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Abstract

This paper uses transaction data to estimate how single stock circuit breakers on the London Stock Exchange affect other stocks that remain in continuous trading. This 'spillover' effect is estimated by calculating the effect of a trading halt on the market quality of stocks that remain in continuous trading and comparing this with the effect of a stock whose absolute returns are of a magnitude nearly sufficient to trigger a trading halt but do not do so. Market quality is measured using a combination of trading costs, volatility and volume. We find that circuit breakers lead to a significant improvement in the liquidity, and reduction in the volatility, of stocks that remain in continuous trading. This might suggest that — at least over the period covered by our data — single stock circuit breakers play an important role in reducing the spillover of poor market quality across stocks.

Key words: Circuit breakers, market microstructure, market quality.

JEL classification: G12, G14, G15, G18.

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1 Introduction

Many equity and futures exchanges have mechanisms that suspend trading temporarily in certain market conditions. These are commonly referred to as circuit breakers. While the precise form that such mechanisms take differs between exchanges, they are generally designed to achieve similar goals – that is, to ameliorate excessive and/or transitory volatility in prices and to reduce incidences of extreme illiquidity. In the aftermath of the 'Flash Crash' in US equities in May 2010, US regulators pointed to the introduction of circuit breakers on single stocks – as well as a recalibration of market-wide circuit breakers – as measures that might reduce the likelihood of such an event reoccurring (U.S. SEC and CFTC, 2010).

This paper assesses the degree to which circuit breakers activated on single stocks are associated with more or less orderly trading of other securities that remain in continuous trading. We refer to this as the 'spillover effect' of circuit breakers.[1] Ex-ante, it is unclear whether this spillover effect is positive or negative:

On the one hand, there might be circumstances in which the application of circuit breakers to one security might forestall a disruption in the price movements of other securities. In the absence of circuit breakers, shocks in the prices of different securities can be correlated even if there is no correlation in firm-specific information. This can arise due, for example, to constraints on the capital and risk taking of financial intermediaries (e.g. Xiong, 2001; Kyle and Xiong, 2001; Yuan, 2005) and/or if some types of investor behave in a manner designed to hide their private information as to a security's value (Pasquariello, 2007). The superior ability and speed with which computer-based traders process and update prices based on machine-readable information (e.g. financial indices) is another potential propagation mechanism for cross-asset returns as in Jovanovic and Menkveld (2015). In each of these circumstances, circuit breakers might play a role in dampening these effects by removing a volatile stock from trading.

On the other hand, particularly during more widespread market disruption, it is possible that the activation of a circuit breaker on one security might be associated with increased volatility in other securities. This might be the case when the activation of the circuit breaker is driven not by individual stock-specific information, but by information

[1] Our use of the term 'spillover effect' refers to the spillovers across stocks (i.e. in the cross-section). This is in contrast to the use of the term 'spillovers' in Kim and Rhee (1997), for example, which refers to effect of the circuit breaker on the suspended security over time.

that affects the value of a large quantity of securities (e.g. changes in macroeconomic conditions or the crystallisation of systemic risk). A similar effect might arise if investors sought to hedge their exposure to the security that had been suspended by trading other stocks. This is likely to be especially relevant for traders who have incurred mark-to-market losses in the suspended security and may therefore face margin calls or be required to reduce their (net) positions to meet leverage ratio requirements.[2] The ability of circuit breakers to transmit stress across markets was one of the factors behind the market volatility of August 2015 (see Anderson et al. (2015)).

A number of existing papers consider the effect of circuit breakers on the liquidity of the suspended security itself (see Gerety and Mulherin, 1992; Lauterbach and Ben-Zion, 1993; Lee and Ready, 1994; Corwin and Lipson, 2000; Goldstein and Kavajecz, 2004; Allan and Bercich, 2017). In addition, Cui and Cozluklu (2016) measure the impact of circuit breakers for US stocks on other securities that remain in continuous trading.

The unique contribution of this paper, however, is to provide robust empirical evidence of the spillover effect of single stock circuit breakers on UK stocks traded on the London Stock Exchange (LSE). To do so, we exploit the discontinuous nature of circuit breakers on the LSE, whereby a stock is removed from continuous trading (i.e. experiences a 'halt') when its price exceeds a pre-determined reference price, while other that stocks trade close to this reference price remain in continuous trading ('near-halts'). We estimate the effect of the circuit breaker in the stock that experiences an actual trading halt on the market quality (defined below) of stocks that remain in continuous trading. We also calculate the market quality of all stocks during an event where a single stock trades within 1% of a trading halt limit, which we refer to as near-halts (excluding the event stock). We then match trading halts to near halts with similar dates and times-of-day, using the nearest-neighbour matching technique of Abadie and Imbens (2006) and Abadie and Imbens (2011). This technique helps control for variation in market quality within – and across – trading day(s) (Admati and Pfleiderer, 1988; Chan et al., 1991; Andersen and Bollerslev, 1998).

Market quality is measured as the bid-ask spread, realised volatility, returns, trading frequency and volume observed in stocks that remain in continuous trading. This notion of market quality matches that elsewhere in the literature (see O'Hara (1995)). In particular, that literature captures the transaction cost faced by investors, as well as the

[2] Some market analysts covering the Chinese equity markets argued that traders' unwillingness to hold risk throughout a trading suspension was one of the key reasons that these mechanisms were seen to exacerbate market volatility in January of 2016 (Yee and Shen, 2016; Stafford and Wildau, 2016). The Chinese Securities Regulatory Commission subsequently chose to suspend the use of market-wide circuit breakers on the Shanghai and Shenzhen Stock Exchanges, less than one week after they were implemented.

degree to which stocks see large and unpredictable swings in their price.[3] We calculate these variables using transaction data on 600 stocks, obtained directly from the London Stock Exchange (LSE) in the period of July-August 2011.

Our results suggest that single stock circuit breakers lead to statistically significant reductions in the volatility of other stocks that remain in continuous trading. The magnitude of this effect is approximately half of one standard deviation of their average volatility. We also document a statistically significant reduction in bid-ask spreads although the magnitude of this effect is relatively smaller at around 5% of one standard deviation. We do not observe statistically significant effects on trading volume, trading frequency or returns. These results suggest that circuit breakers might – at least over the period covered by our data – limit the contagion of poor market quality across individual securities. Such volatility might – in the absence of circuit breakers – transmit across securities due to differences in the information of different investors, the speed with which they trade, and/or constraints on their capital and risk-taking.

That said, the findings of this paper differ to those of other papers, some of which identify a positive spillover effect of circuit breakers. This may in part be due to differences in the design of circuit breakers across different trading venues. For example, Cui and Gozluklu (2016) find that circuit breakers on US stocks lead to spillovers to other stocks, in the form of large price movements and trading volumes. This differing result might, however, arise due to how Cui and Gozluklu (2016) focus on circuit breakers recently implemented by the SEC that are triggered due to abnormal, firm-specific trading rather than the more general price volatility considered here.

Another reason that our results may differ to those elsewhere in the literature is that they deal with the effects of circuit breakers activated primarily by the volatility of *individual* stocks. In contrast, it is possible that – during periods of extreme stress affecting multiple securities – circuit breakers may play a role in leading to the propagation of stress across securities. For example, during the market-wide volatility of 24 August 2015, overnight trading halts in US equity futures were observed by some market commentators to create uncertainty in the price at which other cash equities would begin trading, leading to subsequent volatility in broader equity and derivatives markets (see Anderson (2015)). In contrast, the period covered by the data sample in this paper (July-August 2011), whist containing a period of volatility and the triggering

[3] They also align with some of the characteristics of liquid markets as posited by policymakers. For example, Bank of England (2015) discusses how financial markets should ideally be both (i) effective – with high levels of transactional efficiency, and low execution costs; and (ii) resilient – providing predictable access to end users, without wild and unpredictable swings in prices.

of a number of single-stock circuit breakers, does not include market-wide stress of an intensity seen over other periods. It therefore remains possible that our results would differ were our methodology to be applied to a period of widespread stress.

Nonetheless, our results may be of interest to policy makers tasked with developing regulation to promote market-wide stability and venue operators interested in designing effective trading rules and regulations. In particular, our work might be relevant to regulators in the USA, where the SEC has only recently introduced single stock circuit breakers (U.S. SEC, 2013). Regulation surrounding circuit breakers is also undergoing change in the EU and China (European Securities and Markets Authority, 2011; Shanghai Stock Exchange, 2015). That said, the results of our study based on data from the LSE may not be directly applicable to circuit breaker mechanisms put in place by other jurisdictions.

The paper proceeds as follows. The next section reviews the relevant literature. Further background on the operation of circuit breakers, and how they are implemented on the LSE, is given in Section 3. Section 4 introduces our data set. Our methodology and details of the variables used to measure market quality are given in Section 5. Results are given in Section 6, and a final section concludes.

2 Related Literature

Making causal inference regarding circuit breakers is complicated by the need for a counter-factual ‘control group’ that accurately describes market conditions had the circuit breaker not been triggered, but the evolution of stock prices was otherwise unchanged (Harris, 1998). There has been little work to date estimating the spillover effect of trading suspensions. One exception is Jiang, McInish and Upson (2009) who consider the spillover effect of news-related trading halts on the New York Stock Exchange. These suspensions are associated with the release of new firm-specific information (e.g. an impending material announcement or large order imbalance). They show that while spreads and price impact increase in related securities during suspension, so too does quoted depth, trade numbers and trade volumes. Their paper specifically considers information-related trading halts rather than the trading based circuit breakers that we analyse here.

As discussed above, Cui and Gozluklu (2016) consider the spillover effect of single stock circuit breakers recently implemented by the SEC on US stocks. As discussed in Section 1, such circuit breakers are triggered by firm-specific information (rather than market volatility, which we examine here). There are also important differences in the way circuit breakers are implemented in the US compared with the UK. In the US, circuit breakers are only triggered when prices move 10% or more over a five minute window. There are only 54 such events in the sample of data analysed by Cui and Gozluklu (2016). In contrast, on the LSE, circuit breakers occur when absolute returns exceed a threshold. We have over 169 such events in our sample.

Brogaard and Roshak (2017) also study the implementation of the SEC circuit breakers. They consider the trading behaviour of the stock undergoing the extreme price movement. Similar to our paper, they also exploit near-halt events and find that the probability of extreme price movements decreases after certain changes to the application of circuit breakers.

Allen and Bercich (2017) examine how market quality changes before, during and after the triggering of a circuit breaker at the London Stock Exchange, and how different groups of market participants behave during these events. They find that market quality (as proxied by quoted depth and effective spreads) across all UK venues deteriorates just before and during trading halts. They also find that high-frequency traders effectively ‘lean against the wind’ during abnormal volatility events, by buying on lit markets as prices decrease and continuing to buy during their subsequent recovery.

The approach we use to estimate the spillover effect of circuit breakers is also similar to those used by Kim and Rhee (1997), Huang et al. (2001), Chan et al. (2005) and Bildik and Gülay (2006). These studies, however, estimate the ‘within stock’ effect of trading halts on the market quality of the suspended stock itself. Importantly, in such papers, only events in which prices do not subsequently breach the threshold necessary to trigger a circuit breaker are – by definition – included in the control group. To the extent that the market quality of a stock is affected by changes in its price, this may mean that the results are systemically biased. This is because any differences in the market quality of stocks experiencing near-halts (i.e. the control group) to that of stocks experiencing *actual* halts may reflect how the evolution of prices of stocks in the control group are effectively censored.[4] Put differently, selection into the treatment and control group in such studies is determined by the evolution of a stock’s price, which itself is

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[4] To illustrate, consider a market with a daily return limit of ±10% whereby a breach of this level would lead to a suspension of trading. Furthermore, suppose we assign securities to a control group if the maximum absolute daily return is above 9% but less than 10%. If we compare trading statistics in the period after a true limit event with those of a control stock in the period after the maximum absolute return is reached, the distribution of the latter statistics are conditional not just on the return reaching 1% of the barrier, but also that all subsequent returns during the period being analysed do not breach the limit. That is to say, for some measure of market quality $q_{i,t}$ for some stock in group $i = \{c,e\}$ where c denotes the control group and e denotes the event group, we would be comparing $f(q_{e,t} || r_{e,t} | \geq r$ with $f(q_{c,t} || r_{e,t} | \geq r - \varepsilon, \sup (| r_{c,s} |: t \leq s \leq T) < r)$ where r is the price limit expressed as a return and ε is 1%. Unless the measure of market quality q is independent of the subsequent price process, $q_{c,t}$ will not represent a satisfactory control group as it will be impossible to decompose the effect of the suspension from that of the censoring.

likely to be correlated with our variable of interest – i.e. its market quality. We illustrate this possibility in the Annex.[5]

In contrast, in this paper, rather than comparing the effect of market quality of trading halts versus near halts, we compare the market quality of *all* stocks during a trading halt (apart from that experiencing the trading halt) with that of *all* stocks during a near-halt (apart from that experiencing the near-halt) at a time/date close to that at which a trading halt takes place. To the extent that the market quality of these stocks is not affected by the evolution of the price of the stock that experiences the trading halt, this means that our results are free of the censoring issue found elsewhere in the literature.

3 Circuit Breakers on the London Stock Exchange

The functioning of trading halts differs significantly across exchanges. Such systems can, however, be categorized into two types: price limits, where continuous trading is not stopped but trades are not permitted at any price above or below a predefined level for a set period of time (typically the remainder of that day); and trading halts, where continuous trading is stopped for a set period of time. Trading halts may also differ by whether they apply to a single security or to a number of securities. Table 1 gives a summary of the different variants of price limits and trading suspension rules in place on the ten largest equity exchanges by market capitalisation as of December 2015. These data are taken from World Federation of Exchanges (2016) and the London Stock Exchange (2016).

[5] Annex 1 provides evidence that this censoring issue biases the estimates of the within-stock effect of circuit breakers. To do so we use a fictitious price limit of ±7% for each stock and estimate the within-stock effect using this price limit. These results show that exceeding the placebo barrier has a large positive effect on realised variance, volume, trade intensity and the direction of subsequent returns, despite no actual trading suspension occurring.

Table 1

Circuit breakers and price limits across global equity exchanges (World Federation of Exchanges, 2016 and London Stock Exchange, 2016). The second column indicates whether the exchange employs measures to stop all trading under certain circumstance (circuit breakers). The third column indicates whether the exchange uses price limits (trading is prevented outside certain bands but trading within the bands may still occur). The fourth column reports the total value traded on the exchange during 2013 in billions of US dollars. The fifth column indicates whether these measures are applied to individual securities, or to a market-wide index. *Sources: U.S. SEC, 2013 and Shanghai Stock Exchange, 2016.*

Exchange	**Circuit breakers**	**Price limits**	**Value ($bn)**	**Notes**
NYSE & NASDAQ	Yes	Yes	25,067.5	Market-wide CBs, stock specific limits and CBs
Shanghai & Shenzhen SEs	No	Yes	8,188.0	Stock-specific price limits (Market-wide CBs suspension in Jan 2016)
London Stock Exchange	Yes	No	5,814.3	Stock-specific circuit breakers
Japan Exchange Group	Yes	Yes	4,894.9	Market-wide CBs on index values, stock specific limits
Hong Kong SE	No	No	3,184.9	Discretionary CBs in place
Euronext	Yes	No	3,305.9	Stock-specific CBs
BSE and NSE, India	Yes	No	3,001.3	Market-wide CBs
Deutsche Bourse	Yes	No	1,715.8	Stock-specific CBs
Toronto Stock Exchange	Yes	Yes	1,591.9	Coincides with US markets
SIX Swiss Exchange	No	No	1,519.3	-

The London Stock Exchange (LSE) continuously monitors the state of the order books for stocks with circuit breakers in place. In doing so it compares the price at which trades are about to take place given the current levels and quantities of buy/sell orders against two types of reference price:

- First, *dynamic* reference prices are set at certain distances above or below the price of the last trade in that security.
- Second, *static* reference prices are set at levels above or below the price at which the last auction for a given security settled (typically the opening auction).

The thresholds are determined at the level of market sectors and at values that account for the liquidity of the securities in that sector. All FTSE-100 stocks in our sample had a dynamic threshold of 5% and a static threshold of 10% during the time period spanned by our data. For FTSE-250 stocks, all but one had a static threshold of 10% with dynamic thresholds varying from 5-15%, while for the least liquid stocks in our sample the static threshold was 25%.

If the price at which a trade would execute breaches either of these reference prices, this results in either a 'dynamic' or 'static' trading halt. The market for that security is suspended temporarily for a period known as an automatic execution suspension period (AESP). This initially lasts five minutes, and is followed by an 'uncrossing auction' that resumes continuous trading. During this AESP participants may submit limit and market orders and the exchange continuously publishes the theoretical price and volume that the uncrossing auction would generate were it run at any point in time (London Stock Exchange Group, 2011a).

The suspension can be extended by a predefined period of time if either the price at which the uncrossing auction would settle deviates by too large an amount from the previous price generated by continuous trading (referred to as a price monitoring extension), or if the uncrossing auction would result in unfilled market orders at the resumption of trading (referred to as a market order extension). Suspensions also vary in length by a random period of between zero and thirty seconds before continuous trading resumes. This aims to remove incentives to enter erroneous orders that would unduly affect price formation towards the end of the auction (London Stock Exchange Group, 2000).

4 Data

We obtain transaction data from the LSE that contains all trades executed for every listed security between 1 July 2011 and 31 August 2011 (a total of forty-three trading days). These data cover 3,781 securities listed on the LSE including shares, exchange-traded funds and products, bonds, warrants and structured products. The price, volume, and time of each transaction are recorded to the nearest second, as well as a 'trade type' that identifies the trade as belonging to one of 26 classifications (e.g. ordinary trades, automated trades, late corrections, contra trades etc). The sample period was chosen as it contains a relatively large number of circuit breaker events.[6] We focus our analysis on trades executed on the electronic order book for equities that trade on SETS, the flagship electronic order book of the LSE. Traded securities include members of the FTSE-100, FTSE-250, Small-Cap, Irish, Secondary Listing or 'Other' market segments.[7]

These data comprise a total of 724 equities in these categories with a total of 227 static trading halts in a single security over the sample period. The date and time of these static trading halts was provided to us by the LSE to the nearest second. The majority of static halts occur in securities whose static price limits lie 10% above and below the relevant reference price. A small fraction of securities have price limits of 15% or 25% above and below the reference price. We focus only on occasions on which static trading halts occur. This is because our data do not include flags to separate trading halts by type (e.g. static vs dynamic). In the majority of cases where a static trading halt takes place, however, the previous trade price of a security is such that a dynamic trading halt would also have taken place. We therefore end up excluding only occasions on which only a dynamic – not a static – trading halt takes place.

There are also 183 occasions where the price of at least one security comes to within one percentage point of its static reference price but does not breach that

[6] We do not, however, have access to any larger data set on stocks traded on the LSE with which we might compare the occurrence of circuit breakers here to that over a longer time period.
[7] The 'other' segment mainly contains stocks that were once in one of the other market segments listed here but have since been removed.

price over the following 15 minutes of trading. We define such events as 'near-halts', which – in the analysis that follows – are used as our control group.

For each event, we use the Thompson Reuters Tick History (TRTH) to obtain the best bid and offer price at one second intervals for every stock that is present in the exchange-provided data. From this we calculate the bid-ask spread and realised volatility of mid-quote returns for each security. We match stock tickers from TRTH to those in the data provided by the LSE and retain only stocks for which these correspond exactly. This leaves us with a data set containing a total of 615 stocks, 169 static limit breaches and 135 near-halts (to which we refer collectively as 'events' in the text that follows).

4.1 Summary of trading halt data

The histogram in Figure 1 shows the timing of all in our sample period across the trading day. The clustering of events early in the trading day reflects how - if the opening auction for a given security does not yield a new trade - the static reference price for that security is set to the previous day's closing price. This can sometimes mean that the opening trades in a given security are at a price sufficient to result in a static halt, even if the change in price on open is relatively low. Figure 2 shows the number of halts and near-halts in our data by both market segment and by the level of their associated price limit relative to the last trade in that security.

Figure 1:
All unscheduled automatic execution suspension periods during sample period

A histogram of all unscheduled auction periods (trading suspensions) on the LSE from 1 July 2011 to 31 August 2011 by time of day.

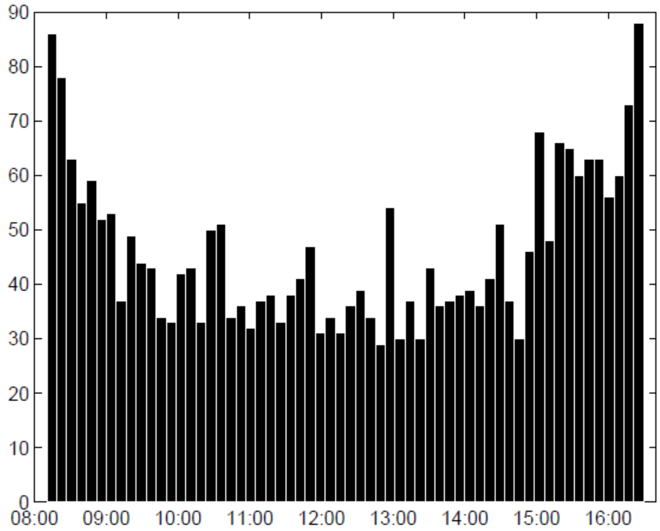
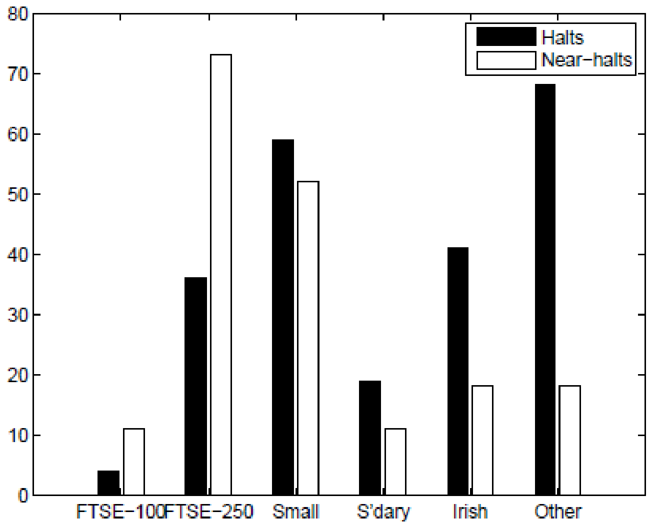
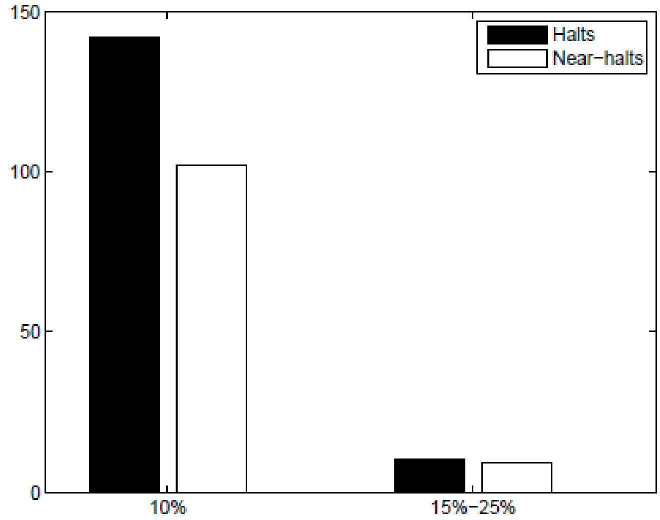


Figure 2: Circuit breakers by LSE market segment and price limit

All halts and near halts by LSE market segment (a) and by static price limit (as a percent deviation from the previous reference price) (b).



(a) Circuit breakers by LSE market segment



(b) Circuit breakers by LSE price limit

5 Methodology

Our empirical approach to identifying the spillover effect of circuit breakers exploits how circuit breakers on the LSE are triggered discontinuously – that is, when prices reach a fixed, pre-determined, threshold.

We define two kinds of event:

- The first is our 'treatment group', and comprises those dates/times at which a stock price triggers a circuit breaker in that stock by exceeding its static price limit.
- The second is our control group, and comprises of those dates/times at which a stock experiences a 'near-halt' – that is, where its absolute return is within one percentage point of a level commensurate with its static price limit but does not breach that level over some fixed period of time that follows (which we refer to as the 'event window').

We then match each event in the treatment group with the five events in the control group to which it is closest with respect to the time and date at which it occurs. We then compare the average market quality of these stocks with that of all stocks (excluding those in the treatment group), using the approach of Abadie and Imbens (2006) and Abadie and Imbens (2011). This allows us to estimate the average treatment effect of trading halts on market quality. These steps are described in detail in Section 5.3.

5.1 Definition of market quality variables

We use six simple measures of market quality that are calculated using both the LSE transaction data and the TRTH quote data.

These are defined as follows:

- Realised variance, which is the sum of squared log-returns taken at one second intervals with respect to the mid-price.
- Bid-ask spread, which is the difference between best ask price and best bid price as a percentage of the mid-price.
- Number of trades, in hundreds, and volume traded, in pounds sterling.
- The log return over the event window. That is, the log difference between the price of stock at the beginning and end of the event: ($logP_{jt_i^E+900s} - logP_{jt_i^E}$, where t_j^E is the time of the j^{th} event).
- A 'Reversals' dummy variable that indicates whether or not changes in the price of a stock following a halt or near-halt are in the same direction as the level of the price limit with respect to the reference price. That is,:

$$Reversal_{ij} = \begin{cases} 1 \;\; if\; sign(r_j^{RP}) = sign(r_{ij}) \\ 0 \quad\; Otherwise \end{cases} \quad \textbf{(1)}$$

  where r_j^{RP} is the percent return on the previous reference price for the event stock at the commencement of event *j* and r_{ij} is the return during the post-event period for stock $i \neq j$ during event *j*. For events at the upper (lower) price limit, $Reversal_{ij}$ takes the value one if the subsequent return in stock i is positive (negative) and zero otherwise.

  When averaged, this variable captures the degree to which a circuit breaker tends to lead to subsequent returns in the same direction as the breached limit price. Values close to one indicate that most stocks that remain in continuous trading have returns in the same direction as the actual or pseudo price limit that was (or would be) exceeded.

We take logs of all positive variables (realised volatility, bid-ask spreads, number and volume of trading).[8]

[8] There were no events in our sample where the average of these variables across all 615 stocks was undefined or equal to zero.

We set the length of the event window – over which the control group (near-halt) events are defined – to 15 minutes. We choose this length of time in order to cover both the period where the stocks subject to the trading halt (i.e. those in the treatment group) are not trading, and when they resume continuous trading. Our choice of a 15 minute window is motivated by how such trading halts typically last 5 minutes, but can last a little longer (see Section 3).

We measure these statistics over the 15 minute interval after the 'near halt' occurs: that is, the time at which a stock's absolute return becomes within one percentage point of a level commensurate with the price limit (that is, a return of of ±9% in the case of a price limit of ±10%). To be classified as a control event, a stock that reaches one percentage point of the price limit cannot breach that price limit for at least fifteen minutes. If the stock does breach the actual price limit within that time, the event would be instead re-classified as a treatment event with the event time corresponding to the beginning of the trading suspension.

Events that occur within 15 minutes of the open or close are removed from the sample. Market quality variables – apart from the reversal dummy – are also Winsorized at the 1% and 99% level to limit the effect of outliers on parameter estimates.

Summary statistics for the market quality variables across all stocks – in both the 15 minute window prior to and following each event – are shown in Table 2. Table 3 contains correlations across the market quality variables for the post-event period. The average bid-ask spread for a stock prior to our events is approximately 1.4% of the mid-price, realised volatility is approximately 0.23 while these stocks trade approximately once per minute for a total value of approximately ₤900 during this 15 minute period. In the post-event period (halts and near-halts), we note there is a modest increase in trading intensity and volatility and a modest reduction in bid-ask spread. Volatility is positively correlated to all variables except returns, while bid-ask spreads are only weakly correlated with trading activity.

Summary statistics are broken down by the treatment and control groups in Section 5.2.

Table 2: Event summary statistics

This table contains summary statistics for realised variance of mid-quote returns, bid-ask spread as a percentage of the mid-quote, the number of trades ('00s), the volume traded (£ '000s) and the Reversals dummy. All dependent variables are defined in detail in Section 5 and are equally weighted across the stocks in our sample during each event. The table below contains the mean, standard deviation and 5% and 95% quantiles for each variable in the pre-event and post-event period.

Panel A: Pre-event Period				
Variable (group mean)	Mean	Std.	5%	95%
Realised Volatility	0.2296	0.1282	0.0681	0.7399
Bid Ask Spread (%)	1.3623	0.1944	0.9673	2.0557
Number of Trades	0.1572	0.0656	0.0696	0.374
Volume Traded	0.9000	0.3443	0.3659	2.0269
Return (%)	-0.0265	0.1042	-0.3925	0.2562
Panel B: Post-event Period				
Variable (group mean)	Mean	Std.	5%	95%
Realised Volatility	0.237	0.1411	0.0652	0.8695
Bid Ask Spread (%)	1.3481	0.1851	0.9756	1.8677
Number of Trades	0.1616	0.0723	0.0498	0.3938
Volume Traded	0.9849	0.4361	0.3555	2.6066
Return (%)	-0.0164	0.1046	-0.4379	0.3592
Reversal Dummy	0.2929	0.1215	0.0537	0.6439
Panel C: All events				
Variable (group mean)	Mean	Std.	5%	95%
Halt Dummy	0.5559	0.4977	0	1
Time of Day	0.5296	0.0974	0.3476	0.6764

Table 3: Dependent variable correlation coefficients

This table contains correlation coefficients for the dependent variables used in the analysis in the post-event period. The variables include the realised variance of mid-quote returns, bid-ask spread as a percentage of the mid-quote, the number of trades ('00s), the volume traded (£ '000s) and the Reversals dummy. All dependent variables are defined in detail in Section 5 and are equally weighted across the stocks in our sample during each event.

	Realised Volatility	Bid-Ask Spread (%)	Number of Trades	Volume Traded	Return (per cent)	Reversal Dummy
Realised Volatility	1.00	-	-	-	-	-
Bid-Ask Spread (%)	0.44	1.00	-	-	-	-
Number of Trades	0.70	-0.02	1.00	-	-	-
Volume Traded	0.68	-0.09	0.95	1.00	-	-
Return (%)	-0.22	0.00	-0.19	-0.24	1.00	-
Reversal Dummy	0.38	0.19	0.28	0.29	-0.05	1.00

As discussed above, this analysis differs to some others in the literature (e.g. Gerety and Mulherin, 1992; Lauterbach and Ben-Zion, 1993; Lee and Ready, 1994; Corwin and Lipson, 2000; Goldstein and Kavajecz, 2004, Allan and Bercich, 2017) in that it does not consider the effect of trading halts on the market quality of stocks that are themselves subject to trading halts (i.e. the 'within stock' effect), but on other stocks that are not subject to halts (i.e. the 'spillover effect').

In doing so, we avoid the censoring issue described in Section 2, present elsewhere in the literature that estimates the 'within stock' effect. This occurs because a stock's classification into the treatment and control group directly affects its market quality, causing results to be biased.

In contrast, the same censoring issue does not apply in our measuring of the spillover effect described here. This is because instead of comparing the effect on market quality of stocks undergoing trading halts versus near halts, we instead compare the market quality of *all other* stocks (apart from that experiencing the trading halt or the near-halt) during each type of event. The salience of this censoring issue in measuring the within-stock effect – and the importance of its being circumvented in this analysis, is demonstrated further in the Annex.

5.2 Simple comparison of market quality variables across treatment and control groups pre and post-events

Although we can be sure that our identification technique does not suffer from the direct censoring issue described above, it is possible that our methodology introduces a second-order censoring effect whereby more volatile periods of trading are less likely to be represented in stocks in the control group. This is because – by definition – stocks giving rise to events in the control group cannot breach their price limit for the duration of the event window (otherwise they would be classified in the treatment group).

We therefore compare the average market quality across treatment and control groups over a short window preceding the time of the event (the time of breach of the price limit or the time of crossing within one percentage point of the price limit without triggering a suspension over the 15 minute event window). Were such measures of market quality to differ between the treatment and control groups *prior* to the application of the circuit breaker, then this might suggest the presence of such second-order censoring.

The means and standard deviations of each of the market quality variables – split out by the halt/near-halt events – are given in Panel A of Table 4 along with the t-statistic testing for any difference between the means. We fail to reject the null hypothesis that there is no difference in the realised volatility and bid ask-spread between the halt and near-halt stocks in the pre-event period at the 10% significance level. This suggests that the halt and near-halt event groups have roughly similar levels of volatility and liquidity. There, is however, some weak evidence that trading volumes and frequency are lower in the pre-event period for the halt group.

Table 4: Dependent variable summary statistics by halt status

This table contains summary statistics for the dependent variables used in the analysis split by halt status. The variables include the log of realised variance of mid-quote returns, log of bid-ask spread as a percentage of the mid-quote, the log of the number of trades ('00s), the log of volume traded (£ '000s), the return and the Reversals dummy. All dependent variables are defined in detail in Section 5 and are equally weighted across the stocks in our sample during each event. The table below contains the mean, standard deviation for each variable in the pre-event and post-event period, split by halt status. The final column contains the t-statistics for a test of equal means across the groups.

Panel A: Pre-Event	**Near-Halts**		**Halts**		
Variable (group mean)	Mean	Std.	Mean	Std.	$t-$test
Realised Volatility	-1.5978	0.5225	-1.6139	0.5033	-0.27
Bid-Ask Spread (%)	0.2916	0.1438	0.3050	0.1413	0.82
Number of Trades	-1.8769	0.4168	-1.9759	0.3834	-2.15
Volume Traded	-0.1299	0.3768	-0.2104	0.3633	-1.89
Return (%)	-0.0381	0.1103	-0.0173	0.0985	1.73
Panel B: Post-Event	Near-Halts		Halts		
Variable (group mean)	Mean	Std.	Mean	Std.	$t-$test
Realised Volatility	-1.5472	0.5213	-1.6164	0.5263	-1.15
Bid-Ask Spread (%)	0.2843	0.1410	0.2932	0.1355	0.56
Number of Trades	-1.8531	0.4286	-1.9615	0.4093	-2.25
Volume Traded	-0.0518	0.4216	-0.1471	0.4126	-1.98
Return (%)	-0.0158	0.1102	-0.0168	0.1002	-0.08
Reversal Dummy	0.2797	0.1223	0.3034	0.1202	1.69
Panel C: All Events	Near-Halts		Halts		
Variable (group mean)	Mean	Std.	5%	95%	$t-$test
Time of Day	0.5429	0.0974	0.5190	0.0963	-2.14
Date	32.096	17.557	31.775	16.981	-0.16

For completeness, Panel B also shows the mean and standard deviation of market quality variables in the period immediately after halts/near-halts. A naïve comparison of these would lead to a conclusion that halts reduce trading frequency and volume, induce a greater proportion of stocks to move in the direction of the limit and have no effect on liquidity or volatility. But Panel C of Table 4 also demonstrates the importance of controlling for time-of-day effects. This is because on average, halts occur earlier in the day than do near-halts. This demonstrates the importance of controlling for time-of-day periodicity in volatility and liquidity.

5.3 Estimating average treatment effects

To estimate the spillover effect of trading halts, we follow the matching process described in Abadie and Imbens (2006, 2011). This involves matching each trading halt event with its five nearest-neighbours from the set of near-halts where 'distance' is taken over the variables time-of-day and the date.

Put formally, for some vector of a date and time $\mathbf{x}_i$, we define the distance between $\mathbf{x}_i$ and $\mathbf{x}_j$ is equal to :

$$\textbf{(2)} \quad \|\mathbf{x}_i - \mathbf{x}_j\| = (\mathbf{x}_i - \mathbf{x}_j)' \mathbf{S}^{-1} (\mathbf{x}_i - \mathbf{x}_j)$$

where S is the inverse of the sample covariance of $\mathbf{X} = (\mathbf{x}_1, ..., \mathbf{x}_n)'$ (or 'Mahalanobis' distance metric).

The nearest-neighbour estimate of the average treatment effect (ATE) of trading halts is then:

$$(\mathbf{3}) \qquad \hat{\tau} = 1/N \sum_{i=1}^{N} \left(Y_i - 1/M \sum_{j \in JM(i)} \mathrm{Y}_j \right)$$

where Y_i is the average of the market quality variable across all stocks excluding the event stock and $JM(i)$ is the set of indices for the first M matches for event i as per Abadie and Imbens (2006) . We estimate equation (3) for each of our six market quality variables over the 15 minute period following each event. Standard errors are computed using the robust Abadie-Imbens standard errors. In doing so we also include the Abadie-Imbens bias adjustment term to allow for the fact that we are matching on two continuous co-variates.

The treatment effect parameter τ is the average treatment effect of circuit breakers across all measures of market quality. Since we are interested in spillover effects of circuit breakers rather than their effect on the suspended stocks, defining our observations of market quality at the market level allows us to interpret τ as the expected change in market quality on stocks in the treatment group due to a trading halt while accounting for potential error dependence across stocks within an event (i.e. clustering of errors at the event level).

6 Results

Table 6 gives estimates of the treatment effect estimates given in equation (3) for the six market quality variables. The second column contains the estimate of τ for each of the market quality variables, the third and fourth column are robust standard errors and associated z-statistics and the fifth column represents the magnitude of treatment effect in the second column divided by the standard deviation of the dependent variable. This column is included to assess the economic significance of the ATEs for each variable.

Table 6 shows that that circuit breakers lead to statistically significant reductions in volatility and liquidity for stocks that remain in continuous trading. In the case of volatility, the magnitude of the estimated ATE of circuit breakers is economically large and is equal to approximately 50% of the sample standard deviation. We estimate that circuit breakers lead to a fall of only approximately 5% in the bid-ask spread of the treatment group relative to the control group, although this is statistically significant at the 5% level. For volume and number of trades, the ATE is estimated to be negative, but is significant at the 10% level for number of trades. The ATE for the reversals dummy is positive but insignificant at the 10% level and insignificant for the log return.

Table 6: Spillover treatment effect estimates

This table contains estimates of the average treatment effect (ATE) for the spillover effect of circuit breakers on the average market quality of stocks that remain in continuous trading. The ATEs are estimated using the nearest-neighbor matching techniques of Alberto and Imbens, 2006 and Abadie and Imbens, 2011. The treatment group is defined by a trading halt occurring in a stock and the control group is defined by a 'near-halt' occurring in a stock. The dependent variables are the realised volatility, the bid-ask spread, number of trades, ₤ volume traded (all in logs), 'reversals' and the return (all defined in Section 5). For each event the dependent variable is the equally weighted average of the market quality of all stocks excluding the event stock in the 15 minutes after the commencement of the event. Column two reports the estimated ATE, column three contains Abadie-Imbens robust standard errors, column four contains the associated robust z-statistic and column five contains the ATE estimate divided by the standard deviation of the dependent variable in our sample. We use two exogenous and deterministic matching variables, the time-of-day and the date. The distance metric is the Mahalanobis (inverse covariance) matrix and the number of matches is five.

Variable	TE Coef.	Std. Err	z-stat	Std.Eff
Realised Volatility	-0.0711	0.0363	-1.96	-50.4%
Bid-Ask Spread (%)	-0.0090	0.0045	-2.01	-4.8%
Number of Trades	-0.0445	0.0262	-1.70	-61.5%
Volume Traded	-0.0280	0.0280	-1.00	-6.4%
Reversal Dummy	0.0230	0.0142	1.62	18.9%
Return (%)	-0.0086	0.0115	-0.75	-8.3%
N	304			
Matches	5			
Distance	Mahalanobis			
VCE Type	Bias adjusted, AI Robust			
Matching Variables	Time of day, Date			

Taken together, we conclude that trading halts are associated with a reduction in both the bid-ask spread and price volatility of securities that remain in trading. This suggests that single stock circuit breakers may stem the sorts of mechanisms described by Xiong (2001), Kyle and Xiong (2001), Yuan (2005), Pasquariello (2007) and Jovanovic and Menkveld (2015) that might otherwise lead to the spread of volatility between stocks. Such mechanisms include the effect of differences in investors' private information on the value of individual securities, differences in the speed with which they can process – and trade upon – information, and the effects of constraints on investors' risk taking and capital. The single stock circuit breakers examined in this paper may play a role in dampening these effects. This conclusion is also consistent with the findings of the LSE who argue that trading halts are successful in maintaining orderly trading without excessively hindering change in price consistent with 'genuine market sentiment' (London Stock Exchange Group, 2011b).

That said, as discussed in the introduction, these findings differ to those elsewhere in the literature.

First, they run contrary to those of Cui and Gozluklu (2016), who find that circuit breakers on US stocks lead to spillovers to other stocks, in the form of large price movements and trading volumes. This differing result might, however, arise due to how Cui and Gozluklu (2016) focus on circuit breakers recently implemented by the SEC that are triggered due to abnormal, firm-specific trading rather than the more general price volatility considered here.

More substantively, however, they also differ to the empirical effects of trading halts on the LSE witnessed during periods of more widespread market stress that affects multiple securities. For example, during the intense market volatility of 24 August 2015, overnight trading halts in US equity futures were observed by some market commentators to create uncertainty in the price at which other cash equities would begin trading, leading to subsequent volatility in broader equity and derivatives markets (see Anderson et al, (2015)). Such contagion may be due to the withdrawal of market-making activity by investors that use information in one security when posting quotes in another security (Cespa and Foucault (2014)). When prices become less informative, liquidity providers worsens face greater uncertainty and post wider quotes.

That our results find the opposite effect – i.e. that trading halts do *not* give rise to such contagion – may be due to how the period covered by the data sample in this paper (July - August 2011) does not include market-wide stress of an intensity seen over other periods. It remains possible, therefore, that our results would differ were our methodology to be applied to a period of systemic market stress – particularly of the sort that caused the withdrawal of risk taking seen during August 2015.

6.1 Robustness of matching procedure

In our analysis we match events in the treatment and control groups via exogenous and deterministic variables (time-of-day and date). As discussed in Section 5, this has the advantage of not using variables that are likely to be endogenous to the selection of events into treatment (circuit breaker) and control (near-halts) groups. But it does potentially come at the cost of meaning that such matching variables may not be sufficient to form adequate control groups for the trading suspensions.

In this subsection we therefore investigate the adequacy of the control group produced by our matching procedure. We do so by using the estimation procedure outlined in Section 5.2 to estimate the average treatment effect of a trading halt on the market quality of securities not experiencing a trading halt during the period immediately prior to a halt or near-halt occurring on other securities. If our matching procedure is forming adequate control groups, this treatment effect should be insignificant.

Table 7 contains the parameter estimates for the ATE in the pre-event period. The fourth column shows the relevant z-statistics. These suggest that the treatment effect in the pre-event period is insignificant at the 5% level and all but one are insignificant at the 10% level (number of trades). We therefore fail to reject a null of there being no difference between treatment and control group in the pre-event period at the 5% level for each dependent variable individually.

This provides further validation of our estimation approach. We also estimate our treatment effect parameters using the inverse variance weighting matrix rather than the Mahalanobis weighting matrix, and also using only one nearest-neighbour match rather than five nearest-neighbours. This yields qualitatively similar results.

Table 7: Spillover treatment effect estimates using pre-event market quality

This table contains estimates of the average treatment effect (ATE) for the spillover effect of circuit breakers on the average market quality of stocks that remain in continuous trading in a 15 minute window preceding each event. It's purpose is to determine whether the matching process is sufficient to form adequate control groups for the event window by comparing the average market quality across the non-event stocks in the period immediately preceding the event.

Variable	TE Coef.	Std. Err	z-stat	Std.Eff
Realised Volatility	-0.0297	0.0386	-0.77	-23.2%
Bid-Ask Spread (%)	-0.0058	0.0049	-1.19	-3.0%
Number of Trades	-0.0463	0.0280	-1.66	-70.6%
Volume Traded	-0.0325	0.0280	-1.16	-9.4%
Reversal Dummy	0.0188	0.0131	1.43	18.0%
Return (%)	-0.0086	0.0115	-0.75	-8.3%
N	304			
Matches	5			
Distance	Mahalanobis			
VCE Type	Bias adjusted, AI Robust			
Matching Variables	Time of day, Date			

6.2 Regression Analysis

To check the robustness of our results further, we also estimate a simple regression of the average market quality variable for each event on a dummy variable that represents whether it is a trading halt, whilst controlling for the time of day and date. That is, we estimate the model:

$$\textbf{(4)} \quad Y_{it} = \gamma_t + \beta_1 time_{it} + \beta_2 Halt_{it} + \varepsilon_{it}$$

where Y_{it} is the average market quality for event *i* occurring on date t , γ_t is a date fixed effect, $time_{it}$ is the time-of-day of the event and $Halt_{it}$ is the halt status dummy variable for event *i* on day *t*. The date fixed effects variables remove any day-specific unobserved components on market quality and the inclusion of the time-of-day term controls for periodicity effects within days. As such, Equation (4) is a regression analogue of our matching estimator. Again, by using the group averages, we are inherently controlling for any clustering of errors within events (as per Angrist and Pischke, 2008) and we therefore estimate Equation (4) with White robust standard errors.

Table 8: Regression Parameter Estimates

This table contains coefficient estimates, standard errors and t-statistics for a regression of average market quality on date fixed effects, time-of-day and halt status. The dependent variables are the realised volatility, the bid-ask spread, number of trades, £ volume traded (all in logs), 'reversals' and the return (all defined in Section 5). For each event the dependent variable is the equally weighted average of the market quality of all stocks excluding the event stock in the 15 minutes after the commencement of the event. Column two reports the estimated coefficient on the halt dummy, column three contains White standard errors and column four contains the associated robust t-statistics.

Variable	Coef.	SE	t-stat
Realised Volatility	-0.0920	0.047	-1.94
Bid-Ask Spread (%)	-0.0067	0.004	-1.73
Number of Trades	-0.0692	0.036	-1.94
Volume Traded	-0.0724	0.036	-2.02
Reversal Dummy	0.0195	0.015	1.33
Return (%)	0.004	0.0133	0.27
N	304		

Table 8 shows the estimate of β_2 which indicates the effect of halt status on average market quality. This also suggests that volatility and bid-ask spreads are lower in the halt group relative to the near-halt group, although we can only reject the null of no effect at the 10% level for these variables in the panel model. We do, however, find economically larger effects on trading activity and can reject a test of no effect of halt status on volume traded at the 5% level. Again we find an insignificant effect on returns and the reversals dummy.

7 Conclusion

This paper uses transaction data to investigate how single stock circuit breakers on the LSE affect the market quality of stocks that remain in continuous trading. To do so it exploits the discontinuous nature of trading halts on the LSE, which are triggered if the absolute percentage change in the price of a stock breaches some predetermined threshold, relative to that of the last trade or exchange auction. Our approach estimates the average treatment effect of trading halts on the market quality of stocks that remain in continuous trading relative to that of a control group of events. This control group is comprised of events where a single stock undergoes a price change of a magnitude nearly sufficient to trigger a trading halt, at a time and date similar to that at which the treatment group experiences an actual trading halt.

Our results suggest that – at least over the period covered by our data – single stock trading halts lead to significant reductions in volatility and bid-ask spreads of stocks that remain in continuous trading. This may support the suggestion in the theoretical literature that in the absence of circuit breakers volatility can pass between stocks. These might occur due the effects of heterogeneous information, differences in the speed with which investors process – and react to – new information, and the effect of their capital constraints.

We also demonstrate the robustness of our methodology by showing that it generates a control group of stocks that have statistically similar market quality in a short window prior to a circuit breaker or control event occurring. These results might suggest that – at least over the period covered by our data – single-stock circuit breakers help ameliorate the scope for contagion of poor market quality between securities.

These results differ to some of those elsewhere in the literature. In particular, they differ to evidence of a significant spillover effect from single-stock circuit breakers on US equity markets (Cui and Gozluklu (2016)) that are triggered due to abnormal, firm-specific trading rather than the more general price volatility considered here. More substantively, they also differ from evidence as to the effects of trading halts during periods of more widespread market stress, where trading halts have led to contagion of volatility across securities. Further work could therefore apply the methodology used here to data covering such periods of market-wide stress.

Further work could also usefully investigate how trading on other trading venues is affected by the activation of trading halts on the LSE. It could usefully examine the effect of circuit breakers applied at the level of stock indices – as, for example, is the case on the Tokyo Stock Exchange. Such alternative types of circuit breaker may differ in their effect on other related securities, to those applied to single stocks.

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Annex

To demonstrate the salience of the censoring issue discussed in Section 5, we create an artificial static price limit for all stocks in our sample at 7% of their reference price.[9] We then identify occasions on which the absolute return on a stocks opening price exceeds 7% for the first time in the day and events where a stock attains a maximum absolute return of greater than 6% but less than 7%, and does not exceed 7% for a 15 minute interval. These serve as 'placebo' groups of trading halts/near-halts.

For each stock in either category we calculate the four market quality variables (realised volatility, volume traded, number of trades and reversals) discussed in Section 5, and regress these on a set of controlling variables and a dummy variable representing the placebo halt. The regression model is

$$y_i = x_i'\beta + \gamma h_i + \varepsilon_i \qquad (5)$$

where y_i is market quality, x_i is the set of control variables (volume, number of trades and realised variance over the fixed interval prior to the event, time of day and its square and a constant term), h_i is a binary variable that takes the value 1 if the event was a breach of the artificial limit and 0 if the event was in the control group (i.e. a near halt) and ε_i is an error term. Consistent with other regression analysis, all variables are Winsorized at the 1% and 99% level. Standard errors are clustered at the FTSE industrial sector level.

Table 9 contains the parameter estimates for this regression. The parameter γ on the dummy variable is significant at the 1% level for all realised volatility and reversals, and at the 5% level for frequency and volume traded. In other words, each of the dependent variables is significantly higher in the placebo group of trading halts than in the placebo group of near trading halts.

Since in this case there is no interruption to the trading process at the assigning price level, the significance of this parameter indicates that the market quality variables have been censored, in forming the treatment and control groups. Inference that ignores this censoring issue and instead assigns all difference in market quality between the treatment and control groups to the effect of the circuit breaker is therefore subject to bias.

[9] . The true static price limit for these stocks is either ±10%, 15% or 25%.

Table 9: Within-stock artificial barrier regressions

This table contains parameter estimates for the effect of crossing an artificial barrier of 7%. The regression model is $y_i = x_i'\beta + \varepsilon_i$ where y_i is the outcome variable, x_i contains a constant term, volume of trades, number of trades and realised variance prior to the breach of the artificial limit price, h_i is the dummy variable taking the value one when the price exceeds the artificial price limit of 7% for the first time on the day and zero when the price is within one percentage point of this barrier but does not cross the threshold for at least a 10 minute interval. The sample includes all events where the price of a stock in our sample reaches one percentage point of the artificial price limit and events that overlap within each stock are removed.

	Realised Volatility		Number of Trades		Volume Traded		Reversal Dummy	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Constant	14.874	2.62	0.3636	1.91	-23.749	-0.19	-2.0862	-3.51
Date	-0.0176	-2.03	-0.0003	-0.52	-0.4529	-0.75	0.0009	0.54
Time	-49.793	-2.24	-1.6217	-2.15	-46.569	-0.09	6.6559	2.93
Time sq.	44.877	2.13	1.7288	2.38	136.35	0.27	-6.0203	-2.8
Reaslied Volatility	0.0542	6.32	-0.0004	-2.84	-0.0254	-0.46	-0.0008	-1.06
Number of Trades	0.2998	2.26	0.983	13.21	66.04	1.11	-0.0939	-1.29
Volume Traded	-0.0004	-2.96	0.0001	1.28	0.9747	13.3	0.0000	0.30
CB	1.1101	6.26	0.0424	2.17	28.634	2.29	0.286	7.88
	N	R^2	N	R^2	N	R^2	N	R^2
	2,574	0.10	2,574	0.83	2,574	0.83	2,574	0.03