Improvements in NYSE Trading and Information Technology: 1878-1984

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Abstract

Improvements in the technology of information flow and execution/clearing at the New York Stock Exchange between 1878 and 1984 were examined for their effects on price volatility and trading volume. Overall, price volatility was found to decrease after an improvement in trading technology, while both volume and intra-day volatility increased after an improvement in information flow. Noise traders may be attracted by faster information flow, even in the absence of new information, and bring additional volatility to the market. Solutions to the problem of such noise traders might involve increasing the ease of trading, and thus liquidity, to dampen price volatility.

I. Introduction

One of the most profound changes in the operation of capital markets is the introduction of the internet. Investors now have access to vast amounts of information in real time, and more importantly, can act on that information and trade more quickly than ever before. Improvements in telecommunications, combined with the ability to use smart systems to analyze information and algorithmically trade based on this analysis, have led to a veritable explosion of innovations in asset trading and price discovery. However, while investors demand real-time information and on-line execution, concerns about excess volatility have led to calls to control trading through a variety of means including circuit breakers, taxes on short-term trading, and short selling restrictions.

What happens to a market as new technology allows faster information flow or cheaper trade execution? This paper examines the effect of several historical improvements in information and trade technology on the volatility of stock prices and returns and the volume of trading. Ten changes in the technology of information delivery and/or of the efficiency of trading on the New York Stock Exchange (NYSE) are analyzed. Analysis of these historical effects, ranging in date from 1878 to 1984, can provide a useful insight into the possible short- and long-term effects of more recently introduced technology changes. Based on these results, the implications for policy to control the effects of noise trading are discussed.

II. Theoretical models

The question of whether technological change impairs the functioning of capital markets has profound policy implications. Securities markets perform the vital societal functions of allocating scarce capital, facilitating risk management, and processing information on investment assets for investors. Two models of investor behavior draw vastly different conclusions about the effects of changing securities market operations and propose sharply different policy prescriptions to deal with these changes. Those who subscribe to the noise model (Black 1986 and DeLong *et al.* 1989; 1990a,b; 1991) believe that many investors trade irrationally, acting on the basis of "noise" rather than on fundamental information (Cipriani *et al.* 2005). Such speculation can move prices away from fundamental values for long time periods. Such noise

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traders are not quickly dispatched by their rational counterparts, and additional systematic risk is created, increasing the volatility of capital markets. Those subscribing to this model will logically propose various schemes to impede the working of the financial markets, to "throw sand in the gears" (Tobin 1984). Impeding the flow of orders or information is antithetical to those who believe in the alternative efficient markets hypothesis (EMH). (See Fama 1965; Ross 1989.) In this model, speculators add liquidity to the market. Noise traders will be quickly eliminated by rational arbitrageurs, driving prices to fundamental values. Thus, there should be as few impediments to trading as possible. A number of empirical studies have tested the DeLong version of the noise model against the EMH (see, for instance, Palomino 1996 on small markets, Brown 1999 on closed-end investment funds, and Sanders *et al.* 1997 on futures markets).

III. Technology

There are two basic ways that technology can change operations in the trading arena. Technology can speed information flow by making prices or news available faster. Technology can also change the trading process itself, making it easier or cheaper to trade. These two changes will have different effects. In an efficient market, increases in the speed of information flow should have little effect on prices. The price of a financial asset should remain close to its equilibrium level until significant new information arrives to change that equilibrium level (Fama 1965); speeding the arrival of information does not increase the amount of news, nor volatility. By contrast, making trading itself more efficient can be expected to increase trading by bringing in additional traders or by increasing the amount of trading done. It is here that the efficient market and noise models part company. Critics of the current operation of US markets argue that the additional traders are not information traders, who value stocks based on a rational interpretation of all available information, but are rather noise traders, who buy and sell on the basis of price trends rather than values (Black 1986). Since noise traders, attracted by innovations that lower transactions cost, will make markets inefficient and give rise to what has been labeled "excess volatility" (Edwards 1988), such innovations must be examined for possible harmful effects, and if harmful, must be controlled. Such controls include circuit breakers currently in place, and proposals to add a tax on short-term securities transactions (Schwert *et al.* 1993). Examples of such policy proposals, formulated after the large decline in stock prices at the end of the 1980s, include Stiglitz 1989 and Summers *et al.* 1989. More recent efforts to deal with increased volatility and large declines in stock prices include calls for the reinstatement of the uptick rule and the prohibition of short-selling in various classes of financial stocks.

While readily embracing improvements in information systems, the NYSE has been slower to change the way the auction market itself works, and alternative trading venues such as ECNs have proliferated to compete by supplying markets attuned to different investor preferences for best price, instantaneous execution, liquidity, and other criteria. While the NYSE has attempted to respond to this competition, the trading system is still overlaid on a specialist system and a method of order execution that remains almost identical to that developed at the turn of the 20th century.

This paper seeks to answer two questions. First, does a change in the technology of the marketplace, either in information flow or in trade execution, change market volatility?

Secondly, does a change in technology attract noise traders? Ten historical technology events are examined. Four of these innovations in technology involve the transmission of transaction price data, and are considered information flow events, and six involve changes in trade execution.

Changes in Information Flow:

(1) Ticker speed (December 1, 1964): ticker speed increased from 500 to 900 characters per minute. With this change, the ticker could report both volume and price on all trades; previously, volume was omitted if the ticker fell behind by more than two minutes.

(2) Automation (February through December, 1966): transmission of transactions data from the specialist posts to the ticker and quote services was automated. "Automation" involved the preparation of a coded computer card at the specialist post with the relevant transaction information. This was submitted immediately to the system, where it was read by a computer and transmitted to information vendors and the tape. Previously, transaction information was written on paper by the specialist, transmitted through a pneumatic tube to a tape-punch operator, and from there the transaction would be reported. According to the Wall Street Journal (12/20/66), this technology change had the effect of reducing the transmission time of price and volume from minutes to seconds. The system was introduced gradually: the first posts were automated in February, 1966, and the last 18 trading posts in December, 1966.

(3) High speed transmission (January 19, 1976): On this date, a new high-speed transmission line began transmitting market data from the NYSE to desktop quotation devices at speeds of up to 36,000 characters per minute, thus allowing anyone with such a device to receive current price information even if the ticker or tape was delayed.

(4) CQS (August 8, 1978): The NYSE inaugurated the Consolidated Quote System which allowed brokers and customers to receive bid and ask quotes, with size, in listed stocks for all US markets. This change increased the price information available to brokers and institutions, Order information, that is, current price information on a stock from all the exchanges on which it was listed, gave traders more price information than the "historic" price information of executed trades included in the consolidated tape.

Changes in Trade Execution:

(5) Telephone (November 13, 1878): On this date, the NYSE trading floor was equipped with telephones. Although the introduction of the telephone may appear to be an information event, its primary effect was to increase the speed of order flow to the Exchange (Sobel 1965). Prior to the telephone's introduction, an order could be executed for a customer only through his physical presence or by means of a messenger. Thus, the main effect of the telephone was that an investor need no longer be physically present in order to buy or sell stocks.

(6) Central clearing (May 17, 1892): Prior to 1892, the NYSE had no clearing procedure. Settlement was left to individual brokers involved in the trade, and without a centralized clearing function, all stock trades resulted in delivery of securities and payment. On this date, the NYSE instituted daily centralized clearing in the four most actively traded stocks (accounting for 1/3 of the total volume on May 16th (Bradstreet's, May 21, 1892)). Four additional stocks were added

the next week. The clearinghouse operated by comparing the daily transactions in stocks submitted to it by member firms, and by 10 AM the next morning delivering to the firms orders regarding the balance of securities to be delivered and the amount of settlement checks required. Bradstreet's (4/9/1892) characterized the clearinghouse as "the most radical innovation which it (the Exchange) has ever introduced into its business methods".

(7) Stock Clearing Corp. (April 26, 1920): The Stock Clearing Corporation was established on this date, replacing the NYSE Clearinghouse. In addition to improving the procedures for stock clearing, the corporation was designed to facilitate loans for members of the NYSE. As evidence of the improvement in clearing procedures, the Financial Chronicle (5/1/20) estimated that the new system would save the drawing of 3,000 checks daily and treble the efficiency of the messenger system.

(8) DOT (March 1, 1976): The Designated Order Turnaround system enables member firms to transmit small-size orders electronically to the NYSE's posts for automatic execution. A market order transmitted to the NYSE receives a "reference price" when it is received by the DOT system. At its introduction, if the specialist did not report execution of the order within three minutes, the order was executed at this reference price for the specialist's own account.

(9) ITS (April through December, 1978): The Intermarket Trading System was the NYSE's electronic linkage to the other two national exchanges (AMEX and NASD) and to the 5 major US regional exchanges. After an initial 11 stocks with dual listings were linked, issues were added periodically so that by the end of 1978 the system included all stocks listed on more than one exchange. At its inception, ITS displayed the price quotes on firm commitments (good for 2 minutes) from the market makers in all seven of the exchanges extant at that time, and included an electronic linkage for intermarket execution. With ITS, a broker on the floor of the NSYE can choose to trade at the specialist's quote or take the ITS order displayed on the specialist's screen.

(10) SuperDOT (November 16, 1984): The SuperDOT system for larger orders was introduced. At the time, the automated order system could handle 95 order transmissions per second and the limit on the number of shares for 3-minute execution was 2,099 (Brady 1988). SuperDOT is still used at the NYSE.

Table I summarizes the ten historical technology events.

Table I
Technology Events

Information Flow Events	Date of Event
(1) Ticker Speed—faster ticker (900 characters)	Dec. 1, 1964
(2) Automation to tape reporting	Feb – Dec 1966
(3) HiSpeed Transaction data to vendors	Jan 19, 1976

(4) Consolidated Quote System	Aug 8, 1978
Execution Events	
(5) Telephone introduced	Nov 13, 1878
(6) Central clearinghouse established	Mar 17, 1892
(7) Stock Clearing Corp. established	Apr 26, 1920
(8) DOT system inaugurated	Mar 1, 1976
(9) Integrated Trade System installed	Apr – Dec, 1978
(10) Super DOT system commences	Nov 16, 1984

IV. Data and Methods

Daily levels for the Dow-Jones Index are taken from the Dow-Jones Averages: 1885-1985 for 90 days prior to and after the event. (Since it appears that a technology is used as soon as it is available (Garbade *et al.* 1978), 90 days is consistent with substantive incorporation of the technology.) The index levels for events after 1900 are for the Dow-Jones Industrial Average of 30 stocks. For 1892, the broadest Dow-Jones Index available is the Dow-Jones 20 (18 railroad and 2 industrial stocks). For the 1878 telephone event, only monthly indexes are available (from Cowles 1939), and monthly levels are taken for a period of two years prior to and after the event. For "split" events (the 1966 and 1978 events involved a gradual introduction of the technology change), index levels were for 90 days prior to the first introduction and 90 days after completion of the innovation. For events after 1892, daily volume figures are given by Dow Jones, and for events after 1920, daily high and low prices are available as well. Returns, r_t, are calculated as the natural logarithm of index levels, I_t: $r_t = \ln (I_t / I_{t-1})$.

Statistical Tests:

Autocorrelation of returns. A significant change in the price formation process should affect the autocorrelation structure of returns. If information is incorporated slowly over a period of days, there should be significant autocorrelation between days. This autocorrelation should decrease after the technology change if the change affected information incorporation.

Volatility. Variances for each before-and-after period, and the F statistics testing equality of variance between periods, were calculated. In addition, z statistics testing equality of mean return between periods were estimated. If market returns increase, then the variance of returns is expected to increase as well. This variance test involves closing prices. High and low prices also contain information on market volatility, so a second estimate of volatility uses the high and low for the trading day. The natural log of the high and low price was calculated, normalized, averaged over the periods before and after, and tested for equality of variance between periods. (See Bookstaber 1991.)

Volume. Average volume was calculated for the period before and after the event, and equality of mean volume tested between periods.

Market movement. To measure market movement before and after, two measures were used. The mean market return, before and after, was calculated and in addition, the mean Dow Jones index value was calculated; equality of means was tested between periods using a z statistic.

V. Results

Confirmation of the Effect of Technological Change:

Table II shows the average autocorrelation for the nine events for which daily index information is available for lags 1 through 15 before and after technological change. There is a sizeable decrease in the autocorrelation structure for 12 of the 15 lags after the change in technology. The probability of this result occurring by random chance is .00139%. This indicates that there was, indeed, an increase in the speed of information incorporation into prices: the technological changes were significant information events.

Table II
Return Autocorrelations Averages for Lags 1 through 15

Lag	Before Event	After Event
1	0.1029	0.0323*
2	0.0100	0.0082*
3	0.0551	-0.0115*
4	-0.0045	-0.0370*
5	-0.0316	-0.0310
6	0.0052	-0.0294*
7	-0.0196	-0.0263*
8	-0.0292	-0.0036*
9	-0.0604	-0.0494
10	-0.0175	-0.0449*
11	0.0858	0.0027*
12	-0.0283	-0.0433*
13	0.0056	-0.0287*
14	-0.0305	-0.0359*
15	0.0302	-0.0334

* = indicates smaller autocorrelation average after technology event

Effect of Historical Changes in Technology: In comparing the effects of information flow events to those of trade execution events, we look at volatility, volume, and market movement. Tables IIIa and IIIb list the major statistical results for the 10 events.

(1) Does a change in the technology of the market change market volatility? While it is noted that the statistical data have limitations, particularly for the earlier time periods, several

intriguing indications can be gathered from the volatility tests. (See Table IIIa.) Under the standard volatility test, almost all of the trade execution events (Events 5 through 10) indicate a decrease in volatility (the exception is the ITS (Event 9), a split event). From this result, it would appear that making trading easier or cheaper may actually decrease trading volatility, particularly over the long run. In comparing the expectations of the noise versus the EMH model, easier entry into the marketplace may serve to speed the work of rational traders, allowing them to more easily arbitrage away the price differences due to irrational traders.

Table IIIa
Volatility Results
Result Summary

	Variance Increase Or Decrease *	High-Low[(a)] Increase or Decrease *
Information Flow Events		
(1) Ticker Speed (1964)	D	I
(2) Automation (1966)	I*	I*
(3) HiSpeed (1976)	D	I*
(4) CQS (1978)	I	I
Execution Events		
(5) Telephone (1878)	D	n/a
(6) Central clrnghse (1892)	D	n/a
(7) Stock Clrng Corp (1920)	D*	n/a
(8) DOT (1976)	D	D*
(9) ITS (1978)	I*	I*
(10) SuperDOT (1984)	D	I

Numerical Results

	Variance estimate			High-low Variance estimate		
Information Flow Events	Var1	Var2	F	H/L1	H/L2	F
(1) Ticker Speed (1964)	.000016	.000014	1.1232	.006854	.007140	1.0854
(2) Automation (1966)	.000018	.000033	1.8293*	.007132	.010758	2.275*
(3) HiSpeed (1976)	.000092	.000069	1.3355	.010401	.017079	1.642*
(4) CQS (1978)	.000066	.000102	1.5339	.008867	.010026	1.2784

Execution Events

(5) Telephone (1878)	.001371	.001195	1.1467	n/a			
(6) Cntrl clrnghse (1892)	.000038	.000034	1.1036	n/a			
(7) Stck Clrng Corp (1920)	.000194	.000111	1.7522*	n/a			
(8) DOT (1976)	.000080	.000050	1.3555	.01532	.00920	1.672*
(9) ITS (1978)	.000054	.000102	1.8949*	.008168	.010246	1.613*
(10) SuperDOT (1984)	.000080	.000062	1.2759	.009932	.010015	1.0168

(a) High-low estimator = $S = \sum_{n=1}^{t} 0.601 \ln(H_t / L_t)$

* = significant at the 5% level

F statistic = $(s_2)^2 / (s_1)^2$

Table IIIb
Volume and Return Results
Results summary

	Volume		Market Return or Average	
	Volume Increase Or Decrease *	% change in volume Decrease*	Market Avg Increase or or Decrease*	Market Ret Increase
Information Flow Events				
(1) Ticker Speed (1964)	I*	6.86	I*	I
(2) Automation (1966)	I*	81	D*	I
(3) HiSpeed (1976)	I*	44	I*	D
(4) CQS (1978)	I*	10	I*	D
Execution Events				
(5) Telephone (1878)	n/a	n/a	I*	I*
(6) Cntrl clrnghse (1892)	n/a	n/a	D*	D
(7) Stck Clrng Corp (1920)	I*	-46	D*	D
(8) DOT (1976)	D*	-22	I*	D
(9) ITS (1978)	I*	53	I*	D
(10) SuperDOT (1984)	I*	17.7	I*	D

Numerical Results

Information Flow Events	Volume Before	Volume After	z stat	Market Average z stat	Market Return z stat
(1) Ticker Speed (1964)	5005.1	5348.5	-2.6070	-4.6398*	-0.1217
(2) Automation (1966)	5430.8	9836.5	-17.6008*	13.7859*	-1.3678
(3) HiSpeed (1976)	18008	2609.6	-7.0902*	-33.3433*	0.8071
(4) CQS (1978)	30870	3400.8	-2.1489*	-11.2556*	1.7241
Execution Events					
(5) Telephone (1878)	n/a	n/a	n/a	-8.9255*	-2.1639*
(6) Cntrl clrnghse (1892)	n/a	n/a	n/a	17.1449*	0.5160
(7) Stck Clrng (1920)	1047.7	556.4	12.5588*	12.5588*	0.3468
(8) DOT (1976)	25499	19932	-10.3270*	-10.3269*	1.1882
(9) ITS (1978)	21734	33276	-26.9916*	-26.9916*	0.6700
(10) SuperDOT (1984)	89749	105650	-2.1594*	-2.1594*	0.2344

* = significant at the 5% level

Using a second volatility measure, high-low price volatility, it appears in contrast to the above that speeding information flow (Events 1 through 4) may lead to increased intra-day volatility. Examination of price movements within the day shows that there is more volatility when traders receive information more quickly. All four events lead to increased volatility; in two cases, the increase is significant at the 5% level or better.

Why would the speed of information flow increase the volatility of intra-day prices? One explanation is that faster information flows trigger additional and more concentrated trading. Noise traders are attracted to trade, not by new information, but by the appearance of increased market activity. Such a concentration of trading activity leads, in turn, to greater order imbalances and larger price moves. Thus, market liquidity may be a concern when information becomes available to the market more quickly. This finding can help to explain the apparent increase in volatility experienced more recently in the wake of the SEC ruling on company announcements to analysts. As companies have announced information to the general market at the same time that they release it to stock analysts, these announcements have generated much larger changes in stock prices than occurred previously. The information flow has led to more concentrated trading on that flow as everyone trades on that information at the same time.

Does technology change affect market volatility? We may tentatively conclude that information flow events may increase intra-day volatility, while trade execution events may decrease daily volatility.

(2) Does a change in technology lead to an increase in the volume of trading and noise trading? For all of the information flow events (Events 1 through 4), volume increased

significantly after the change (see Table IIIb). Faster information flow seems to lead to increased trading. This may indicate that noise traders are attracted to trade by the increased availability of information, even in the absence of new information.

Examination of trade execution events (Events 5 through 10), on the other hand, indicates that noise traders are not necessarily attracted to trading if it is made easier for them. Making trades easier or cheaper did not have a clear effect on the subsequent volume of trading. Sometimes volume increased (as with the ITS and SuperDOT improvements), at other times it did not (as with the DOT and clearing corporation improvements). Thus, interfering with the trading process itself may not be an effective remedy for excess volatility. Since noise traders do not necessarily increase their trading when the process is made easier or cheaper, they may not be so easily discouraged by making trading slower or more expensive.

Further, the direction of volume change after trade execution improvement was not closely correlated with a bull or bear market. This is an interesting result in that it shows that even when the market average increases significantly, facilitation of trading does not necessarily attract more trading. Thus, in a rising market, attempts to avoid speculative bubbles by "throwing sand in the gears", making trading more expensive or more difficult, may not in fact address the mechanism by which such bubbles begin.

Does technology change influence volume of trading? We may conclude that information flow events seem to increase market volume, while trade execution events may not have such a direct effect. Again, these results are subject to the limitations of the statistical tests.

(3) Does an increase in trading caused by technology change increase the volatility of stock returns? The answer, again subject to the limitations of these statistical tests, is yes. Price volatility appears to follow volume changes very closely (Table IIIc.) Significant decreases in volatility are associated with the largest decrease in trading, and significant increases in volatility are associated with the largest volume increases. This is consistent with the results in Schwert (1989), who, like many others, found a significant relation between stock market volatility and trading volume reaching back to 1857. (For a review of the research on volume and volatility in stock prices, and models proposed to explain the relationship, see Karpoff 1987.) Thus, changes that affect volume of trading have the most impact on market volatility.

Table IIIc
Volume and Volatility Results

		High-Low Increase or Decrease *	% change in volume
I.	DOT (1976)	D*	-22
(1)	Ticker speed (1964)	I	6.86
(4)	CQS (1978)	I	10

(10)	SuperDOT (1984)	I	17.7
(3)	Hi-speed trans (1976)	I*	44
II.	ITS (1978)	I*	53
(2)	Automation (1964)	I*	81

* = significant at the 5% level

VI. Implications

What attracts noise traders to the market? It appears that increasing the speed of information flow---without providing new information to the market---leads to increased trading and increased market volatility. The EMH postulates that only new information can lead to a change in market prices, while the noise model argues irrational investors acting on the basis of something other than fundamental information can change prices. As we see here, it appears that at least some investors are trading in response to a substitute for new information—an increase in the speed of information flow.

Given this result, it would seem then that such 'excess volatility' could be addressed directly through the slowing of information flow to the market. However, current regulatory philosophy, at least in the United States, would find such an impediment to the free flow of information to markets unappealing to say the least.

If the information flow to the market is not subject to restrictions, should the trading process itself be controlled to discourage noise traders? The evidence from the execution events suggests that the answer is no. It is the volume of trading that exerts the strongest effects on volatility. Noise traders do not necessarily increase their trades when trading is made easier. Since trade execution does not have a direct effect on the volume of trading, it is difficult to argue that noise traders would necessarily be discouraged from trading were trading made harder to do.

More importantly, the execution events studied here also show that it is precisely when trade execution is made easier or cheaper that price volatility seems to decrease. It appears that ease of execution may make it possible for speculators to defeat noise traders more easily as the EMH asserts that they will. Calls for impeding trade execution might actually defeat this adjustment process, or at least slow it considerably. Rather than diminish volatility, trading restrictions could actually increase it.

VIII. Conclusion

Historical events can shed valuable light on current issues in the market. In looking at past technology changes and their effects on market volatility, volume, and returns, several results stand out. First, technological innovations which increase the speed of information lead to greater trading volume and to higher returns volatility. As noise theory maintains, it would appear that noise traders are attracted to trade in the absence of new information, and bring additional volatility to the market when they do.

Secondly, technological innovations which facilitate trade execution seem to lead to decreased market volatility, but not necessarily increased volume, even in a rising market. This is consistent with the EMH argument that easier entry into the market facilitates the work of rational traders in diminishing the movement of prices away from fundamental values. At the same time, there is little evidence that changes in trade execution technology affect noise traders' willingness to trade. We have thus argued that solutions to the problem of noise traders should be approached through an effort to increase liquidity and attract rational investors rather than through slowing trading for all.

Finally, the effect of the latest technological innovations at the NYSE, such as the internet, can be expected to increase the speed of information flow dramatically. Based on past changes in technology examined here, such improvements may in turn increase both volume and volatility in the market. Given the continual improvement in the speed of new technology, the problem of excess market volatility--and the need for regulators to fashion a workable solution--can be expected to persist and indeed to grow.

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