

**The Complexity of Price Discovery in an Efficient Market:
The Stock Market Reaction to the Challenger Crash**

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J Corp Fin 9 (2003)

The Challenger crash was a highly visible event whose underlying cause was not publicly revealed until much later.

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.

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 discern exactly 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?

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.

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"

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

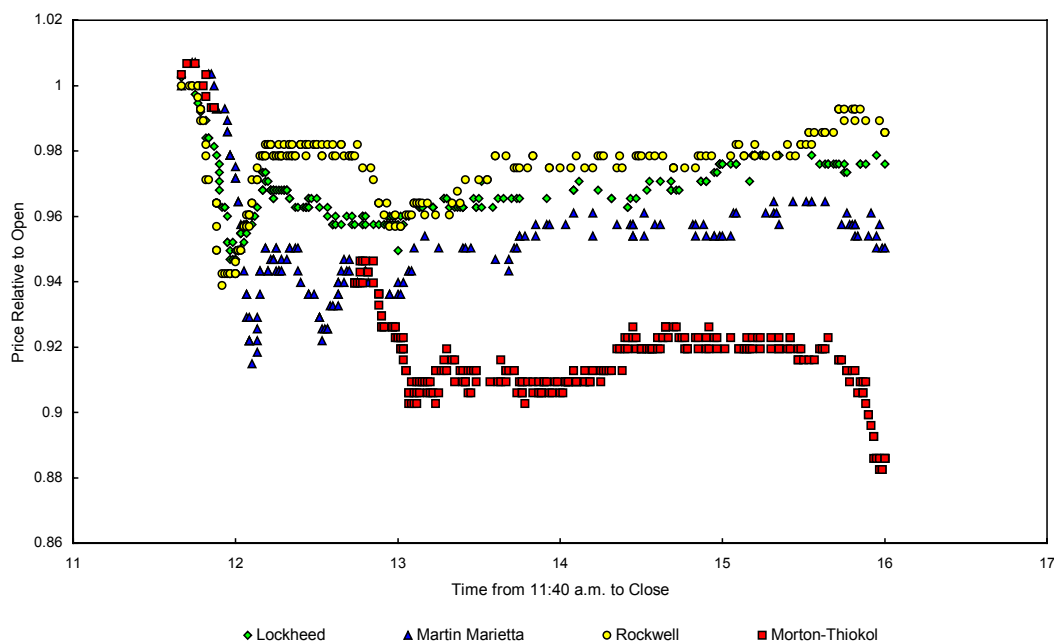
Rogers Commission press conference

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

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 seemingly had attributed culpability for the crash to Morton Thiokol, 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, Morton Thiokol experienced a sell-induced trading halt while the other shuttle firms bore significant price declines.

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.

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."



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.

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?

What explains the initial price volatility of Rockwell, Martin Marietta, and Lockheed?

If the stock price declines for all four firms were only attributable to expected revenue declines due to a slowdown in the NASA shuttle program, Morton Thiokol's price should have dropped only on the order of 4.5 percent.

The percent of sales coming from NASA for each firm was 8.53 percent for Lockheed, 10.95 percent for Martin Marietta, 11.86 percent for Rockwell, and 18.23 percent for Morton Thiokol.

Interestingly, the \$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.

Legal settlements with the families of the astronauts: \$7 million

Direct forfeiture to NASA: \$10 million

Repair work of \$409 million at no profit: \$40 million

Dropped out of the bidding for \$1.5 billion NASA contract: \$150 million

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.

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.

Both NASA and Morton Thiokol had been aware of the O-ring problem for at least a year. 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. It is natural to imagine that insiders at Morton Thiokol were the first to act on the news of the disaster.

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.

Sales of Morton Thiokol shares over the 13 minute window following the crash prior to the trading halt were \$1.95 million. When the market reopened the value of these shares was \$1.84 million. At most \$113,575 in equity losses were avoided. See Table 3.

200,000 shares that were exchanged upon resumption of trading were unable to avoid the \$2 price decline, or \$400,000 loss in value.

Table 3
Trading in Morton Thiokol Immediately Following the Crash

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 which 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).

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	16200	(a)	37.125
11:51	10000	(a)	37.000
11:52	100		37.000
11:52	1000		37.000
11:52	10000		37.000
Trading Halted			

There was a trading halt in the market for Morton Thiokol shares but not in the market for shares of the other companies even though the share prices in the other companies fluctuated by as much as or more than Morton Thiokol. Liquidity was available to keep these markets operating.

Who provided the liquidity: insiders with private information or floor traders?

Insiders: Buy innocent firms on the way down, sell out when price recovers.

See Table 4.

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 \$23,625 or .53 percent. As a comparison, the Dow Jones Industrial Index was up 1.13 percent for the day.

Deferring sales of the accumulated positions until the end of the next day would have resulted in a profit of \$47,887 or slightly more than 1 percent. Again by comparison, the Dow Jones Industrial Index was up 1.3 percent over the two day period.

If insider trading provided the liquidity, these individuals did not make much money.

Table 4
Capitalizing on the Knowledge of Who Was Not Responsible

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.

<i>Firm:</i>	Lockheed	Martin Marietta	Rockwell
Stock Price prior to Crash	\$47.000	\$35.250	\$34.750
Lowest Price	44.625	32.250	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:	\$46.250	\$35.000	\$34.500
Cumulative Volume:	37,100	32,300	49,900
Cumulative Position:	\$1,697,825	\$1,098,575	\$1,688,025
Unwind Value on January 28:	\$1,704,738	\$1,091,763	\$1,711,550
Percent Return	0.41%	-0.62%	1.39%
Unwind Value the Next Day:	\$1,715,875	\$1,069,938	\$1,746,500
Percent Return	1.06%	-2.61%	3.46%
Unwind Value after 1 Month:	\$2,072,963	\$1,292,000	\$1,889,963
Percent Return	22.10%	17.61%	11.96%

Floor traders: Examine the details of the trading in these stocks on the NYSE during the trading halt in Morton Thiokol.

See Table 5.

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 even though 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 percent of the trades on which price moved, the price changed by only 1/8th of a dollar.

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 ten biggest trades in all four companies.

Less than 20 percent of the ten largest trades in each stock moved price more than one tick. 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.

Table 5

Trades in Other Firms during Morton Thiokol Trading Halt

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.).

	<i>Stock:</i>	Lockheed	Martin Marietta	Rockwell
Total Volume		233,800	176,000	290,400
Number of Trades		101	85	120
<i>Distribution of Trades by Price Change</i>				
-3/8 ^{ths}		1		
-1/4 th		3	16	6
-1/8 th		27	11	16
no change		54	39	78
+1/8 th		11	11	18
+1/4 th		5	8	2

Table 6
Price Changes and Trade Sizes

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.

<i>Firm:</i>	Absolute Price Change	Average Trade Size	Number of Trades
Lockheed	no change	2011	160
	1/8 th	2302	92
	1/4 th	4660	10
	3/8 ^{ths}	1471	7
	1/2	5000	1 ^a
	1	1225	4 ^b
Martin Marietta	no change	1894	103
	1/8 th	1399	71
	1/4 th	3397	37
Rockwell	no change	1789	154
	1/8 th	1592	90
	1/4 th	4307	14
Morton-Thiokol	no change	3278	141
	1/8 th	2066	125
	1/4 th	5421	29
	3/8 ^{ths}	600	1
	2	200000	1 ^c

Notes: (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

This table shows the ten largest trades for each firm, the price and 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.

<i>Firm:</i>	Trade Volume	Price Change	Price	Time
Lockheed	27,900	no change	47.000	10:22 a.m.
	25,000	-1/8 th	47.000	10:44 a.m.
	11,900	no change	47.000	10:54 a.m.
	24,000	1/8 th	47.000	11:16 a.m.
	16,000 ^a	1/4 th	44.750	11:59 a.m.
	20,000	no change	45.250	12:23 p.m.
	10,200	-1/8 th	45.250	12:31 p.m.
	28,300	-1/8 th	45.000	12:43 p.m.
	15,000 ^b	-1/4 th	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	-1/4 th	35.000	11:13 a.m.
	25,000	no change	35.250	11:18 a.m.
	50,000	1/4 th	35.500	11:44 a.m.
	14,700	1/8 th	33.250	12:39 p.m.
	10,000	1/8 th	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	1/8 th	32.750	11:56 a.m.
	16,000	no change	32.750	12:00 p.m.
	30,000	1/4 th	33.250	12:03 p.m.
	11,000	no change	33.375	12:05 p.m.
	12,000	1/8 th	34.125	12:11 p.m.
	10,000	no change	34.125	12:27 p.m.
	10,000	1/8 th	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	-1/4 th	37.125	11:49 a.m.
	200,000 ^c	-2	35.000	12:44 p.m.
	50,000	-1/8 th	35.000	12:51 p.m.
	50,000	-1/8 th	33.750	1:52 p.m.
	50,000	-1/8 th	34.000	2:23 p.m.
	14,000	no change	34.250	2:34 p.m.
	13,000	-1/8 th	34.125	3:03 p.m.
	19,000	1/8 th	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.

Notes: (a) Short sale. (b) Time corrected to reflect true sequence of trade. (c) Shares traded in call auction when trading resumed after halt.

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.

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.

See Table 8.

Over all three stocks, liquidity providers made a profit of \$47,737. There were a total number of 700,200 shares exchanged in 134 trades with a value of \$11.8 million and requiring capital of \$6.7 million. The profit per trade is not huge: about \$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.

Required capital is the sum of the absolute values of the maximum inventory positions in each stock.

Table 8

Market Liquidity during Morton Thiokol Trading Halt

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.

	<i>Stock:</i>	Lockheed	Martin Marietta	Rockwell
<i>Liquidity Providing Trades</i>				
Number		46	46	42
Volume		119,300	121,600	134,400
Largest Buy	\$	1,273,500	\$ 166,250	\$ 198,000
Largest Sell		224,375	1,775,000	997,500
Maximum Value of Inventory		2,835,000	n/a	776,475
Maximum Inventory Deficit		(9,425)	(1,775,000)	(2,085,038)
Sum of Trades		(2,839,813)	1,822,925	2,027,063
Value of Inventory		2,820,313	(1,722,350)	(2,060,400)
Net Gain/Loss		(19,500)	100,575	(33,338)

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 one-day decline of 12 percent 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. 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.

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.