index to be too low. Also, although predictions about mean returns are similar, the price pressure and stale price models have different predictions about the higher order moments of returns.

To understand the different implications of the two models, recall that the stale price model explains the mean effects in terms of prices of individual stocks *not* reflecting current information at all times. At the individual stock level, returns would show little serial correlation if the stock traded with a roughly constant information lag throughout the day. However, differential degrees of staleness in prices across securities means that when individual stock returns are aggregated into index portfolio returns, positive serial correlation is induced in the index, and the "smoothing" of the index will decrease the estimated variance of portfolio returns. The portfolio returns of stocks with less staleness (say, S&P 500 stocks) will tend to lead those with a greater degree of staleness (non-S&P 500 stocks), and index futures and option returns, which did not experience the printer queues of the NYSE, will tend to lead the returns of individual stocks and stock portfolios.

By contrast, there is no necessity in the liquidity models for stocks to trade at prices that are based on old information, and hence there are no predictions from these models concerning higher order moments. While liquidity effects and stale prices are not necessarily mutually exclusive, neither Blume et al. (1989) nor the London Report suggest the existence of unusual behavior in higher order moments. If anything, they imply that prices are based on current information. The London Report attributes a discount in futures to easier access to that market, rather than mispricing in the cash market. Blume et al. regard the notion that S&P stocks reflected information more rapidly than non-S&P stocks as an "alternative" hypothesis, which suggests that information is reflected in both sets of stocks equally under the liquidity hypothesis, at least after accounting for nontrading. Blume et al. explicitly discuss the possibility that nontrading may mean that in "a rapidly changing market, some of these past prices may be stale and not reflect current conditions," discuss an approach to mitigate the problem, and conclude that after the first hour and a half of trading "this approach virtually eliminates the bias from stale prices" (p. 831).[8]

While there is no necessary inconsistency between liquidity and stale price effects, we assume that a pure liquidity model takes prices as reflecting current information (after accounting for nontrading), in order to contrast the implications of the two approaches. Consequently, if prices reflect all current information, we assume that both individual stocks and indexes constructed from those stocks should have returns which are uncorrelated with past

[8] Note that Blume et al. (1989) define stale prices solely in terms of nontrading, in contrast to the definition used in this paper.

returns—both their own and those of other series such as index futures and options.[9] The pure liquidity model's implication of zero serial and cross correlation in returns is in sharp contrast with the implications of the stale price model.

IV. Stocks, Futures, and Options: Empirical Evidence

This section presents detailed evidence on the relations among stocks, futures and options, under normal trading conditions and during the October 19, 1987 crash, in order to evaluate the price pressure and stale price arguments presented in Section III. First, we examine the evidence on the S&P 500 and non-S&P 500 index stocks. The individual stock returns are documented to be essentially serially uncorrelated. Next, we compare the higher order moments of the S&P 500 and S&P 100 cash indexes. Both series have strong serial correlation on October 19, and the S&P 100 returns tend to lead those of the S&P 500. The focus then turns to interrelations of the returns of the cash indexes with returns in the derivative security markets. The S&P 500 futures returns are serially uncorrelated (as are individual stocks) and tend to lead S&P 500 cash index portfolio returns, while *implied* S&P 100 index returns are also serially uncorrelated (as are individual stocks) and tend to lead S&P 100 cash index portfolio returns. Moreover, the return relation between the S&P 500 futures and the implied S&P 100 index is predominantly contemporaneous. Based on these results, the conclusion is that the major source of breakdown between markets is the cash market, and the results confirm the importance of the physical order processing problems on the NYSE.

A. S&P 500 Stocks and Non-S&P 500 Stocks

Table I documents the higher order moments of five-minute intraday returns for the S&P 500 and non-S&P 500 stocks for October 1–15 and October 19, 1987.[10] For October 19, all statistics are calculated from 11:00

[9] While in principle expected returns need not be unpredictable, this assumption is reasonable given the short time intervals in question, the lack of predictability of futures returns, and the fact that, based on past movements in the cash indexes, futures prices and option prices, the predicted return on the cash indexes was typically *negative* on October 19.

[10] The original individual stock transaction data were kindly provided by the SEC, and were carefully checked for errors. All corrections indicated by the transactions codes were checked and carried out. For October 1 to 15, of 639,964 records, 1,539 error codes indicated corrections; the corresponding numbers for October 19 are 204,241 and 525. Further, after flagged corrections were made, the prices used to create five-minute returns were filtered for any additional unflagged errors, and all prices failing the filters were hand checked and corrected or deleted as appropriate. For S&P 500 stocks, October 1–15, all absolute returns exceeding 5% were investigated; of 29 stocks which violated the filter (some with multiple violations, particularly in low priced stocks), two errors were corrected. For October 19, all absolute returns exceeding 20% were checked, and in fact all apparent errors exceeded 30% (absolute). The filter was violated by 19 stocks (with frequent multiple violations for low priced stocks); 14 errors were corrected. October 16 was not used in individual calculations since many data were missing or corrupted in our database.

A.M. to close to eliminate any nontrading effects. Results for five-minute return standard deviations and autocorrelations are presented for those individual stocks which had no missing five-minute returns after trading commenced. The means of the distributions of the statistics across the individual stocks are given for October 1–15 and for October 19.

Both the liquidity and stale price explanations of cash market behavior on October 19 are consistent with individual stock returns having zero autocorrelation. The results in Table I corroborate this result. The panel showing serial correlation coefficients (for five-minute returns) gives mean coefficients for stocks both in and out of the S&P 500 that are close to zero for October 19. For example, the mean first-order autocorrelation coefficient for S&P 500 stocks is 0.12, while that for non-S&P 500 stocks is -0.05. Note that during October 1–15, the mean first-order autocorrelation is -0.15 for stocks in the S&P 500 index, which is usually attributed to bid-ask bounce. On October 19, the mean coefficients are closer to zero for both S&P 500 and non-S&P 500 stocks, which may indicate mitigation of bid-ask bounce; two possibilities are that specialists were actively maintaining continuity, or that given the order flow on October 19 there was simply less bounce than usual. In any event, the results are consistent with the predictions of both the liquidity and stale price models: individual stocks have essentially zero autocorrelation on October 19.

B. S&P 500 and S&P 100 Cash Indexes

The pure liquidity model's prediction concerning autocorrelation in the index is opposite the stale price model's. The former predicts that indexes constructed from stocks without nontrading problems (after 11:00 A.M. on October 19, for example) will also have zero autocorrelation. In contrast, the stale price model predicts that although individual stocks may have uncorrelated returns, they are differentially displaced relative to current information, so that an index will be based on current and past information which induces positive serial correlation.

The five-minute, intraday return series are computed for the S&P 500 and S&P 100 indexes in each day of the sample period October 1–15 and October 19, 1987. All results for October 19 are calculated from 12:30 P.M. to close, the period over which the S&P 100 index options were actively traded on October 19.

Table II shows that the standard deviation of the five-minute S&P 100 index returns is higher than the standard deviation of the S&P 500 index returns in both the pre-crash and crash periods. This result may be driven by the fact that the S&P 500 index portfolio is more well-diversified than the S&P 100. The lag 1 and 2 serial correlation coefficients are somewhat higher during the October 1–15 period for the S&P 500 index (0.37 and 0.11) than for the S&P 100 index (0.28 and 0.08). In all likelihood, this difference is attributable to less frequent trading of stocks in the S&P 500 index than those in the S&P 100 index.

On October 19, both the lag 1 and lag 2 serial correlations are dramatically higher for the S&P 500 (0.72 and 0.48) and S&P 100 indexes (0.60 and 0.40)

Table I

Mean Standard Deviation and Serial Correlation of Five-Minute Intraday Returns for S&P 500 and Non-S&P 500 Stocks During the Period October 1 Through 15, 1987 and During October 19, 1987

The sample contains all NYSE stocks with no missing five-minute returns during October 1–15 and October 19, 1987. The sample size is 1,159 companies for S&P 500 companies during the period October 1–15 and 278 S&P 500 companies and 66 non-S&P 500 companies on October 19. All returns are calculated over the interval 9:30 A.M.–4:00 P.M. during the period October 1–15 and 11:00 A.M.–4:00 P.M. on October 19. The approximate standard error of the serial correlation coefficients under the null hypothesis of zero correlation is 0.12.

		October 1–15, 1987	October 19, 1987	
		S&P 500 Stocks	S&P 500 Stocks	Non-S&P 500 Stocks
Standard deviation (%)		0.46	1.18	1.59
Serial correlations				
Lag k	1	−0.15	0.12	−0.05
	2	−0.05	0.10	0.02
	3	−0.05	0.07	−0.01
	4	−0.03	0.05	−0.02
	5	−0.03	0.01	−0.05
	6	−0.03	−0.01	−0.03

than in the October 1–15 period. These results are seen even in indexes specifically constructed to eliminate the effects of nontrading (e.g., see Harris (1989, Figures 5–7)). However, the difference between the serial correlation functions is consistent with the predictions of the stale price model, which implies that stocks in the index are differentially displaced relative to current information. An observed index that is based on current and past information, as was likely the case on October 19, should exhibit positive serial correlation in returns. Moreover, the positive serial correlation should be higher where the differential displacement of information is greatest (the S&P 500 index with its smaller capitalization stocks).

The cross correlations of S&P 100 returns with S&P 500 returns at lag k show that the rates of return of the two indexes are very close substitutes. The contemporaneous correlation is 0.95 for October 1–15 and 0.93 on October 19. Even during the crash, these two indexes were closely linked (presumably due to overlapping index composition). Significant positive correlation at negative lags indicates that there is a tendency for the S&P 100 index returns to lead the returns of the S&P 500 index. The lag -1 coefficient in the October 1–15 subperiod is 0.40, and, during October 19, the lag -1 cross correlation is 0.74. The positive cross correlation at low positive lags indicates that the S&P 500 returns occasionally lead the S&P 100 returns, although the S&P 100 index on balance tends to lead the S&P 500 index.

Table II

Standard Deviation, Serial Correlation, and Cross-Correlation of Five-Minute Intraday Returns for S&P 500 and S&P 100 Cash Indexes During the Period October 1 Through 15, 1987 and During October 19, 1987

Five-minute intraday returns are computed for the S&P 500 and S&P 100 cash indexes over the interval 10:00 A.M.–4:00 P.M. during the period October 1–15 and 12:30–4:00 P.M. on October 19. Note that with each additional lag during the October 1–15 period, the number of returns in the correlation coefficient computations drops by 11, the number of trading days. The approximate standard error of the serial correlation coefficients under the null hypothesis of zero serial correlation is $1/\sqrt{n}$, where n is the number of observations used in the computation. Cross correlations are for the S&P 500 cash index return with the S&P 100 cash index return at lag k. The approximate standard error of the cross correlation coefficients under the null hypothesis of zero cross correlation is $\sqrt{(1 + 2\rho_{SP500}\,\rho_{SP100})/n}$, assuming only first-order serial correlation in the S&P 500 (ρ_{SP500}) and S&P 100 (ρ_{SP100}) index returns.

		October 1–15, 1987			October 19, 1987		
		No. of Observations	S&P 500 Cash	S&P 100 Cash	No. of Observations	S&P 500 Cash	S&P 100 Cash
Standard deviation (%)		814	0.09	0.11	41	0.40	0.53
Serial correlations							
Lag k	1	803	0.37	0.28	40	0.72	0.60
	2	792	0.11	0.08	39	0.48	0.40
	3	781	0.03	0.00	38	0.30	0.22
	4	770	0.02	0.02	37	0.17	0.03
	5	759	0.02	0.02	36	−0.04	−0.08
	6	748	−0.01	−0.02	35	−0.24	−0.29
Cross correlations							
Lag k	−6	748	−0.00		35	−0.23	
	−5	759	0.05		36	−0.02	
	−4	770	0.04		37	0.15	
	−3	781	0.04		38	0.32	
	−2	792	0.15		39	0.52	
	−1	803	0.40		40	0.74	
	0	814	0.95		41	0.93	
	1	803	0.26		40	0.61	
	2	792	0.05		39	0.34	
	3	781	−0.01		38	0.21	
	4	770	0.01		37	0.06	
	5	759	−0.00		36	−0.14	
	6	748	−0.03		35	−0.32	

C. S&P 500 Cash and S&P 500 Futures

Table III documents the properties of the S&P 500 cash index returns and S&P 500 futures returns. Unlike the S&P 500 cash index, the S&P 500 futures autocorrelation coefficients are not significantly different from zero. In the case of the futures, the nontrading and stale price problems are nonexistent.

Table III

Standard Deviation, Serial Correlation, and Cross Correlation of Five-Minute Intraday Returns for S&P 500 Cash and S&P 500 Futures During the Period October 1 Through 15, 1987 and During October 19, 1987

Five-minute intraday returns are computed for the S&P 500 and S&P 500 futures over the interval 10:00 A.M.–4:00 P.M. during the period October 1–15 and 12:30–4:00 P.M. on October 19. Note that with each additional lag during the October 1–15 period, the number of returns in the correlation coefficient computations drops by 11, the number of trading days. The approximate standard error of the serial correlation coefficients under the null hypothesis of zero serial correlation is $1/\sqrt{n}$, where n is the number of observations used in the computation. Cross correlations are for the S&P 500 cash index return with the S&P 500 futures return at lag k. The approximate standard error of the cross correlation coefficients under the null hypothesis of zero cross correlation is $1/\sqrt{n}$, assuming zero serial correlation in the futures returns.

		October 1–15, 1987			October 19, 1987		
		No. of Observations	S&P 500 Cash	S&P 500 Futures	No. of Observations	S&P 500 Cash	S&P 500 Futures
Standard deviation (%)		814	0.09	0.13	41	0.40	1.39
Serial correlations							
Lag k	1	803	0.37	0.06	40	0.72	0.16
	2	792	0.11	0.02	39	0.48	0.07
	3	781	0.03	0.08	38	0.30	−0.04
	4	770	0.02	0.01	37	0.17	−0.08
	5	759	0.02	−0.02	36	−0.04	−0.01
	6	748	−0.01	0.02	35	−0.24	−0.09
Cross correlations							
Lag k	−6	748	−0.02		35	0.12	
	−5	759	0.04		36	0.04	
	−4	770	0.05		37	0.09	
	−3	781	0.12		38	0.31	
	−2	792	0.18		39	0.60	
	−1	803	0.63		40	0.59	
	0	814	0.50		41	0.30	
	1	803	0.06		40	0.24	
	2	792	0.00		39	0.07	
	3	781	0.04		38	−0.03	
	4	770	0.03		37	−0.29	
	5	759	−0.01		36	−0.21	
	6	748	−0.02		35	−0.16	

The striking differences in the standard deviations of return on October 19 between the cash and the futures reported in Table III lends support to the stale price model. If the prices of the stocks in the cash index are differentially lagged relative to that of the futures, the (smoothed) index standard deviation will be lower than that of the futures.[11] Table III shows that the standard deviation of the S&P 500 futures (1.39) is more than three times that of the underlying S&P 500 cash index (0.40).

[11] See Kleidon (1992), Proposition 1.

The first-order serial correlation of the S&P 500 futures returns during the October 1–15 period (0.06) is not significantly different from zero. This result is consistent with the individual stock results reported in Table I, since both individual stock and futures returns appear to be unpredictable. The fact that the serial correlation is positive for the futures and negative on average for the individual stocks in the S&P 500 indicates that the bid/ask spread contributes less to return variability for the futures than for individual stocks. As for individual stocks in the S&P 500, the first-order serial correlation of the futures returns is positive on October 19. While the coefficient is not statistically significant, the positive sign may be a reflection of unusual order flow on October 19.

The cross correlation results also support the stale price hypothesis. The pure liquidity model predicts that the returns of individual stocks and hence the S&P 500 cash index will have zero correlation with lagged futures returns in the absence of nontrading problems, while the stale price model predicts positive correlation with lagged futures beyond that induced by nontrading. Table III shows that the S&P 500 futures returns lead the S&P 500 cash index returns. During the October 1–15 period, the lag −1 cross correlation coefficient, 0.63, is, in fact, higher than the contemporaneous coefficient, 0.50.[12] On October 19, the first-, second-, and third-order lagged correlations (0.59, 0.60, and 0.31, respectively) are greater than the contemporaneous correlation (0.30), documenting significant delays in the stock market.

D. Observed and Implied S&P 100 Index Levels

Next, we compare the returns of the S&P 100 cash index with those of the implied S&P 100 index. Estimates of the S&P 100 index level are obtained using the methodology described in the Appendix. Table IV contains the standard deviations, serial correlations and cross correlations of the five-minute, intraday return series.

Several observations are pertinent. First, during October 1–15, the standard deviation of the observed index returns (0.11%) is lower than that of the implied returns (0.16%). One explanation is that nontrading of S&P 100 stocks tends to smooth the price movements of the cash index, thereby reducing the measured standard deviation of cash index returns. Another explanation is that the standard deviation of the implied index returns is overstated as a result of noise in the estimation of the implied index level.

The difference between the return standard deviations is even more striking on October 19. The S&P 100 cash index standard deviation (0.53%) is less than one fourth of that of the implied S&P 100 index (2.24%). Here, the nontrading explanation must be ruled out since most stocks were very actively traded. On the other hand, we have already argued that differentially stale prices on October 19 can smooth cash index price movements and

[12] Stoll and Whaley (1990) document the lead/lag behavior of the S&P 500 futures/cash relation after adjusting for nontrading of index stocks.

Table IV

Standard Deviation, Serial Correlation, and Cross Correlation of Five-Minute Intraday Returns for S&P 100 Cash and Implied S&P 100 Indexes During the Period October 1 Through 15, 1987 and During October 19, 1987

Five-minute intraday returns are computed for the S&P 100 cash and implied S&P 100 indexes over the interval 10:00 A.M.–4:00 P.M. during the period October 1–15 and 12:30–4:00 P.M. on October 19. The implied S&P 100 index levels are computed by simultaneously estimating the index level and index volatility from all S&P 100 bid/ask quotes during each five-minute interval during the trading day. Note that with each additional lag during the October 1–15 period, the number of returns in the correlation coefficient computations drops by 11, the number of trading days. The approximate standard error of the serial correlation coefficients under the null hypothesis of zero serial correlation is $1/\sqrt{n}$, where n is the number of observations used in the computation. Cross correlations are for the S&P 100 cash index return with the implied S&P 100 index return at lag k. The approximate standard error of the cross correlation coefficients under the null hypothesis of zero cross correlation is $1/\sqrt{n}$, assuming zero serial correlation in the implied index returns.

		October 1–15, 1987			October 19, 1987		
		No. of Observations	S&P 100 Cash	Implied S&P 100	No. of Observations	S&P 100 Cash	Implied S&P 100
Standard deviation (%)		814	0.11	0.16	41	0.53	2.24
Serial correlations							
Lag k	1	803	0.28	0.08	40	0.60	0.27
	2	792	0.08	0.06	39	0.40	0.08
	3	781	0.00	0.14	38	0.22	−0.06
	4	770	0.02	−0.00	37	0.03	0.09
	5	759	0.02	0.02	36	−0.08	−0.16
	6	748	−0.02	−0.03	35	−0.29	−0.26
Cross correlations							
Lag k	−6	748	−0.02		35	−0.07	
	−5	759	0.02		36	−0.08	
	−4	770	0.00		37	−0.19	
	−3	781	0.03		38	0.05	
	−2	792	0.13		39	0.50	
	−1	803	0.46		40	0.49	
	0	814	0.55		41	0.46	
	1	803	0.24		40	0.40	
	2	792	0.12		39	0.39	
	3	781	0.04		38	0.26	
	4	770	0.02		37	−0.07	
	5	759	0.05		36	−0.12	
	6	748	−0.03		35	−0.19	

hence reduce observed return volatility, consistent with the increased difference between the standard deviations of the S&P 100 cash and implied S&P 100 returns.

Second, the estimated serial correlation coefficients of the implied index returns show expected patterns in both the October 1–15 and October 19 periods. Since the implied index level is based on the price of only one security—the index option—the effects of neither infrequent trading nor stale prices should appear. In the October 1–15 period, the first-order serial correlation (0.08) is marginally significant, but not much larger than the serial correlation in the futures during the same period (0.06). On October 19, the first-order serial correlation is larger (0.27), as it was for the S&P 500 futures and the individual stocks, but it is not statistically significant at conventional levels.

Third, the cross correlation results of the cash index returns and the implied index returns at lag k are consistent with the results from Table III. For the October 1–15 period, the strongest associations between the S&P 100 cash index and the implied S&P 100 index are at lags 0 and -1, just as they were in the case of the S&P 500 cash/S&P 500 futures. The contemporaneous correlation between the observed and the implied index returns is 0.55, while the lag -1 cross correlation is 0.46.[13] In other words, although there appears to be a strong contemporaneous association between the two series of index returns, there is also a strong tendency for the implied index to lead the observed index.[14]

As for the S&P 500 cash index/S&P 500 futures, the dependence of the S&P 100 cash index on the implied S&P 100 index lasts longer on October 19. For example, instead of leading by five minutes as during October 1–15, the implied index returns appear to lead by at least ten minutes on October 19. In fact, the lag -2 cross correlation coefficient is largest (0.50), followed by the lag -1 coefficient (0.49), and finally by the contemporaneous coefficient. However, as for the S&P 500 results, the effect does not appear to be completely unidirectional. The lag 1 and 2 coefficients are smaller but nonetheless statistically significant.

As a postscript to this analysis, it is interesting to note the intraday behavior of the implied market volatilities obtained from our estimation procedure. Figures 3 and 4 show estimated market volatility by time of day on October 13 and 19, 1987, respectively. First, with respect to October 13 (a typical trading day), the implied volatility obtained using the observed index level appears to have about the same level on average as the implied volatility obtained by simultaneously estimating volatility and the index level. This is simply another way of showing that the observed S&P 100 index level is approximately equal to the implied S&P 100 index level. Second, the volatility series obtained using the observed index has greater dispersion than the series obtained by simultaneous estimation of the index

[13] Although the leading effect of the implied S&P 100 index appears to be less than for the S&P 500 futures, Table IV shows how well the S&P 100 returns are predicted and Table III shows how well the S&P 500 returns are predicted. We established in Table II that the S&P 100 returns tend to lead the S&P 500 returns.

[14] Stephan and Whaley (1990) document the opposite effect for stock options, that is, observed stock price changes appear to lead stock price changes implied by option prices for CBOE options. One explanation is that informed investors tend to trade in markets that are the deepest and most liquid. In the case of firm-specific information, the deepest and most liquid market tends to be the stock market. In the case of market information, the S&P 100 index options and S&P 500 futures markets tend to dominate.

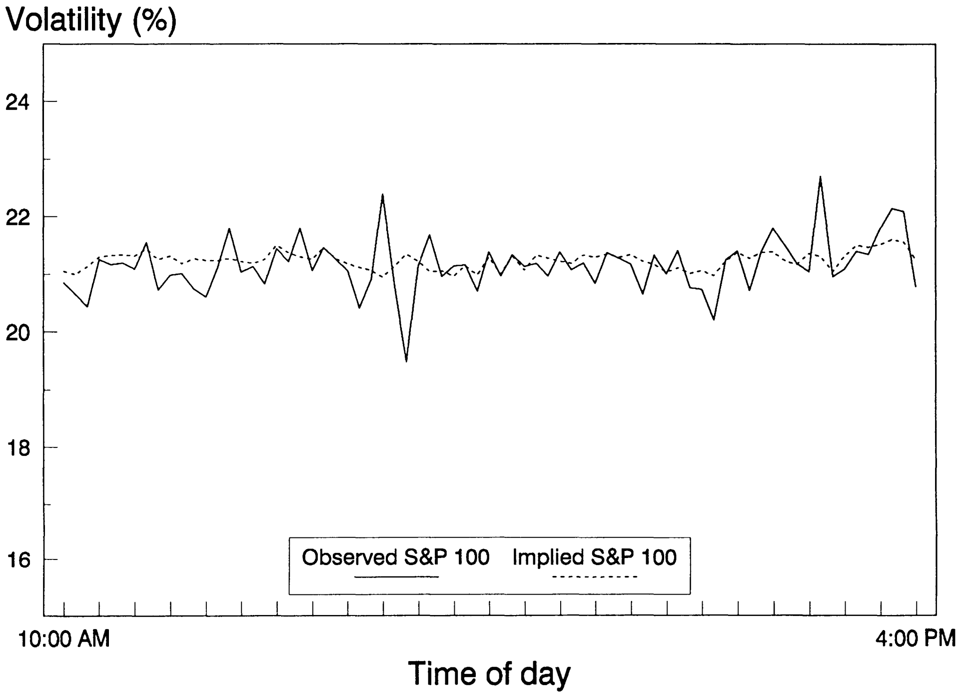

Figure 3. Implied S&P 100 return volatilities at five-minute intervals during the trading day, October 13, 1987. The implied S&P 100 volatilities are computed on the basis of November 1987 S&P 100 index option price quotes during each five-minute interval. The figure contains two implied volatility estimates: one computed by solving for implied volatility using the observed S&P 100 index level at the time of each price quote, and the other computed by simultaneously solving for the implied S&P 100 index level and its volatility.

level and volatility. One explanation of the apparent mean reversion is nontrading in the stocks that comprise the index. The behavior of the volatility series based on the observed index is analogous to spurious but predictable behavior in the S&P 500 futures basis that Miller, Muthuswamy, and Whaley (1991) ascribe to nontrading. Third, the October 19 volatility results shown in Figure 4 are comparable with the October 1–15 results in Figure 3. The volatility series based on the observed index levels has greater dispersion and mean reversion than the series based on simultaneous estimation. It is also noteworthy that although market volatility, as reflected through index option prices, increased dramatically during the trading day on October 19, the closing volatility estimated using the observed index level was considerably greater than that estimated solely from option prices.

E. Implied S&P 100 Index Levels and S&P 500 Futures

Our final analysis examines the time series properties of the implied S&P 100 index returns vis-à-vis S&P 500 futures returns. Here, the nontrading and stale price contaminants should be absent. The direct comparison of the

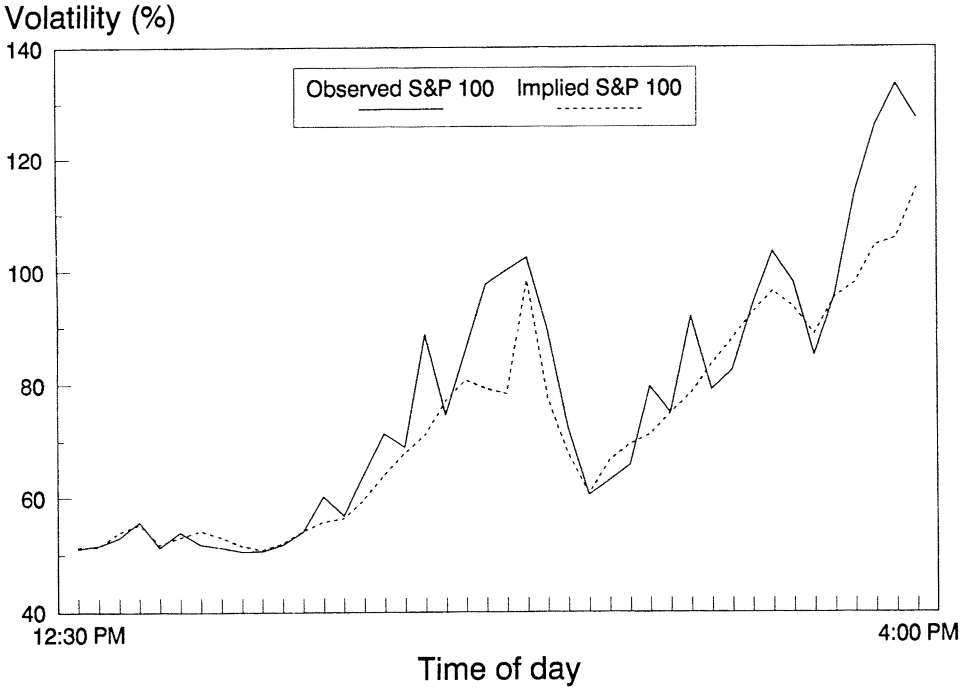

Figure 4. Implied S&P 100 return volatilities at five-minute intervals during the trading day, October 19, 1987. The implied S&P 100 volatilities are computed on the basis of November 1987 S&P 100 index option price quotes during each five-minute interval. The figure contains two implied volatility estimates: one computed by solving for implied volatility using the observed S&P 100 index level at the time of each price quote, and the other computed by simultaneously solving for the implied S&P 100 index level and its volatility.

return series in Table V indicates that the standard deviation of implied index returns is higher than that of the futures returns in both the October 1–15 period and on October 19. As noted above, some of this difference, particularly on October 19, may be attributable to estimation error in the implied S&P 100 index levels.

The cross correlation results indicate that during normal times the S&P 500 futures returns have a slight tendency to lead the implied S&P 100 index returns. The dominant relation between these two derivative markets is, of course, at the contemporaneous level, with a correlation of 0.61. At lag -1, however, the coefficient is 0.28. A possible explanation for the slight lead is that traders in the S&P 100 market price S&P 100 options on the basis of the S&P 500 futures rather than the observed S&P 100 index level, because the observed index is a stale indicator of true value (due to nontrading of stocks within the index under normal conditions).

The October 19 results for the standard deviation, serial correlations and cross correlations have interpretations similar to the October 1–15 period, although the magnitudes of the estimated parameters are higher. There appears to be a slight increase in the lead of the futures market over the

Table V

Mean, Standard Deviation, Serial Correlation, and Cross Correlation of Five-Minute Intraday Returns for Implied S&P 100 Index and S&P 500 Futures During the Period October 1 Through 15, 1987 and During October 19, 1987

Five-minute intraday returns are computed for implied S&P 100 index and S&P 500 futures over the interval 10:00 A.M.–4:00 P.M. during the period October 1–15 and 12:30–4:00 P.M. on October 19. Note that with each additional lag during the October 1–15 period, the number of returns in the correlation coefficient computations drops by 11, the number of trading days. The approximate standard error of the serial correlation coefficients under the null hypothesis of zero serial correlation is $1/\sqrt{n}$, where n is the number of observations used in the computation. Cross correlations are for the implied S&P 100 index return with the S&P 500 futures return at lag k. The approximate standard error of the cross correlation coefficients under the null hypothesis of zero cross correlation is $1/\sqrt{n}$, assuming zero serial correlation in the index and futures returns.

		October 1–15, 1987			October 19, 1987		
		No. of Observations	Implied S&P 100	S&P 500 Futures	No. of Observations	Implied S&P 100	S&P 500 Futures
Standard deviation (%)		814	0.16	0.13	41	2.24	1.39
Serial correlations							
Lag k	1	803	0.08	0.06	40	0.27	0.16
	2	792	0.06	0.02	39	0.08	0.07
	3	781	0.14	0.08	38	−0.06	−0.04
	4	770	−0.00	0.01	37	0.09	−0.08
	5	759	0.02	−0.02	36	−0.16	−0.01
	6	748	−0.03	0.02	35	−0.26	−0.09
Cross correlations							
Lag k	−6	748	0.02		35	−0.15	
	−5	759	−0.01		36	0.11	
	−4	770	0.06		37	0.24	
	−3	781	0.05		38	0.18	
	−2	792	0.15		39	0.14	
	−1	803	0.28		40	0.41	
	0	814	0.61		41	0.62	
	1	803	0.16		40	0.20	
	2	792	0.04		39	−0.15	
	3	781	0.01		38	−0.18	
	4	770	0.03		37	−0.29	
	5	759	0.01		36	−0.09	
	6	748	−0.02		35	−0.17	

option market. The highest cross correlation between the rate of return series remains the contemporaneous correlation, but the lag −1 coefficient increases from 0.28 in the October 1–15 period to 0.41 on October 19.

F. Summary of Results Across Markets

The analyses of returns from the stock, futures and option markets conducted in this section all point toward the stale price model as being a reasonable explanation of cash market behavior on October 19, 1987. The behavior of individual S&P 500 and non-S&P 500 stocks, together with indexes from the cash, futures and option markets, clearly support the predictions of the stale price model in both means and, significantly, higher order moments.

While it is quite likely that there were some liquidity related price effects during the crash, the observed higher order moments of returns on October 19 are simply inconsistent with a pure price pressure hypothesis that does not account for some form of nonsynchronous pricing in the absence of nontrading. In spite of the fact that stocks traded more or less continuously after 11:00 A.M. (EST), index returns exhibit large positive serial correlation, in contrast to individual stocks, index futures and options.

Two other issues also deserve discussion. First, much of the support for the liquidity model in Blume et al. (1989) came from the fact that the S&P 500 index opened higher on Tuesday than it closed on Monday, whereas the non-S&P 500 index opened at roughly the same level as it closed (see Blume et al., p. 832). However, an equally plausible explanation is that favorable information was released overnight, leading to higher opening prices for the S&P 500 stocks. Certainly there were information releases which could account for this increased confidence; for example, prior to the open of trading on October 20, "the Fed staff in Washington released Chairman Alan Greenspan's statement pledging to supply liquidity during the crisis" (Metz (1988), p. 173).[15] Further, the stale price model implies that processing lags will develop after trading begins; at open of trade, since backlogs from the previous day do not carry forward, the prices of the futures and individual stocks should be based on current information. This implies that the futures, the cash and the non-S&P indexes *should* have begun on Tuesday at about an equal level, as they did.15

Second, Blume et al. (1989) emphasize that stocks with the greatest price declines on Monday had the greatest recovery on Tuesday. Again, however, if new (favorable) information arrived between Monday close and Tuesday open, and if the futures reflected current information at Monday close, then we would expect the futures to rise between close and open. Further, the stale price model predicts that the cash index will fall on Monday less than the futures, and also, as developed in this paper, it explains why the non-S&P 500 index may fall less than the S&P 500 cash index; yet it predicts that the futures, the cash, and the non-S&P index should open at the same level on Tuesday. These statements together imply that greatest recovery on Tuesday morning for those stocks which fell the most on Monday is consistent with both the liquidity and stale price models, and so does not distinguish between them.

V. Conclusions

This paper provides new evidence regarding the degree of integration among the markets for stocks, futures and options. In particular, we

[15] The Brady Report (1988, p. v) also noted: "Timely intervention by the Federal Reserve System provided confidence and liquidity to the markets and financial system."

reexamine price and return behavior in the days prior to and during the October 1987 market crash. Where previous analyses of market behavior have resulted in recommendations for the implementation of circuit breakers, the coordination of margin requirements across markets, and changes in regulatory jurisdiction, we suggest that delinkage between markets during the crash was primarily caused by an antiquated mechanism for processing stock market orders.

The empirical results of this paper support three primary conclusions. First, under normal trading conditions, the stock, futures, and option markets are highly integrated and essentially one market. Our investigations of return behavior of stocks, index futures, and index options during the first half of October 1987 show that usually price movements in one market are virtually simultaneously mirrored in the others.

Second, during the October 1987 crash, this usual integration broke down, but the problem largely lay with the stock market. The usual links between the futures and option markets were largely intact. By contrast, both the futures and option markets were delinked from the cash market, which showed price levels much higher than those in either of the other markets, and unusual higher order moment behavior (variances, autocovariances, and lagged cross correlations with futures).

Third, the stale price model of Kleidon (1992) accurately predicts the behavior observed for the stock market on October 19, 1987. Analyses of stock return variances and autocovariances, and lagged cross correlations of stock returns with futures and option returns, point to a slowness in the processing of orders in the cash market. By contrast, the pure price pressure argument cannot completely explain cash market behavior during the crash, as shown by the observed higher order moments of returns. Something like the stale price argument is necessary to explain them, even if the mean effects were entirely attributable to price pressure. However, once the stale price model is accepted to explain higher order moments, it simultaneously delivers a substantial negative basis, without any assumption of price pressure (see Kleidon (1992), Fig. 2).

The failure of stocks, stock index futures and stock options to act as one on October 19, 1987 was not caused by the fact that these markets have different regulatory authorities. Indeed, the results reported in this study indicate that the changes in regulatory authority recommended in the Brady Report are misplaced. With order queues in printers at the specialists' posts being up to seventy-five minutes long by noon on October 19, eventual stock transaction prices were stale relative to their true values, resulting in a delinkage between markets. But the delinkage was between the stock market and the markets for derivative instruments, not between the different derivative instrument markets. Consequently the breakdowns were not tied to regulatory authority, since the SEC had jurisdiction over both stock and option markets which were delinked, while the integrated options and futures markets were regulated by the SEC and CFTC, respectively. The answer to the market integration issue, at least as evidenced by the crash, appears to lie in developing more efficient means of trade order execution in the stock market, rather than in imposing a common regulatory structure.

Appendix: S&P 100 Index Levels Implied By Option Prices

The estimation of the true S&P 100 index level involves the simultaneous estimation of both the index level and the index return volatility. The estimation is performed using all S&P 100 index option prices in five-minute intervals centered on the five-minute markings of a clock. For example, the 10:00 A.M. (EST) interval contains all prices of S&P 100 options in the interval from 9:57:30 through 10:02:29 A.M. The estimates of market volatility and the index level are computed by performing a nonlinear regression of the option prices on model prices in each five-minute interval, that is,

$$v_j = v_j(\hat{S}, \hat{\sigma}) + \varepsilon_j, \tag{A1}$$

where v_j represents the observed price of the option, $v_j(\hat{S}, \hat{\sigma})$ is the model's price (where all arguments with the exception of the index level $\hat{S}$ and the volatility $\hat{\sigma}$ are known) and ε_j is a random disturbance. The structural form of $v_j(S, \sigma)$ is the dividend-adjusted binomial method as used by Harvey and Whaley (1992a). Note that we are implicitly assuming that the volatility and the index level are constant across the five-minute interval, and that the average timing of the estimation is the center of the interval (which allows us to match the implied index levels to the five-minute observed S&P 500 and S&P 100 index levels and the S&P 500 futures prices).

The model price $v_j(S, \sigma)$ has four determinants other than S and σ. The exercise price X and the time to expiration T are terms of the option contract. A maximum of six different options are used in the estimation procedure each day. These are determined by the three closest at-the-money call and put options as of the beginning of the day.[16] Only November 1987 S&P 100 option contracts are used. The sample includes all option prices during October 1–15 and October 19, 1987.[17]

The S&P 100 option prices were obtained from the Chicago Board Options Exchange's Market Data Retrieval (MDR) file. The file contains both records of time-stamped transactions and time-stamped bid/ask quotes. On each record is the observed cash index level at the time the transaction or bid/ask quote was entered into the MDR system. In terms of our analysis, establishing the times of the option price observations is critical. For this reason, we use only bid/ask price quotes. These quotes are recorded instantly as they are heard on the exchange floor. The transaction prices appearing in the file, on the other hand, have time stamps that may be a few minutes or more after the transaction has taken place. This delay occurs because the ticket has to

[16] On October 19, 1987, for example, the S&P 100 index level opened at 274.13. The exercise prices used in the estimation procedure on October 19 were therefore 270, 275, and 280.

[17] Initially, October 20 was also included in the sample. It was later deleted because the S&P 100 index option market did not trade continuously until late in the afternoon.

be filled out and carried to the transaction reporter, who, in turn, must enter the ticket information (price and volume) into the MDR system.

Aside from the option prices, which we take to be the average of the bid and ask price quotes, the estimation procedure requires values of the riskless rate of interest and the dividends paid during the option's life. The riskless rates used in the option valuation formula were for the T-bill maturing on November 26, 1987. These rates were computed on the basis of the bid and ask discounts appearing in various issues of *The Wall Street Journal*. The dividend series for the S&P 100 index was obtained from Harvey and Whaley (1992b).

If fewer than three different options traded during any five-minute interval, no estimates of volatility and index level are made. Fortunately, this condition was not met very frequently. Across all days in the October 1–15 and October 19 sample period, volatility and index level were estimated simultaneously for 975 different five-minute intervals. The average number of different options used in each estimation was 5.20, and the average number of transactions was 35.07.

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