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An experimental study of circuit breakers: The effects of mandated market closures and temporary halts on market behavior☆

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Abstract

This paper analyzes the effect of circuit breakers on price behavior, trading volume, and profit-making ability in a market setting. We conduct nine experimental asset markets to compare behavior across three regulatory regimes: market closure, temporary halt, and no interruption. We find that the presence of a circuit breaker rule does not affect the magnitude of the absolute deviation in price from fundamental value or trading profit. The primary driver of price behavior is information. By comparison, trading activity is significantly affected by the presence of a circuit breaker. Market participants advance trades when a trading interruption is imminent.

JEL classification: D82; G18

Keywords: Circuit breaker; Experimental asset markets; Trading interruption

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1. Introduction

Recent dramatic swings in the U.S. stock market have resurrected the circuit breaker debate though researchers and regulators have reached no consensus on whether circuit breakers provide a moderating influence. Though circuit breakers can take many forms, in this paper we focus on the impact of market-wide mandated trading halts triggered by extreme market movements.[1] Circuit breakers were advocated by the members of the Brady Commission who argued that these mechanisms "cushion the impact of market movements, which would otherwise damage market infrastructures" (Presidential Task Force on Market Mechanisms, 1988, p. 66). American exchanges instituted circuit breakers in the year following the 1987 market crash in an effort to protect investors and markets in the event of a future extreme market adjustment. Opponents contend that mandated trading halts impede the natural movement of stock prices and introduce unnecessary and artificial barriers.[2]

On October 27, 1997 the circuit breaker provision was triggered for the first time in history as the Dow Jones Industrial Average (DJIA) fell 554 points or 7.2 percent. As Table 1 details, the trading halt rules originally called for trading interruptions when the DJIA fell 250 and 400 points. Because of increases in the level of the market, the point breakers were widened in 1997 and then tied to percentage changes in the DJIA in 1998. At 2:36 p.m. on October 27, 1997, the DJIA was down 350 points from the previous day's close and the New York Stock Exchange's (NYSE) Rule 80B was triggered. After a 30-min trading interruption, the market reopened at 3:06 p.m. By 3:30 p.m. the market was down 550 points and the NYSE shut down trading for the remainder of the day. On the following day, the DJIA rose 337 points, the largest one-day point rise at the time.[3]

The extreme market movements observed in October 1997 could have resulted from a market reaction to a change in expectations about fundamental values.[4] We use an experimental market setting to examine the effect of circuit

[1] Trading restrictions include the NYSE's Rule 80A that restricts stock index arbitrage. Trading halt rules include the price limits commonly imposed in futures markets and firm-specific trading halts called in response to order flow imbalances or pending news releases.

[2] Some theoretical evidence suggests that circuit breakers are beneficial. For example, in Greenwald and Stein (1991), mandated halts can play a useful role in reducing transactions risk. Other theoretical evidence suggests that circuit breakers are detrimental. For instance, Subrahmanyam (1994, 1995) shows that circuit breakers may have the perverse effect of increasing price variability by forcing agents to advance their trades.

[3] For further insight into the dynamics of trading on these significant days, the reader is referred to Ross and Sofianos (1998).

[4] The extreme market movements also could result from a failure in the liquidity provision process. Goldstein and Kavajecz (2000) examine this issue and conclude that specialists fulfilled their obligation to provide liquidity, though limit orders declined dramatically.

Table 1
Circuit breaker history

This table provides details on U.S. circuit breaker rules since they were first put in place in response to the market crash of October 1987. The original circuit breakers were triggered when the DJIA moved by a given number of points. More recently, actual point levels are fixed quarterly based on the average closing level of the Dow industrials in the previous month.

• First circuit breaker implemented in October 1988	
250 point drop in DJIA	Trading halt for 1 h
400 point drop in DJIA	Trading halt for 2 h if additional 150 point drop after trading resumes
• Circuit breakers widened in January 1997	
350 points drop in DJIA	Trading halt for half an hour
550 points drop in DJIA	Trading halt for one hour if additional 200 point drop after trading resumes
• Current circuit breaker rule adopted in February 1998	
10% drop	Halt trading for 1 h if before 2:00 p.m. Halt trading for 30 min if between 2:00 and 2:30 p.m. No halt in trading if after 2:30 p.m.
20% drop	Halt trading for 2 h if before 1:00 p.m. Halt trading for 1 h if between 1:00 and 2:00 p.m. Close the market for the day if after 2:00 p.m.
30% drop	Close the market for the day

breakers on price behavior, trading volume, and trading profit. This approach allows us to control extraneous factors, which although important, create potential confounds when using archival data.[5] Using an experimental method, we can specify the level of uncertainty, the distribution of information across traders, and the fundamental determinants of asset value. More importantly, the experimental method allows us to examine behavior under alternative market structures (e.g., in the presence and absence of circuit breakers). Such an examination cannot be conducted in naturally

[5] Other experimental studies have examined related issues. Isaac and Plott (1981) and Smith and Williams (1981) find that even non-binding price controls affect market dynamics and reduce market efficiency. Smith et al. (1988) and King et al. (1993) report that price change rules do not mitigate price run-ups and crashes in experimental asset markets. Finally, in an examination of price limits and trading suspensions, Coursey and Dyl (1990) find that prices adjust more efficiently when trading is unconstrained and that efficiency losses are higher with trading suspensions as compared to price limits.

occurring markets.[6] For our purposes, empirical regularities observed in the laboratory provide insight into the effect of circuit breakers on market performance.

We conduct nine experimental asset markets to compare behavior across three regulatory regimes: market closure, temporary halt, and no interruption. In the sessions with market closures, no transactions are permitted for the remainder of a trading period if the circuit breaker is triggered. With temporary halts, market activity is interrupted when a price movement triggers the breaker. Finally, in the sessions with no interruptions, market participants are free to transact at any price during the trading period. We conduct three market sessions with each institutional structure. In each market we vary the asymmetry of information among traders.

The foremost conclusion is that deviations from the expected price are not affected by the presence of circuit breakers. The primary driver of price deviations from fundamental value is information in the market. In fact, when some traders have private information pertaining to the fundamental value of the asset, the deviation in price from fundamental value is twice as large as that in other periods. Our analysis of trading volume indicates that circuit breakers affect trading activity in a significant way. When an interruption in trading is imminent, trading activity accelerates. Finally, circuit breakers do not affect the trading profits of informed or uninformed agents.

The paper is organized as follows. Section 2 describes our experimental design and procedures. Section 3 presents empirical tests and evidence on market dynamics with and without circuit breakers. Section 4 provides discussion of the results and concludes the paper.

2. Experimental method

2.1. Design

Nine experimental asset markets are conducted. Each market includes 6 years and each year consists of three periods. All markets have 8 traders and all

[6] Archival studies of the effects of circuit breakers encounter numerous empirical demands because it is impossible to determine the net effect of breakers on the market. Stock prices and associated volatility may change for a variety of reasons, including the distribution of informed and uninformed traders, macroeconomic factors, and investor sentiment. These changes may or may not be related to shifts in underlying fundamentals. Moreover, archival methods do not permit the researcher to ascertain what would have happened in the absence of circuit breakers. Not surprisingly, archival findings on the role of circuit breakers in moderating volatility and enhancing efficiency are inconclusive (e.g., Harris, 1998).

Table 2
Overview of the experiment

This table provides information on the parameters of our experiment, including how dividend payments are determined. The dividends received for each certificate held at the end of periods B and C are determined randomly from one of the distributions I–V, whereas the dividend received at the end of period A is always determined using distribution III. Each dividend is equally likely so that the average dividend per period over many draws is $5.00.

Panel A: Experimental parameters

Regulatory regime	Markets 1–3	Market closure
	Markets 4–6	Temporary halt
	Markets 7–9	No interruption
Fraction informed	Period A	0/8
	Period B	2/8
	Period C	8/8
Endowments (certificates, cash)		1, $125.00
		2, $110.00
		3, $95.00
		4, $80.00
Fixed cost		$100.00
Payout ratio		10%

Panel B: Distribution of dividends

Distribution	Possible dividends (Equally likely)							Average dividend
I	$1.50	$2.00	$2.50	$3.00	$3.50	$4.00	$4.50	$3.00
II	$2.50	$3.00	$3.50	$4.00	$4.50	$5.00	$5.50	$4.00
III	$3.50	$4.00	$4.50	$5.00	$5.50	$6.00	$6.50	$5.00
IV	$4.50	$5.00	$5.50	$6.00	$6.50	$7.00	$7.50	$6.00
V	$5.50	$6.00	$6.50	$7.00	$7.50	$8.00	$8.50	$7.00

traders are inexperienced in that none participated in an earlier session. Table 2 provides an overview of the experimental parameters. In markets 1–3, trading is shut down on a permanent basis if a circuit breaker is triggered. The actual procedure used for closure is described subsequently. In markets 4–6, trading is halted on a temporary basis if an extreme price movement activates a circuit breaker. Finally, in markets 7–9, participants are free to transact without any threat of a trading interruption.

Each year market participants trade certificates with three-period lives, referred to as periods A, B, and C. At the end of each period, participants receive

a common dividend for each certificate held.[7] Certificates are not carried across years. Thus, the payoff for a certificate held throughout all periods in a year is the dividends paid in periods A, B, and C.

The asymmetry of information is varied across traders within each market. Each year the period A dividend is drawn from a distribution known to all participants. The dividends for periods B and C are also drawn from a given distribution, but the specific distribution is unknown to participants at the beginning of the year. At the beginning of period B, two traders receive information that narrows the distribution of possible dividend values.[8] At the start of period C, this information is made public to all traders. Hence, the ability of traders to refine their price expectations increases as trading progresses from period A to C. Overall, our design provides a basis from which we can compare the effect of permanent and temporary trading halts on market price dynamics, trading volume, and profit-making ability.

2.2. Procedures

At the beginning of each market session, participants receive a set of instructions, which an experimenter reads aloud.[9] Substantially all participants were master's students at Georgia Tech who had successfully completed a required finance course or were currently enrolled in the course. The average compensation across the 72 traders in our markets was $30.35, which includes trading earnings, a $3.00 bonus if on time for the session, and $2.00 for completing a post-experiment questionnaire. The markets take approximately 2 h to complete.

Each trader is endowed with certificates and cash at the beginning of the trading session. There are four endowment classes with two traders receiving the same endowment. The specific endowments are summarized in Table 2. These endowments are assigned randomly prior to the start of each year from the set of four possible endowments.

During each market year, participants trade certificates with three-period lives. All markets are organized as double oral auctions. Traders are free to make verbal offers to buy or sell one certificate at a designated price at any time, and all offers are publicly announced and recorded. Outstanding offers stand

[7] Although they receive a common dividend, participants trade certificates in our experiment because of divergent, uncontrolled preferences.

[8] In our experimental setting, information narrows the range of dividend values but does not identify the dividend with certainty. The design reflects the fact that prices in naturally occurring markets respond to new information pertaining to shifts in the process that generates fundamental value.

[9] The instructions are available from the authors upon request.

until accepted or replaced by a better bid or ask price. Short sales are not permitted. If a circuit breaker is not triggered, all market periods last 3 min. Participants are not informed of the number of years to be conducted beforehand.

Uncertainty regarding the actual dividend exists until the market closes for the period. The dividend paid in period A is always selected randomly from distribution III given in Panel B of Table 2. Participants are informed of the distribution beforehand and told that each dividend is equally likely so that the mean of the distribution is $5.00. The dividends for periods B and C are drawn from one of the five distributions given in Table 2 with the constraint that the dividends are drawn using the same distribution for periods B and C within the same trading year. Note that this does not imply that the period B and C dividends are equal, but only that they have an equal ex ante expectation. The experimenters randomly determine the actual distribution for periods B and C prior to the experiment, and the same sequence of distributions is used across all markets.[10] At the beginning of period B, two traders are provided with information concerning the distribution from which period B and C dividends are drawn.[11] The other traders know only what they can infer from the trading behavior of others until the end of period B, at which time the experimenters announce the distribution to all the participants. The procedures repeat in years 2–6.

During each trading period, participants are free to trade certificates in the no interruption condition. However, in the market closure and temporary halt conditions, trading can be halted or interrupted when there are large upward or downward price movements in the market for *all* certificates. Our circuit breaker rules are designed to reflect the fact that actual rules tie interruptions in trading to movements in the overall market, as measured by the DJIA. Participants are told that market movements are positively, but not perfectly, correlated with the prices of the certificates they trade. Participants are aware, however, of the circuit breaker trigger levels so they can anticipate when a halt is more or less likely.

After each completed transaction, the trading interruption rule is assessed. In period A, the circuit breaker rule is implemented as follows. The probability of a trading halt increases as the price moves away from $15.00, the expected value of a certificate. The probability of a halt is 50 percent if the price moves more than 5 percent but less than 10 percent from $15.00. The probability of a halt increases to 90 percent if the price moves 10 percent or more from $15.00. The circuit breaker rules in period B (C) are constructed similarly with the

[10] See Cason and Friedman (1996) on the benefits of using a pre-selected sequence.

[11] All traders are informed the same number of times throughout the experiment.

permissible trading price ranges centered about the last transaction price in period A (B) less $5.00, the average one-period dividend value.[12] An experimenter determines whether trading actually halts by drawing a card from one of two decks. The first set has 5 (5) cards labeled "stop" ("go") and the second has 9 (1) labeled "stop" ("go").

In the market closure condition, the market does not reopen until the following market period if a breaker is triggered. In the temporary halt condition, trading is suspended for 30 s. After a suspension, trading resumes as before with the circuit breaker rule for transaction price ranges centered around the last transaction price prior to the trading interruption. However, trading is never halted in the last 60 s of a period.

After the experimenter announces the year's dividend, traders calculate their cash balance by multiplying the number of certificates held by the dividend and adding their earnings from certificate holdings to their cash on hand. Certificates and cash are carried forward across periods within a market year (but not across years). At the end of period C, participants keep cash in excess of a fixed cost of $100. Each trader's endowment is reinitialized at the start of a new market year.

At the end of the experiment, participants are paid in cash. Trading profit is converted to take-home earnings by multiplying profit by 10 percent. During this time, participants complete a post-experiment questionnaire. Participants receive an additional compensation of $2.00 in order to provide them with an incentive to carefully complete the questionnaire. The purpose of the questionnaire is to collect general information about the traders and how they viewed the experiment.[13]

3. Results

3.1. Descriptive information

Table 3 provides descriptive data on trading time for the mandated closure and temporary halt regimes. Trading may last a maximum of 180 s per period, and in the no interruption sessions, markets are always open the maximum

[12] The specific dollar ranges are detailed in the experimental instructions that are available from the authors upon request.

[13] Participants' responses to the post-experiment questionnaire suggest that they found the experiment interesting and the monetary incentives motivating. Participants responded on a seven-point scale as to how interesting they found the experiment, where 1 = not very interesting and 7 = very interesting. The mean response was 6.22. Participants also responded on a seven-point scale as to how they would characterize the amount of money earned for taking part in the experiment, where 1 = nominal amount and 7 = considerable amount. The mean response was 4.44.

Table 3
Descriptive data on trading time for the market closure and temporary halt regimes

For each period and year, the table presents the average number of seconds the markets in the market closure and temporary halt regimes are open for trading. Sessions with no circuit breaker rule are always open 180 seconds per period, which is the maximum number of seconds for trading across all market structures.

Year	Period	Market closure	Temporary halt
1	A	174	160
	B	87	150
	C	99	160
2	A	128	170
	B	110	150
	C	47	150
3	A	129	170
	B	34	170
	C	54	160
4	A	125	170
	B	47	170
	C	17	140
5	A	130	180
	B	125	170
	C	31	170
6	A	124	180
	B	67	130
	C	60	130
Average	A–C	88	160

amount of time. In the two halt regimes, circuit breakers are often triggered. The average trading time is 88 (160)s with mandated market closures (temporary halts). Trading time is greater in markets with temporary halts because trading always resumes after a circuit breaker is triggered. Further, the data indicates that markets are open longer in period A than periods B and C, with little noticeable difference across years.

Table 4 presents the number of halts and draws by period and year for the two halt regimes. The observed frequencies are nearly identical in the market closure and temporary halt regimes.[14] Not surprisingly, fewer halts and draws are

[14] The frequencies of halts triggered by upward and downward price movements are similar across the market closure and temporary halt regimes. Time series graphs of transaction prices do not suggest divergent behavior when prices move toward the upper or lower breaker. We repeated the analyses reported subsequently in the paper controlling for upward and downward breaker triggers and inferences were unaffected.

Table 4
Descriptive data on the frequency of trading halts, draws, and transactions

In Panel A (B), the table presents the number of halts and draws by period (year) for the market closure and temporary halt sessions. Also reported is the total number of transactions for all three market structures.

Panel A: Frequencies by period

Period	Market closure			Temporary halt			No interruption
	Halts	Draws	Transactions	Halts	Draws	Transactions	Transactions
A	6	7	71	6	8	98	129
B	14	29	50	13	23	84	78
C	18	19	29	18	23	84	92
Total	38	55	150	37	54	266	299

Panel B: Frequencies by year

Year	Market closure			Temporary halt			No interruption
	Halts	Draws	Transactions	Halts	Draws	Transactions	Transactions
1	6	7	28	8	12	43	47
2	6	9	25	7	8	41	51
3	7	7	19	4	7	46	49
4	7	15	27	6	9	42	52
5	5	7	26	2	4	45	60
6	7	10	25	10	14	49	50
Total	38	55	150	37	54	266	309

observed in period A, but no pattern is evident across years. Table 4 also presents the total number of transactions by period and year for all three market structures. The transactions data are consistent with the time the markets are open. The number of transactions is largest with no interruptions, slightly less with temporary halts, and smallest with market closures. In addition, more transactions are observed in period A than periods B and C. As before, no differences are evident across years.

3.2. Price deviations

We examine price deviations from fundamental value, where such value is determined by the risk-neutral expected price. In periods A and C, information

Table 5
Price predictions

For each period, the table presents the risk-neutral expected value or predicted price, the dividend realized, and the distribution used to determine the period's observed dividend. In Period B the predicted price is conditioned on the dissemination of private information.

Year	Period	Predicted price	Realized dividend	Dividend distribution
1	A	15	4.5	III
	B	8	3.5	II
	C	4	3.0	
2	A	15	5.5	III
	B	12	5.5	IV
	C	6	7.5	
3	A	15	6.0	III
	B	6	2.5	I
	C	3	2.0	
4	A	15	3.5	III
	B	12	7.0	IV
	C	6	6.5	
5	A	15	6.5	III
	B	10	6.0	III
	C	5	4.0	
6	A	15	5.0	III
	B	14	8.0	V
	C	7	6.0	

is common to all market participants. In period B, the expected price is determined assuming that private information is disseminated. The expected prices by year and period are summarized in Table 5, along with the actual dividend drawn and the randomly chosen distribution from which the dividend per period is selected.

To provide insight into whether prices converge to expected value, we first examine the time series of transaction prices across periods and years for each market. Figs. 1–3 detail transaction prices across periods A–C within a year for selected markets for year 6. For each figure we select a market from each regulatory regime: Figs. 1, 2 and 3 are from the market closure, temporary halt, and no interruption regimes, respectively. The figures include the circuit breaker in place, as detailed previously, and the expected price per period. The figures show that asset prices roughly converge to the expected price and are not consistently above or below

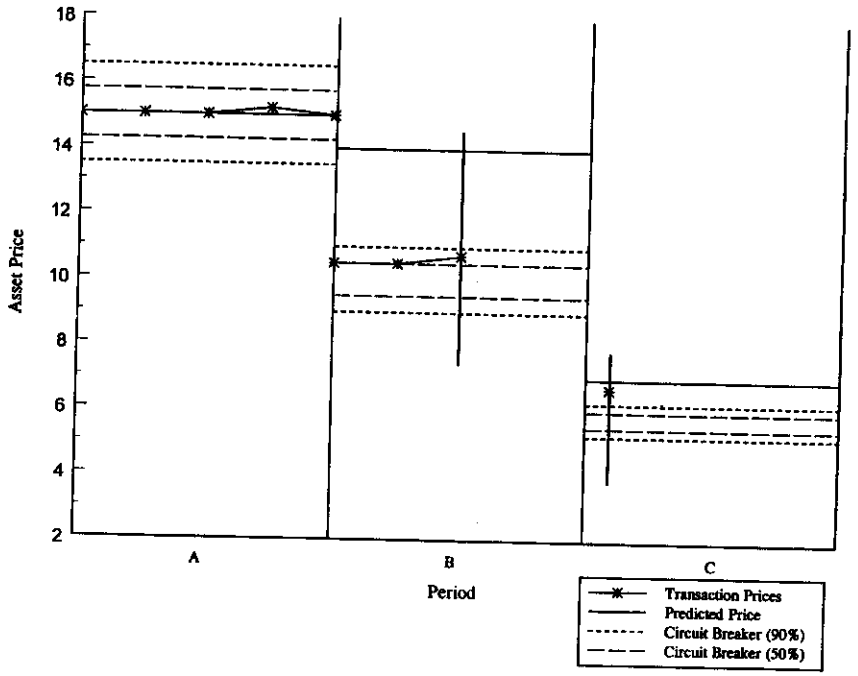

Fig. 1. Market 3, Period 6 transaction prices. This figure shows the time series of transaction prices in market 3 during year 6 with each star representing one trade. The figure also shows the circuit breakers in place during each trading period. In this market a price movement outside a breaker may trigger closure of the market.

predictions.[15] Notably, in sessions with market closures (Fig. 1) and temporary halts (Fig. 2), prices appear to move toward the expected price despite the circuit breaker rule in place. In period B, transaction prices move toward the expected price, which is calculated assuming dissemination of private information.

Fig. 4 provides insight into price behavior across all nine market sessions. It shows the normalized absolute price deviation, calculated as the absolute value of the difference between the transaction price and predicted price, normalized by the predicted price. The figure reports the average deviation over sessions

[15] Experimental bubbles markets consistently report price run-ups followed by crashes relative to fundamental value (Smith et al., 1988). In these markets, as in ours, participants trade finite-lived certificates with a common dividend determined by a probability distribution at year-end. We do not report price bubbles in our markets because of the short time horizon (3 periods). Another distinction between our study and bubbles markets is that in our study the probability distribution that determines the dividend is not fixed and known by traders at the beginning of each market year.

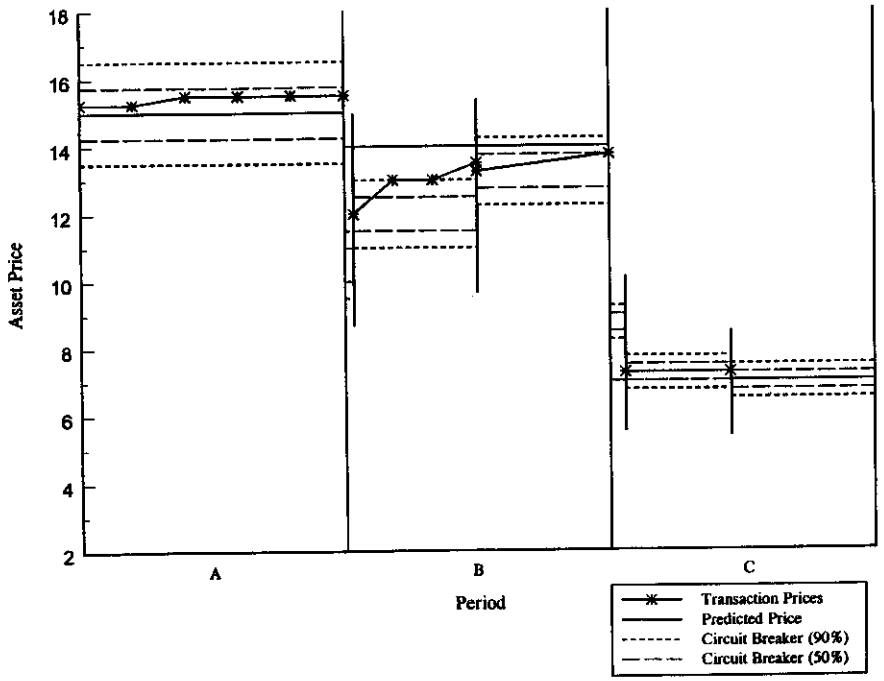

Fig. 2. Market 4, Period 6 transaction prices. This figure shows the time series of transaction prices in market 4 during year 6 with each star representing one trade. The figure also shows the circuit breakers in place during each trading period. In this market a price movement outside a breaker may trigger a temporary halt in trading.

within each of the three regimes for each period and year. Price deviations are larger in period B as compared to periods A and C and some large price deviations from fundamental value are observed in the earlier years. Across the three circuit breaker regimes, no clear pattern emerges.

To further investigate price behavior in period B we count the number of times that the last price in period B reflects the dividend distribution known only to informed traders. We use the last transaction price because earlier prices are informative. The last price is compatible with private information if it falls between two times the low and high values of the dividend distribution. We multiply the minimum and maximum dividends by two because the distribution determines the dividends paid in periods B and C. Consider the following example for illustrative purposes. If private information indicates that distribution IV is used to determine dividends (refer to Table 2), the asset price in period B should fall between \$9 (two multiplied by \$4.50) and \$15 (two multiplied by \$7.50). These bounds, though not stringent, rule out the presence of arbitrage opportunities.

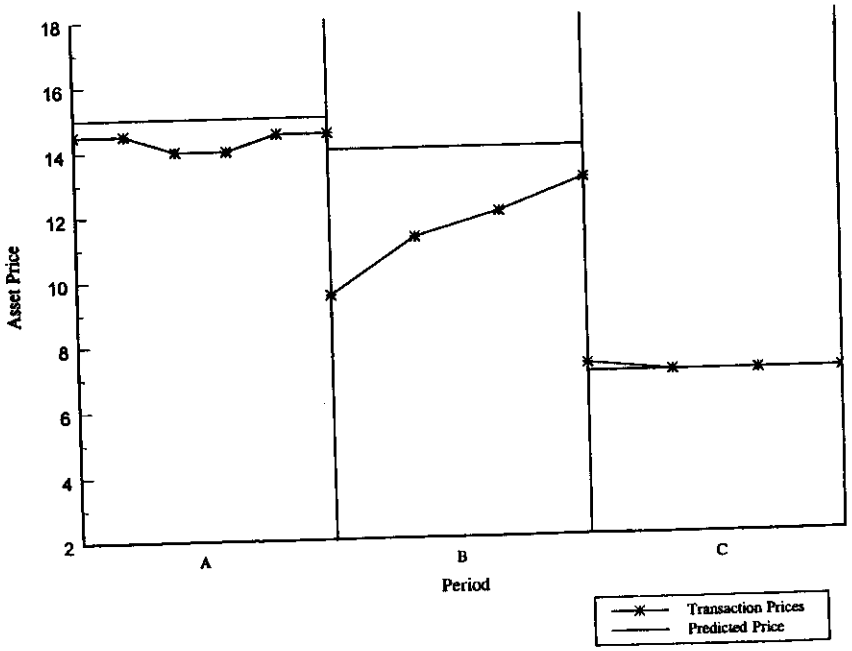

Fig. 3. Market 9, Period 6 transaction prices. This figure shows the time series of transaction prices in market 9 during year 6 with each star representing one trade. There is no circuit breaker rule in this market.

Using data across years 1–6, we find that the last price is compatible with private information in 12 of 18 cases, 14 of 18 cases, and 17 of 18 cases in the mandated closure, temporary halt, and no interruption regimes, respectively. We perform a chi-square test to determine whether differences arise across market structures. The χ^2-statistic is not statistically significant ($\chi^2 = 4.338$, $p = 0.114$) and suggests that market structure does not affect information dissemination.

Next, we formally test the effect of a circuit breaker rule on deviations in price from fundamental value across all periods. We perform an analysis-of-variance (ANOVA), where the dependent variable is the absolute value of the deviation in price from the predicted price, normalized by the predicted price.[16] In periods

[16] Analysis of variance is a procedure to test for differences among group means. It is appropriate when the dependent variable is continuous and the independent variables are categorical. For further discussion of ANOVA, the reader is referred to Neter et al. (1990).

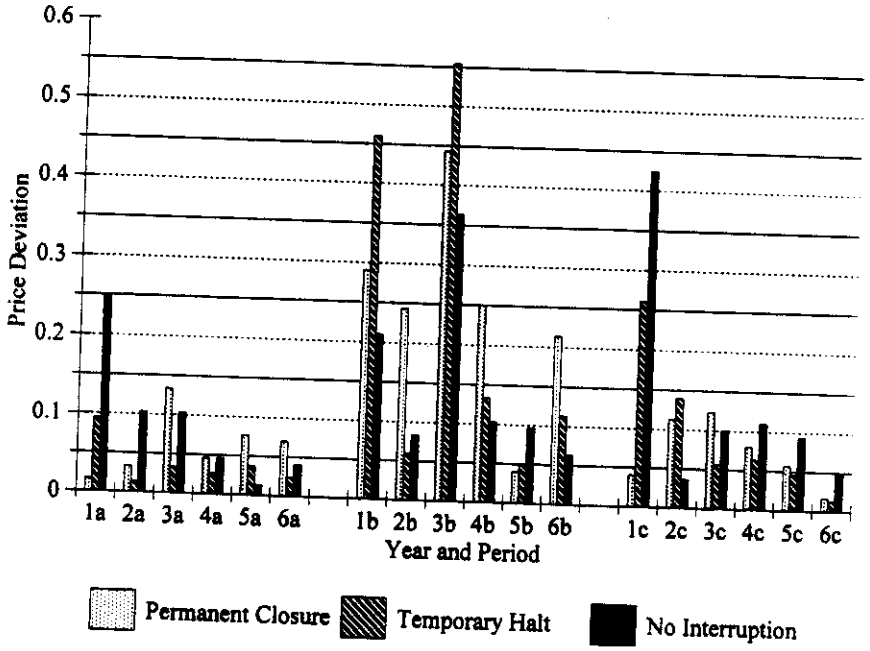

Fig. 4. Normalized absolute price deviation. This figure shows the absolute value of the difference between transaction price and predicted value, normalized by the predicted price for each period, year, and market regime, averaged over sessions within a regime.

A and C, we use the median transaction price.[17] In period B we use the last transaction price. The independent variables include market structure (market closure, temporary halt, and no interruption), period (A, B, and C), and an interaction term. Period proxies for the information asymmetry among traders within a market year, with asymmetry in period B and common information in periods A and C.

The ANOVA results using data from years 1–6, presented in Panel A of Table 6, indicate that period is significant at $p < 0.001$ and the interaction term is marginally significant at $p = 0.074$. Consistent with our earlier observations regarding Fig. 4, the significant main effect arises because the mean price deviation in period B (0.2097) is greater than that in periods A (0.0639) and C (0.1086). Tukey HSD multiple comparison tests (Hays, 1981) indicate that the mean deviation in period B is significantly different from the mean deviations for

[17] When we include all transactions the results are similar to those reported subsequently. Inferences are also unaffected if we use the final or average transaction price in periods A and C.

Table 6
Analysis of price behavior

The table presents the results of an ANOVA to test the effects of market structure on deviations in transaction prices from fundamental value. The dependent variable is the absolute value of the transaction price minus the predicted price, normalized by the predicted price. For periods A and C, the transaction price used in determining the absolute deviation is the median price per period. For period B, the price used is the final price per period. The independent variables include market structure (market closure, temporary halt, and no interruption), period (A, B, and C), and an interaction term. The analysis reported in Panel A (B) includes data from years 1–6 (4–6).

Source	df	Sum of squares	*F*-statistic	*p*-value
Panel A: ANOVA results using data from years 1–6				
Market	2	0.0034	0.531	0.589
Period	2	0.6020	9.449	0.000
Interaction	4	0.2780	2.183	0.074
Error	153	4.8730		
Panel B: ANOVA results using data from years 4–6				
Market	2	0.0022	1.523	0.225
Period	2	0.0092	6.408	0.003
Interaction	4	0.0029	1.024	0.401
Error	72	0.5150		

the other two periods at $p < 0.01$. The greater period B mean most likely results because private information creates greater divergence in expectations, whereas in periods A and C the absence of private information results in less divergence in expectations.

To assess the statistical significance of the interaction term, we perform additional analyses. We find that period significantly affects price deviations in the market closure and temporary halt groups. Tukey HSD tests indicate that period B is significantly different from the other two periods at $p < 0.01$, with the greater deviation in period B. Notably, information asymmetry is present in period B and not in periods A and C. Inspection of the data suggests that period is not statistically significant for the no interruption group because of large price fluctuations at early stages of trading (i.e., the first 3 years). This initial large variation is not surprising as an understanding of the experiment requires an initial learning phase. Previous studies of experimental asset markets find that an initial learning phase often occurs before behavior stabilizes (e.g., Williams, 1980; Forsythe et al., 1982, 1984).

We repeat the ANOVA excluding data from years 1–3. Analysis of price behavior excluding data from the initial trading years may be more informative because traders are given the opportunity to gain an understanding of the mechanics of the market and behavior settles down. Panel B of Table 6 reports

the ANOVA results using data from years 4–6.[18] Only the period variable is statistically significant ($p = 0.003$). The data indicate that, on average, price deviations from fundamental value are larger in period B (0.1185), than in periods A (0.0415) and C (0.0546). Tukey HSD tests indicate that the mean deviation in period B is significantly different from the mean deviations in the other two periods at $p < 0.01$. We do not find a significant difference across market structures. Thus, the primary driver of deviations from the expected price is information in the market.

We provide further insight into price behavior by examining the frequency with which a circuit breaker is triggered when it should not be. In other words, we count the number of times a breaker is triggered when the fundamental value lies inside the circuit breaker bounds. In the market closure group, the percentages are 33.33, 0.00, and 27.78, in periods A, B, and C, respectively. In the temporary halt group, the percentages are 20.83, 0.00, and 2.78, in periods A, B, and C, respectively. Significantly, when there was private information in the market (period B), the circuit breaker rule was *never* triggered when it should not have been. These percentages provide evidence that the circuit breaker trigger level does not act as a magnet, attracting the price when fundamentals do not support such a price movement. Instead, when a circuit breaker is triggered there is information in the market that leads traders to revise their expectations.

Lastly, we examine the bid–ask spread in the presence of a circuit breaker rule. We use the difference between the last bid and ask prices immediately preceding a transaction to compare the spread before and after a temporary halt. The evidence indicates that spreads are significantly wider before (1.98) as compared to after (0.65) a temporary halt at $p = 0.001$. We also find that spreads are wider in periods with halts, as compared to periods without (0.9676 with halts and 0.4212 without) at $p < 0.05$. Results are similar in the market closure group (0.8947 with halts and 0.3797 without). These results apply across periods. Moreover, the results apply if we consider the spread before and after the first draw (rather than halt): that is, when the circuit breaker is first evaluated. In sum, our results indicate that the spread narrows after a trading interruption or when a halt is not imminent.

3.3. *Trading volume*

We examine trading volume across the three regulatory regimes. As noted previously and shown in Table 4, the total number of transactions decreases across the no interruption, temporary halt, and market closure groups.

[18] When we use data from years 1–3, the results are similar to those reported using data from years 1–6.

Table 7
Analysis of trading volume

The table presents the results of an ANOVA to test the effects of market structure on trading volume. The dependent variable is the number of transactions per period normalized by the number of seconds that the market is open for trading. The independent variables include market structure (market closure, temporary halt, and no interruption), period (A, B, and C), and an interaction term. The analysis reported in Panel A (B) includes data from years 1–6 (4–6).

Source	df	Sum of squares	*F*-statistic	*p*-value
Panel A: ANOVA results using data from years 1–6				
Market	2	0.0005	8.803	0.000
Period	2	0.0000	0.698	0.499
Interaction	4	0.0004	3.877	0.005
Error	153	0.0043		
Panel B: ANOVA results using data from years 4–6				
Market	2	0.0007	11.642	0.000
Period	2	0.0000	0.410	0.665
Interaction	4	0.0002	7.832	0.132
Error	72	0.0022		

Correspondingly, the average number of transactions per period is 5.54, 4.93, and 2.78, respectively. Tukey HSD tests indicate that the market closure group is significantly different from the other two groups at $p < 0.001$. This result indicates that fewer trades occur when the potential for market closure is present. However, to formally assess the effect of market structure on trading activity, we must control for the time that the market is open.

We perform an ANOVA to formally test the effect of the circuit breaker rule on trading volume where the dependent variable is the number of transactions per period normalized by the number of seconds that the market is open for trading. As before, the independent variables are market structure (market closure, temporary halt, and no interruption), period (A, B, and C), and an

at $p < 0.001$ ($F = 9.553$, df = 2, 53). Tukey HSD tests indicate that the market closure group is significantly different from the other two groups at $p < 0.01$, with more trades occurring per second in the closure regime.

Panel B of Table 7 reports the ANOVA results using data for years 4–6. Market is statistically significant and the data suggest that, on average, volume per second is largest in the market closure treatment. Again Tukey HSD tests indicate that the market closure regime is significantly different from the other two regimes at $p < 0.01$, with more trades occurring per second in the closure regime. The presence of private information in period B does not have a significant effect on trading activity. Consistent with Subrahmanyam (1994), circuit breakers may force market participants to advance their trades. However, whether trading activity accelerates because a halt in trading is possible or imminent remains to be determined.

We next compare the number of trades before and after a temporary halt and find significantly more trades per second before (0.0601) a trading halt than after (0.0293) at $p = 0.024$. In the market closure group we compare the volume per second in periods with (0.0489) and without (0.0278) halts and find significantly more trades per second in periods with a halt at $p < 0.001$. We repeat the analysis for the market closure group for periods with and without a draw that may trigger the circuit breaker and inferences are unaffected. Notably, in all periods a halt in trading is possible but in periods with draws, a trigger of the circuit breaker is imminent.

We also compare the number of offers (bids and asks) per second and find results similar to those discussed above. In the temporary halt group, we find significantly more offers per second before halts (0.2089) than after halts (0.1616) at $p < 0.05$. In the market closure group, we find significantly more offers per second in periods with halts (0.1899) than without halts (0.1326) at $p < 0.001$. Inferences are unchanged if we compare offers per second in periods with and without draws. Overall, the results suggest that participants accelerate trade when a halt is imminent.

To provide further insight into the effect of a circuit breaker rule on volume, we examine whether the circuit breaker rule has a similar impact on the trading activity of informed and uninformed traders. We perform a multivariate ANOVA to test whether market structure affects trading activity in period B. The dependent variables are the number of transactions per year for informed and uninformed traders normalized by the length of trading time, and the independent variable is market structure. The multivariate results indicate that market structure is significant at $p = 0.006$ using data for years 1–6 ($F = 3.818$, df = 4, 102) and at $p = 0.092$ for years 4–6 ($F = 2.128$, df = 4, 48). The univariate results, reported in Table 8, indicate that market structure has an important effect on trading activity, regardless of whether a trader is informed. As shown in Panels A and B, the result holds using data for years 1–6 and 4–6. The numbers of trades for the informed and uninformed are greater when a circuit breaker

Table 8
Analysis of trading by informedness

The table presents the results of univariate ANOVAs to test the effects of market structure on informed and uninformed trading in period B. The dependent variables are the number of transactions for informed and uninformed traders in period B normalized by the number of seconds that the market is open for trading that period. The independent variable is market structure (market closure, temporary halt, and no interruption). The analysis reported in Panel A (B) includes data from years 1–6 (4–6).

Dependent variable	Source	df	Sum of squares	*F*-statistic	*p*-value
Panel A: Univariate ANOVA results using data from years 1–6					
Informed trades	Market	2	0.0003	4.482	0.016
	Error	51	0.0020		
Uninformed trades	Market	2	0.0006	7.623	0.001
	Error	51	0.0022		
Panel B: Univariate ANOVA results using data from years 4–6					
Informed trades	Market	2	0.0004	3.839	0.036
	Error	24	0.0012		
Uninformed trades	Market	2	0.0005	4.899	0.016
	Error	24	0.0013		

may result in market closure than when trading may resume after a halt or in the absence of halts.

We also examine whether market structure affects the number of offers per second by informed and uninformed traders. We do not find a statistically significant effect for either group of traders using data for years 1–6 and 4–6. To further analyze the data, we partition quotes into those indicating a price to buy or sell (POST) and those indicating an acceptance (HIT). Market structure affects the number of HITs, but does not affect the number of POSTs. For both informed and uninformed traders, HITs are greater in the market closure group than in the temporary halt or no interruption groups.

Subsequently, we explore one-sided HITs. A one-sided HIT occurs when the first offer to buy or sell at posted prices is a HIT. For example, bid prices are posted, but no one has posted an ask price. If the first offer to sell is an acceptance, it is termed a one-sided HIT. We find that over years 1–6, the one-sided HITs of informed traders are more advantageous (at a better price) than those of uninformed traders. The average deviation of price from fundamental value, normalized by fundamental value, of one-sided HITs to buy is smaller for informed (-0.1462) than uninformed (0.0934) traders. The means indicate that informed traders buy below fundamental value, whereas uninformed traders buy above fundamental value. Likewise, the average price deviation of one-sided HITs to sell is greater for informed (0.1741) than

uninformed (0.0287) traders. The results hold across the three market structures; however, the results disappear when looking at years 4–6. As discussed in the next subsection, the findings are consistent with informed traders generating greater profit than uninformed traders in the early years of a market, but not in the later years.

We also examine the trading activity of the informed and uninformed surrounding a trading halt (or draw). Both the informed and uninformed trade more before a temporary halt (or draw) as compared to after. In contrast, for both groups of traders the total number of offers per second does not differ significantly before and after a halt. In addition, we do not observe any significant differences when comparing HITs and POSTs for each group of traders before and after halts.

Finally, we analyze transaction direction among traders to see if endowments and current position impact trade. At the point of each transaction, traders' positions are updated to reflect the transaction. We examine whether assets moved from traders with more shares to those with fewer, from those with fewer to those with more, or across traders with similar holdings. Across the nine markets, the proportion of trades that fall into each category is 34 percent, 54 percent, and 16 percent, respectively. A separate analysis of each market setting (market closure, temporary halt, and no interruption) produces similar proportions. These results suggest that there is trade because market participants have different expectations of the worth of the asset, and not because their current holdings differ. Overall, traders who hold a greater number of shares are more likely to purchase additional shares because their expectation of asset value is higher than that of others.

3.4. *Trading profits*

We perform an ANOVA to formally test the effect of market structure on traders' abilities to generate profit. The dependent variable is the profit generated per trader each year.[19] The independent variables include market structure (market closure, temporary halt, and no interruption), informedness (informed and uninformed), and an interaction term. The results reported in Table 9 indicate that when the analysis includes data from years 1–6 or 4–6 none of the independent variables significantly impact trading profit at $p < 0.05$. Yet when the analysis focuses on the initial trading years (1–3), informedness has a significant effect on trading profit at $p < 0.001$ ($F = 15.005$, df $= 1, 216$). The data indicate that the mean profit per year of informed traders ($41.39) is greater than

[19] We also perform an ANOVA with the dependent variable defined as the profit generated in periods B and C (i.e., the difference in a trader's cash balance at the end of period C and the beginning of period B). Inferences are unchanged.

Table 9
Analysis of trading profit

The table presents the results of an ANOVA to test the effects of market structure on traders' ability to generate profit. The dependent variable is the profit generated per trader each year. The independent variables include market structure (market closure, temporary halt, and no interruption), informedness (informed and uninformed), and an interaction term. The analysis reported in Panel A (B) includes data from years 1–6 (4–6).

Source	df	Sum of squares	*F*-statistic	*p*-value
Panel A: ANOVA results using data from years 1–6				
Market	2	103	0.110	0.896
Informedness	1	1,277	2.724	0.100
Interaction	2	745	0.794	0.452
Error	426	199,681		
Panel B: ANOVA results using data from years 4–6				
Market	2	8	0.008	0.992
Informedness	1	743	1.585	0.209
Interaction	2	158	0.337	0.714
Error	210	98,454		

that of uniformed traders ($29.17).[20] The superior profit-making ability of the informed, however, does not persist throughout the experiment. These results are consistent with Ackert and Church (1998).

If market prices reflect private information, we might expect to find no differences in profit across informedness groups. Table 9 suggests that this is the case, a result consistent with previous observations. Time series plots of transaction prices and subsequent analysis suggest that transaction prices tend toward fundamental value. Moreover, although at least one informed agent is involved in period B transactions 62 percent of the time, the informed are unable to consistently generate superior trading profit.

As discussed in the previous subsection, the results suggest that both the informed and uninformed advance trades when the trigger of a circuit breaker may cause trading to cease. Nonetheless, market structure does not have a significant effect on traders' abilities to generate profit.

4. Discussion and concluding remarks

In this study, we use an experimental method to analyze the impact of circuit breakers on price dynamics, trading volume, and profit-making ability. We

[20] These mean yearly profit figures appear large until one recalls that a participant's take home earnings are 10 percent of experimental profits.

examine behavior in three institutional settings: (1) markets with mandated closures, (2) markets with temporary trading halts, and (3) markets with no interruptions. The objective of the study is to gain insight into the behavior of investors in naturally occurring markets under alternative market structures.

An important finding is that the absolute deviation in price from the expected price is not significantly different across regulatory regimes. The primary driver of deviations in price from fundamental value is information in the market. Our analysis of trading volume reveals that circuit breakers affect trading activity in a significant way. In particular, market participants accelerate their trade if a trading interruption is imminent. Finally, market closures and temporary halts do not effect trading profits in a significant way.

Our results suggest that mandated trading interruptions are not meaningful impediments to pricing efficiency. However, traders attempt to make advantageous trades faster. Such behavior is consistent with Subrahmanyam's (1994) argument that mandated trading halts cause market participants to advance trades. However, in Subrahmanyam's model, accelerating trade is a suboptimal strategy, and we find no evidence that market structure has a significant effect on trading profit or price deviations from fundamental value.

Additional insight is gained by examining participants' responses to the post-experiment questionnaire. Participants were asked how the possibility of an interruption in trading would affect their behavior, if at all. Participants in the market closure treatment frequently responded that they advanced their trades. For example, one participant noted that he "tried to get that first trade in ASAP. Make a sell or buy quickly if I knew the distribution." Others responded that they "had to be faster in accepting to buy or sell because trading could stop" and that the "possibility of interruption made me aggressive." In the temporary halt sessions several participants indicated that trading interruptions provided time to assimilate information. For example, one participant stated that the possibility of a halt "gave me more time to think and consider my prices." According to another, it allowed him to "take a step back" and "prepare a strategy."

Regulators and policy makers clearly exercise caution before permanently shutting down markets. The circuit breakers currently in effect (described in Table 1) suggest that they recognize the costs of market closure as it takes a dramatic 30 percent drop in value to close the nation's exchanges for the day. The circuit breaker rule in effect on October 27, 1997 was based on fixed-point breakers established in 1987. Our experimental setting is based on the percentage breakers, now currently in effect. A trigger of the more recent rule has not occurred.

Our results suggest that although a circuit breaker rule has the unintended consequence of accelerating trade, the price discovery process is not impeded. Because trading may be interrupted, market participants rationally attempt to effect trades before a breaker is triggered. While no real downside risk to

a circuit breaker rule is suggested, the benefit is also not apparent. When there is private information in the market, a circuit breaker is *never* triggered when it should not be. Thus a circuit breaker rule does not prevent unwarranted price movements but may (temporarily) prevent price from moving toward fundamental value.

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