The Relation between Price Changes and Trading Volume: A Survey

Jonathan M. Karpoff*

Abstract

This paper reviews previous and current research on the relation between price changes and trading volume in financial markets, and makes four contributions. First, two empirical relations are established: volume is positively related to the magnitude of the price change and, in equity markets, to the price change *per se*. Second, previous theoretical research on the price-volume relation is summarized and critiqued, and major insights are emphasized. Third, a simple model of the price-volume relation is proposed that is consistent with several seemingly unrelated or contradictory observations. And fourth, several directions for future research are identified.

I. Introduction

This paper is a review of empirical and theoretical research into the price-volume relation in financial markets.[1] There are at least four reasons why the price-volume relation is important. First, it provides insight into the structure of financial markets. The models discussed below predict various price-volume relations that depend on the rate of information flow to the market, how the information is disseminated, the extent to which market prices convey the information, the size of the market, and the existence of short sales constraints. Empirical relations between prices and volume can help discriminate between differing hypotheses about market structure.

Second, the price-volume relation is important for event studies that use a combination of price and volume data from which to draw inferences.[2] If price

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[1] To keep this task manageable, the price-volume relation is narrowly defined. A substantial amount of empirical and theoretical work also relates to the costs of transacting in securities markets and the price-setting behavior of floor specialists and dealers (see Cohen, Maier, Schwartz, and Whitcomb 1979 for a survey, and also [27], [14], and [7]). Epps ([21]) examines the effect of transaction costs on volume. Volume has also been used to examine the existence of dividend clienteles ([1], [58]) arbitrage around ex-dividend days ([47], [32]), the effects of information uncertainty [4], and arbitrage activity [50].

[2] Volume has been used to infer whether an event had "informational content" and whether investors' interpretations of the information were similar or different ([5], [47], [25], [53], [59], [57], and [2], [3]; for a critique, see [63]). Harris and Gurel [37] use price and volume effects to examine the price pressure hypothesis. The dividend studies cited in note 1 are other examples.

changes and volume are jointly determined, incorporating the price-volume relation will increase the power of these tests. For example, Richardson, Sefcik, and Thompson [58] examine trading volume and price changes to test for the existence of dividend clienteles. In other tests, price changes are interpreted as the market evaluation of new information, while the corresponding volume is considered an indication of the extent to which investors disagree about the meaning of the information.[3] The construction of tests and validity of the inferences drawn depend on the joint distribution of price changes and volume.[4]

Third, the price-volume relation is critical to the debate over the empirical distribution of speculative prices. When sampled over fixed calendar intervals (e.g., days), rates of return appear kurtotic compared to the normal distribution. Two competing hypotheses to explain this are (1) rates of return are best characterized by a member of a class of distributions with infinite variance (the stable Paretian hypothesis), and (2) the distribution of rates of return appears kurtotic because the data are sampled from a mixture of distributions that have different conditional variances (the mixture of distributions hypothesis). Price-volume tests generally support the mixture of distributions hypothesis. This, in turn, has several implications. As an example, it appears price data are generated by a conditional stochastic process with a changing variance parameter that can be proxied by volume. Knowledge of the price-volume relation can then be used in event studies to measure changes in the variance of the price process from nonevent to event time.[5]

And fourth, price-volume relations have significant implications for research into futures markets. Price variability affects the volume of trade in futures contracts ([17], [49]). This has bearing on the issue of whether speculation is a stabilizing or destabilizing factor on futures prices [61]. The time to delivery of a futures contract affects the volume of trading, and through this effect, possibly also the variability of price [29]. The price-volume relation can also indicate the importance of private versus public information in determining investors' demands [56].

The plan of this paper is as follows. Part II provides a brief review of early research into the price-volume relation. In subsequent research, two empirical relations emerge as "stylized facts:" (1) The correlation between volume (V) and the absolute value of the price change ($|\Delta p|$) is positive in both equity and futures markets; and (2) the correlation between volume and the price change *per se* (Δp) is positive in equity markets.[6] Part III examines research that supports the former, while the work covered in Part IV supports the latter relation.

[3] A statement of this hypothesis is found in Beaver ([5], p. 69): "An important distinction between the price and volume tests is that the former reflects changes in the expectations of the market as a whole while the latter reflects changes in the expectations of individual investors."

[4] Inferences from volume data also depend on the theoretical connection between information and volume (see [68], [44]). Hypotheses of the price-volume relation can also yield inferences from empirical tests that are otherwise unobtainable (see, for examples, [70], [52]).

[5] The problem of changing return variance in event time is discussed by Christie [9]. Using volume to proxy for the variance of the price process is implied by discussions in Rogalski [60] and Harris [34].

[6] Throughout this paper, the term "price change" is used, although most of the empirical work uses price change relatives, computed as the first difference in the log price or the percentage price change.

Most theoretical models are unable to explain both price-volume relations,[7] but in Part V we argue that these two empirical findings can be mutually consistent. Finally, in Part VI, some unsolved questions and directions for further research are discussed.

II. Early Research

Academic treatment of a price-volume relation can be traced to Osborne [54], who attempted to model the stock price change as a diffusion process with variance dependent on the number of transactions. This could imply a positive correlation between V and $|\Delta p|$, as later developed by Clark [10], Tauchen and Pitts [65], and Harris [34]. However, by assuming transactions are uniformly distributed in time, Osborne was able to reexpress the price process in terms of time intervals, and did not directly address the volume-price issue.

An early empirical examination of the volume-price relation was conducted by Granger and Morgenstern [30]. Using spectral analysis of weekly data from 1939–1961, they could discern no relation between movements in a Securities and Exchange Commission composite price index and the aggregate level of volume on the New York Stock Exchange. Data from two individual stocks also displayed no price-volume relation. In 1964, Godfrey, Granger, and Morgenstern presented new evidence from several data series, including daily and transaction data for individual stocks. But once again they could find no correlation between prices or the absolute values of price differences and volume.

Another finding by Godfrey, Granger, and Morgenstern is that daily volume correlates positively with the difference between the daily high and daily low. This is supported by a later finding [31] that daily volume correlates with the squared difference between the daily open and close. The authors attribute this correlation to institutional factors such as stop-loss and buy-above-market orders that increase volume "as the price diverges from its current mean" ([28], p. 20). However, Epps and Epps [24] have suggested that volume moves with measures of within-day price variability because the distribution of the transaction price change is a function of volume.

The failure of Godfrey et al. to uncover a price-volume relation motivated the empirical tests of Ying [72] and Crouch [19]. Ying applied a series of chi-squared tests, analyses of variance, and cross-spectral methods to six-year, daily series of price and volume. Prices were measured by the Standard and Poor's 500 composite index adjusted for dividend payouts, and volume by the proportion of outstanding NYSE shares traded. The following list is a subset of his findings:

"(1) A small volume is usually accompanied by a fall in price.

(2) A large volume is usually accompanied by a rise in price.

(3) A large increase in volume is usually accompanied by either a large rise in price or a large fall in price." ([72], p. 676).

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[7] Exceptions include Jennings, Starks, and Fellingham [41], Karpoff [43], Harris [36]. More than one of the researchers whose work is cited below seemed unaware of either the absolute value or the *per se* correlations (for examples, see Morgan [51], pp. 505–536, or Kelles [45]).

Ying's empirical methods are easily criticized,[8] but note that items (1) and (2) suggest V and Δp are positively correlated, and item (3) is consistent with a correlation between V and $|\Delta p|$. As discussed below, each of these interpretations has been supported in subsequent tests. Thus, Ying was the first to document both price-volume correlations in the same data set.

III. Volume and the Absolute Value of the Price Change

A. Empirical Evidence

It is an old Wall Street adage that "It takes volume to make prices move." Although one can question the asserted causality, numerous empirical findings support what will be called here a "positive volume-absolute price change correlation." Crouch ([18], [19]) found positive correlations between the absolute values of daily price changes and daily volumes for both market indices and individual stocks. Clark [10] found a positive relation between the square of a measure of the price change and aggregated volume using daily data from the cotton futures markets. Using four-day interval and monthly data from a total of 51 stocks, Morgan [51] found that in all cases the variance of price change was positively related to trading volume. Westerfield [69] found the same relation in a sample of daily price changes and volumes for 315 common stocks, as did Tauchen and Pitts [65] using daily data from the Treasury bill futures market. Epps and Epps [24] found a positive relation between the sample variances of price changes at given volume levels and the volume levels using transactions data from 20 stocks, and Wood, McInish, and Ord [71] also report a positive correlation between volume and the magnitude of the price change at the transactions level. Jain and Joh [38] document a similar correlation over one-hour intervals, using data from a market index. Cornell [17] found positive relations between changes in volume and changes in the variability of prices, each measured over two-month intervals, for each of 17 futures contracts. The relation was almost entirely contemporaneous, as most leading and lagged relations were statistically insignificant. Grammatikos and Saunders [29] also found volume to be positively correlated with price variability, but for foreign currency futures. Rutledge [61] found significant correlations between daily volume and the absolute value of the daily price change for 113 out of 136 futures contracts analyzed. Comiskey, Walkling, and Weeks [12] found a similar correlation using yearly data on individual common stocks. Richardson, Sefcik, and Thompson [58] found that trading volume increases with the square of a measure of abnormal return around announcements of dividend changes. And Harris [34] found a positive correlation between volume and the square of the price change using daily data from 479 common stocks. The strength of the correlation varied across securities [36] and the correlation was also found to be stronger for daily than for transactions data [35].

[8] One problem arises because Ying's price series (S & P's 500 index) and volume series (NYSE percentage volume) are not necessarily comparable. A second problem arises from his adjustments to the data for dividends and total NYSE shares outstanding. Ying's daily price series was adjusted by quarterly dividend data, and the daily volume series was adjusted by monthly data on the number of outstanding shares, each using linear interpolations. Also, several of Ying's findings (not listed here) are inconsistent with weak form market efficiency.

These empirical results are summarized in Table 1. They prompt three observations that will be discussed below. First, the V, $|\Delta p|$ correlation appears in both the equity and futures markets. Second, despite the almost universal finding of a positive correlation, some of these tests indicate that the correlation is weak. For example, the average squared correlation coefficient obtained by Crouch was 0.20 among the stock indices and 0.23 among the individual firms. It is argued in Part V that this stems from heteroskedastic error terms that are generated when a straight line is fit to data from markets in which short sales are relatively costly. Third, this correlation appears with price and volume data measured over all calendar intervals, but it appears to be weaker in transactions data.

TABLE 1

Summary of Empirical Studies from which Inferences Can be Made about the Correlation of the Absolute Value of the Price Change ($|\Delta p|$) with Trading Volume (V)[a]

Author(s)	Year of Study	Sample Data	Sample Period	Differencing Interval	Support Positive ($|\Delta p|$, V) Correlation?
Godfrey, Granger, and Morgenstern	1964	Stock market aggregates, 3 common stocks	1959–62, 1951–53, 63	weekly, daily, transactions	No
Ying	1966	Stock market aggregates	1957–62	daily	Yes
Crouch	1970[18]	5 common stocks	1963–67	daily	Yes
Crouch	1970[19]	Stock market aggregates, 3 common stocks	1966–68	hourly and daily	Yes
Clark	1973	Cotton futures contracts	1945–58	daily	Yes
Epps and Epps	1976	20 common stocks	Jan., 1971	transactions	Yes
Morgan	1976	17 common stocks, and 44 common stocks	1962–65, 1926–68	4-days, monthly	Yes
Westerfield	1977	315 common stocks	1968–69	daily	Yes
Cornell	1981	Futures contracts for 17 commodities	1968–79	daily[b]	Yes
Harris	1983	16 common stocks	1968–69	daily	Yes
Tauchen and Pitts	1983	T-bill futures contracts	1976–79	daily	Yes
Comiskey, Walkling, and Weeks	1984	211 common stocks	1976–79	yearly	Yes
Harris	1984	50 common stocks	1981–83	transactions, daily	Yes
Rutledge	1984	Futures contracts for 13 commodities	1973–76	daily	Yes
Wood, McInish, and Ord	1985	946 common stocks, 1138 common stocks	1971–72, 1982	minutes	Yes
Grammatikos and Saunders	1986	Futures contracts for 5 foreign currencies	1978–83	daily	Yes
Harris	1986	479 common stocks	1976–77	daily	Yes
Jain and Joh	1986	Stocks market aggregates	1979–83	hourly	Yes
Richardson, Sefcik, and Thompson	1987	106 common stocks	1973–82	weekly	Yes

[a] This table summarizes the *general* conclusions of these studies about the correlation of $|\Delta p|$ and V. Results that indicate no significant correlation are listed as not supporting a positive correlation. These studies employ various measures of the price change and trading volume For more precise descriptions of the data and variable transformations, the reader is referred to the original papers.

[b] The daily data are transformed into a series of estimated average daily volumes and daily return variances for successive two-month intervals.

B. Theoretical Explanations[9]

Copeland ([15],[16]) has constructed a "sequential arrival of information"

[9] An early but flawed attempt to explain the positive volume-price correlation is in Crouch [18]. All trading occurs through a dealer. In one version of the theory, the dealer irrationally satisfies all demands to trade even though he expects to lose on each trade (i.e., the dealer has an infinite supply of securities and cash). Amending this version, Crouch assumes that investors' demands change at

model in which information is disseminated to only one trader at a time and that implies a positive correlation between V and $|\Delta p|$. The information causes a one-time upward shift in each "optimist's" demand curve by a fixed amount δ and a downward shift of δ in each "pessimist's" demand curve. Trading occurs after each trader receives the information, but uninformed traders do not infer the content of the information from informed traders' actions. Also, short sales are prohibited.

With N traders, there will in general be k optimists, r pessimists, and N-k-r uninformed investors at any point in time before all investors become informed. The values of k and r depend on the order in which investors become informed. Because of the short sales prohibition, volume generated by a pessimist is generally less than that generated by an optimist (i.e., the pessimist cannot sell short upon receiving the information). So the price change and trading volume when the next trader becomes informed depend upon both (i) the previous pattern of who has been informed and (ii) whether the next trader is an optimist or pessimist. Likewise, the total volume after all traders become informed depends on the path by which the final equilibrium is reached. It is a random variable with an expected value equal to a weighted average of the total volumes under each possible path of information dispersion. Simulation tests indicate that V is highest when investors are all optimists or all pessimists. Also $|\Delta p|$ is lowest at the same percentage of optimists at which V is lowest, and rises with V. This supports a positive correlation of V and $|\Delta p|$.

This model is open to at least two criticisms. First is the assumption that prohibits traders from learning from the market price as other traders become informed. Second is the implication that volume is greatest when all investors *agree* on the meaning of the information. This is contrary to the inference drawn from high measures of volume ([10], [5], [46], [26], [2], [3]), and is inconsistent with the empirical findings of Comiskey, Walkling, and Weeks [12]. Copeland attributes this to the short sales constraint, but that is only part of the story. Also important is the rather peculiar interpretation of disagreement among traders, who are forced into a binary response to new information (demands shift up by δ or down by δ).[10]

Copeland's model has been extended by Jennings, Starks, and Fellingham ([42]; see section IV.B. below) and by Morse [52], who derives from the sequential arrival of information process the hypothesis that trading volume will be abnormally high during the same periods in which the absolute values of returns are

different times, and the necessary supply of securities (when demands increase) or cash (when demands decrease) comes from other sellers or buyers. While this change anticipates Copeland's notion of sequential information arrival, it also guts Crouch's theory, which boils down to an assertion that when some investors' demands change, the resulting realignment of securities causes a simultaneous increase in volume and a price revision.

[10] The implication that volume increases with the degree of homogeneity across investors follows because, once an optimist has traded (by buying units from other investors), a later pessimist will have fewer units to sell when it is his turn to trade, whereas a later optimist has no fewer units available for purchase. Likewise, if an optimist follows a pessimist, he has fewer units available for purchase (since the pessimist previously sold some of his units). On the other hand, an optimist who follows other optimists has an increased number of suppliers from whom to buy, while a pessimist who follows other pessimists has an increased supply of assets to trade away. As a result, a mix of optimists and pessimists leads to lower V and smaller $|\Delta p|$ than when one type of trader predominates.

serially correlated. Jennings and Barry [40] consider an extension of the sequential information arrival model by permitting informed traders to take speculative positions. Speculation causes prices to adjust more quickly to new information, but the effect on trading volume is ambiguous. Their model implies a positive correlation between V and $|\Delta p|$ for a given investor's trade, but this correlation can get obscured with data sampled over time intervals as long as a day.

Another explanation of the positive correlation between V and $|\Delta p|$ comes from research into the distribution of speculative prices. Daily price changes of speculative assets appear to be uncorrelated with each other and symmetrically distributed, but the distribution is kurtotic relative to the normal distribution ([25], [10]). One explanation is that daily price changes are sampled from a set of distributions that are characterized by different variances. This is the "mixture of distributions hypothesis" (MDH).

In one form of the MDH, Epps and Epps [24] derive a model in which the variance of the price change on a single transaction is conditional upon the volume of that transaction. Transaction price changes are then mixtures of distributions with volume as the mixing variable. In a second form of the MDH ([10], [65], [34]), the daily price change Δp is the sum of a variable number m of independent within-day price changes. For a given m, the Central Limit Theorem implies that Δp is approximately normal with variance proportional to m. For a variable m, however, the Central Limit Theorem is inapplicable and the distribution of Δp is subordinate to the distribution of m.[11] It is intuitively attractive to interpret m as the number of within-day information arrivals, so the conditional variance of Δp is considered to be an increasing function of the rate at which new information enters the market. The V, $|\Delta p|$ correlation results because volume is also an increasing function of the number of within-day price changes.

The Epps and Epps model is similar to the sequential information arrival model in that it places a particular structure on the way investors receive and respond to information. Epps and Epps provide empirical support for their contention that a V, $|\Delta p|$ correlation occurs at the transaction level, a finding that is confirmed by Wood, McInish, and Ord [71]. However, Harris [37] finds that this correlation, as well as other observed properties of daily data, are *not* characteristics of transactions data.

The central proposition of the models by Clark, Tauchen and Pitts, and Harris is that transaction time intervals are variable. There is also some empirical support for this contention. Clark's tests use volume as a proxy variable for the number of transactions variable m, and show that the leptokurtosis in the empirical distribution of daily price changes largely disappears when the changes are grouped by volume classes. This finding is supported by Morgan [51] and Westerfield [69]. By assuming the variation of m varies across securities, Harris [36] derives inferences that sample measures of price change kurtosis, volume skewness, and correlation of squared price change with volume should all be positively correlated across securities. These hypotheses are supported in his tests. Additional support is provided by Upton and Shannon [66], but conflicting evidence comes from Wood, McInish, and Ord [71], who find that the absolute size

[11] See [10] or [69] for discussions of subordinated processes. Loosely, the distribution of the daily price change is "subordinate" to that of m because its parameters are functions of m.

of the price change at the transactions level is positively related to the length of time between transactions. This is inconsistent with a central assumption of these models that the distribution of the transaction-level price change is independent of the number of transactions within a fixed calendar interval.

The hypothesis that transactions time differs from calendar time provides insights into several related market phenomena. The Tauchen and Pitts model implies that the V, $|\Delta p|$ correlation increases with the variance of the daily rate of information flow, and that, as the number of traders increases, the volume of trade increases and price variability decreases. This latter prediction is consistent with evidence from the relatively new Treasury bills futures market. Another extension has been made by Grammatikos and Saunders [29], who argue that the variance of the price change process in futures contracts decreases with the time to maturity of the contract. Lehvari and Levy [48] have demonstrated that empirical estimates of systematic risk are sensitive to the calendar time intervals over which returns are calculated. Carpenter and Upton [8] have suggested that the number of information arrivals m is a measure of ''effective time'' in the evolution of the price process, so estimates of beta will also be sensitive to m. This suggests a role for the use of volume in the adjustment of returns for risk, since volume is a proxy variable for the rate of information flow m. As was mentioned in Part I, another application of the MDH may be to indicate methods to adjust test statistics in event studies to take into account changes in the conditional variance of the price change process.

One drawback of these models is that they imply no relation between volume and the price change *per se*. This is inconsistent with most of the evidence discussed in the following section, in which it is suggested that a positive $\mathrm{cov}(\Delta p, V)$ arises because of short sales restrictions. The Tauchen and Pitts and Harris models explicitly assume away short sale constraints, and it is unclear whether their inclusion would imply a correlation between Δp and V.

Another explanation for a postive correlation between V and the $|\Delta p|$ is implied in a model by Pfleiderer [56], which extends previous work on information aggregation in markets. A rational expectations equilibrium is established in which speculators' private information is only partially aggregated by the market price because of noise introduced by life-cycle trading. Speculative trading increases with the precision of private information and is uncorrelated with $|\Delta p|$, but life-cycle trading randomly affects the supply available to speculators. The volume of life-cycle trading thus has an effect on the magnitude of price changes. This model also implies that the strength of the correlation between V and $|\Delta p|$ increases with the relative importance of life-cycle trading in the market.

It should be noted that, while the Epps and Epps model requires all investors to receive information simultaneously, the Clark, Tauchen and Pitts, Harris, and Pfleiderer models can be mutually consistent with sequential informational arrival. While these models imply simultaneous dispersion of an information bit, they do not require it. The successive equilibria presumed by these models can result from a gradual dissemination of a single bit of information, as in the sequential information arrival model, or from a process in which investors receive information simultaneously. These models are also more general than the sequential arrival of information model, for two reasons. First, they are consistent with either simultaneous or gradual information dissemination, while Copeland's model implies a *negative* V, $|\Delta p|$ correlation when simultaneous information arrival is imposed. And second, they explain a greater number of phenomena. The MDH is consistent with the empirical distribution of price changes and the difference in the V, $|\Delta p|$ correlation over different frequencies, while Pfleiderer's model considers the informational content of the market price.[12]

IV. Volume and the Price Change Per Se

A. Empirical Evidence

Another familiar Wall Street adage is that volume is relatively heavy in bull markets and light in bear markets. As support, Epps developed tests, first from the bond market [20], then from the stock market [22], which indicate that the ratio of V to $|\Delta p|$ is greater for transactions in which the price ticks up than for transactions on downticks. This was found to hold even when V and $|\Delta p|$ were measured over daily intervals [22], and without regard for the general movement in prices [33]. Conflicting evidence was found by Wood, McInish, and Ord [71], who found that the ratio of V $|\Delta p|$ is higher for downticks. And Smirlock and Starks [64] found the relation to hold only during periods in which they could distinguish the arrival of information *ex ante*. In other periods, they found slight evidence that the ratio of V to $|\Delta p|$ is lower for upticks than for downticks, which they attribute to positive transaction costs and the lack of information arrival. However, using hourly data from a broad market index, Jain and Joh [38] find that volume is positively related to the magnitude of the price change, but that volume is more sensitive to positive than negative price changes.

The findings of Epps, Hanna, Jain and Joh, and parts of Smirlock and Starks could imply a positive correlation between volume and the price change *per se* (Δp). Such a correlation is implied by Ying's items (1) and (2), and several researchers have directly tested and found a positive correlation. Using monthly data from 10 stocks and 10 warrants, Rogalski [60] found a contemporaneous correlation between price change and volume, but no lagged correlations. Morgan [51] and Harris ([35],[37]) each found a positive correlation between price changes and volume even though it appears they were not looking for one, as did Richardson, Sefcik, and Thompson [58]. Comiskey, Walkling, and Weeks [12] found positive cross-sectional correlations between annual measures of turnover and price change. However, James and Edmister [39] found no such cross-sectional correlation.[13]

This empirical evidence is summarized in Table 2. Two features of these tests will be further discussed below. First, and unlike the empirical correlations between V and $|\Delta p|$ reported in Part III, these findings are all reported from stock or bond market data. This correlation has not been reported in futures markets. Second, and like some of the findings reported in Part III, many of the statistical

[12] Each model also yields additional insights. For examples, the sequential information arrival and MDH models are both consistent with increasing volume as the number of market agents increases (see [65], [15]) and with positive skewness in the distribution of volume ([34], [15]), while the Pfleiderer model is consistent with an increase in futures trading as the delivery date approaches.

[13] In current research, this author has found positive correlations between returns and trading volume using daily data from broad market indices.

results are weak. For example, Rogalski's correlations were low, the average being 0.395 among the stock data and 0.318 among the warrant data. In addition, there were several findings inconsistent with a positive correlation.

TABLE 2

Summary of Empirical Studies from which Inferences Can be Made about the Correlation of the Price Change (Δp) with Trading Volume (V)[a]

Author(s)	Year of Study	Sample Data	Sample Period	Differencing Interval	Support Positive (Δp, V) Correlation?
Granger and Morgenstern	1963	Stock market aggregates, 2 common stocks	1939–61	weekly	No
Godfrey, Granger, and Morgenstern	1964	Stock market aggregates, 3 common stocks	1959–62, 1951–53, 63	weekly, daily, transactions	No
Ying	1966	Stock market aggregates	1957–62	daily	Yes
Epps	1975	20 NYSE bonds	Jan., 1971	transactions	Yes
Morgan	1976	17 common stocks, and 44 common stocks	1962–65, 1926–68	4-days, monthly	Yes
Epps	1977	20 common stocks	Jan , 1971	transactions, daily	Yes[b]
Hanna	1978	20 NYSE bonds	May, 1971	transactions	Yes
Rogalski	1978	10 common stocks and 10 associated warrants	1968–73	monthly	Yes
James and Edmister	1983	500 common stocks	1975, 77–79	daily[c]	No
Comiskey, Walkling, and Weeks	1984	211 common stocks	1976–79	yearly	Yes
Harris	1984	50 common stocks	1981–83	transactions, daily	Yes
Smirlock and Starks	1985	131 common stocks	1981	transactions	Yes[d]
Wood, McInish, and Ord	1985	946 common stocks 1138 common stocks	1971–72, 1982	minutes	No
Harris	1986	479 common stocks	1976–77	daily	Yes
Jain and Joh	1986	Stocks market aggregates	1979–83	hourly	Yes
Richardson, Sefcik, and Thompson	1987	106 common stocks	1973–82	weekly	Yes

[a] This table summarizes the *general* conclusions of these studies about the correlation of Δp and V Results that indicate no significant correlation are listed as not supporting a positive correlation These studies employ various measures of the price change and trading volume For more precise descriptions of the data and variable transformations, the reader is referred to the original papers.

[b] Support for a positive correlation between Δp and V at the transactions level depends on the treatment of volume over transactions with no price changes.

[c] Stocks are grouped into deciles ranked by average daily volume Decile ranking is compared with mean daily return.

[d] The data are consistent with a positive correlation between Δp and V on days in which there is known information arrival. On other days, the correlation appears insignificant or negative.

B. Theoretical Explanations

Several authors have attempted to explain these findings. Morgan [51] suggests that volume is associated with systematic risk, and through this, to stock returns. Harris ([35], [36]) points out that the mixture of distributions hypothesis implies a positive V, Δp correlation if the conditional mean of the stock price process is proportional to the number of information arrivals. Then the mean of the price change process is subordinate to the same parameter as the mean of the volume process. But it is unclear how either of these connections would work. In fact, the MDH with mean subordination is inconsistent with market equilibrium, since it implies the expected price change from an information arrival is positive.

Epps [20] has constructed a model that implies that volume on transactions in which the price change is positive is greater than for negative price changes. He assumes two groups of investors—"bulls" and "bears." The key distinctions are that ''bulls'' are more optimistic about the value of the asset at the end of the trading period, and they react only to positive information about the asset's value. The pessimistic ''bears'' react only to negative information. The transaction demand curve in this market consists only of the demand prices of ''bulls,'' while ''bears'' comprise the transaction supply curve. Epps demonstrates that the relative optimism of the ''bulls,'' combined with appropriate assumptions about investors' utility functions, implies the market demand curve is steeper than the supply curve. Because of this, the ratio of volume to a positive price change (when bulls' demands increase) is greater than the absolute value of the ratio of volume to a negative price change (when bears' demands decrease).

While this model has been used by other researchers, e.g., Kelles [45] and Smirlock and Starks [64], it must be seriously questioned, since it requires all investors to systematically and selectively ignore pertinent information. This implies investor irrationality. Without additional restrictions, the model also implies a situation in which ''bulls'' acquire increasingly large numbers of shares from ''bears,'' who hold increasingly negative quantities of shares.[14]

In an extension of Copeland's sequential information arrival model to incorporate real world margin constraints and short selling, Jennings, Starks, and Fellingham (JSF) [42] provide an alternate theory consistent with the correlation between V and Δp. The key innovation is that short positions are possible but are more costly than long positions, which implies that the quantity demanded of an investor with a short position is less responsive to price changes than the quantity demanded of an investor with a long holding. JSF are able to show that, for many (but not all) cases, the volume that results when a previously uninformed trader interprets the news pessimistically is less than when the trader is an optimist. Since price (marginally) decreases with a pessimist (who sells) and increases with an optimist (who buys), it is argued that volume is relatively high when the price increases and low when the price decreases.

While it is consistent with the empirical correlation between V and Δp, this model is subject to the same criticisms as Copeland's: it relies on a peculiar interpretation of heterogeneity across investors, it prohibits uninformed investors from learning from the trades of investors who are early in the information queue, and it relies on a behavioral distinction between groups of investors. Nevertheless, the absence of documentation of a positive correlation between V and Δp in futures markets, where the costs of taking long and short positions are symmetric, indicates that the differential cost of short sales is very likely one key to a theory of the volume-price change correlation.

This insight is adopted in a paper by this author [43], in which a model is constructed that depends on asymmetries in the costs of going long and short. Costly short sales restrict some investors from acting on their information when the effect is to decrease their demands. This decreases the variance of interperiod shifts in transaction supply relative to that for transaction demand, which in turn creates a positive covariance between volume and price change over the period. Consistent with this costly short sales hypothesis, empirical tests are presented that reveal that the empirical relation between Δp and V found in stock and bond market data is absent in futures market data.

[14] In addition, see the critique of this model by Schneller [62] and the response by Epps [23].

V. A Synthesis of Previous Research

It has been alternatively concluded that (1) no volume-price correlation exists; (2) a correlation exists between V and $|\Delta p|$; (3) the correlation is between V and Δp; and (4) V is higher when prices increase than when prices decrease. Certainly, items (3) and (4) can be mutually consistent. But it is argued here that (2), (3), and (4) are probably all true, at least in markets in which short positions are more costly than long positions. The reason for these seemingly inconsistent findings is that most tests are based on implicit assumptions that the price-volume relations are functional and/or monotonic, when it is likely that the V, Δp relation is not monotonic and the V, $|\Delta p|$ relation is not a one-one function. Thus, a researcher may find weak support for any one of the above hypotheses and stop looking for the others.

Define the sets of transformations

$$\begin{aligned} W &= \{w = w(\Delta p) \mid w'(\,|\Delta p|\,) > 0\} \\ X &= \{x = x(\Delta p) \mid x'(\Delta p) > 0\} \\ Y &= \{y = y(V) \mid y'(V) > 0\}\ . \end{aligned}$$

Examples include $w(\Delta p) = \Delta p^2$ or $y(V) = \ln V$. Empirical tests, have, in general, specified monotonic, linear relations between either $w \varepsilon W$ and $y \varepsilon Y$ or between $x \varepsilon X$ and $y \varepsilon Y$. (Exceptions include the nonparametric tests of Epps [20], Smirlock and Starks [64], and Harris [35], [36]). But it is possible that volume (elements of the set Y) correlates positively with the elements of *both* sets W and X. To illustrate, consider Figure 1, in which it is assumed for simplicity that $w(\Delta p) = |\Delta p|$, $x(\Delta p) = \Delta p$, $y(V) = V$, and the expected volume is related linearly to the price change (the solid line), but with a discontinuity at $\Delta p = 0$ such that the relation is *not* monotonic. For positive price changes, the conditional expected volume-price relation is $V^+ = f(\Delta p \mid \Delta p \geqslant 0)$; for negative price changes, it is $V^- = g(\Delta p \mid \Delta p \leqslant 0)$. If $f' > |g'|$ is assumed, then for any given expected level of volume $E(V) = E(V^+) = E(V^-)$, $E(V^+/\Delta p) > E(V^-/|\Delta p|)$. This would be consistent with the findings of Epps [20], [22], Hanna [33], Smirlock and Starks [64], and Jain and Joh [38]. Similarly, a test for linear dependence between V and Δp *per se,* although misspecified, would discover a positive correlation. This is represented by the dashed line, and is consistent with the findings of Ying (items 1 and 2), Morgan [51], Rogalski [60], Harris [35], [36], Richardson, Sefcik, and Thompson [58], and Comiskey, Walkling, and Weeks [12]. The assumption that $f' > |g'|$ also implies the relation between V and $|\Delta p|$ is not a one-one function, as demonstrated when the conditional expected volume on negative price changes is plotted in the first quadrant, $V^- = h(|\Delta p| \mid \Delta p \leqslant 0)$. A test for linear dependence between V and $|\Delta p|$, also misspecified, would yield positive results, as data would be generated along the solid and dotted lines in the first quadrant. This is consistent with most of the findings listed in Table 1. However, notice that both of the specified linear relations are wrong, so one would expect empirical tests that specify linear relations would yield statistically weak results. As previously noted, this is also consistent with several of the studies reported, and can account for the failure of a minority of researchers to uncover statistically significant volume-price correlations.

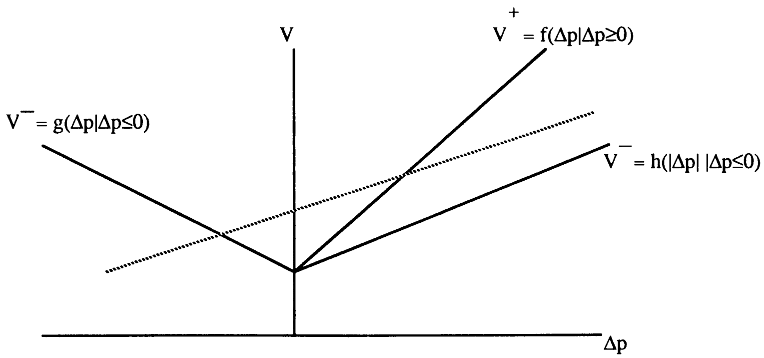

FIGURE 1

Illustration of an Asymmetric Volume-Price Change Relation

Call Figure 1 a representation of an "asymmetric volume-price change hypothesis," indicating the relation is fundamentally different for positive and negative price changes. It implies the following empirical propositions, each of which is apparent from inspection of Figure 1.

(1) The correlation between volume and positive price changes is positive.

(2) The correlation between volume and negative price changes is negative.

(3) Tests using data on volume and the absolute value of price changes will yield positive correlations and heteroskedastic error terms.

(4) Tests using data on volume and price changes per se will yield positive correlations. When ranked by the price change, the residuals from a linear regression of volume on price changes will be autocorrelated.

VI. Conclusions: Issues for Further Research

It is likely that observations of simultaneous large volumes and large price changes—either positive or negative—can be traced to their common ties to information flows (as in the sequential information arrival model), or their common ties to a directing process that can be interpreted as the flow of information (as in the mixture of distributions hypothesis). And the relatively large cost of taking a short position provides an explanation for the observation that, in equity markets, the volume associated with a price increase generally exceeds that with an equal price decrease, since costly short sales restrict some investors' abilities to trade on new information. This summarizes much of what is known about the price-volume relation. We conclude by identifying several issues that merit further inquiry.

(1) Is the price-volume relation asymmetric, as proposed in Part V? An asymmetric relation explains the two major empirical findings reported in this survey, but it is not the only plausible explanation. Ying [72], Morgan [51], Harris [35], [36], and Richardson, Sefcik, and Thompson [58] each found both correlations in the same data set. This provides some support for the hypothesis of an asymmetric relation, but the somewhat anomalous findings of Wood, McInish, and Ord [71] indicate that the asymmetry occurs in the opposite direction.

(2) What would account for the asymmetric price-volume relation? If the

key is short sale constraints, then futures market data would reveal no correlation between V and Δp, as reported in Karpoff [43]. To the extent organized option trading reduces the cost of taking net short positions, the asymmetry should be attenuated in price and volume data from optionable securities. This proposition has not been tested.[15]

(3) Does the size of the market affect the price-volume relation? This analysis suggests two possible effects of market size. First, in equity markets, heavily traded issues are more likely to be optionable in organized exchanges (see the preceding paragraph). The second possible effect is suggested by Tauchen and Pitts' results, which predict that the covariance of volume and the squared price change increases with the number of investors, but at a decreasing rate.

(4) Do properties of the rate of information flow affect the price-volume relation? All of the models discussed in this review use the notion that information, or something that is interpreted as information, drives the market to its successive equilibria. Price-volume relations then arise because of assumptions about the nature of investors' reactions. In the mixture of distributions models of Tauchen and Pitts [65] and Harris [34], the correlation of the squared daily price change and the daily volume increases with the variance of the daily rate of information flow. This implies that this price-volume relation is strongest in markets or at times in which the flow of information is most volatile. On the other hand, Pfleiderer [56] argues that the strength of the relation increases as more trading occurs for noninformational reasons.

(5) Are the price-volume relations reported here identical over different frequencies? Tauchen and Pitts' model implies that V and Δp are independent at the transaction level. Epps' [20] model implies a positive correlation at the transaction level, while the Epps and Epps' and Jennings and Barry models imply a correlation between V and $|\Delta p|$ at the transaction level. Copeland's model implies this same correlation, but over the length of time necessary for each piece of information to reach all investors. The empirical work to date indicates that the empirical correlation of V and $|\Delta p|$ is stronger over fixed time intervals than over a fixed number of transactions ([35], [6]).

(6) Can the price-volume relation be exploited to improve event study statistics? The models that hypothesize daily price changes are mixtures of distributions that imply the conditional variance of the price change is proportional to volume. Volume, in turn, proxies for an entity that can be interpreted as information flow. If the rate of information flow tends to be higher around "event" periods, then the variance of the "true" price process is higher around the event date, indicating that statistical tests of abnormal returns around the event should be done with a sample variance adjusted for the rate of information flow. With a

[15] Exactly how options trading should affect the price-volume asymmetry is not obvious. Investors with unfavorable information can now buy puts or write calls rather than sell the stock short. This would further decrease stock trading volume over intervals with unfavorable information. However, arbitrageurs would sell the stock to maintain put-call parity, increasing the volume of trade. The net effect should be an increase in trading volume associated with unfavorable information, since the cost of trading on such information is lower. A referee has pointed out that whether options are traded depends on characteristics of the security that may also affect the correlation of price and volume, e.g., the size of the market or information flows (see points 3 and 4 below). Thus, a test for whether the correlation between V and Δp is attenuated in optionable securities requires further constraints to distinguish between future research points 2, 3, and 4.

higher rate of information flow around event dates, tests for statistical significance should be more stringent than what is frequently used.[16]

(7) Is information arrival, in general, sequential or simultaneous? Smirlock and Starks [63] find support for sequential over simultaneous information arrival, but their hypothesis is tested jointly with a test of Copeland's model. The issue of "sequential or simultaneous" is in part a semantic issue. Empirical research indicates that price adjustment to new information is "very quick," (e.g., [56]), but "very quick" can be interpreted as nearly instantaneous or as supporting gradual information dissemination (the interpretation given by Jennings and Barry [40], [41]). More puzzling is evidence that abnormally high volume persists for some time *after* informational events, after the time period over which price effects are measured.[17] Does this indicate trading by investors who are late in the queue of a gradual information release process? If so, does it mean that "uninformed" investors do not know that they are late in the queue? If abnormally high volume around events represents churning by "uninformed" traders, this casts doubt on the interpretation of volume statistics as measures of "information content" in event studies.[18]

(8) Is the theory that guides empirical work in this area adequate? The models reviewed in this paper sacrifice generality for tractability, and this has led to some artificial behavioral classifications such as "optimists/pessimists" and "bulls/bears." An important but difficult area for further work in this area is to develop a theoretical understanding of markets that incorporates many diverse agents, each of whom maximizes a multiperiod objective function subject to a stochastic environment. The joint distribution of price and volume could emerge in such a model as a result of idiosyncratic shocks that impinge on individual traders, and aggregate shocks that affect all market agents.[19]

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[16] Pincus [57] uses measures of abnormal volume and price change to identify the period of adjustment to earnings announcements, and examines the variance of the price change during this period.

[17] For example, see [5] and [53]. Karpoff [44] argues that this may be due to market frictions that keep all demands from instantaneously clearing.

[18] For examples of uses of volume in event studies, see footnote 3.

[19] An important step in this direction is the work by Pfleiderer [56]. Another recent example is a model by Varian [67] in which trades are motivated by differences in opinions (priors). However, the one unambiguous conclusion reached about the price-volume relation is that, as beliefs are more dispersed (and the derivative of investors' risk tolerance is less than 1), equilibrium prices decrease while volume increases. This cannot explain most of the empirical evidence cited in this survey, which supports a positive correlation between V and Δp. Finally, another possible source for future work on the price-volume relation are market microstructure models along the lines of Garman [27], which focus on the market dealer's inventory and bid-ask quote decisions.

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