The Impact of Trading Technology:

Evidence from the 1980 NYSE Post Upgrades*

David Easley
Cornell University

Terrence Hendershott
U. C. Berkeley

Tarun Ramadorai
University of Oxford and CEPR

This version: November 18, 2006

Abstract

Between 1980 and 1981 the NYSE upgraded all of its specialist trading posts, instituting a major change to trading technology. This upgrade took place in two significant steps. First, for a group of stocks there was a technological upgrade which allowed improved communication on the trading floor. Second, for another group of stocks, there was a technological upgrade which significantly reduced the latency experienced by traders off the floor. Eventually, all stocks received both upgrades. We find that the latency reducing upgrade had significant effects on turnover and returns, and that the on-floor upgrade had little effect on either turnover or returns. A portfolio which is long stocks that received the on-floor upgrade, and short those that received the latency reducing upgrade has a risk-adjusted return of -3.8 percent in the 20 days immediately following the latency reducing upgrade. We attribute the effect of the latency improvement on returns to the reduction in the value of the free option given to those on the floor.

JEL Classifications: G12, G14
Keywords: market structure, stock exchange, trading volume, information, latency, technology upgrade

---

* We thank Larry Glosten, Joel Hasbrouck, and seminar participants at the Stockholm School of Economics for comments. We are indebted to Archivist Janet Lindeh and the NYSE for providing us with the information used in this study. We thank Abhishek Saxena and especially Tian Liang for excellent research assistance. Hendershott gratefully acknowledges support from the National Science Foundation. Part of this research was conducted while Hendershott was the visiting economist at the New York Stock Exchange.

David Easley: dae3@cornell.edu; Terrence Hendershott: hender@haas.berkeley.edu; Tarun Ramadorai: tarun.ramadorai@sbs.ox.ac.uk

1. Introduction

Securities markets make changes to their trading platforms constantly. A cursory glance at the websites of the NASDAQ and the NYSE reveals that over the years since the formation of these exchanges, a host of changes have been made to the rules surrounding trading, and to the technology utilized to process securities transactions.[1] Despite the frequency of these changes, the effects of different types of changes on stock returns have not been extensively documented. More generally, the empirical examination of the impacts of innovation and technological advances in finance is an important and understudied area (Frame and While [2004]). To address these issues we employ a unique event: the 1980 NYSE specialist post upgrades.

According to the market microstructure literature there are at least two routes through which changes in the trading environment impact stock returns. First, the literature shows that transactions costs and liquidity affect investors' demand for assets, and anything that changes the costs inherent in these factors should have an impact on stock returns. Amihud and Mendelson [1986, 1988, 1989] use the bid-ask spread as proxy for liquidity and show that stocks that have larger spreads have lower returns. Eleswarapu [1997] and Chalmers and Kadlec [1998] provide additional empirical support for this argument.[2] Datar, Naik, and Radcliffe [1998] and Brennan, Chordia and Subrahmanyam [1998] use turnover and dollar volume as alternative proxies for liquidity and find negative relationships between returns and these variables.[3]

[1] A NYSE chronology is available at http://www.nyse.com/about/history/timeline_chronology_index.html.
[2] However, Chen, Grundy and Stambaugh [1990], Chen and Kan [1996], Eleswarapu and Reinganum [1993] and Easley, Hvidkjaer, and O'Hara [2001] find no support for the effect of spreads on returns.
[3] Brennan and Subrahmanyam [1996] and Easley, Kiefer, O'Hara and Paperman [1996] use asymmetric information based approaches that provide additional information about these effects. Finally, Pastor and Stambaugh [2003] and Acharya and Pedersen [2005] argue that liquidity is a priced factor in returns.

Second, innovations which affect the ability of agents on the floor of the exchange, the specialist and floor brokers, to exploit agents off the floor should affect the demand for assets. Ready [1999] and Stoll and Schenzler [2006] argue that if these insiders have some flexibility to decide when an order is executed they may be able to take advantage of the free option afforded by this flexibility. An innovation that reduces latency reduces the value of this option, and thus reduces the premium demanded by investors to compensate them for bearing this execution risk. Therefore, reductions in latency should generate increases in stock returns.

In 1980, the NYSE replaced the specialists' trading posts that had been in place since the 1920's with cogwheel shaped trading posts that utilized newer technology.[4] This event is uniquely suited to analyzing the differential impacts of changes to the trading environment for two reasons. First, the NYSE's innovations typically affect all stocks traded on the exchange. This makes untangling the effect of an innovation from other changes that may have occurred in the economy at or near the same time difficult. In contrast, the 1980 post upgrade was implemented in a staggered fashion, allowing for better identification of its effects on returns. Second, the 1980 upgrade is the only such sequentially-implemented event which incorporated two types of changes to the trading environment. The first is that it improved information publication and reporting times on the exchange trading floor, and the second, that it reduced latency experienced by off-floor traders. These two changes took place sufficiently far apart in time that they allow us to ascertain their differential effects on stock returns. However, they do not occur so far apart in time that they are incommensurable.

[4] We describe the upgrade process in detail in the appendix.

The first type of change took place in Phase I of the upgrade, which commenced in July 1980. Phase I comprised innovations that were meant to substantially reduce the publication time of transaction and quote information to floor members. New card readers were installed at each post, which were used to process punch cards containing last trade and quote information. Concurrently, an expanded price display unit was installed in each post, to increase the volume and clarity of information available to floor members. However, in this phase, the information that was put through the new system did not include off-floor transactions routed via the designated order turnaround system (DOT) or the inter-market trading system (ITS).[5] These off-floor transactions constituted a significant fraction of total daily volume.

The second set of innovations, those which reduced the latency experienced by those off the floor of the exchange, took place in upgrade Phases II, III and IV, which began in November 1980. In these phases, the eight card readers installed in each new post began processing DOT and ITS cards. According to internal NYSE documents, the implementation was anticipated to reduce DOT and ITS turnaround time-frames significantly, thus reducing the latency experienced by those off the floor of the exchange. During Phases II, III and IV, posts that were upgraded received both the innovations that improved communication on the floor, as well as the innovations that reduced latency. However, posts that were upgraded during Phase I did not receive the latency reducing improvements until the retrofit program, which began in January 1981.

[5] Detailed records of DOT and ITS use during the sample period are not available. DOT was introduced in 1976 initially to execute 100 share market order was later expanded to allow for limit orders. Based on summary data available from the NYSE DOT use (599 share market and 500 share limit orders at the time of the upgrade) was growing rapidly in the late 1970s. In the third quarter of 1978 there were roughly 30,000 DOT orders per day and DOT orders participated in 40% of NYSE transactions. Extrapolating a linear trend from 1977-1978 would project the number of DOT orders to be about 50,000/day at the time of the upgrade. In November 1980 ITS was about 5% of trading volume.

Our empirical tests compare stocks in the Blue Room of the exchange which experience Phase I between July 14, 1980 and August 11, 1980, with those stocks in the Main Room which experience Phases II, III and IV between November 10, 1980 and January 5, 1981. We call the first group Room 1 stocks, and the second group Room 3 stocks. Upon the completion of the phases, the retrofit program was rolled out, during which Room 1 stocks received Phases II, III and IV.

Our most significant finding is that a portfolio which is long Room 1 stocks and short Room 3 stocks exhibits a substantial negative return in the twenty day window beginning with the introduction of Phase II. That is, when the latency experienced by investors in Room 3 stocks was reduced, and the latency experienced by investors in Room 1 stocks was unchanged, Room 3 stocks appreciated relative to Room 1 stocks. The return on the long-short portfolio is approximately 19 basis points a day for a total return of about 3.8 percent over the window. This excess return is robust to correction for the Fama-French and momentum factors. It is also robust to the selection of a matched sample of stocks from Rooms 1 and 3, where the matching is done on market capitalization and prior turnover. Furthermore, we find that this return effect is more pronounced for small market capitalization stocks than for large and medium stocks.

In contrast, the effect of the improved information flow on the floor experienced by Room 1 stocks in Phase I (not experienced by Room 3 stocks until much later) is ambiguous. If anything, this innovation disadvantaged Room 1 stocks relative to Room 3 stocks. These return movements are small and at best significant at the ten percent level.

As expected, we find that the retrofit program reversed these effects on turnover and returns. This reversal is, however, not always complete.[6] It is most significant for small stocks. In particular, the long-short portfolio of small stocks exhibits a total return of 4.1 percent over the 20 day period following the retrofit program.

While the impacts of innovations to the trading environment on stock returns are our primary focus, we also find that the reduced latency for Room 3 stocks increased the rate of trading in Room 3 stocks relative to that in Room 1 stocks. Cumulative turnover for Room 3, relative to Room 1, increased by about 2.5 basis points of market capitalization per day over the 20 day window at the beginning of Phase II. This represents an increase of 13.5 percent over the average daily turnover of Room 3 stocks over the year prior to the upgrade. This result is robust to correction for market turnover and to the selection of a matched sample of stocks. This effect is also more pronounced for small market cap stocks than for large and medium stocks.

We also present evidence of a secular decline in commonly accepted measures of transactions costs following the upgrades. Across all sizes of stocks, we find evidence that both the Roll [1984] spread and the Amihud [2002] ILLIQ measure exhibit statistically significant declines in the six months following the upgrades, relative to their values in the six month period prior to the implementation of the upgrades.

Our study is related to research by Amihud, Mendelson and Lauterbach [1997], Muscarella and Piwowar [2001] and Garbade and Silber [1983]. Amihud et. al. analyze stocks on the Tel Aviv Stock Exchange that move (in batches selected on the basis of 'perceived marketability') from a once a day call auction to an opening call auction followed by iterated continuous trading. They find that stocks that moved experienced

[6] The retrofit returns for Room 1 stocks for the most comparable samples–the small and matched sample portfolios–essentially reverse the Room 3 Phase II returns (see Figure 2, Panel B and Figure 4).

increases in liquidity, and generated an abnormal return of about 5.5 percent over a 35 day window. Muscarella and Piwowar find that stocks on the Paris Bourse that moved from a call market to continuous trading earned an abnormal return of more than five percent over 40 days, and exhibited significant increases in volume and liquidity.

The conclusions of these two studies, i.e., that improving the trading system leads to increased liquidity and increased returns, are consistent with our results. There are, however, several differences between our studies. First, because the NYSE undertook two types of modifications in sequence we are able to study the differential impact of improving information on the floor and reducing latency. Second, the NYSE applied its phases to stocks based on the room in which they were traded, so there is no apparent sample selection issue in our study. Third, the NYSE did not change its method of trading, but rather, it augmented its pre-existing facilities. This narrower focus allows us to draw sharper conclusions about how details of the trading process affect turnover and returns.

Finally, Garbade and Silber [1983] examine the impact of the introduction of the consolidated tape on price differentials between the prices of cross-listed stocks on the NYSE and regional markets. This technology change improved the access to information of NYSE participants to regional market price information. The authors do not find any substantive effect on inter-market price differentials. In contrast, our study reveals that reducing latency experienced by off-floor market participants (an information improvement almost the reverse of the one considered by Garbade and Silber) has significant impacts on securities prices.

The organization of this paper is as follows: Section 2 presents our hypotheses and methodology for examining the impacts of the post upgrades. Section 3 describes the data employed. Section 4 presents the results of our estimation. Section 5 concludes.

2. Hypotheses and Methodology

2.1. Hypotheses

Our primary concern is to analyze the differential impact of changes to the trading environment on returns. We consider two types of changes: reductions to the publication and reporting time of transaction information to on-floor market participants, and reductions in latency.

There is extensive evidence beginning with Amihud and Mendelson [1986], that reductions in illiquidity (the cost of immediate execution of transactions), lead to current increases in prices and decreases in expected returns. Increased information flow on the floor in the form of reduced publication and reporting times of transaction information to on-floor members may aid in the reduction of execution costs. This leads to our first hypothesis:

Hypothesis 1: The implementation of Phase I of the post upgrades, which is meant to increase information flow on the floor of the exchange, will result in price increases for the stocks experiencing this upgrade phase.

Our second hypothesis draws on Ready [1999] and Stoll and Schenzler [2006], who analyze the discretion of the specialist to execute orders at a time of their choosing. This discretion provides these agents with a free option in the presence of execution latency. Reductions in latency experienced by off-floor market participants, therefore, should reduce the premium demanded by these investors to compensate them for bearing this execution risk. This leads to our second hypothesis:

Hypothesis 2: The implementation of Phases II, III and IV, which are meant to reduce the execution latency of DOT and ITS transactions, will result in price increases for the stocks experiencing these upgrade phases.

We test these two hypotheses against the null that the upgrades have zero impacts on stock returns. This could occur for a variety of reasons. One innocuous reason would be a lack of power in our specifications to detect a difference from zero in price movements. A less innocent reason would be that exchanges claim that the changes that they make to the trading environment will benefit market participants, when in actual fact these modifications are ineffective at achieving the announced impacts.

The next section outlines our methods to test Hypotheses 1 and 2.

2.2 Analysis of Returns

2.2.1 Event Study

The standard technique employed to analyse the effects of events such as the one we consider is the event-study methodology pioneered by Fama, Fisher, Jensen and Roll [1969]. Since the post upgrades occurred in a staggered fashion, the implementation sequence indicated in the upgrade schedule (see Table A.1. in the appendix) can be used to study the impacts of Phase I of the upgrades, which commences on 7/14/1980, separately from Phases II, III and IV of the upgrade, which commence on 11/10/1980.

Following the standard procedure, we group stocks by upgrade phases, lining them up according to the day on which they resume trading after upgrade implementation. We then measure abnormal returns using a market model, and sum these abnormal returns over windows of time surrounding the events, to form cumulative abnormal

returns (CARs). These CARs are a measure of the abnormal price increase. Tests of Hypotheses 1 and 2 are, in this framework, tests of whether the CARs are statistically different from zero prior to and following the implementation of each phase.

2.2.2. Long-Short Portfolios in Calendar Time

There are at least two problems with using the event-study methodology outlined in section 2.2.1 to test our two hypotheses. The first is that the events are occur very close to one another in calendar time, indeed many of the stocks experience upgrades on the same day. This generates contemporaneous cross-sectional correlation in the data. As Kothari and Warner [2005] point out, "…if the test statistic in an event study is calculated ignoring cross-dependence in data, even a fairly small amount of cross-correlation in data will lead to serious misspecification of the test. In particular, the test will reject the null of no effect far more often than the size of the test..." One standard solution to this problem, utilized in papers such as Brav and Gompers [1997], Barber, Lyon and Tsai [1999], Fama [1998] and Mitchell and Stafford [2000] is to group stocks into a portfolio in calendar time, and to regress the returns on this portfolio on a factor model. The 'Jensen's alpha' of this portfolio is an estimate of the abnormal return.

The second problem is that the specific event that we are investigating affects every stock in the market, over a reasonably short time period. This means that the benchmark that we use to evaluate abnormal performance is itself changing over time. This renders accurate measurement of abnormal returns difficult. A simple example illustrates this point: assume that half the stocks in the market portfolio undergo a change that generates abnormal returns over a 60 day period. Abnormal returns for any

remaining stocks that experience the same change during this 60 day window, measured relative to the upward-moving market portfolio, will be biased downward.

To insulate ourselves from this second problem, we modify the calendar time procedure, measuring returns in the two phases of the upgrade relative to one other, in an attempt to use stocks not undergoing any change as a natural benchmark for stocks undergoing changes on account of the upgrades. The schedule reveals that the dates of the rollout of Phase I and Phase II of the upgrades do not coincide in Rooms 1 and 3. The returns of the stocks in the two rooms can be considered as a control for one another, as they are not contemporaneously subject to the same upgrade-rollout generated movements.[7] We implement this control by creating portfolios that are long Room 1 and short Room 3 stocks.

It is conceivable that specialists, floor brokers and investors anticipated the effects of these innovations, and so some of the effects may have taken place after the innovation process was announced, but before it was actually implemented. It is also likely that it took market participants some time to understand how to best use the technology and that it took time for this knowledge to spread throughout the investor population. Thus some of the effects of the innovations may not have appeared until well after the innovations occurred. In order to control for both of these possibilities, we examine the returns to the long-short portfolios over various twenty day windows before, during, and after the upgrade process.

We begin by assessing the impacts of the upgrades on returns, estimating the following equation:

[7] We present results for the Room 1 subset of Phase I stocks to ensure that the pre- and post-upgrade windows do not overlap, but our results are not sensitive to expanding Room 1 to include all Phase I stocks.

$$(R_{Room1,t} - R_{Room3,t}) = \sum_{i=1}^{10} \mathrm{a}_i D_i + u_t \quad (1)$$

, and

$$(R_{Room1,t} - R_{Room3,t}) = \sum_{i=1}^{10} \mathrm{a}_i D_i + \beta_{Rm}(R_{mt} - R_{ft}) + \beta_{SMB} SMB_t + \beta_{HML} HML_t + \beta_{UMD} UMD_t + u_t \quad (2)$$

The left-hand side variable in both equations is created by subtracting off the mean return across all stocks in Room 3 ($R_{Room3,t}$) from the mean return across all stocks in Room 1 ($R_{Room1,t}$) each day. In our specifications we use both equal-weighted and market capitalization-weighted mean returns when computing the returns of the long Room 1 short Room 3 portfolio. The ten dummy variables $D_1,...,D_{10}$ pick out the pre- and post-periods surrounding the rollouts of Phase I and Phase II of the upgrade, and the retrofit programme.

Furthermore, equation (2) risk-adjusts the return on this long-short portfolio by regressing it on the Fama-French-Carhart four-factor model. The intercepts $\mathrm{a}_1,...,\mathrm{a}_{10}$ from equation (2) can therefore be viewed as the average abnormal returns to a trading strategy that that goes long Room 1 and short Room 3 stocks over the periods selected by the dummy variables, $D_1,...,D_{10}$.

We redo all of our analysis for the small stocks in our sample, i.e. the bottom tercile of stocks sorted by market capitalization, to check whether there are significant differences in the results of our estimation for these stocks. Finally, we utilize t-statistics computed using standard errors estimated with the method of Newey and West (1987). These are robust to heteroskedasticity and autocorrelation.

2.2.3. Matched Portfolios in Calendar Time

In order to obtain clean estimates of the impact of the post upgrades, we attempt to control for the factors that drive returns on the right-hand side of equation (2). However, it is possible that our results are driven by differences in the characteristics of the stocks in the two rooms that we do not adequately control for with our factor proxies.

To insure ourselves against this possibility, we match stocks in Room 1 with stocks in Room 3, based on the market capitalization and turnover of these stocks. We assign the stocks in each room to market capitalization deciles and then further subdivide these into quintiles ranked by turnover. We then randomly order the stocks in Room 1. For the first stock in this order, we select the Room 3 stock located in the same market capitalization and turnover cell with the closest market capitalization. If no such stock exists the Room 1 stock is dropped. We repeat this process until all Room 1 stocks are exhausted. We then drop any pair for which the market capitalization differential or turnover differential is greater than 50 percent. We repeat this process 1,000 times with independent randomizations of the order of Room 1 stocks. Our matched sample is generated by the repetition with the greatest number of matches.

Once matched, we conduct the same analysis as before, i.e. we re-estimate equation (1), substituting the difference between the equal- or value-weighted returns of matched Room 1-Room 3 pairs as the left hand-side variables:

$$(R_{MatchRoom1,t} - R_{MatchRoom3,t}) = \sum_{i=1}^{10} \mathrm{a}_i D_i + u_t \qquad (3)$$

2.3 Evidence on Liquidity

We investigate whether the upgrades are accompanied by movements in measures of liquidity. We employ turnover, a commonly utilized measure of liquidity, analyzing it in the same fashion as returns. First, we estimate:

$$(Turn_{Room1,t} - Turn_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + u_t \quad (4)$$

The left-hand side variable is created by subtracting off the equally-weighted mean turnover across all stocks in Room 3 ($Turn_{Room3,t}$) from the equally-weighted mean turnover across all stocks in Room 1 ($Turn_{Room1,t}$) each day.

We then check that our results are not driven by the propensity of stock-specific turnover to co-move with market turnover, estimating:

$$(Turn_{Room1,t} - Turn_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + \beta Turn_{Mkt,t} + u_t \quad (5)$$

The measure of market-wide turnover on the right-hand side of equation (5), $Turn_{Mkt,t}$, is computed by equally-weighting turnover across all stocks in the NYSE universe each day.

We then undertake a matched sample analysis of turnover, estimating:

$$(Turn_{MatchRoom1,t} - Turn_{MatchRoom3,t}) = \sum_{i=1}^{10} a_i D_i + u_t \quad (6)$$

Where the left-hand side variable in equation (6) is the average difference between the turnover of matched Room 1-Room 3 pairs.

To provide additional confirming evidence, we compute two commonly utilized measures of liquidity over six month windows prior to and following the implementation of the upgrades. First, the Amihud measure for a stock *i* on day *t* is computed as:

$$Amihud_{it} = \min\left(10, 10^6 * \frac{abs(R_{it})}{abs(P_{it}) * V_{it}}\right) \quad (7)$$

Here, R_{it}, P_{it} and V_{it} are respectively, the return, price and volume for stock *i* on day *t*. On days with zero volume, the measure is set to 10. We average the stock-day specific Amihud measures across all stocks in each size tercile in the periods prior to and following the entire process of upgrades and compare these measures to one another.

Second, the Roll measure for a stock *i* in the before and after periods is computed as:

$$Roll_i = \sqrt{-2\,\mathrm{cov}(R_{it}, R_{it-1})} \quad (8)$$

We average the stock-specific Roll measures (where defined) across all stocks in each size tercile in the periods prior to and following the entire process of upgrades and compare these measures to one another.

3. Data

Table I presents descriptive statistics for the stocks grouped by the room in which they are located.[8] The table shows that there are 159 stocks in total that can be identified as having trading posts located in Room 1, and 286 in Room 3, leaving 981 'other' identified stocks not in either of the two rooms. The average size of the stocks in Room 3 is U.S. $670 million, which is higher than that in Room 1, at $486 million. The mean market capitalization of the other stocks lies in between these two numbers. However, in the smallest tercile of stocks, the mean market capitalization is virtually identical for Room 1 ($40 million) and Room 3 ($41 million) stocks. The mean turnover and turnover beta of stocks in Room 1 is slightly higher than that in Room 3 for all stocks. However,

[8]There was some reorganization of stocks' locations during the upgrade for which exact dates are not available (see Appendix). Stocks whose upgrade date could not be identified are categorized as Others.

both turnover and return betas are close to one on average in both rooms, across all size quintiles of stocks. [9]

Table II presents summary statistics from pairs of stocks matched on turnover and market capitalization across Room 1 and Room 3. There are a total of 115 matched pairs of stocks. The means of market capitalization and turnover across the two rooms are very close, a result of the matching procedure. The next section presents and discusses the results from estimating the specifications outlined in the previous section.

4. Results

4.1. Event Study Results

Figure 1 presents results from a market-model event study of the differential impacts of Phase I versus Phases II, III and IV. Panel A (B) of the figure plots the cumulative abnormal returns for 30 days before and 60 days after the implementation of Phase I (Phases II, III and IV). Panel A represents evidence on Hypothesis 1 and Panel B constitutes evidence on Hypothesis 2.

The graph suggests that there is some anticipation of Phase I, with the CAR rising to 1.42 percent over the 30 day window prior to its implementation. However, in the 60 days following Phase I, there is no real pattern to the residuals, which fluctuate around zero.

Panel B offers an interesting contrast, with little evidence of systematic return movements prior to the implementation of Phases II, III and IV, but a very strong

[9]It is not surprising that stocks in the different rooms look fairly homogeneous. Historically, the NYSE's limited floor space and the limited processing power of the human floor traders provided incentives for stocks with different characteristics to be uniformly located across the floor. This ensures "load balancing" of capacity so traders and locations on the floor are not overwhelmed when news arrives and/or trading activity increases. This incentive to assign stocks evenly across the floor is helpful in mitigating selection biases over the upgrade process.

response in the 60 day window after the implementation – the CAR stands at 3.58 percent on the 60^{th} day post-implementation.

While these results suggest that there may be positive impacts around both phases, we must address the issues of contemporaneous correlation and the shifting benchmark to draw clearer inferences. We now turn to the results from the calendar time portfolio analysis.

4.2. Calendar Time Results

Figure 2 shows the movement of returns in the periods surrounding the rollouts of Phase I, Phase II and the retrofit. Both panels of the figure reveal that there is a large downward movement in the return differential between Room 1 and Room 3 immediately following the rollout of Phase II in Room 3, and an increase in the return differential immediately after the rollout of the retrofit programme. Table III confirms this result, presenting estimates of equations (1) and (2). In this table, both a_6 and a_9 are statistically significant, with a_6 negative and a_9 estimated positive. These return increases are relatively large. For the 20 days following the rollout of Phase II in Room 3, a_6 shows that the average stock in Room 3 outperforms that in Room 1 by 18.8 basis points per day after risk adjustment using the Fama-French-Carhart four-factor model. This translates into a cumulative abnormal return of 3.8 percent over the 20 day period. For small stocks, the response is even higher, at 25 basis points per day after risk-adjustment, which translates into a cumulative abnormal return of five percent over the 20 day period. The relatively large size of the return response could be attributed to the fact that the price, being a forward-looking variable, responds to what is likely a permanent reduction in

future trading costs. The results here are consistent with Figure 1, and offer strong support for Hypothesis 2.

The 20 day period following the retrofit program exhibits a similarly high return response in Room 1 stocks relative to Room 3 stocks. The coefficient a_9 reveals that for small stocks, there is a significantly positive return differential of 19.6 basis points per day between Room 1 and Room 3 stocks, constituting a cumulative return of 3.9 percent over 20 days after risk-adjustment using the four-factor model. This is an additional benefit of using the calendar-time approach – we are able to identify the effects of the retrofit program, about which we cannot draw inferences using the event-study approach. This provides further evidence in favor of Hypothesis 2.

However, the effect of the improved information flow on the floor experienced by Room 1 stocks in Phase I (not experienced by Room 3 stocks until much later) is ambiguous. In Tables III and IV, a_2 and a_3 are small and at best significant at the ten percent level. If anything, this innovation disadvantaged Room 1 stocks relative to Room 3 stocks. In short, we are unable to find any evidence to support Hypothesis 1.

Finally, the return differential that we detect between the two rooms does not persist outside of the period of the upgrades, i.e. a_{10} is statistically insignificant for all the specifications. This is reassuring, as it offers additional verification that the return differentials between rooms that we are picking up are not an artefact of improper risk-adjustment, or the different characteristics of stocks in the two rooms.

Table IV re-estimates equations (1) and (2), market capitalization-weighting rather than equal-weighting the returns of stocks within each of the Room 1 and Room 3 portfolios. The Table shows that the main findings of Table III are virtually unchanged for small stocks, and qualitatively similar although statistically insignificant for the entire

group of stocks. This confirms that the primary driver of the results is the group of small stocks in the sample.

4.3. Matching Results

Table V presents results from a regression of the return differential between Room 1 and Room 3 matched stocks on time period-specific intercepts. The results in the table confirm that a_6 is significantly negative, with magnitudes close to those in Tables III and IV. This supports the evidence in Tables III and IV, in favor of Hypothesis 2.

However, a_9 is no longer significantly positive in the matched return analysis, although inspection of figure 3 reveals that there is an increase in the return differential in the 20 days following the rollout of the retrofit for small stocks. The regression results could be attributed to insufficient power to detect a difference from zero in the return differential. Table II reveals that the matching procedure is accomplished at a cost, as the total (small stock) sample size falls from 445 (139) stocks in both rooms to 230 (74) matched pairs across the two rooms.

Finally, the matched sample analysis in Table V reveals that a_2 and a_3 are statistically insignificant, confirming the evidence in Tables III and IV. We are unable to find evidence in favor of Hypothesis 1.

4.4 Evidence on Liquidity

Table VI shows the results from estimating equations (4) and (5). There are four main points to note here. First, there is a slight tendency for the equal-weighted mean turnover across all stocks to be higher for Room 1 stocks than for Room 3 stocks in the pre-upgrade period, even after controlling for the higher turnover beta of Room 1 stocks

found in Table I. Second, the intercept a_6 is significantly negative across three out of the four specifications for different stock samples. This indicates that turnover in Room 3 is higher than in Room 1 immediately following the rollout of Phase II in Room 3. The coefficient magnitude indicates that turnover in Room 3 is significantly higher by approximately 2.3 basis points of market capitalization per day in the group of all stocks, and 6.8 basis points higher on average across the group of small stocks in the 20 day period immediately following the rollout. For all (small) stocks, this represents an increase of 12.4 (34.8) percent over the average daily turnover in the pre-upgrade period. Visual evidence of this change in turnover is provided in both panels of figure 4, which show the decline in the Room 1-Room 3 turnover differential immediately after the rollout of Phase II in Room 3.

Third, for small stocks, the intercept a_9 is positive and statistically significant. This indicates that turnover in Room 1 is greater than that in Room 3 by 2.9 (4.5) basis points per day for all (small) stocks, immediately after the rollout of the retrofit programme. This represents an increase of 15.2 (24) percent over the average daily turnover for Room 1 stocks in the pre-upgrade period. This is confirmed in panel B of figure 4, which shows an increase in the Room 1-Room 3 turnover differential following the rollout of the retrofit programme.

The increase in turnover occurs for a period of 20 days following the rollout of Phase II in Room 3, and following the implementation of the retrofit programme. This increase does not appear to be sustained past the 20 day mark for the Phase II implementation in Room 3 (a_7 is never statistically significant). This temporary movement in turnover post-Phase II is consistent with a model in which the relaxation of a trading constraint on a group of stocks permits portfolio rebalancing at lower cost,

leading to an initial surge in trading volume as market participants achieve their desired allocations. While the costs of rebalancing may be permanently lower, the timing of turnover increases will also depend on the return horizon of market participants. Furthermore, the design of our study only allows us to observe relative changes in turnover between Room 1 and Room 3 stocks – and the retrofit programme commences one trading month after the Phase II rollout in Room 3.

Finally, in the period after the upgrade, for all stocks, the Room 1 stocks revert to their tendency to have a slightly higher turnover than the Room 3 stocks. For all stocks, the magnitudes of a_{10} are virtually identical to the magnitudes of the intercepts a_1, which capture the mean differential in the pre-upgrade period. For small stocks, however, there is a tendency for Room 1 stocks to have a higher mean turnover in the period after the upgrade.

Table VII presents estimates of equation (6). There are three main findings here. First, intercepts a_3 and a_4 are significantly negative, indicating a fall in turnover for Room 1 stocks in the period following the rollout of Phase I in Room 1. Second, the table confirms the Table VI result: intercept a_6 is statistically significant and negative for all stocks, as well as for the group of small stocks. The magnitudes of the a_6 coefficients are now higher than their corresponding magnitudes in Table VI. The turnover of all (small) Room 3 stocks is higher than that of their matched counterparts in Room 1 by 5.2 (8.6) basis points per day, an increase of 25.7 (40) percent relative to their pre-upgrade means. Third, as in Table VI, a_9 is estimated to be statistically significant and positive for the sample of small stocks. The average turnover of Room 1 small stocks is higher than the average turnover of their matched counterparts in Room 3 by 6.7 basis points per day, an increase of 32 percent relative to the pre-upgrade mean in the sample of Room 1 matched

stocks. Puzzlingly, for the group of all stocks, there is also a small but precisely estimated negative coefficient a_{10}, although the coefficient a_{10} is not statistically different from zero for the group of small stocks.

Finally, Table VIII presents estimates of equations (7) and (8) in the six month periods prior to and immediately following the implementation of all upgrades. We restrict ourselves to these short windows in the knowledge that liquidity has experienced a secular increase over the past few decades (see Pastor and Stambaugh [2003]). Both Roll and Amihud measures exhibit statistically significant declines subsequent to the upgrades. While this evidence suggests that the upgrades are associated with reductions in liquidity, it is always difficult to draw sharp conclusions when employing broad market measures.

5. Conclusion

This paper uses a unique event to investigate whether changes to the trading environment benefit listed firms and their stockholders: the 1980 upgrade of the technology used in NYSE specialist posts. The upgrade consisted of two distinct components, one which improved information flow on the floor of the exchange, and one which reduced the latency experienced by off-floor traders.

We find that the upgrade to information flow on the floor of the exchange has, if anything, marginally negative effects on returns. However the latency reducing component of the upgrade is accompanied by a statistically significant and economically important increase in stock returns. Viewed in this light, the first result may not be as puzzling. Perhaps the improvement of information flow on the floor served mainly to increase the disparity in information access between on-floor and off-floor market participants, which is why the effects of the first change appear negative.

Taken together, the results of this study suggest that changes to the technology of trade are an important area of investigation for market participants and exchanges alike, potentially generating interesting implications for the design of market mechanisms and measuring the impact of financial and technological innovation. The results also suggest that leveling the playing field between the public and intermediaries leads to higher liquidity and higher prices, especially for smaller, less liquid securities.

Appendix
Details of the 1980-1981 NYSE Specialist Post Upgrades

In the 1980-81 post upgrades, the exchange replaced trading posts that had been in place since the 1920's with a cogwheel shaped trading post that could accommodate new technology. The entire program was anticipated (in internal exchange documents) to cost the exchange $12 million, excluding the costs of data processing equipment. Ten large posts and four smaller posts were installed, with large (small) posts holding 22 (16) specialist positions.

Figure A.1 shows the location of specialist posts on the NYSE trading floor on October 19, 1979 prior to the upgrades, and figure A.2 shows what the floor looked like in February 1981 following the completion of the upgrades. The upgrades were accompanied by some changes in the location of specialist firms which were made in order to consolidate their position on the floor. For example, Robb, Peck, McCooey and Company, located on old posts 18 and 21 prior to the upgrade, moved to post 4 following the upgrade.

The upgrades were conducted on weekends beginning with 12-13 July 1980, and continuing at one-to-three week intervals through the first weekend in 1981. The detailed schedule of the upgrades is presented in Table A.1. We used the supporting documents accompanying figures A.1 and A.2, lists of stock locations on specific posts, to identify the dates at which specific stocks received the upgrades. For example, if a stock was located on post 16 according to the October 1979 list and on post 4 according to the February 1981 list, we classify it as having experienced Phase I of the post upgrade on September 8, 1980. As some stocks switched locations, and given the consolidation of specialists across posts, we are not able to unambiguously identify the upgrade date associated with every stock on the exchange floor.

The upgrade was deployed in several phases. At each phase, functionality implemented in the previous phase was made operational, along with additional functionality specific to the phase. For example, the Phase II implementation was actually an implementation of Phases I and II simultaneously. At the conclusion of the phases, a retrofit program was rolled out and posts at which only earlier phases were implemented were brought up to date. For example, posts at which Phase I was originally implemented only received Phase II and Phase III functionality during the retrofit program.

Phase I of the upgrade involved the installation of new Chatsworth card readers in each post, which were used to read punch cards containing last trade and quote information. In this phase, the information that was put through the new system did not include designated order turnaround system (DOT) or intermarket trading system (ITS) transactions. The new equipment was, according to the exchange's estimates, meant to reduce the publication time of non-DOT and non-ITS transaction and quote information to floor members from one to two minutes to 20 seconds. Concurrently, an expanded price display unit was installed in each post, a CRT screen with the capacity to display six ITS stocks, or 12 non-ITS stocks, or combinations of the two.

In Phase II, the eight card readers installed in each new post were to begin processing DOT cards. According to internal NYSE documents, the implementation was anticipated to reduce DOT turnaround time-frames substantially, presumably by a factor of eight – previously there was only one card reader per post processing DOT cards. This change was anticipated to reduce the latency experienced by those off the floor of the exchange.

Phase III involved the installation of mini-printers and ITS universal mark-sense card readers which were anticipated to cut ITS processing time for outgoing commitments by half, and to reduce transcription errors by card operators. Unfortunately, in the NYSE archives there is no available documentation about Phase IV, which was implemented at old posts 6 and 7 on January 5, 1981.

Finally, the retrofit program was rolled out, to bring on-line all the existing systems installed, but not active at each new post during the previous installation phases. Figure A.3 is a schematic of the new trading post, detailing the functionality installed during the various phases.

Table A.1
Post Upgrade Schedule

Room	Remove Old Post	Install New Post	Dates	Equipment Available
Blue Room	21 & 22	14	July 14, 1980	Phase I
	19 & 20	12	August 4, 1980	Phase I
		13	August 11, 1980	Phase I
Garage	15 & 17	3	August 25, 1980	Phase I
	16	4	September 8, 1980	Phase I
	14 & 18	2	September 15, 1980	Phase I
	13	1	October 6, 1980	Phase I
Main Room	10 & 11	7	October 13, 1980	Phase I
	2 & 3	9	October 27, 1980	Phase I
	5 & 9	5	November 10, 1980	Phase II
	1	6	November 17, 1980	Phase II
	8 & 12	10	December 8, 1980	Phase II
	4	11	December 15, 1980	Phase III
	6 & 7	8	January 5, 1981	Phase IV
			January 19, 1981	Begin Retrofit Program
			First Quarter, 1981	Begin Turnaround Printer Pilot

Figure A.1.
The NYSE Trading Floor, October 1979

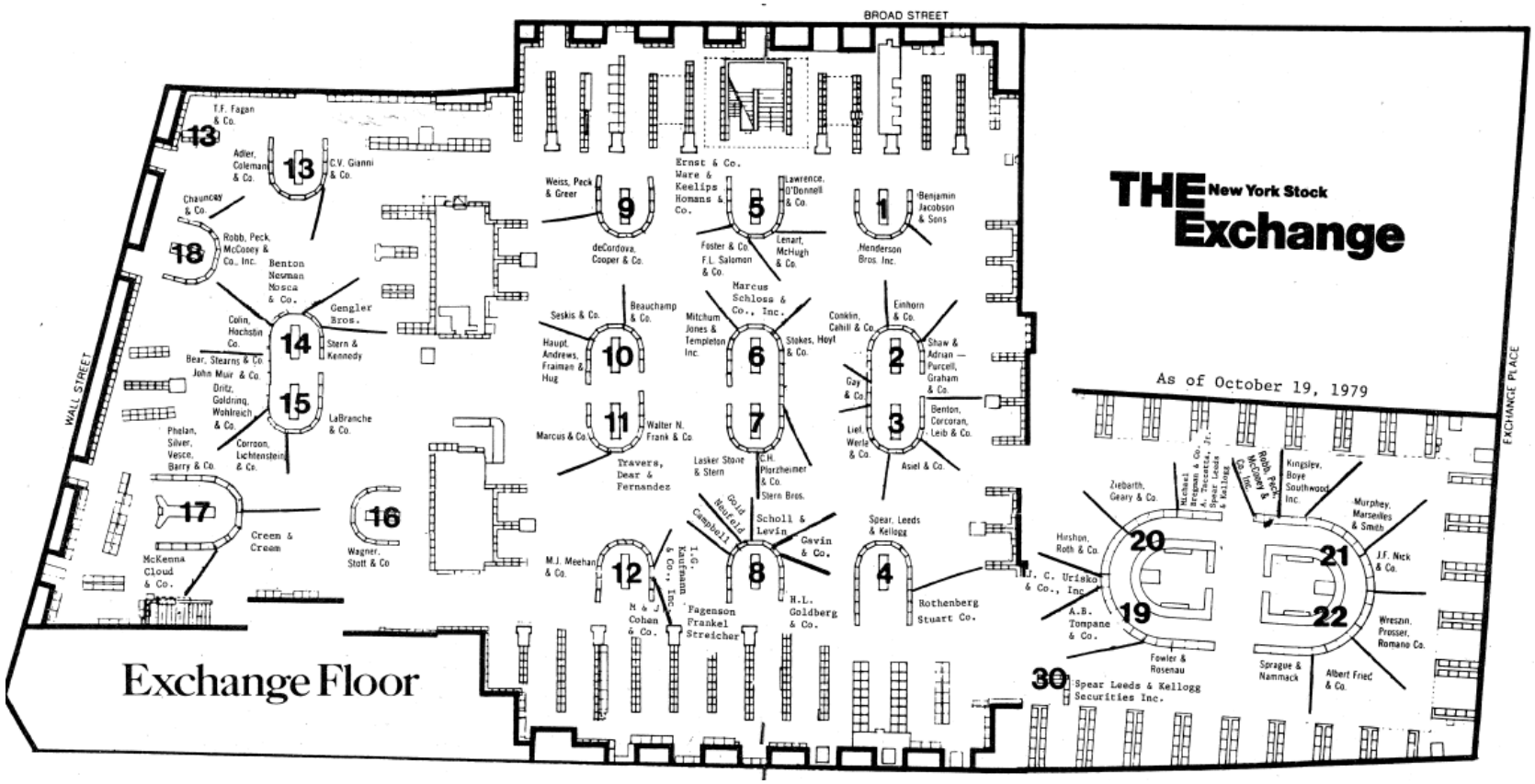


Figure A.2.
The NYSE Trading Floor, February 1981

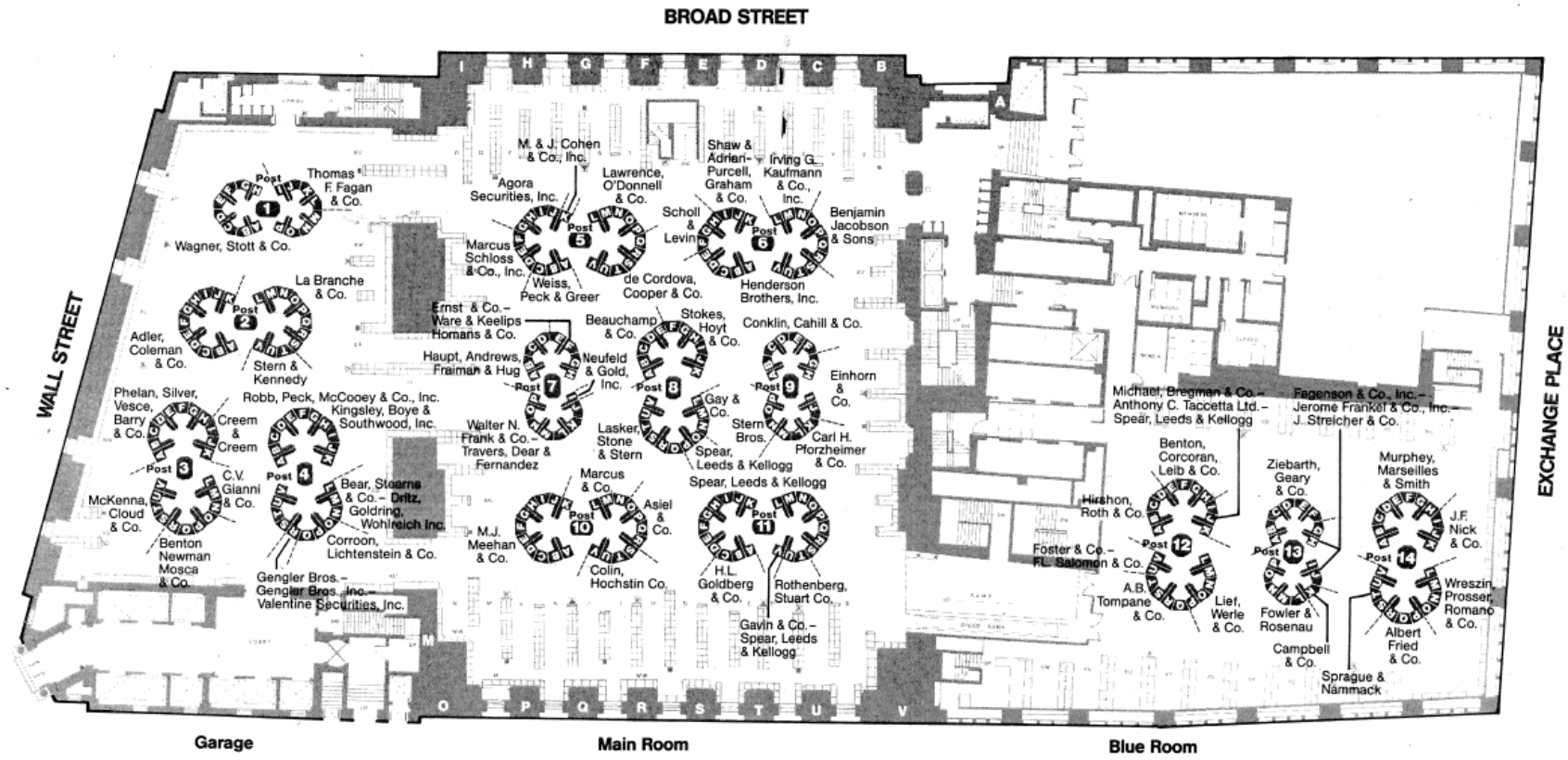
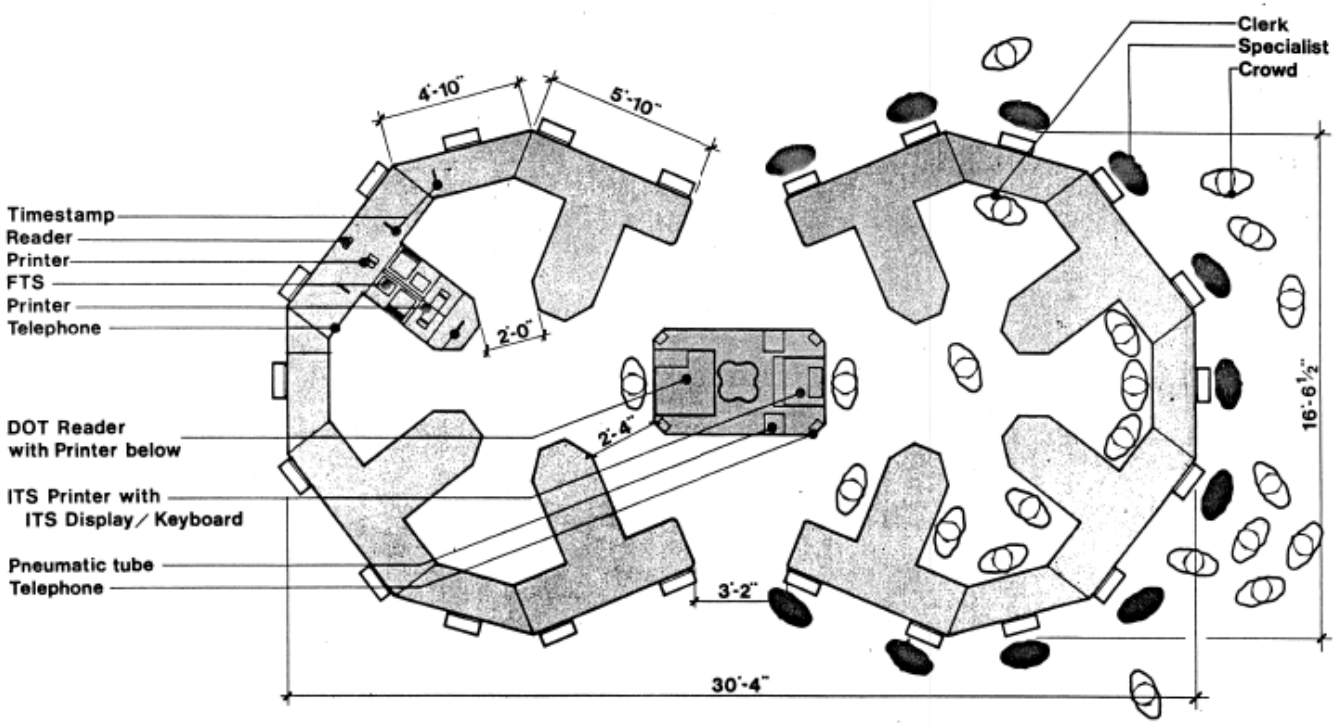


Figure A.3.
New Specialist Post



References

Acharya, V., and L. H. Pedersen, 2005 Asset pricing with liquidity risk. Journal of Financial Economics 77, 375-410.

Amihud, Y., 2002. Illiquidity and stock returns: Cross-section and time-series effects. Journal of Financial Markets 5, 31-56.

Amihud, Y., and H. Mendelson, 1986, Asset pricing and the bid-ask spread, Journal of Financial Economics 17, 223-249.

Amihud, Y., and H. Mendelson, 1988, Liquidity and asset prices: Financial management implications, Financial Management 17, 5-15.

Amihud, Y., and H. Mendelson, 1989, The effects of beta, bid–ask spread, residual risk and size on stock returns, Journal of Finance 44, 479–486.

Amihud, Y., H. Mendelson, and B. Lauterbach, 1997, Market microstructure and securities values: evidence from the Tel Aviv exchange, Journal of Financial Economics 45, 365–390.

Brennan, M.J., and A. Subrahmanyam, 1996, Market microstructure and asset pricing: on the compensation for illiquidity in stock returns, Journal of Financial Economics 41, 441–464.

Brav, A., and P. Gompers, 1997, Myth or reality? The long-run underperformance of initial public offerings: Evidence from venture and nonventure capital-backed companies, Journal of Finance 52, 1791-1821.

Brennan, M. J., T. Chordia, and A. Subrahmanyam, 1998, Alternative factor specifications, security characteristics, and the cross-section of expected stock returns, Journal of Financial Economics 49, 345-373.

Chalmers, J. M., and G. B. Kadlec, 1998, An empirical examination of the amortization spread, Journal of Financial Economics 48, 159-188.

Chen, N., B. Grundy, and R. Stambaugh, 1990, Changing risk, changing risk premiums, and dividend yield effects, Journal of Business 63, S51-S70.

Chen, N. and R. Kan, 1996, Expected returns and the bid-ask spread, in Modern Portfolio Theory and Applications.

Datar, V.T., N.Y. Naik, and R. Radcliffe, 1998, Liquidity and stock returns: an alternative test, Journal of Financial Markets 1, 205–219.

Easley, D., N. Kiefer, M. O'Hara, and J. Paperman, 1996, Liquidity, information, and infrequently traded stocks, Journal of Finance 51, 1405-1436.

Easley, D., Hvidkjaer, S. and M. O'Hara, 2002, Is information risk a determinant of asset returns? Journal of Finance 57, 2185-2221.

Eleswarapu, V. R., 1997, Cost of transacting and expected return in the Nasdaq market, Journal of Finance 52, 2113-2127.

Eleswarapu, V. R. and M. R. Reinganum, 1993, The seasonal behavior of the liquidity premium in asset pricing, Journal of Financial Economics 34, 373-386.

Fama, E., 1998, Market efficiency, long-term returns, and behavioral finance, Journal of Financial Economics 49, 283-306.

Fama, E., Fisher, L., Jensen, M., Roll, R., 1969, The adjustment of stock prices to new information. International Economic Review 10, 1-21.

Frame, W.S., and L. J. White, 2004, Empirical studies of financial innovation: Mostly talk and not much action? Journal of Economic Literature 42, 116-144.

Garbade, K. D. and W. L. Silber, 1978, Technology, communication and the performance of financial markets: 1840-1975, Journal of Finance 33, 819-832.

Kothari, S. P., and J. B. Warner, 2005, The econometrics of event studies, in B. Espen Eckbo (ed.), Handbook of Corporate Finance: Empirical Corporate Finance (Handbooks in Finance Series, Elsevier/North-Holland), Chapter 1.

Lyon, J., B. M. Barber, and C. Tsai, 1999, Improved methods of tests of long-horizon abnormal stock returns, Journal of Finance 54, 165-201.

Mitchell, M., and E. Stafford, 2000, Managerial decisions and long-term stock price performance, Journal of Business 73, 287-329.

Muscarella, C. J. and M. S. Piwowar, 2001, Market microstructure and securities values: Evidence from the Paris Bourse, Journal of Financial Markets 4, 209-230.

Newey, W. K., and K. D. West, 1987, A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix, Econometrica 55, 703-708.

Pastor, L., and R. Stambaugh, 2003, Liquidity risk and expected stock returns, Journal of Political Economy 111, 642-685.

Ready, M., 1999, The specialist's discretion: stopped orders and price improvement, Review of Financial Studies, 12, 1075-1112.

Roll, R., 1984. A simple explicit measure of the effective bid-ask spread in an efficient market. Journal of Finance 39, 1127-1139.

Stoll, H. R., and C. Schenzler, 2006, Trades outside the quotes: reporting delay, trading option or trade size? Journal of Financial Economics 79, 615-653.

Table I
Summary Statistics: Rooms

The column headings denote the summary statistics that are calculated over the time period prior to the upgrade (1/1/79-4/14/80), except for the statistics pertaining to market capitalization and price, which are calculated as on 4/14/80. Daily turnover is calculated as share volume divided by daily shares outstanding reported in CRSP. The turnover and return betas (from a market model, described in the text) are calculated only for those stocks with more than 250 return observations, over (1/1/79-4/14/80), and then averaged across the group of stocks denoted in the row headings. The row headings denote the group of stocks for which the statistics are calculated (stocks in Room 1, Room 3 and 'Other' stocks, which are not in Room 1 or Room 3). The summary statistics are first calculated across all stocks in each of the rooms, and then for the large, medium and small stocks (sorted by market capitalization as on 4/14/80) separately.

Stocks	Number	Mean Mkt. Cap	Mean Price	Mean Return	Std. Return	Mean Beta Return	Mean Turnover	Std. Turnover	Mean Beta Turnover
		($MM)	($)	(%)	(%)		(%)	(%)	
All									
Room 1	159	486	20.451	0.090	2.297	1.020	0.191	0.243	1.058
Room 3	286	670	23.049	0.096	2.236	0.989	0.184	0.230	1.007
Others	981	563	21.497	0.092	2.287	0.995	0.184	0.232	0.986
Large									
Room 1	51	1,257	31.510	0.094	1.918	0.983	0.173	0.174	1.008
Room 3	104	1,629	33.648	0.081	1.828	0.972	0.169	0.178	0.819
Others	320	1,502	32.824	0.083	1.820	0.950	0.157	0.154	0.790
Medium									
Room 1	58	192	19.050	0.087	2.304	1.061	0.209	0.276	1.143
Room 3	93	199	21.379	0.094	2.201	0.973	0.190	0.234	1.100
Others	325	177	20.982	0.101	2.252	1.003	0.194	0.251	1.088
Small									
Room 1	50	40	10.796	0.089	2.677	1.011	0.187	0.275	1.009
Room 3	89	41	12.409	0.116	2.749	1.027	0.195	0.286	1.139
Others	336	41	11.208	0.093	2.767	1.032	0.201	0.287	1.081

Table II
Summary Statistics: Matched Sample

The column headings denote the summary statistics that are calculated over the time period prior to the upgrade (1/1/79-4/14/80), except for the statistics pertaining to market capitalization and price, which are calculated as on 4/14/80. Daily turnover is calculated as share volume divided by daily shares outstanding reported in CRSP. The turnover and return betas (from a market model, described in the text) are calculated only for those stocks with more than 250 return observations, over (1/1/79-4/14/80), and then averaged across the group of stocks denoted in the row headings. The row headings denote the group of stocks for which the statistics are calculated. Each Room 1 stock is matched with a Room 3 stock based on market capitalization and turnover. The summary statistics are first calculated across all matched stocks in each of the rooms, and then for the large, medium and small stocks (breakpoints computed using the market capitalization of stocks in Room 3 as on 4/14/80, breakpoints then used to sort Room 1 stocks) separately.

Stocks	Number	Mean Mkt. Cap	Mean Price	Mean Return	Std. Return	Mean Beta Return	Mean Turnover	Std. Turnover	Mean Beta Turnover
		($MM)	($)	(%)	(%)		(%)	(%)	
All									
Room 1	115	517	20.926	0.093	2.271	1.051	0.191	0.238	1.032
Room 3	115	510	22.871	0.098	2.315	1.052	0.202	0.248	1.090
Large									
Room 1	40	1253	31.059	0.094	1.899	1.026	0.167	0.166	0.925
Room 3	40	1240	34.459	0.079	1.893	1.046	0.173	0.176	0.896
Medium									
Room 1	38	203	19.770	0.090	2.241	1.048	0.200	0.252	1.045
Room 3	38	200	20.089	0.095	2.340	1.031	0.220	0.264	1.183
Small									
Room 1	37	44	11.157	0.094	2.704	1.085	0.210	0.303	1.139
Room 3	37	41	13.201	0.121	2.745	1.081	0.215	0.311	1.212

Table III
Equal Weighted Long-Short Portfolio: Returns

This table presents results from estimating:

$(R_{Room1,t} - R_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + u_t$ and $(R_{Room1,t} - R_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + \beta_{Rm}(R_{mt} - R_{ft}) + \beta_{SMB} SMB_t + \beta_{HML} HML_t + \beta_{UMD} UMD_t + u_t$

The D_i select the events and time periods denoted in the first column. The other columns denote the stock sample used in the analysis, 'All' stocks, and the bottom tercile of stocks sorted by market capitalization, 'Small' stocks. $R_{Room1,t}$ ($R_{Room3,t}$) is the equal-weighted average return across stocks in Room 1 (Room 3) on day t. $R_{mt} - R_{ft}, SMB_t, HML_t, UMD_t$ are the four Fama-French factors. Newey-West t-statistics are robust to heteroskedasticity and autocorrelation.

		Stock Sample			
Time Period	**Coefficient**	**All**	**All**	**Small**	**Small**
Before Upgrades (1/1/79 to 6/12/80)	$\mathbf{a_1}$	-0.004	-0.008	-0.020	-0.022
		-0.330	*-0.620*	*-0.810*	*-0.910*
Phase I, Room 1 (-19,0) (6/13/80 to 7/11/80)	$\mathbf{a_2}$	-0.003	-0.013	-0.052	-0.070
		-0.040	*-0.210*	*-0.510*	*-0.680*
Phase I, Room 1 (+1,+20) (7/14/80 to 8/8/80)	$\mathbf{a_3}$	-0.081	-0.090	-0.064	-0.084
		-1.170	*-1.300*	*-0.640*	*-0.810*
(8/11/80 to 10/9/80)	$\mathbf{a_4}$	-0.011	-0.013	-0.063	-0.058
		-0.420	*-0.450*	*-1.110*	*-0.990*
Phase II, Room 3 (-19,0) (10/10/80 to 11/7/80)	$\mathbf{a_5}$	-0.012	-0.008	-0.002	0.009
		-0.300	*-0.210*	*-0.020*	*0.120*
Phase II, Room 3 (+1,+20) (11/10/80 to 12/7/80)	$\mathbf{a_6}$	**-0.192**	**-0.188**	**-0.272**	**-0.250**
		-3.810	*-3.540*	*-3.180*	*-2.630*
(12/8/80 to 12/17/80)	$\mathbf{a_7}$	-0.020	0.018	0.075	0.131
		-0.280	*0.230*	*0.770*	*1.250*
Retrofit (-19,0) (12/18/80 to 1/16/81)	$\mathbf{a_8}$	0.039	0.018	0.022	-0.018
		1.000	*0.500*	*0.320*	*-0.280*
Retrofit (+1,+20) (1/19/81 to 2/13/81)	$\mathbf{a_9}$	**0.083**	0.070	**0.215**	**0.196**
		1.770	*1.450*	*2.160*	*1.950*
After Upgrades (2/16/81 to 12/31/81)	$\mathbf{a_{10}}$	0.003	0.000	-0.037	-0.038
		0.190	*0.000*	*-1.250*	*-1.300*
	R_m-R_f		3.296		4.097
			1.510		*1.110*
	SMB		**7.214**		9.260
			2.070		*1.610*
	HML		5.463		3.801
			1.520		*0.600*
	UMD		0.581		-4.072
			0.260		*-0.920*
R^2		0.022	0.043	0.014	0.021
Observations		759	759	759	759

Table IV
Value Weighted Long-Short Portfolio: Returns

This table presents results from estimating:

$(R_{Room1,t} - R_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + u_t$ and $(R_{Room1,t} - R_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + \beta_{Rm}(R_{mt} - R_{ft}) + \beta_{SMB} SMB_t + \beta_{HML} HML_t + \beta_{UMD} UMD_t + u_t$

The D_i select the events and time periods denoted in the first column. The other columns denote the stock sample used in the analysis, 'All' stocks, and the bottom tercile of stocks sorted by market capitalization, 'Small' stocks. $R_{Room1,t}$ ($R_{Room3,t}$) is the market capitalization-weighted average return across stocks in Room 1 (Room 3) on day t. $R_{mt} - R_{ft}, SMB_t, HML_t, UMD_t$ are the four Fama-French factors. Newey-West t-statistics are robust to heteroskedasticity and autocorrelation.

		Stock Sample			
Time Period	**Coefficient**	**All**	**All**	**Small**	**Small**
Before Upgrades (1/1/79 to 6/12/80)	a_1	**0.052**	**0.035**	-0.029	-0.029
		2.520	*1.950*	*-1.150*	*-1.150*
Phase I, Room 1 (-19,0) (6/13/80 to 7/11/80)	a_2	-0.098	**-0.121**	-0.073	-0.084
		-1.320	*-1.720*	*-0.620*	*-0.720*
Phase I, Room 1 (+1,+20) (7/14/80 to 8/8/80)	a_3	-0.079	-0.105	-0.149	-0.141
		-0.790	*-1.160*	*-1.450*	*-1.320*
(8/11/80 to 10/9/80)	a_4	0.082	0.013	-0.109	-0.066
		1.350	*0.210*	*-1.500*	*-0.930*
Phase II, Room 3 (-19,0) (10/10/80 to 11/7/80)	a_5	0.046	0.007	-0.024	-0.005
		0.710	*0.120*	*-0.260*	*-0.050*
Phase II, Room 3 (+1,+20) (11/10/80 to 12/7/80)	a_6	-0.013	-0.105	**-0.359**	**-0.288**
		-0.150	*-1.380*	*-3.780*	*-2.780*
(12/8/80 to 12/17/80)	a_7	0.126	0.217	0.018	0.071
		1.100	*1.550*	*0.120*	*0.510*
Retrofit (-19,0) (12/18/80 to 1/16/81)	a_8	-0.035	0.014	0.078	-0.007
		-0.260	*0.140*	*0.740*	*-0.090*
Retrofit (+1,+20) (1/19/81 to 2/13/81)	a_9	-0.046	-0.060	**0.233**	0.172
		-0.790	*-0.960*	*2.250*	*1.620*
After Upgrades (2/16/81 to 12/31/81)	a_{10}	0.047	0.038	-0.049	-0.058
		1.390	*1.050*	*-1.300*	*-1.590*
	R_m-R_f		-0.370		2.404
			-0.120		*0.640*
	SMB		**24.196**		**11.240**
			4.620		*1.910*
	HML		7.639		**14.941**
			1.310		*2.180*
	UMD		**21.523**		**-7.845**
			5.020		*-1.700*
R^2		0.009	0.154	0.020	0.048
Observations		759	759	759	759

Table V
Matched Long-Short Portfolios: Returns

This table presents results from estimating the following equation:

$$(R_{MatchRoom1,t} - R_{MatchRoom3,t}) = \sum_{i=1}^{10} a_i D_i + u_t \,.$$

Each stock in Room 1 is matched with a stock in Room 3. The dummy variables D_i select the different events and time periods denoted in the first column. The remaining columns denote the group of stocks within each of the rooms which are used in the analysis, either 'All' stocks, or 'Small' stocks, selected as those having a market capitalization in the bottom tercile across all Room 3 stocks sorted on 4/14/80. $R_{MatchRoom1,t}$ ($R_{MatchRoom3,t}$) is computed as the equal-weighted average return across all matched stocks in Room 1 (Room 3) on day t. Newey-West t-statistics are robust to heteroskedasticity and autocorrelation.

		Equal-Weighted		**Value-Weighted**	
		Stock Sample		**Stock Sample**	
Time Period	**Coefficient**	**All**	**Small**	**All**	**Small**
Before Upgrades (1/1/79 to 6/12/80)	a_1	-0.004	-0.006	0.021	-0.016
		-0.260	*-0.170*	*1.010*	*-0.490*
Phase I, Room 1 (-19,0) (6/13/80 to 7/11/80)	a_2	0.009	-0.095	0.037	-0.105
		0.160	*-1.080*	*0.590*	*-0.840*
Phase I, Room 1 (+1,+20) (7/14/80 to 8/8/80)	a_3	-0.128	-0.131	-0.122	-0.279
		-1.610	*-0.820*	*-1.490*	*-1.570*
(8/11/80 to 10/9/80)	a_4	-0.030	-0.059	0.030	-0.033
		-0.680	*-0.830*	*0.570*	*-0.380*
Phase II, Room 3 (-19,0) (10/10/80 to 11/7/80)	a_5	0.010	0.053	0.048	-0.044
		0.240	*0.630*	*0.510*	*-0.550*
Phase II, Room 3 (+1,+20) (11/10/80 to 12/7/80)	a_6	**-0.202**	**-0.222**	**-0.128**	**-0.303**
		-3.070	*-1.840*	*-1.730*	*-2.530*
(12/8/80 to 12/17/80)	a_7	-0.038	0.007	-0.084	-0.088
		-0.230	*0.030*	*-0.330*	*-0.340*
Retrofit (-19,0) (12/18/80 to 1/16/81)	a_8	0.065	0.033	0.047	-0.007
		0.810	*0.250*	*0.420*	*-0.040*
Retrofit (+1,+20) (1/19/81 to 2/13/81)	a_9	0.100	0.152	0.005	0.085
		1.330	*0.860*	*0.090*	*0.440*
After Upgrades (2/16/81 to 12/31/81)	a_{10}	0.012	-0.042	0.021	-0.028
		0.610	*-1.060*	*0.610*	*-0.570*
R^2		0.019	0.007	0.007	0.009
Observations		759	759	759	759

Table VI
Equal Weighted Long-Short Portfolio: Turnover

This table presents results from estimating:

$$(Turn_{Room1,t} - Turn_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + u_t \text{, and } (Turn_{Room1,t} - Turn_{Room3,t}) = \sum_{i=1}^{10} a_i D_i + \beta Turn_{Mkt,t} + u_t .$$

The dummy variables D_i select the different events and time periods denoted in the first column. The remaining columns denote the group of stocks within each of the rooms which are used in the analysis, either 'All' stocks, or the bottom tercile of stocks sorted by market capitalization, 'Small' stocks. $Turn_{Room1,t}$ ($Turn_{Room3,t}$) is computed as the equal-weighted average of turnover (share volume divided by shares outstanding per stock-day) across all stocks in Room 1 (Room 3) on day t. $Turn_{Mkt,t}$ is computed by equally-weighting turnover across all stocks in the NYSE universe on day t. Newey-West t-statistics are robust to heteroskedasticity and autocorrelation.

		Stock Sample			
Time Period	**Coefficient**	**All**	**All**	**Small**	**Small**
Before Upgrades (1/1/79 to 6/12/80)	$\mathbf{a_1}$	**0.010**	**0.014**	**-0.011**	0.006
		5.430	*2.900*	*-3.030*	*0.560*
Phase I, Room 1 (-19,0) (6/13/80 to 7/11/80)	$\mathbf{a_2}$	0.006	0.010	-0.007	0.010
		1.070	*1.450*	*-0.990*	*0.830*
Phase I, Room 1 (+1,+20) (7/14/80 to 8/8/80)	$\mathbf{a_3}$	0.000	0.006	-0.006	0.016
		0.010	*0.780*	*-0.540*	*0.940*
(8/11/80 to 10/9/80)	$\mathbf{a_4}$	0.003	0.009	**-0.043**	-0.021
		0.760	*1.160*	*-5.210*	*-1.410*
Phase II, Room 3 (-19,0) (10/10/80 to 11/7/80)	$\mathbf{a_5}$	0.005	0.010	-0.014	0.005
		1.220	*1.470*	*-0.860*	*0.270*
Phase II, Room 3 (+1,+20) (11/10/80 to 12/7/80)	$\mathbf{a_6}$	**-0.023**	**-0.017**	**-0.068**	**-0.046**
		-3.350	*-1.970*	*-3.430*	*-2.010*
(12/8/80 to 12/17/80)	$\mathbf{a_7}$	-0.002	0.003	-0.014	0.006
		-0.160	*0.240*	*-0.860*	*0.290*
Retrofit (-19,0) (12/18/80 to 1/16/81)	$\mathbf{a_8}$	-0.002	0.003	-0.008	0.012
		-0.250	*0.280*	*-0.620*	*0.730*
Retrofit (+1,+20) (1/19/81 to 2/13/81)	$\mathbf{a_9}$	-0.005	0.000	**0.029**	**0.045**
		-1.130	*-0.070*	*2.330*	*2.930*
After Upgrades (2/16/81 to 12/31/81)	$\mathbf{a_{10}}$	**0.007**	**0.012**	0.005	**0.023**
		2.680	*2.220*	*1.030*	*2.110*
	Mkt Turn		**-10.372**		-2.199
			-2.970		*-0.270*
$\mathbf{R^2}$		0.045	0.046	0.075	0.079
Observations		759	759	759	759

Table VII
Equal Weighted Matched Portfolio: Turnover

This table presents results from estimating:

$$(Turn_{MatchRoom1,t} - Turn_{MatchRoom3,t}) = \sum_{i=1}^{10} a_i D_i + u_t .$$

Each stock in Room 1 is matched with a stock in Room 3. The dummy variables D_i select the different events and time periods denoted in the first column. The remaining columns denote the group of stocks within each of the rooms which are used in the analysis, either 'All' stocks, or 'Small' stocks, selected as those having a market capitalization in the bottom tercile across all Room 3 stocks sorted on 4/14/80. $Turn_{MatchRoom1,t}$ ($Turn_{MatchRoom3,t}$) is computed as the equal-weighted average of turnover (share volume divided by shares outstanding per stock-day) across all matched stocks in Room 1 (Room 3) on day t. Newey-West t-statistics are robust to heteroskedasticity and autocorrelation.

		Stock Sample	
Time Period	**Coefficient**	**All**	**Small**
Before Upgrades (1/1/79 to 6/12/80)	a_1	-0.004	-0.002
		-1.620	*-0.340*
Phase I, Room 1 (-19,0) (6/13/80 to 7/11/80)	a_2	0.001	-0.008
		0.230	*-0.680*
Phase I, Room 1 (+1,+20) (7/14/80 to 8/8/80)	a_3	**-0.023**	**-0.035**
		-3.120	*-2.720*
(8/11/80 to 10/9/80)	a_4	**-0.039**	**-0.060**
		-8.430	*-5.280*
Phase II, Room 3 (-19,0) (10/10/80 to 11/7/80)	a_5	0.001	0.021
		0.200	*1.590*
Phase II, Room 3 (+1,+20) (11/10/80 to 12/7/80)	a_6	**-0.052**	**-0.086**
		-4.940	*-3.360*
(12/8/80 to 12/17/80)	a_7	-0.025	-0.012
		-1.480	*-0.620*
Retrofit (-19,0) (12/18/80 to 1/16/81)	a_8	**-0.015**	0.016
		-1.820	*1.390*
Retrofit (+1,+20) (1/19/81 to 2/13/81)	a_9	-0.006	**0.067**
		-1.040	*4.390*
After Upgrades (2/16/81 to 12/31/81)	a_{10}	**-0.013**	0.002
		-3.260	*0.320*
R^2		0.095	0.084
Observations		759	759

Table VIII
The Roll Spread and Amihud ILLIQ Before and After the Upgrades

The Roll spread and the Amihud ILLIQ measures are calculated for each stock separately over two periods: before the implementation of upgrades (1/1/80 to 6/30/80) and after the implementation of the upgrades (7/1/81 to 12/31/81). The measures are only calculated for stocks for which return data is available for all days in these two periods.
The Roll measure for a stock *i* in the before and after periods is computed as:

$$Roll_i = \sqrt{-2\,\mathrm{cov}(R_{it}, R_{it-1})},$$

where daily returns are taken from CRSP. We then average the stock-specific Roll measures (where defined) across all stocks in each size tercile each of the before and after time periods, resulting in the aggregate measures reported in the table.
The Amihud measure for a stock *i* on a day *t* is calculated as:

$$Amihud_{it} = \min\left(10, 10^6 * \frac{abs(R_{it})}{abs(P_{it}) * V_{it}}\right)$$

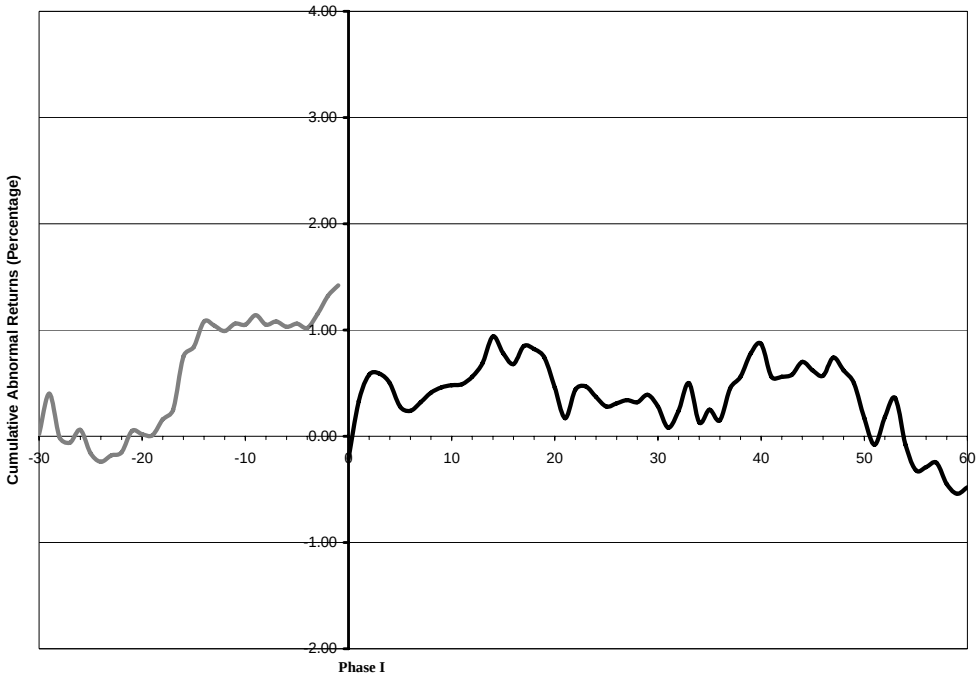
On days with zero volume, the measure is set to 10. We then average the stock-day specific Amihud measures across all stocks in each size tercile in each of the before and after time periods, resulting in the aggregate measures reported in the table. Newey-West t-statistics are robust to heteroskedasticity and autocorrelation. Columns labeled 'Crit. Val. Diff.' report the t-statistic of a test of equality of the measures across the before and after periods.

	Roll Spread (%)			**Amihud ILLIQ**		
Tercile	**Before**	**After**	**Crit. Val. Diff.**	**Before** 1/1/80 to 6/30/80	**After** 7/1/81 to 12/31/81	**Crit. Val. Diff.**
Small	**1.516**	**1.258**	3.33	**1.103**	**0.962**	3.66
	29.287	*22.268*		*32.711*	*49.278*	
Medium	0.981	0.921	1.12	**0.240**	**0.219**	2.59
	25.449	*20.543*		*38.638*	*49.360*	
Large	**0.769**	**0.658**	2.32	0.031	0.031	0.19
	21.858	*21.418*		*34.935*	*35.161*	
All	**1.172**	**1.003**	3.89	**0.456**	**0.399**	3.75
	38.763	*32.483*		*34.259*	*54.175*	

Figure 1
Event Study

Panel A (Panel B) of this figure plots the cumulative equal-weighted abnormal return from a market model across all stocks undergoing Phase I (Phases II, III or IV). The vertical bar shows the implementation date of the phase (stocks are lined up in event time) highlighted in the legend beneath each graph. The grey (black) line cumulates the return in the window prior to (following) the implementation of the upgrade.

Panel A: Phase I



Panel B: Phases II, III and IV

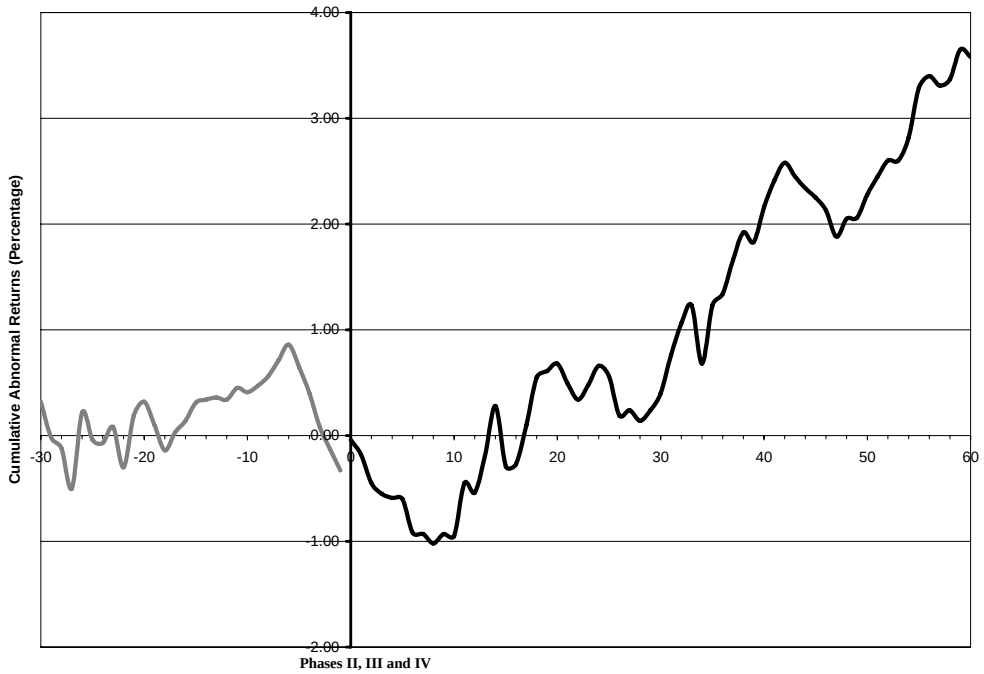
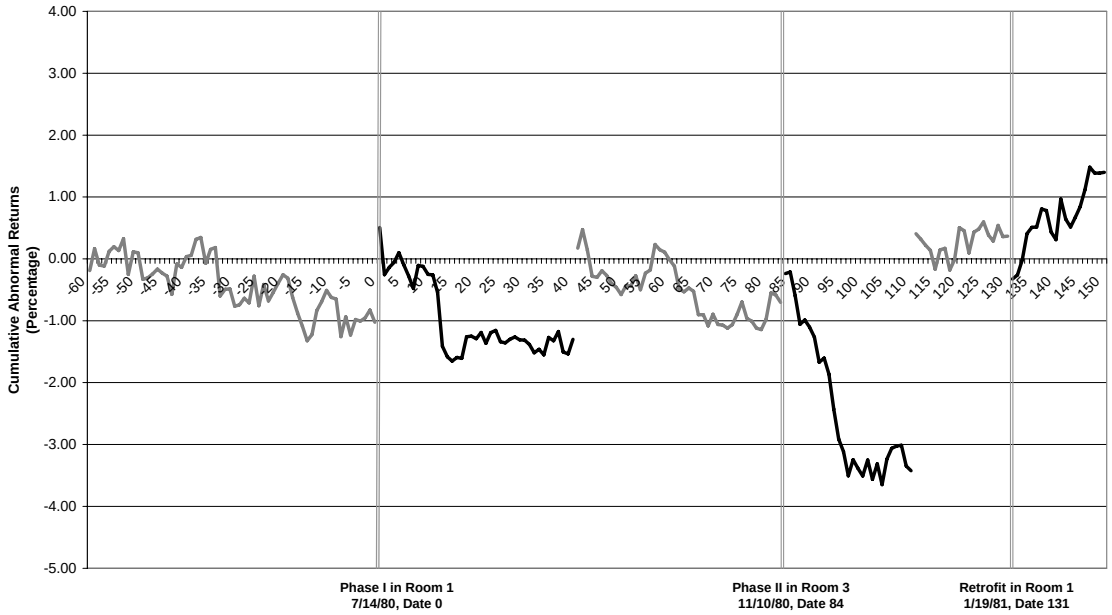


Figure 2
Cumulative Abnormal Returns: Equal-Weighted Long-Short Portfolio

Panel A (Panel B) of this figure plots the cumulative difference in abnormal equal-weighted returns across all (small) stocks between Room 1 and Room 3. The vertical bars show the implementation dates of various phases highlighted in the legend beneath each graph. The grey (black) line cumulates the return in the window prior to (following) each implementation date.

Panel A: All Stocks



Panel B: Small Stocks

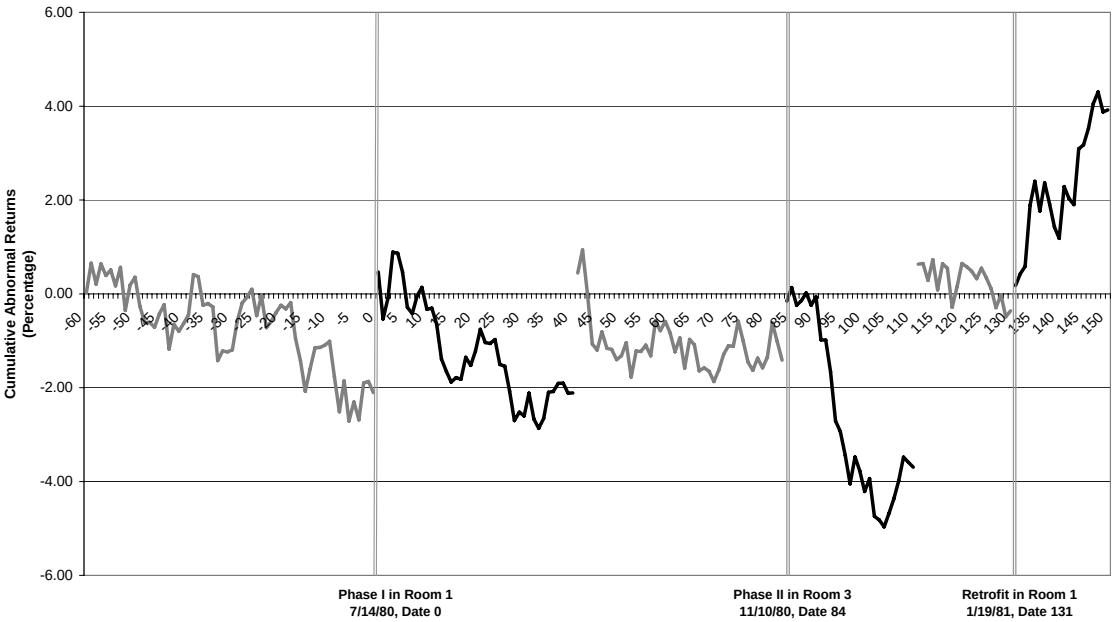
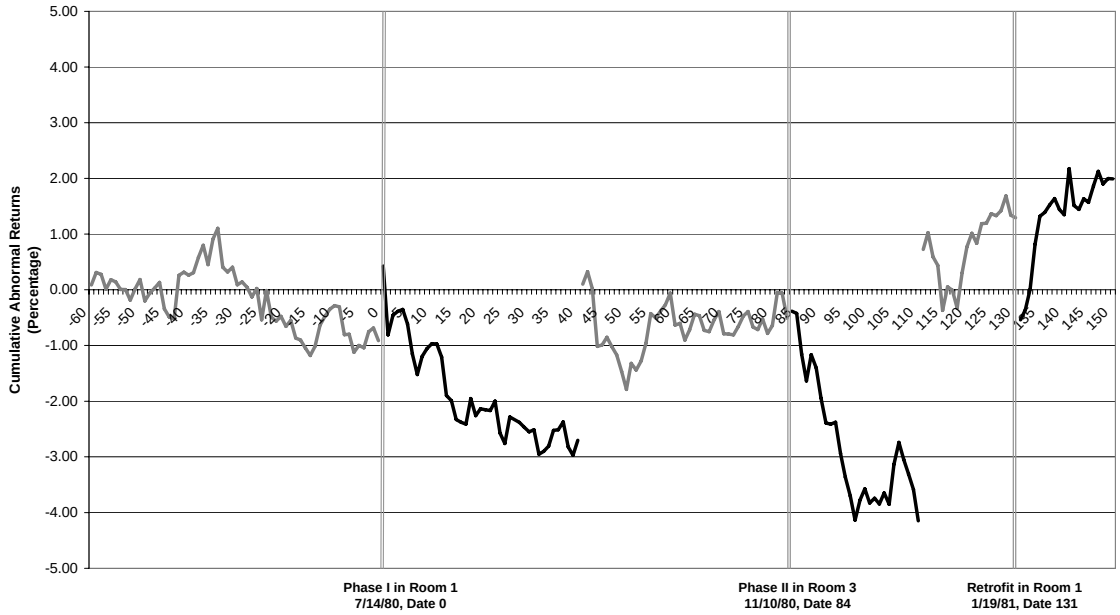


Figure 3
Cumulative Abnormal Returns: Equal-Weighted Matched Portfolio

Panel A (B) of this figure plots the cumulative difference in equal-weighted returns across matched pairs of all (small) stocks between Room 1 and Room 3. The vertical bars show the implementation dates of various phases highlighted in the legend beneath each graph. The grey (black) line cumulates the return in the window prior to (following) each implementation date.

Panel A: All Stocks



Panel B: Small Stocks

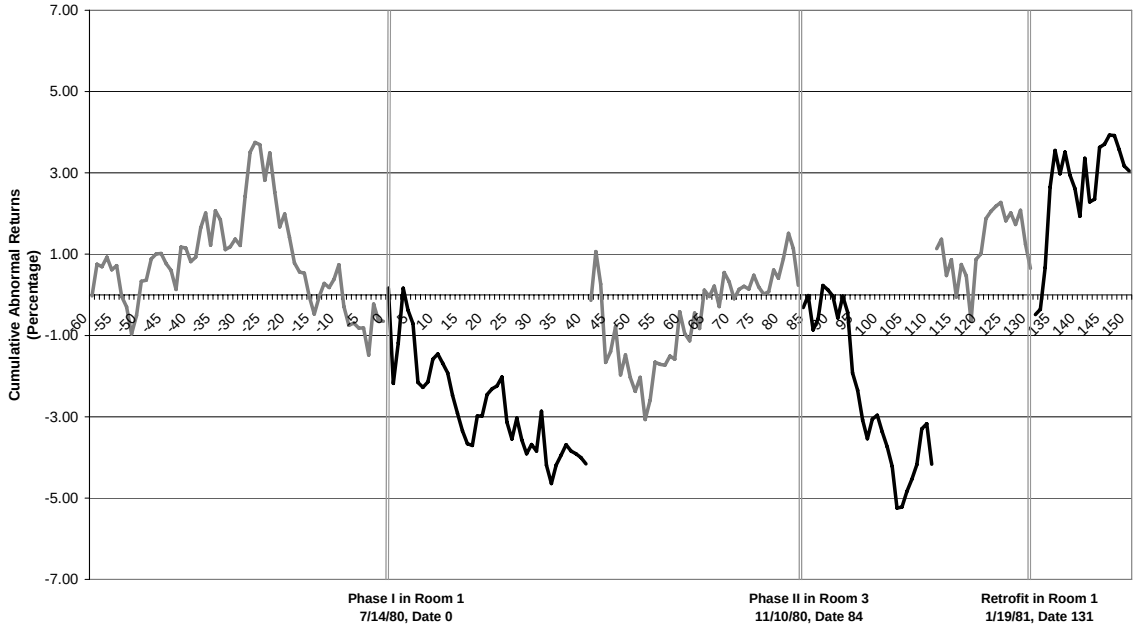
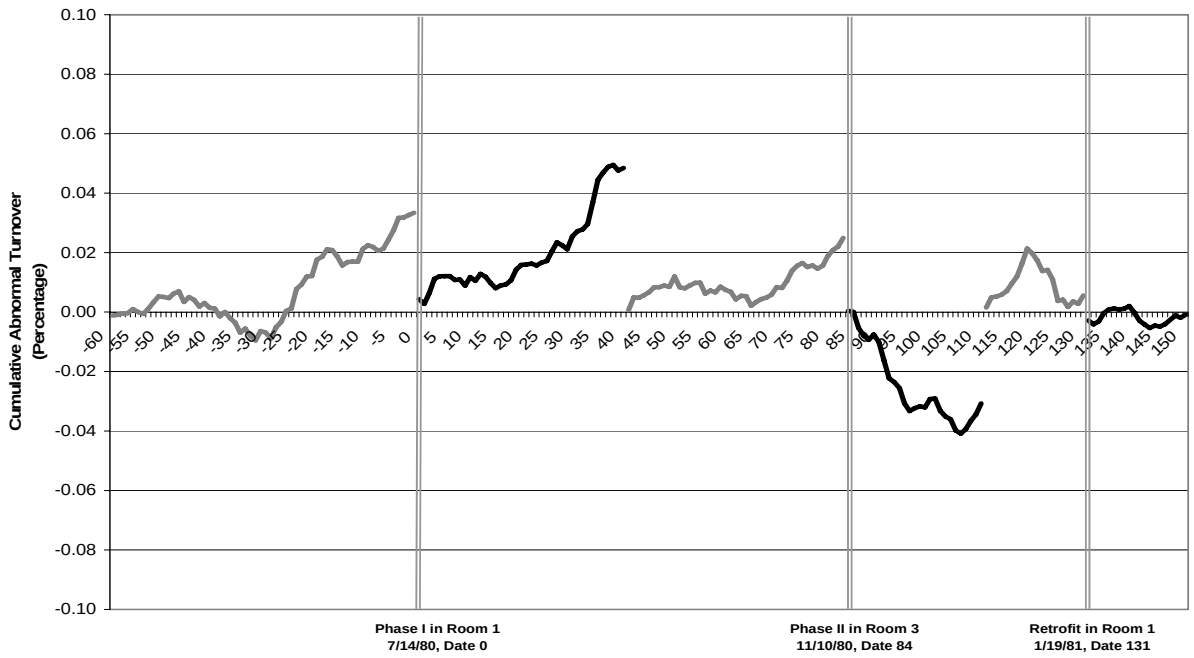


Figure 4
Cumulative Abnormal Turnover: Equal-Weighted Long-Short Portfolio

Panel A (Panel B) of this figure plots the cumulative difference in market adjusted equal-weighted turnover across all (small) stocks between Room 1 and Room 3. The vertical bars show the implementation dates of various phases highlighted in the legend beneath each graph. The grey (black) line cumulates the return in the window prior to (following) each implementation date.

Panel A: All Stocks



Panel B: Small Stocks