ELSEVIER

Journal of Corporate Finance 9 (2003) 453–479

Journal of CORPORATE FINANCE

www.elsevier.com/locate/econbase

The complexity of price discovery in an efficient market: the stock market reaction to the Challenger crash☆

Michael T. Maloney[a,*], J. Harold Mulherin[b,1]

[a] *Department of Economics, Clemson University, Clemson, SC 29634, USA*
[b] *Department of Economics, Claremont McKenna College, Claremont, CA 91711, USA*

Received 15 November 2001; received in revised form 8 February 2002; accepted 12 July 2002

Abstract

We provide evidence on the speed and accuracy of price discovery by studying stock returns and trading volume surrounding the crash of the space shuttle Challenger. While the event was widely observed, it took several months for an esteemed panel to determine which of the mechanical components failed during the launch. By contrast, in the period immediately following the crash, securities trading in the four main shuttle contractors seemingly singled out the firm that manufactured the faulty component. We show that price discovery occurred without large trading profits and that much of the price discovery occurred during a trading halt of the firm responsible for the faulty component. Finally, although we document what are arguably quick and accurate movements of the market, we are unable to detect the actual manner in which particular informed traders induced price discovery.

JEL classification: G14 information and market efficiency
Keywords: Price discovery; Stock market; Challenger

☆ This paper is an outgrowth of "Efficient Markets: The Space Shuttle Challenger Story," by Erik Larsen, Master's Thesis, Clemson University, July 1992, which reported the stock market reaction to the crash based on daily and monthly returns. We have received helpful comments by a number of individuals and we particularly acknowledge Bobby McCormick, Clark Nardinelli, and Skip Sauer, as well as the referee and editor.

* Corresponding author. Tel.: +1-864-656-3430.
E-mail addresses: maloney@clemson.edu (M.T. Maloney), harold.mulherin@claremontmckenna.edu (J.H. Mulherin).
[1] Tel.: +1-909-607-3141.

0929-1199/02/$ - see front matter
doi:10.1016/S0929-1199(02)00055-X

1. Introduction

In this paper, we apply event study techniques to the crash of the space shuttle Challenger. We choose this case because of its unique information attributes. The Challenger crash was a highly visible event whose underlying cause was not publicly revealed until much later. We use this event to highlight the relation between complex information about business activities and the process of price discovery in markets.

In the terminology of the corporate finance and market microstructure literatures, the event we study had both public and private information components.[2] French and Roll (1986, p. 9) note that the dichotomy between public and private information is somewhat artificial and that "most information falls in the continuum between [the two]." More recent theory by Dow and Gorton (1993) argues that this continuum is not linear. They model price discovery in an environment where information is multidimensional and where the resulting price dynamics are complex. The Challenger crash offers an excellent case study of the multifaceted information structures envisioned by these researchers.

Methodologically, the event has appealing features. It was an exogenous occurrence. There was no leakage that induced run-up or run-down in the pre-event period. Hence, the analysis is free of the concerns of endogeneity raised in the conditional event study literature. (Eckbo et al., 1990; Prabhala, 1997) We can also exactly time the occurrence of the event. As studied by Brown and Warner (1985) and reemphasized by Fama (1991) and MacKinlay (1997), the precision in timing the event frees the analysis from the sensitivity of a particular technique or asset pricing benchmark. Further avoidance of the bad model problem (Fama, 1998) comes from the internal control sample enabled by the firms proved not to be at fault in the crash. Indeed, we can gauge the speed of the stock market reaction to the crash not only by the time that the guilty firm was discovered, but also by the time in which the innocents were released.

Our basic analysis provides a test of market efficiency. How quickly and accurately did the stock market process the implications of the space shuttle crash? As an extension, we also attempt to exactly discern how the price discovery unfolded on the day of the crash. Who provided the information that was imbedded in market prices? How valuable was the information?

We also examine issues related to the process of price discovery and tie these to avenues for future research: What is the source of trading volume? What are the interfirm implications of public announcements? Does a trading halt in one firm shift price discovery to firms that are close substitutes? Does the nature of the information spillover vary with news-related versus order-imbalance halts? Finally, we draw on our example to address policy issues facing securities markets: How obvious is the detection of insider trading around visible corporate events? What is meant by fairness in information disclosure?

[2] Empirical research in corporate finance generally maintains semi-strong form market efficiency and derives valuation implications from identifiable corporate events. (MacKinlay, 1997). By contrast, market microstructure considers the roots of the price discovery process and dissects the incorporation of information into market prices. (O'Hara, 1999) Using the terminology of French and Roll (1986) and Fama (1970, 1991), corporate finance emphasizes public information while market microstructure focuses on private information.

We develop the paper as follows: Section 2 reports the evidence on the stock market reaction to the crash. Section 3 considers the nature of the price discovery process. Section 4 provides generalizations of the analysis to issues in corporate finance and market microstructure. Section 5 offers concluding comments.

2. The market reaction to the disaster

2.1. Chronology of the crash

The Challenger explosion occurred at 11:39 a.m. eastern standard time on January 28, 1986. (See Appendix A for a list of the news stories and pertinent dates during the Challenger episode.) The announcement of the crash came across the Dow Jones News Wire at 11:47 a.m. In additional stories crossing the Wire in the next hour, Rockwell International, the maker of the shuttle and its main engines, and Lockheed, the manager of shuttle ground support, issued "no-comment" reactions to the crash. Press coverage that day also identified Martin Marietta as the manufacturer of the shuttle's external fuel tank and Morton Thiokol as the maker of the shuttle's solid fuel booster rocket.

The crash caught nearly everyone by surprise. The headlines the following day in the *New York Times* asked "How Could It Happen" and stated that there were "No Ideas Yet to the Cause." Because of the unprecedented nature of the event, the *Financial Times* on January 30th predicted that "it will be months rather than weeks before NASA has any real answers to the question—What went wrong with the Challenger?"

To find answers to this question, President Reagan appointed a blue-ribbon panel headed by former Secretary of State William Rogers. After several months of testimony and deliberation, the commission concluded that the cause of the crash was the lack of resiliency at low temperatures in the seals of the shuttle's booster rockets supplied by Morton Thiokol.[3] In its June 1986 report, the Rogers Commission also found fault with the chain of command at the booster's manufacturer, Morton Thiokol, as well as within NASA itself.[4]

Of the four main manufacturing firms involved in the shuttle project, the commission laid blame on only one of them. After more than 4 months of study by engineering experts and renowned scientists, Morton Thiokol was definitively adjudged to be the culprit.

2.2. The stock market on the day of the crash

Table 1 reports the stock returns and trading volume of the four shuttle firms on the day of the explosion. Data are taken from the S&P Daily Stock Price Record. As reported in

[3] See Report of the Presidential Commission on the Space Shuttle Challenger Accident (1986) called the Rogers Commission Report. See also Lewis (1988).

[4] Indeed, subsequent lawsuits raised the possibility that Morton Thiokol and NASA conspired to impede the dissemination of information about the crash. Although such charges were later dismissed, the apparent information failure associated with the Challenger accident is cited by business-school behaviorists as a classic case of organizational miscommunication. See, e.g., Elliot et al. (1993), Lighthall (1991), Maier (1992), and Schwartz (1987).

Table 1
Daily stock market behavior around the challenger crash

Variable	Morton Thiokol	Lockheed	Martin Marietta	Rockwell International
Panel A. Daily stock returns				
January 28	− 11.86%	− 2.14%	− 3.25%	− 2.48%
3-Month average	0.21%	0.07%	0.14%	0.06%
3-Month standard deviation	1.86%	1.36%	1.79%	1.79%
Z statistic	6.49	1.63	1.89	1.42
Panel B. Daily trading volume				
January 28	1739.9	667.5	446.2	563.2
3-Month average	100.5	347.9	199.9	221.2
3-Month standard deviation	59.5	159.4	136.5	117.1
Z statistic	27.57	2.00	1.80	2.92

This table compares the stock returns and trading volume of the four major space-shuttle firms on January 28, 1986, the day of the Challenger crash, to averages of the same variables in the 3 months (October 28, 1985 to January 27, 1986) prior to the crash. Trading volume is in thousands of shares. *Z* statistics test the null that the observation on January 28 equals the average from the prior 3 months. Data are taken from the *S&P Daily Stock Price Record*.

Panel A, Morton Thiokol's stock return stands out from the other three firms. Morton Thiokol's 1-day return was − 11.86%, more than 6 standard deviations greater than the firm's average daily stock return in the 3 months prior to the crash. By contrast, the stock returns of Lockheed, Martin Marietta, and Rockwell, while all negative, were less than 2 standard deviations different than the average return for the firms in the 3 months preceding the crash.[5]

As shown in Panel B of Table 1, Morton Thiokol also experienced an unprecedented amount of trading volume on the day of the crash. The 1.74 million shares traded in Morton Thiokol on January 28th were substantially greater than the average of 100,000 shares per day in the 3 months preceding the event. The other three firms also had above-average trading volume on the day of the crash, although not on the order of Morton Thiokol.

2.3. The speed of the market reaction

The daily data on stock returns and trading volume indicate that the Challenger explosion was a major event and that by the end of trading on the day of the event, the stock market had seemingly attributed culpability for the crash to Morton Thiokol,[6] but most interesting is the speed and manner in which the market distinguished Morton Thiokol from the other three firms. In the period immediately following the explosion,

[5] Two other papers report evidence on the daily stock returns of shuttle contractors around the crash. See Chegrin and Herget (1987) and Blose et al. (1996).

[6] While we argue that the market ferreted out the pertinent facts of the case, this summary indictment of Morton Thiokol was not universally perceived at the time. While many conjectures as to the cause were offered in the press, only one newspaper, the Chicago *Sun Times*, reported the disparate reactions of the stock prices of the affected firms on the day of the crash.

Table 2
Intraday stock market behavior around the Challenger crash

Time	Morton Thiokol	Lockheed	Martin Marietta	Rockwell International
Panel A. Stock price movements				
11:30 a.m.	US$37.25	US$47.25	US$35.38	US$34.75
Noon	Halt	US$44.50	US$34.25	US$32.75
12:36 p.m.	US$35.00	US$45.00	US$32.50	US$34.13
1:00 p.m.	US$34.38	US$45.00	US$33.00	US$33.25
Panel B. Stock returns				
11:30–Noon	Halt	− 5.82%	− 3.18%	− 5.76%
Noon–12:36	− 6.04%	1.12%	− 5.11%	4.20%
12:36–1:00	− 1.79%	0.00%	1.54%	− 2.56%

This table reports the price movements and stock returns of the four major space-shuttle firms in the period immediately surrounding the 11:39 a.m. crash of the space shuttle Challenger on January 28, 1986. There is no reported price for Morton Thiokol at noon because of an NYSE trading halt in that stock from 11:52 a.m. to 12:44 p.m. The first post-crash trade in Morton Thiokol occurred at 12:36 p.m. on NASDAQ. Data are taken from the price sheets of Francis Emory Fitch.

Morton Thiokol experienced a sell-induced trading halt while the other shuttle firms bore significant price declines.[7]

To analyze intraday price movements, we used data from Francis Emory Fitch. As reported in Table 2, by 12 noon, within 21 min of the crash and 13 min of the News Wire account, Lockheed had fallen 5.05%, Martin Marietta had declined 2.83%, and Rockwell was down 6.12%. Martin Marietta continued to slide for the next few minutes, finally reaching a low of 8.51% off from its pre-crash price.

At resumption of trading in Morton Thiokol at 12:36 p.m., it was down 6% from its pre-crash price.[8] As reported in Fig. 1, which benchmarks intraday prices to the price at the open on January 28th, Morton Thiokol continued to decline throughout the remainder of trading. By contrast, the other three firms rebounded from their initial price declines.

The price movements on the day of the crash were sustained over time. Fig. 2 plots the movements of the four shuttle firms in the two months following the crash. All prices are relative to their level on January 27, 1986 and the Dow Jones Industrial Index provides a market benchmark. As shown in the figure, the decline of Morton Thiokol on January 28th is maintained in the subsequent months while the other three firms track or outperform the market.

In a most important way, traders reacted differently between Morton Thiokol and the other shuttle firms. The fact that market liquidity was available to maintain a market in Lockheed, Martin Marietta, and Rockwell while the market for Morton Thiokol dried up suggests that the stock market discerned the guilty party within minutes of the announcement of the crash.

[7] The NYSE defines a trading halt in the following way: ''When unusual market conditions arise, such as extreme imbalances of buyers or sellers or significant corporate news, NYSE floor officials consider whether [to implement] a delay or halt in trading.'' This quote comes from www.nyse.com/content/articles/NT0002412E.html-11k-1999-10-18.

[8] Trading resumed on the NYSE at 12:44 p.m. The trade at 12:36 p.m. was on the Nasdaq for 50,000 shares.

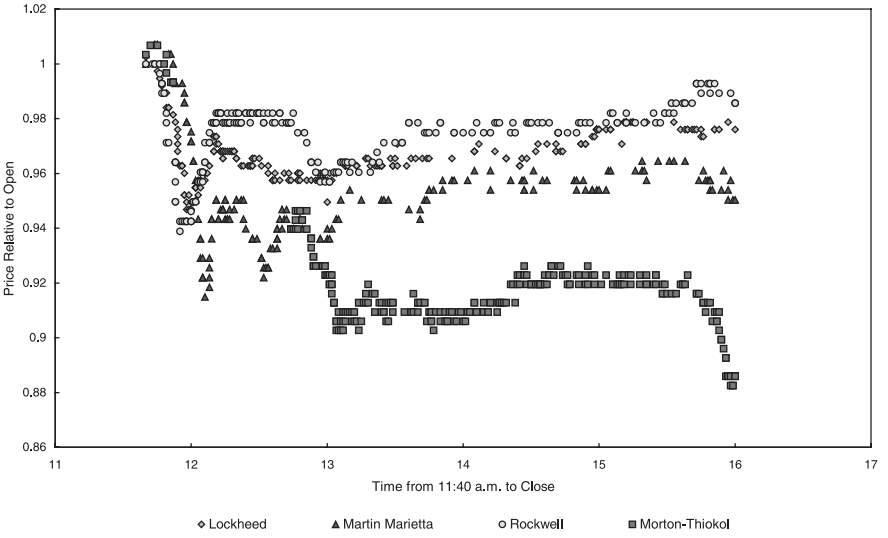

Fig. 1. Intraday stock price movements following the challenger disaster.

2.4. The accuracy of the market forecast

It is clear from the data that all shuttle firms experienced price volatility on the day of the crash. The data also suggest that the trading related to this volatility singled out Morton Thiokol. We build on these two points by addressing the following two queries:

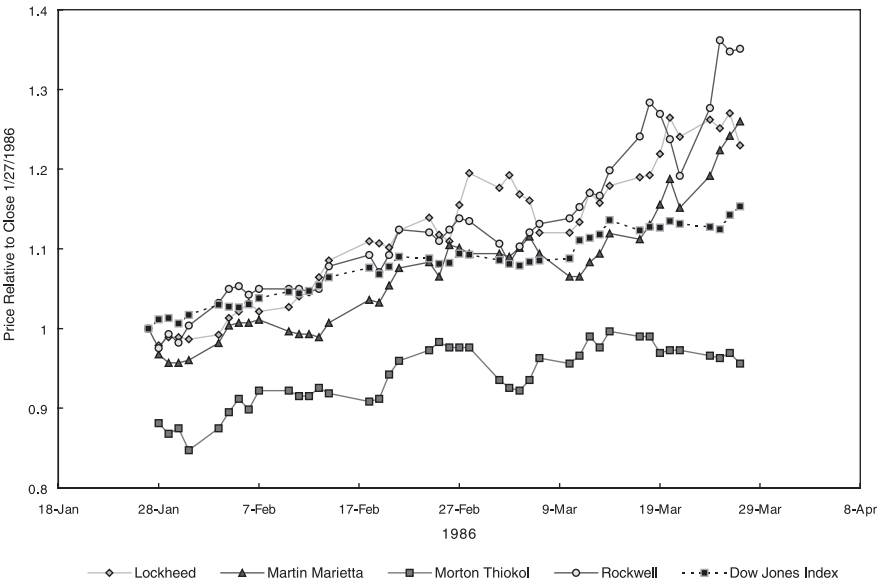

Fig. 2. Three-month stock price movements following the challenger disaster.

What explains the initial price volatility of Rockwell, Martin Marietta, and Lockheed? Were the stock price movements of all four firms on the day of the crash consistent with an indictment by the market against Morton Thiokol and a no-fault ruling for the other firms?

The crash event clearly had several potential implications. One is that the entire shuttle program might be severely delayed or possibly terminated, which would have hurt all four firms. However, on the day of the crash, President Reagan promised a continued commitment to space exploration, and the shuttle program did maintain operations albeit with a 2-year delay. The other implication is that being judged, the party at fault in the disaster was likely to have serious consequences over and above any delays that the program experienced.

The initial decline of Lockheed, Martin Marietta, and Rockwell may have been attributable to concerns about the continuation of the shuttle program or uncertainty to their culpability in the disaster. At all events, while these firms suffered initial declines of substantial magnitude, their prices rebounded. Morton Thiokol, on the other hand, was not as lucky in either its market valuation or its subsequent expenses. The firm's 1-day price decline was 12%, a loss in equity value of US$200 million.

The stock price decline for Morton Thiokol was substantially larger than the stock price declines for the other firms and hence was not likely based only on an expected delay in the shuttle program. While true that Morton Thiokol had more sales tied up in the shuttle project than the other companies, the difference was not large enough to explain the difference in the stock price movements. The percent of sales coming from NASA for each firm was 8.53% for Lockheed, 10.95% for Martin Marietta, 11.86% for Rockwell, and 18.23% for Morton Thiokol.[9] If the stock price declines for all four firms were only attributable to expected revenue declines because of a slowdown in the NASA shuttle program, Morton Thiokol's price should have dropped only on the order of 4.5%, i.e., about twice the stock price decline of the other firms rather than the 12% that it suffered on the day.

Interestingly, the US$200 million equity decline for Morton Thiokol seems in hindsight to have been a reasonable prediction of lost cash flows that came as a result of the judgement of culpability in the crash by the Rogers Commission. Morton Thiokol suffered substantial costs as an outcome of the shuttle accident. These included legal settlements with the families of the astronauts amounting to US$7 million and a direct forfeiture to NASA of US$10 million in retainers. Additionally, to mitigate future accidents, Morton Thiokol performed repair work of US$409 million at no profit, implying US$40 million in foregone profits (assuming a profit rate of 10%). Most importantly, the firm dropped out of the bidding for a US$1.5 billion NASA contract for the next generation of solid fuel booster rockets, implying US$150 million in lost profits. While this is an undiscounted value, it is representative of the reputational value placed in jeopardy as a result of the disaster.[10] All told, a rough estimate of the losses directly attributable to the shuttle

[9] See Blose et al. (1996).

[10] Soon after bowing out of the NASA bidding, the company broke itself into Morton International, producing salt, specialty chemicals and auto airbags, and Thiokol, an aerospace-only firm (announced February 28, 1989).

accident is approximately equal to the US$200 million loss in Morton Thiokol equity value on the day of the crash.

Morton Thiokol's stock price reaction was larger than the other companies and by our accounting most of the loss seems to be linked to the expectation of winning future government contracts. All four firms were at risk in this regard because all had wide berths at the government trough. Value Line (1985) reports that while 40% of Morton Thiokol's sales were to government, Lockheed had 83% of its sales tied to government contracts. Moody's (1985) says that 80% of sales for Martin Marietta were to government. Neither Moody's nor Value Line give a precise estimate of the percent of sales to government for Rockwell. However, Value Line points out that Rockwell's future opportunities all hinged on winning new government contracts in defense and aerospace one of which was construction of the space station for NASA. All told, culpability in the shuttle disaster would probably have been more devastating in a reputational sense to Lockheed, Martin Marietta, and Rockwell than it was to Morton Thiokol. We think that it is arguable that uncertainty on this margin by some investors may be the explanation for the volatility observed in the stock prices of these firms immediately following the crash.

3. The price formation process

3.1. Where did the information come from?

For most observers, the cause of the crash—the problem with Morton Thiokol's booster rockets—was made public on February 11, 1986, when Nobel-winning physicist Richard Feynman demonstrated that the material forming the shuttle O-rings loses resilience under cold temperatures.[11] However, both NASA and Morton Thiokol had been aware of this problem for at least a year. Testimony indicated that in July 1985, a NASA analyst warned of problems in the seals of the shuttle booster rockets on prior flights, especially those launches done in cold temperatures. Related testimony indicated that NASA had expressed concerns about the seals as early as 1982, and 3 months prior to the crash, Morton Thiokol itself had made a broad call for assistance in solving its O-ring problem to a meeting of experts at the Society of Automotive Engineering. Moreover, on the morning of the launch, Morton Thiokol engineers in Salt Lake recommended that the launch be postponed because of concern over the O-rings given the weather at the launch site.

Although the problem of the O-rings was known to some, it was not public information in the normal sense. A search of the various financial media such as the Wall Street Transcript, the Value Line Investment Survey, and other sources for evidence that analysts were aware of the O-ring problems reveals no obvious concern about Morton Thiokol either before or after the crash. A story from the Wall Street Transcript on January 27,

[11] See Feynman and Leighton (1988) for a description of the way the Rogers Commission came to its ultimate conclusion.

1986, the day before crash, indicated that Kidder Peabody analysts were quite bullish on Morton Thiokol. Following the crash, a Prudential Bache analyst quoted in the February 17, 1986, Wall Street Transcript considered the decline in Morton Thiokol's price to represent an overreaction by the market. A similar sentiment was conveyed by the analysts of several other securities brokerages following the crash: Donaldson, Lufkin and Jenrette on February 6, 1986, Piper, Jaffray on March 6, 1986, and Bear, Stearns on May 30, 1986. Similarly, the analysts in the April 11, 1986, Value Line Investment Survey considered the shuttle accident to represent "only a moderate setback" for Morton Thiokol. In general, if securities analysts knew about the potential for disaster or even the extent of it for Morton Thiokol, this information was passed to clients via confidential recommendations that were never made public.

3.2. Who brought the information to the market?

The existence of prior knowledge of the O-ring problem suggests that investors who were aware of this private information facilitated the price discovery process on the day of the explosion. It is natural to imagine that insiders at Morton Thiokol were the first to act on the news of the disaster.

We searched the Invest/Net Insider Trading Monitor available from Dialog Information Services for evidence of insider trading by Morton Thiokol people on the day of the crash. The data show no evidence of trading by insiders on January 28, 1986. The sale closest to the event was a disposition of 5000 shares on February 24, 1986, by a divisional officer of the firm. For the 1 year following the crash, the largest insider sale was by the company chairman on August 7, 1986. Both of these sales occurred well after the news of the crash was incorporated into stock prices.

This does not necessarily mean that Morton Thiokol insiders were not responsible for bringing the private information to the market. The information concerning the O-rings was apparently possessed by low-level managers and engineers, people who are not required by law to report their trades. Moreover, higher-up managers might have engaged in trades without reporting them or Morton Thiokol insiders may have bought shares in the other shuttle firms in an attempt to capitalize on their knowledge.

There were 52,500 shares of Morton Thiokol traded on the NYSE from the time of the crash up to the time trading was suspended. Another 200,000 shares traded in the call auction at the resumption of trading on the NYSE. Approximately the same number of shares traded in the other companies over this time period.

Table 3 shows the pattern of trading in Morton Thiokol in the minutes following the crash before trading was halted. Five thousand shares were traded at 11:42 a.m. on an up-tick. The fact that this trade occurred on an up-tick suggests that it was not initiated by a sell order and hence was probably not motivated by news of the disaster. At 11:48 a.m., there was a trade of 3200 shares on a down-tick of 1/4th. This was just following the time that the story flashed across the Broad Tape headline service on the floor of the exchange. Both the size of the price change and the coincidence of the news flash suggest that this trade could have been informationally motivated. Although it was followed by up-tick trade, two down-tick trades of 16,200 and 10,000 shares moved price by 3/8ths to US$37. These were followed by trades in the next minute

Table 3
Trading in Morton Thiokol immediately following the crash

Time	Trade size	Price
11:40	700	37.375
11:42	5000	37.500
11:45	5000	37.500
11:48	3200 (a)(b)	37.250
11:49	2000	37.375
11:49	16,200 (a)	37.125
11:51	10,000 (a)	37.000
11:52	100	37.000
11:52	1000	37.000
11:52	10,000	37.000
Trading halted		

This table shows trades in Morton Thiokol shares from the time of the crash up to the time trading was suspended (11:39 to 11:52). These are trades occurring on the NYSE. Down-tick trades that are most likely to have been initiated by sell orders are denoted by (a). News of the disaster crossed the Broad Tape on the floor of the exchange at 11:47; the trade immediately following is denoted by (b).

totaling 11,100 shares after which the specialist closed the market. The last three trades occasioned no price change and were likely filled out of the specialist's order book.

Selling shares in Morton Thiokol prior to the trading halt had some value. Sales of Morton Thiokol shares over the 13-min window following the crash prior to the trading halt were US$1.95 million. When the market in Morton Thiokol reopened on the NYSE at 12:44 p.m., the value of these shares was US$1.84 million. Hence, if we attribute the sale of all of these shares to private information about the cause of the crash, US$113,575 in equity losses were avoided by exercise of this knowledge.[12] The 200,000 shares that were exchanged upon resumption of trading were unable to avoid the US$2 price decline, or US$400,000 loss in value.

3.3. How was the information disseminated?

While we cannot attribute the price discovery process to particular informed traders, clearly some segment of the market quickly reacted to the news of the disaster. There was a trading halt in the market for Morton Thiokol shares but not in the market for shares of the other companies. This was true although the share prices in the other companies fluctuated by as much as or more than Morton Thiokol fell when its trading resumed. Liquidity was available to keep these markets operating.

This liquidity may have come from investors possessing private information about the cause of the crash and attempting to profit from this knowledge. However, another possibility is that the private information came to the market, maybe in the form of the early trades in Morton Thiokol—maybe from other sources, where it was quickly digested

[12] If we exclude the up-tick trades, then US$83,825 in avoided losses would be attributed to this information.

Table 4
Capitalizing on the knowledge of who was not responsible

Firm	Lockheed	Martin Marietta	Rockwell
Stock price prior to crash	US$47.000	US$35.250	US$34.750
Lowest price	US$44.625	US$32.250	US$32.625
Percent change	− 5.05%	− 8.51%	− 6.12%
Time period of decline	11:45–11:58 a.m.	11:53 a.m.–12:06 p.m.	11:46–11:55 a.m.
Number of trades	21	25	18
Average size of trades	1767	1292	2616
Largest trade	9000	5000	15,000
Price at time of largest trade	US$46.250	US$35.000	US$34.500
Cumulative volume	37,100	32,300	49,900
Cumulative position	US$1,697,825	US$1,098,575	US$1,688,025
Unwind value on January 28	US$1,704,738	US$1,091,763	US$1,711,550
Percent return	0.41%	− 0.62%	1.39%
Unwind value the next day	US$1,715,875	US$1,069,938	US$1,746,500
Percent return	1.06%	− 2.61%	3.46%
Unwind value after 1 month	US$2,072,963	US$1,292,000	US$1,889,963
Percent return	22.10%	17.61%	11.96%

This table analyzes trading in the firms who were ultimately judged not to have been responsible for the Challenger disaster. While trading in the at-fault firm, Morton Thiokol, halted as a result of an order imbalance at 11:52 a.m., trading in the not-at-fault firms continued. Each of their prices declined in the same percent as that of Morton Thiokol and over a relatively short time span. This table shows the cumulative position that an informed investor might have taken in each security during the downward price movement. The table also shows the relative gains from unwinding these positions.

by floor traders and specialists who then acted on it by providing liquidity for trading in the three innocent companies.[13]

To investigate the first possibility, we estimated how much money might have been made by exercising private information by buying shares in the innocent companies. To estimate the potential value of the private knowledge that Lockheed, Martin Marietta, and Rockwell were not at fault in the crash, we simulate a trading strategy in which an investor purchases shares in these three shuttle firms between the time of the crash through the lowest price reached for each firm on the day of the crash. Table 4 notes the prices at which the three firms traded immediately following the crash. Rockwell quickly reached its minimum for the day; the period of decline was 10 min and covered 18 trades. The total position that investors took in the security in this period was US$1.69 million. Lockheed's price decline spanned 14 min and 21 trades in which investors took a cumulative position of US$1.7 million. Martin Marietta's price decline also lasted for 14 min, involved 25 trades, and entailed a US$1.1 million investment.

[13] Floor traders and specialists may have pieced together private information from many sources. Possibly they learned the source of the early sell orders in Morton Thiokol. Possibly they made telephone inquiries to rocket scientists. Possibly they learned of insider purchases in the three innocent firms. The data show no purchases by the insiders at Lockheed and Rockwell. Data for Martin Marietta indicate that the company president acquired 30,000 shares on the day of the crash, although this was done via the exercise of options rather than an actual purchase in the market. The timing of this trade during the day is unknown.

We next estimate the profits made by unwinding the accumulated positions at the end of trading on the day of the crash.[14] As shown in Table 4, the US$1.69 million position in Rockwell was worth US$1.71 million at the end of the day, a return of 1.4%. The position in Lockheed returned 0.41%. Trading in Martin Marietta was actually a losing proposition, resulting in a −0.62% return. The total profit on buying the three innocent shuttle firms on their way down and then unwinding this position at the end of the day was US$23,625 or 0.53%. As a comparison, the Dow Jones Industrial Index was up 1.13% for the day.

Deferring sales of the accumulated positions until the end of the day following the crash would have led to larger gains for investments in Rockwell and Lockheed, but even more negative returns for Martin Marietta. Buying Rockwell on the way down and selling it the next day yielded a profit of US$58,475 for a return of 3.5%. The same strategy for Lockheed earned 1%, but Martin Marietta lost 2.6%. The total profit across all three firms was US$47,887 or slightly more than 1%. Again by comparison, the Dow Jones Industrial Index was up 1.3% over the 2-day period. As reported at the bottom of Table 4, holding the firms for a period of 1 month following the crash would have garnered more sizable gains, but would have exposed investors to market risks that were independent of the private information about the cause of the crash.

3.4. What was the evolution of prices?

The evidence shown in Table 4 does not make a compelling case that liquidity in the innocent firms came from outside the market. There does not seem to have been much money to be made by buying shares in the innocent firms. If we assume, then, that the liquidity in the innocent firms was provided by the market makers, it is reasonable to consider how these traders might have reacted.

To this end, we examine the details of the trading in these stocks on the NYSE during the trading halt in Morton Thiokol. The period of interest is from 11:39 a.m. to 12:44 p.m. This is the time of the crash up to the time that trading in Morton Thiokol shares resumed on the NYSE. Table 5 gives some details about trades in the other three stocks over this window. There were 120 trades of Rockwell stock totaling 290,400 shares. Lockheed had 101 trades for a total of 233,800 shares. Martin Marietta had 176,000 shares change hands in 85 transactions.

Most trades occurred without changing price although the price of all three stocks did move substantially over the period. The trading was orderly. Of the trades on which price moved, only once did price move by as much as three ticks (37.5¢) and 70% of the trades on which price moved, the price changed by only 1/8th of a dollar. Thus, the overwhelming majority of trades that moved price only moved price by one tick.

[14] From the accumulated positions acquired by buying each firm from the time of the crash through their lowest point, we matched trades at the end of the day. For instance, the strategy of buying Rockwell on the way down accumulated 49,900 shares. We matched these to the trading prices of the last 49,900 shares traded at the end of the day.

Table 5
Trades in other firms during Morton Thiokol trading halt

Stock	Lockheed	Martin Marietta	Rockwell
Total volume	233,800	176,000	290,400
Number of trades	101	85	120
Distribution of trades by price change			
− 3/8ths	1		
− 1/4th	3	16	6
− 1/8th	27	11	16
No change	54	39	78
+ 1/8th	11	11	18
+ 1/4th	5	8	2

This table examines trades in the three firms not responsible for the crash. The period examined covers the time of the crash up to the resumption of trading in Morton Thiokol on the NYSE (11:39 a.m. to 12:44 p.m.).

3.4.1. The characteristics of trade sizes and price movement

Tables 6 and 7 put this into perspective by looking at trade sizes and price movements during the entire day. Our analysis here is similar to Barclay and Warner (1993). Table 6 shows the distribution of the average number of shares traded at each of the different price changes observed in each stock. For each company, the largest number of trades occurred

Table 6
Price changes and trade sizes

Firm	Absolute price change	Average trade size	Number of trades
Lockheed	no change	2011	160
	1/8th	2302	92
	1/4th	4660	10
	3/8ths	1471	7
	1/2	5000	1[a]
	1	1225	4[b]
Martin Marietta	no change	1894	103
	1/8th	1399	71
	1/4th	3397	37
Rockwell	no change	1789	154
	1/8th	1592	90
	1/4th	4307	14
Morton Thiokol	no change	3278	141
	1/8th	2066	125
	1/4th	5421	29
	3/8ths	600	1
	2	200,000	1[c]

This table shows the average trade size and the number of trades in each of the securities throughout the entire day at each absolute change in price.

[a] Short sale at 1:27 p.m.

[b] Sequence of short sales followed by a bounce-back trades all at 3:03 p.m. Trades sizes in order: 2000, 100, 2500, 300. Short sales depressed price.

[c] Call auction that resumed trading after halt.

Table 7
Ten largest trades for each firm

Firm	Trade volume	Price change	Price	Time
Lockheed	27,900	no change	47.000	10:22 a.m.
	25,000	− 1/8th	47.000	10:44 a.m.
	11,900	no change	47.000	10:54 a.m.
	24,000	1/8th	47.000	11:16 a.m.
	16,000[a]	1/4th	44.750	11:59 a.m.
	20,000	no change	45.250	12:23 p.m.
	10,200	− 1/8th	45.250	12:31 p.m.
	28,300	− 1/8th	45.000	12:43 p.m.
	15,000[b]	− 1/4th	45.000	1:02 p.m.
	10,000	no change	45.375	1:42 p.m.
Martin Marietta	15,000	no change	35.000	11:07 a.m.
	11,400	no change	35.000	11:07 a.m.
	10,000	no change	35.000	11:07 a.m.
	25,000	− 1/4th	35.000	11:13 a.m.
	25,000	no change	35.250	11:18 a.m.
	50,000	1/4th	35.500	11:44 a.m.
	14,700	1/8th	33.250	12:39 p.m.
	10,000	1/8th	33.250	1:04 p.m.
	20,000	no change	33.500	1:27 p.m.
	15,700	no change	33.500	1:44 p.m.
Rockwell	15,000	no change	34.500	11:47 a.m.
	10,000	1/8th	32.750	11:56 a.m.
	16,000	no change	32.750	12:00 p.m.
	30,000	1/4th	33.250	12:03 p.m.
	11,000	no change	33.375	12:05 p.m.
	12,000	1/8th	34.125	12:11 p.m.
	10,000	no change	34.125	12:27 p.m.
	10,000	1/8th	33.500	1:06 p.m.
	20,000	no change	33.875	1:56 p.m.
	12,200	no change	34.250	3:37 p.m.
Morton Thiokol	16,200	− 1/4th	37.125	11:49 a.m.
	200,000[c]	− 2	35.000	12:44 p.m.
	50,000	− 1/8th	35.000	12:51 p.m.
	50,000	− 1/8th	33.750	1:52 p.m.
	50,000	− 1/8th	34.000	2:23 p.m.
	14,000	no change	34.250	2:34 p.m.
	13,000	− 1/8th	34.125	3:03 p.m.
	19,000	1/8th	34.000	3:48 p.m.
	100,000	no change	33.000	4:00 p.m.
	85,400	no change	33.000	4:00 p.m.

This table shows the 10 largest trades for each firm, the price, the time of day at which they occurred, and the price change that they occasioned. Except for the resumption of trading in Morton Thiokol, none of the biggest trades were associated with price changes in excess of two ticks.

[a] Short sale.

[b] Time corrected to reflect true sequence of trade.

[c] Shares traded in call auction when trading resumed after halt.

at zero price change, and while the average trade size is not the largest, more total volume was recorded for each company at no change in price than at any other price movement. The second most common event was for a trade to move the stock price by one tick. Indeed, the relative paucity of price changes in excess of one tick is striking. Except for Martin Marietta, the volume recorded at one-tick price changes was second to zero price change. There were no trades at price changes larger than two ticks for Martin Marietta and Rockwell, and only 14 trades at price changes of three or more ticks across all firms including the US$2 price adjustment occurring at the call auction resumption of trading in Morton Thiokol.[15]

Table 6 suggests a loose relation between trade size and price change. Even so, the emphasis is probably best placed on the word "loose." Table 7 shows the trade size and price change for the 10 biggest trades in all four companies. Less than 20% of the 10 largest trades in each stock moved price more than one tick. Except for the reopening of Morton Thiokol, none of these trades occasioned a price change of more than two ticks. And, the most common event for these largest trades was no change in price. It is interesting to note that 185,400 shares in Morton Thiokol traded at no price change to close the day. This amounted to nearly the same volume as traded at the reopening after the trading halt in this security.

3.4.2. Market liquidity during the halt

Tables 6 and 7 do give us a way of judging the liquidity that was provided in the three innocent firms from the time of the crash through the trading halt in Morton Thiokol. Although, overall, there is only a loose relation between trade size and price changes, we see that a disproportionately large share of the biggest price changes in the three innocent firms occurred during this period. More than half of the trades associated with price changes in excess of one tick took place during this window.

While we do not have records that tell us which trades were engaged by the specialists in each stock, it is enlightening to examine trades from the perspective of the specialist. For sake of discussion, we assume that the trades that move price are trades that require the market maker to provide liquidity. If price increases, the market needs liquidity on the sell side. That is, if price increases, it increases because buying relative to selling pressure has increased since the last trade. In order to clear the market, liquidity providers must come in on the selling side. On the other hand, if price decreases, there is increased selling pressure and market liquidity is required on the buying side.

Simply enough, we define "liquidity trades" as buys when price decreases and sells when price increases, and given these definitions, we look at the amount of liquidity that the market in these three stocks required over this period. We could choose different definitions. For instance, we could examine only those trades where price changed by two

[15] There were four curious trades in Lockheed at 3:03 p.m. A short sale of 1000 shares is reported to have dropped price US$1, following by a sale of 100 shares that bounced price back up by US$1. This was immediately repeated by a short sale of 1000 again dropping price by US$1. Price again bounced back on a trade of 300 shares. Generally speaking, specialists are not allowed to change price this dramatically. Most likely, these trades were recorded out of sequence and not corrected.

ticks, or where price changed in the same direction twice, or the like. However, the picture is substantively the same.

Table 8 shows that there were 42 liquidity trades in Rockwell and 46 in both Lockheed and Martin Marietta. As we might imagine, liquidity trades accounted for a larger percentage of shares than nonliquidity trades. That is, while the majority of trades occurred with no change in price, the majority of shares were exchanged in trades that did change price.

In Rockwell, the largest liquidity-providing buy was a purchase of shares for US$198,000; the largest liquidity providing sell was US$997,500. The largest liquidity buy overall was in Lockheed shares. It was a purchase of US$1,273,400. This trade took place only moments before trading resumed in Morton Thiokol, was for 28,300 shares, and occurred on a down-tick of 1/8th. The largest liquidity sale was for US$1,775,000 in Martin Marietta. It took place at 11:44 a.m., was for 50,000 shares, and occurred on an up-tick of 1/4th.

To get a sense of how much liquidity the market required over this period, we can follow the path of liquidity trades in terms of the net gains and losses to the liquidity providers and the magnitude of their inventory adjustments in shares of the three stocks. In Rockwell, liquidity providers ended the period with a net decrease in shares. Liquidity trades amounted to a net reduction in shares of Rockwell valued at US$2,060,400. This ending inventory is valued at the price of the last trade during the period (whether or not it was a liquidity trade). The maximum inventory reduction over the period was slightly larger than this. At one point during this window, liquidity traders had gained inventory of US$776,475.

Similarly, liquidity trades in Martin Marietta left market makers with US$1,722,350 less inventory at the end than at the start. On the other hand, liquidity traders in Lockheed were forced to accumulate inventory. Inventory in this stock increased over the period by US$2,835,000.

Table 8
Market liquidity during Morton Thiokol trading halt

Liquidity providing trades	Stock		
	Lockheed	Martin Marietta	Rockwell
Number	46	46	42
Volume	119,300	121,600	134,400
Largest buy	US$1,273,500	US$166,250	US$198,000
Largest sell	US$224,375	US$1,775,000	US$997,500
Maximum value of inventory	US$2,835,000	n/a	US$776,475
Maximum inventory deficit	US$(9425)	US$(1,775,000)	US$(2,085,038)
Sum of trades	US$(2,839,813)	US$1,822,925	US$2,027,063
Value of inventory	US$2,820,313	US$(1,722,350)	US$(2,060,400)
Net gain/loss	US$(19,500)	US$100,575	US$(33,338)

This table examines trades in the three firms not responsible for the crash. The period examined covers the time of the crash up to the resumption of trading in Morton Thiokol on the NYSE (11:39 a.m. to 12:44 p.m.). Liquidity Providing Trades are defined as buys when price changes are negative and sells when price changes are positive. In calculating Sum of Trades, buys are negative cash flow and sells are positive. Value of Inventory is based on price at last trade in each stock before Morton Thiokol reopened.

We can see how liquidity traders fared on these transactions by summing the buys and sells and netting the value of the inventory change. In Rockwell, there was more liquidity selling than buying. The sum of the trades, negative cash flow for buys and positive for sells, was US$2,027,063. Given the accumulated inventory deficit of −US$2,080,400, liquidity trades cost the market makers −US$33,338. By the same calculations, liquidity trades in Lockheed also resulted in a loss; in this stock, the loss was −US$19,500. On the other hand, liquidity trades in Martin Marietta resulted in a profit of US$100,575.

Thus, over all three stocks, liquidity providers made a profit of US$47,737. There were a total number of 700,200 shares exchanged in 134 trades with a value of US$11.8 million and requiring capital of US$6.7 million.[16] The profit per trade is not huge: about US$350 per trade. The profit per share traded was 6.8¢. Both of these are roughly equivalent to the commission on a full commission trade. While the return on the liquidity provided is fairly large if it is considered on an annualized basis, the standard deviation of the profit across the three companies is also large. The simple standard deviation is US$73,646, so the ratio of the total profit to this measure of risk is very similar to average return and risk for the market.

4. Generalizations

4.1. Market efficiency and the source of price movements

The textbook definition of market efficiency gauges the extent to which stock prices quickly and accurately respond to new information. Our case provides broad support for market efficiency. Within an hour, the market seems to have placed the blame for the crash on Morton Thiokol, the party ultimately judged by authorities to have been at fault. The firm's 1-day decline of 12% was quick, permanent, and reasonably corresponds to the subsequent losses in terms of legal liability, repair costs, and lost future business. By contrast, the other firms involved in the shuttle program suffered only temporary stock price setbacks that recovered for the most part by the end of trading on the day of the crash. Similar to research by Mitchell and Maloney (1989) on airline crashes, the stock market seems adept at detecting fault.

Of course, some might interpret the evidence on the innocent firms as noise trading, at least on an ex post basis. The three innocent shuttle firms experienced a great deal of trading volume in the hour following the crash, and this volume was accompanied by a substantial decline in the firms' stock prices. Subsequent trading led to a rebound in the prices of the three firms such that the firms had insignificant stock returns for the day. To some extent, therefore, the market initially overreacted to the Challenger crash.

But viewing the stock price behavior of the three other shuttle firms as a market overreaction seems misguided. Although some uninformed investors chose to sell

[16] We call required capital the sum of the absolute values of the maximum inventory positions in each stock. One could discount this using standard margin requirements.

immediately following the crash, their loss was a gain to the investors who provided liquidity based on their private information. Hence, the case is more consistent with a Grossman and Stiglitz (1980) world rather than an environment of systematic mispricing. Indeed, our case best fits the model of Dow and Gorton (1993, p.646) in which there is "a rich pattern of price responses, while remaining consistent with rationality."

In seeking explanations for market inefficiencies, Shleifer and Vishny (1997) suggest that there can be persistent deviations from fundamentals because of the costs and risks of arbitrage. Our case finds that the market quickly discovers prices even when the gains from arbitrage are not large. The investors who took positions in the three innocent shuttle firms did not garner large absolute or risk-adjusted gains that day.

The price discovery related to the Challenger crash provides a novel twist on the inquiry accentuated by French and Roll (1986) as to whether stock price movements emanate from public or private information. Clearly, the crash of the Challenger was a public event. And consistent with the French-Roll classification, much of the price movement of Morton Thiokol occurred with no trading volume.

Yet the reason that Morton Thiokol had no trading volume in the period immediately following the crash was because of an NYSE trading halt in the firm's common stock. But while trading in Morton Thiokol was halted, the remaining shuttle firms continued to trade and to provide price discovery. Indeed, an important piece of information to all market participants was which of the shuttle firms had trading halts and which were able to maintain trading.

Hence, the information on Morton Thiokol's O-rings that underpinned the stock market reaction is probably best viewed as private information. Indeed, there is no evidence that the knowledge of the O-ring problem had affected market prices before the day of the disaster. We examine trading in Morton Thiokol on days of prior shuttle launches and found that there had been no abnormal volume or stock price movements. Similarly, there was no abnormal short interest in Morton Thiokol on the days of previous launches, nor were there any short sales of Morton Thiokol on the day of the explosion prior to launch time. Indeed, Morton Thiokol's stock price was marginally up from its open during the period just before the launch.

As noted by French and Roll (1986, p. 9), the simple dichotomy between public and private information is somewhat artificial. The Challenger case reemphasizes that the information processed by the market is not simply some linear combination of private and public components. Instead, the information structure dealt with by market participants is often complex and, as modeled by Dow and Gorton (1993), can produce complicated price patterns in which the relation between information arrival and price discovery is not always direct.

4.2. Implications for corporate finance

The results from the Challenger case have a variety of implications for event study research. We discuss the importance of the sequential, multidimensional nature of information, the sources of trading volume, and the interfirm transfer of information.

4.2.1. The sequential, multidimensional nature of information

Although a rather unique event, the information structure in the Challenger case bears resemblance to the standard sequence in a corporate event. There was internal corporate consideration of information, public revelation of raw data, and finally resolution of the event. Consider the following comparison between the Challenger case and a generic corporate restructuring event:

Information event	Challenger case	Corporate restructuring event
Internal consideration	Internal Morton Thiokol memo on O-ring problem | Entreaties at engineering conference to help solve the O-ring problem | Call for postponement on morning of launch	Board directs management to consider restructuring alternatives | Merger partners considered | Merger partner chosen
Public revelation	Challenger crash	Firm publicly announces hiring of investment bank
Event resolution	Rogers Commission concludes fault was in O-rings	Firm announces a formal merger agreement

The similarity indicated by the timeline is that some internal members of a firm and possibly members of the financial community often have private information not known by the representative market participant. But the information is probabilistic and merely one piece of a multidimensional puzzle regarding firm value. Hence, in both the Challenger case and in the corporate restructuring event, there is not simply a single piece of information that gestates from private genesis to public maturity. In the Challenger case, it was internally known that cold temperature could compromise the sealing of O-rings, but this was not necessarily a problem given historic weather conditions in Florida. For corporate restructuring, the initial charge of a corporate board has a variety of possible outcomes that even the board itself may not be aware of at the time it assigns the task to management.

This comparison is pertinent to the implementation of event studies. As noted by Fama (1991, p. 1601), the strength of the event study methodology in distilling information lies in the ability to pinpoint the analysis to precise dates. The Challenger example, however, illustrates that even when the event can be precisely dated, the distillation process is often complex. Our results suggest the need for more research along the lines of Lee et al. (1993) that details the microstructure process around earnings announcements.

The comparison between the Challenger crash and corporate restructuring events also has important policy implications. For corporate events such as mergers, the price discovery that occurs prior to the formal public announcement is often offered as de facto insider trading (Keown and Pinkerton, 1981). Jarrell and Poulsen (1989) counter that there are often public rumors prior to formal announcement dates. The Challenger example further illustrates that price discovery does not always obtain from easily identifiable insiders. Instead, the basic

competition created by organized financial markets induces analysts, broadly defined, to decipher the implications of a sequence of events. As studied by Dann et al. (1977), some of these "analysts" include transactors on the floor of stock exchanges.

4.2.2. The source of trading volume

The Challenger case also provides implications on the interpretation of trading volume surrounding corporate events. As surveyed by Karpoff (1987), volume is often used to infer the information content of corporate events. Of course, given the definition of French and Roll (1986, p. 9) that "public information affects prices before anyone can trade on it," the use of volume to infer information around reported corporate events is not clear-cut. The Challenger case further indicates the complexity of the volume-information relation. The crash was clearly an information event for Morton Thiokol and that firm had noticeably abnormal volume. But the event also held information for the innocent firms; yet the daily volume in those firms was not as striking relative to recent trading history.

The complexity of the interpretation of trading volume shown in the Challenger case generalizes to corporate restructuring. For example, a number of papers study trading volume surrounding corporate takeover announcements. An often-reported result is that abnormal volume only occurs *after* the public announcement of the takeover (Sanders and Zdanowicz, 1992; Meulbroek and Hart, 1997). Hence, both the Challenger case and the takeover research confirm that there is no simple dichotomy between the effects of public and private information on stock prices.

The complexity of the volume–information relation has implications for insider trading policy. The standard measure of damages in insider trading applies to the traders who were hurt by dealing with better-informed traders. But if the above-average trading occurs after the public recognition of the event, does this dampen the apparent harm of insider trading? As Cornell and Sirri (1992, p. 1053) note, "the process by which the market infers information from insider trading is complicated." Perhaps the more important issue is the potential takeovers that are impeded by pre-announcement run-up (Meulbroek, 1992; Meulbroek and Hart, 1997).

4.2.3. The interfirm transfer of information

The Challenger case indicates a rich interfirm information process. In determining the fault of the explosion, the stock market engaged in price discovery not only in the guilty firm but also drew inferences about the firms not at fault.

The active interfirm information process provides support for novel implementation of event studies in corporate finance. For example, research such as Hulburt et al. (2002) contrasts information and agency theories by studying the stock price movement of rivals on the date that a given firm announces corporate restructuring. But the Challenger case also illustrates that, given the active nature of the interfirm information process, researchers must take care to discern the date on which the proposed restructuring first reaches the market and to account for the sequential nature of restructuring information.

One specific event for the future study of interfirm information transfer is a trading halt. A number of papers have studied the informational implications of firms subject to trading halts in securities markets (Lee et al., 1994; Corwin and Lipson, 2000; Christie et al., 2002). A natural extension of this work would be to analyze the price discovery in related firms

during the trading halt. A leading cause of trading halts is takeover announcements.[17] In such cases, one could follow Song and Walkling (2000) to define "related firms" as other potential targets from the same industry. A further aspect of such analysis would be to contrast the information spillover that emanates from news-induced trading halts versus order imbalance halts. For a more general treatment of interfirm information spillover during trading halts, one could study close substitutes along the lines of Wurgler and Zhuravskaya (2000).

4.3. Implications for market structure

The Challenger case also provides some implications on various aspects of securities market structure. One straightforward implication is definitional: a firm-specific trading halt is not the same as a market-wide circuit breaker. As illustrated by the Challenger case, the trading halt of Morton Thiokol did not stop the price discovery on the floor of the NYSE.

This simple illustration is quite pertinent to ongoing academic research on market liquidity. For example, Corwin and Lipson (2000, p. 1800) note differences between their results for firm-specific trading halts and the results of Goldstein and Kavajecz (2000) for a market-wide circuit breaker. Future theory and empirical research can add to the conceptual and operational distinctions between firm-specific and market-wide cessations in trading.

Our case also provides some relevant food for thought for a query posed by Professor Stigler some years ago. In what was arguably the first paper on market microstructure, Stigler (1964, p. 133) inquired, "Should floor traders' orders be delayed in execution to achieve parity with outsiders?" In his customary prescience, Stigler anticipated the current era in which the SEC aims towards fairness in information disclosure. When the question is directed at the Challenger event, there was clear parity in knowledge that the disaster had occurred, but it is also clear that there was differential information about the cause. However, regulating parity in information about the cause would have been a difficult matter to operationalize, which may be what Stigler was suggesting in his usual, enigmatic way.

5. Conclusion

The natural reaction to a major event is to ask, What happened? On the NYSE in January 1986, the initial reaction to the Challenger crash was heightened trading in the stock of the four firms most closely linked to the disaster. Out of this trading arose the inference that a single firm was responsible, a conclusion that was substantiated by a presidential commission several months later. But while the commission members were noted scientists and industry experts, the identity of those bringing the information to the market on the day of the crash is much less clear.

These results echo the bipolar aspects of the analysis of securities markets that have been noted recently by O'Hara (1999). The Challenger case is consistent with her

[17] See, e.g., Table 1 in Christie et al. (2002). For a set of 10 takeovers within his broader sample, Asquith (1983) notes that that takeover targets experiencing trading halts had different leakage patterns in the pre-announcement period.

statement (p. 84) that "Microstructure models can be viewed as learning models in which market makers watch some particular market data and draw inferences about the underlying true value of an asset." At the same time, the case also reflects O'Hara's observation (p. 83) of "... the perplexing situation that while markets appear to work in practice, we are not sure how they work in theory."

Our analysis of the Challenger case is also pertinent to the information theory of Hayek (1945). He notes (p. 521) that "there is beyond question a body of very important but *unorganized* knowledge ... the knowledge of the particular circumstances of time and place." (emphasis added) What the Challenger episode adds to Hayek's insights is that securities markets are a vehicle for amalgamating unorganized knowledge.

To outside observers, stock exchanges are a scene of "moil and tumult."[18] Yet, evolutionary models such as Alchian (1950) argue that the market as a whole creates knowledge out of the chaos of individual trades. Such knowledge creation lies at the heart of the hypothesis of semistrong market efficiency that is maintained in corporate finance.

Appendix A. News stories and pertinent dates

January 28, 1986

11:39 a.m.: Shuttle explodes
11:47 a.m.: *Dow Jones News Wire*: "Space Shuttle Explodes"
12:17 p.m.: *Dow Jones News Wire*: "Lockheed Has No Immediate Comment"
12:52 p.m.: *Dow Jones News Wire*: "Rockwell Intl Has No Comment"

January 29, 1986

New York Times: "How Could It Happen? Fuel Tank Leak Feared"

Martin Marietta, maker of external fuel tank, has no comment
Chicago Sun Times: "Morton Big Loser in Dip of Shuttle-Tied Stocks"

Speculation that the explosion was related to the solid-fuel booster rockets

January 30, 1986

New York Times: "Inquiry Agenda: Many Questions but No Answers"

Did a malfunction of the solid fuel rocket booster damage the external fuel tank?

January 31, 1986

Dow Jones News Wire: "Experts Study Chance that Booster Led to Shuttle Explosion

[18] From O'Rourke (1998, p. 38). Later in the article, he notes some method in the madness.

February 2, 1986

New York Times: "The Shuttle Inquiry"

Faulty seals, flawed casings and poorly packed fuel are among the flaws that could explain a rupture in a solid-fuel booster rocket.

February 3, 1986

Dow Jones News Wire: "Reagan Names Board to Investigate Shuttle Explosion"
New York Times: "Morton Thiokol is Facing the Closest Scrutiny"
Wall Street Journal: "NASA Appears to Be Narrowing Cause of Shuttle Explosion to Booster Rocket"

February 6, 1986

Wall Street Journal: "Frigid Weather at Launch Site Stirs Questions"

February 7, 1986

New York Times: "NASA Was Worried by Cold's Effects"

Rogers Commission told of concern over temperature and booster seals.

February 10, 1986

New York Times: "Panel Asks NASA for Its Reports on Booster Risks"

February 11, 1986

Rogers Commission press conference

Nobel-winning physicist Richard Feynman demonstrated that the material forming the shuttle O-rings loses resilience under cold temperatures.

February 13, 1986

New York Times: "Inexperience of Author Led NASA to Discount Warning"

Memo by NASA analyst Richard Cook on July 24, 1985, had noted problem with seals.

February 18, 1986

Wall Street Journal: "Morton Thiokol Trims Work Force at Booster Plant"

February 19, 1986

New York Times: "Rocket Engineer Describes Arguing Against Launching"

Thiokol engineer had warned NASA about temperature and seals.

February 23, 1986

New York Times: "Effects of Cold Emerge as Focus of Shuttle panel"

February 25, 1986

New York Times: "Shuttle Crash: Where Clues Have Led So Far"

NASA concerns with seals dated at least to 1982.

March 4, 1986

Financial World: "The Race for Profits in Space"

Notes that Lockheed, Martin Marietta, Morton Thiokol and Rockwell were all top NASA contractors and all received more than 10% of their revenues from the space agency.

March 24, 1986

Wall Street Journal: "NASA Searches for Reason Seal Failed on Shuttle Booster"

March 31, 1986

Fortune: "Challenger's O-Rings"

In October 1985, Thiokol had made appeal for solution to O-ring problem at annual meeting of Society of Automotive Engineers.

April 30, 1986

New York Times: "Virtual Certainty of failure Shown for Shuttle Seal"

June 6, 1986

Wall Street Journal: "NASA Is Urged to Seek a Second Source for Rockets"

250 members of Congress urge a second supplier for booster rockets.

June 9, 1986

Rogers Commission Report

Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident: Cites faulty seals as cause.
"The consensus of the Commission and participating investigative agencies is that the loss of the Space Shuttle Challenger was caused by a failure in the joint between the two lower segments of the right Solid Rocket Motor. The specific failure was the destruction of the seals that are intended to prevent hot gases from leaking through the joint during the propellant burn of the rocket motor. The evidence assembled by the Commission indicates that no other element of the Space Shuttle system contributed to this failure" (p. 40).
"A careful analysis of the flight history of O-ring performance would have revealed the correlation of O-ring damage and low temperature" (p. 148).

October 30, 1986

Wall Street Journal: "Morton Aide Who Opposed Challenger Launch to Quit"

Roger Boisjoly had been reassigned since testifying to Rogers Commission.

March 2, 1987

Aviation Week and Space Technology: "Morton Thiokol Will Forfeit US$10 Million in Lieu of Contract Penalty"

September 19, 1987

Chemical and Engineering News: "Space Shuttle Passes Final Tests, Is Readied for Return to Space"

March 14, 1988

Business Week: "Morton Thiokol: Reflections on the Shuttle Disaster"

Company to perform US$409 million worth of redesign work for NASA at no profit.

June 13, 1988

Aviation Week and Space Technology: "Thiokol Drops out of the Bidding for Advanced Shuttle Rocket"

June 20, 1988

Time: "Aerospace: Countdown to a Thiokol Exit"

August 19, 1988

Chemical and Engineering News: "U.S. Space Shuttle: Last Big Tests Clear Return to Space"

February 28, 1989

Wall Street Journal: "Morton Thiokol Is to Spin Off Chemical Line"

The company broke itself into Morton International, producing salt, specialty chemicals and auto airbags, and Thiokol, an aerospace-only firm.

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