

# Intraday Patterns in the Cross-Section of Stock Returns

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# Motivation

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- Persistence in investment flows
- Optimal trading
  - Algorithmic trading
- Periodicity in volume and order imbalances

# Almgren & Chriss (2001)

18 R. Almgren and N. Chriss

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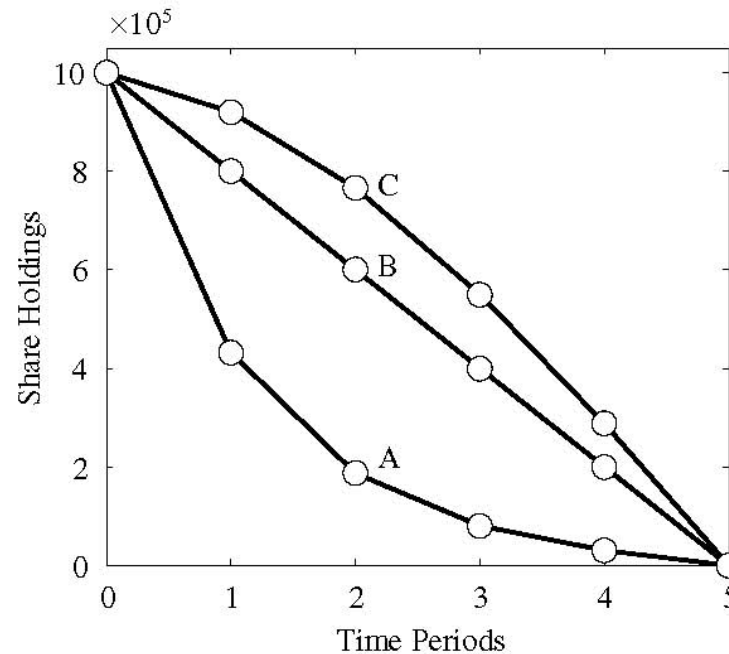


FIGURE 2. Optimal trajectories. The trajectories corresponding to the points shown in Figure 1. A:  $\lambda = 2 \times 10^{-6}$ , B:  $\lambda = 0$ , C:  $\lambda = -2 \times 10^{-7}$ .

# Huberman & Stanzl (2005)

OPTIMAL LIQUIDITY TRADING

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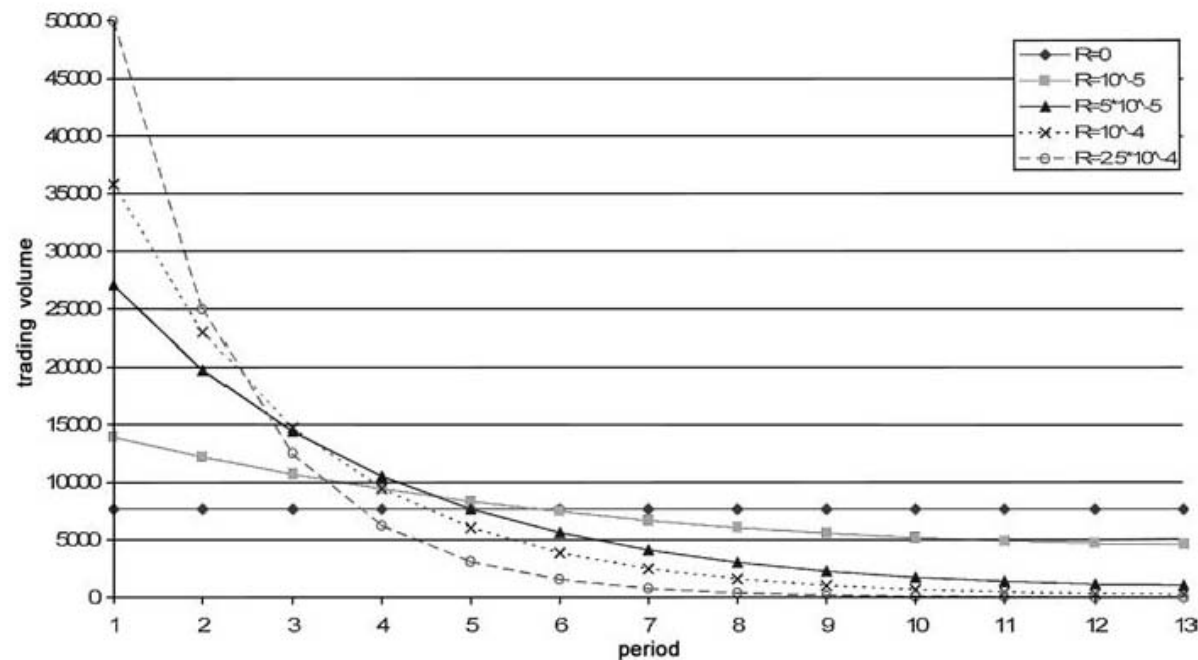
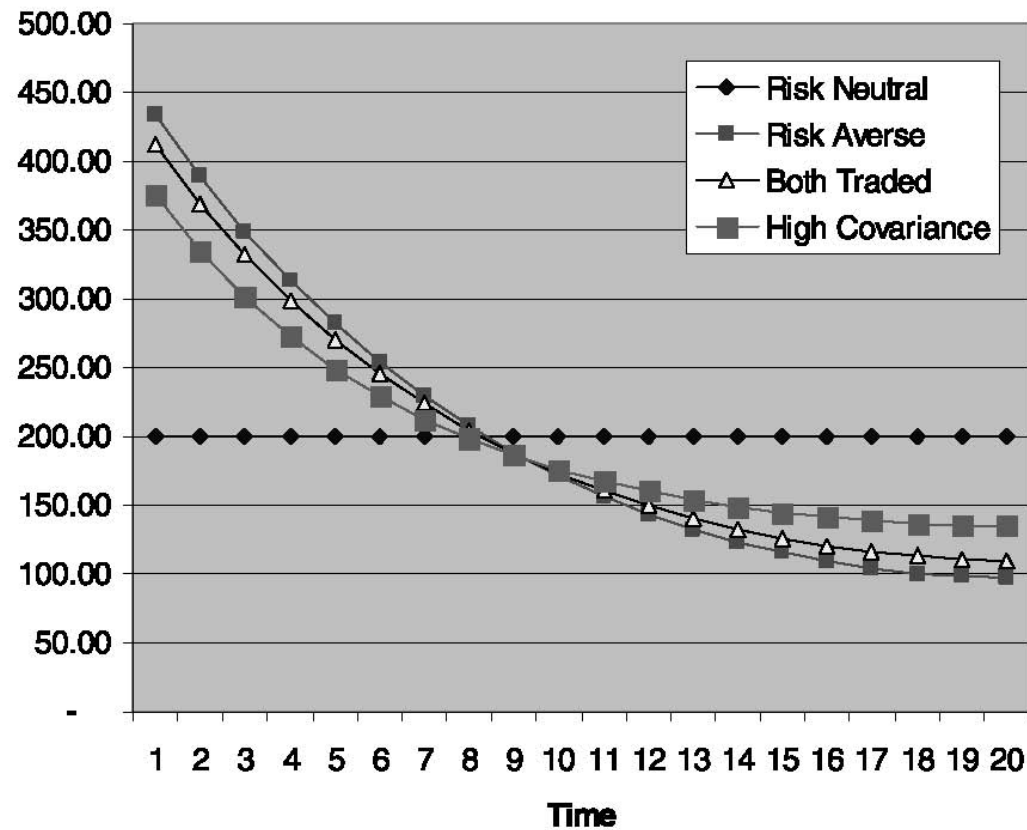


Figure 1a. Optimal trading volume and risk aversion.  $N = 13$ ,  $p_0 = 20$ ,  $Q = 10^5$ ,  $\alpha = 0$ ,  $\lambda = 10^{-5}$ ,  $\sigma_\varepsilon^2 = 0.02$ , and  $\sigma_\eta^2 = 1000$ .

# Engle & Ferstenberg (2007)

## EXHIBIT 2

Optimal Execution with Second Asset



WINTER 2007

# Hora (2006)

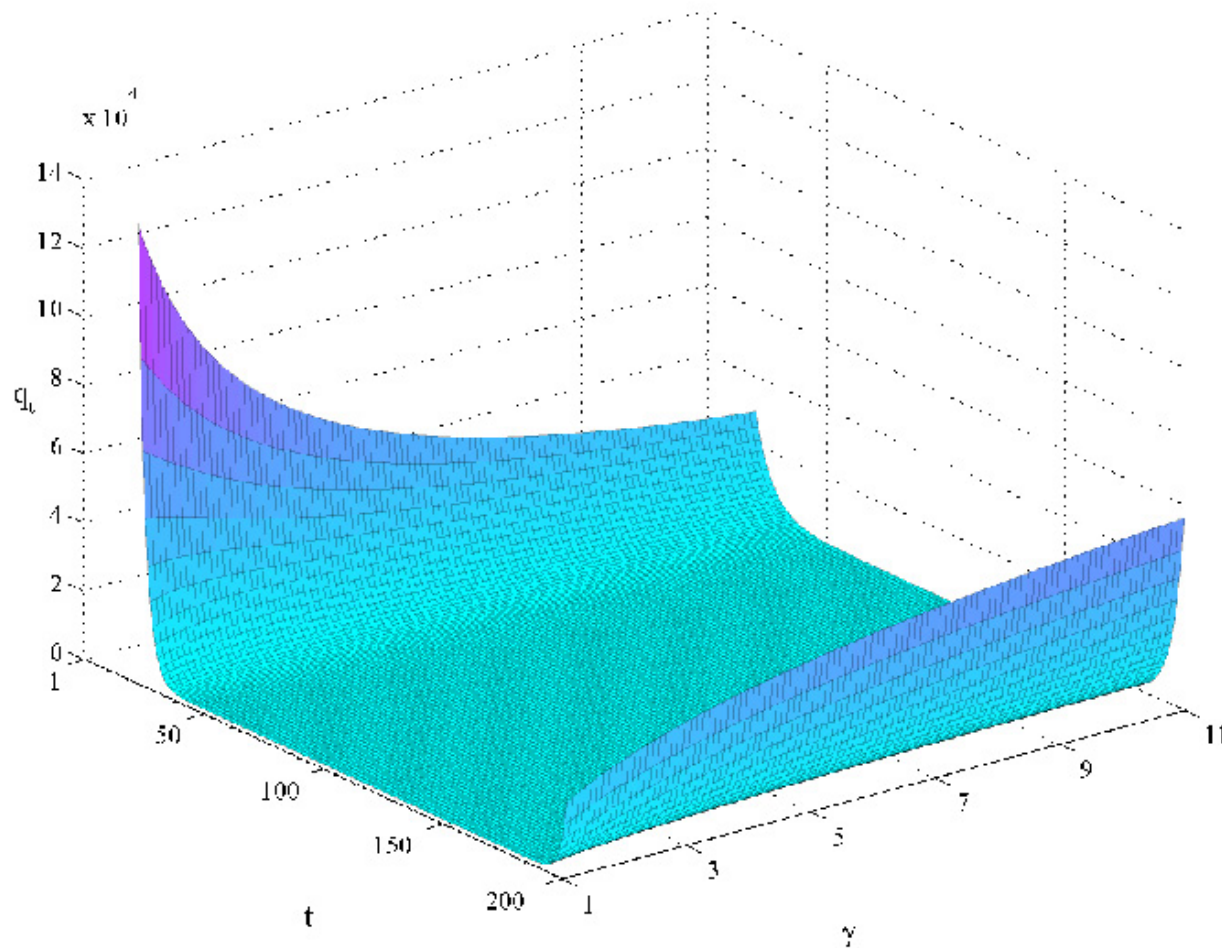


Figure 1: The expected optimal policy as the impact parameter  $\gamma$  increases from  $1.0e-6$  to  $11e-6$ , holding  $\alpha = 0.5$  and  $\lambda = 2$ .

# This Study

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- If the patterns are fully anticipated, then they should not lead to periodicity in stock returns
- We study periodicity in stock returns using half-hour intervals
- Findings:
  - Negative autocorrelation over recent trading intervals
  - But positive autocorrelation at the daily frequency that lasts at least 40 days

# Data and Analysis

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- NYSE TAQ database
  - 2001-2005
    - Decimalization completed February 2001
  - Use transaction prices to compute half-hour returns from 9:30am – 4:00pm
    - 13 returns per trading day
    - We omit overnight returns
  - We also use bid, ask, volume, volatility, order imbalance, trade size



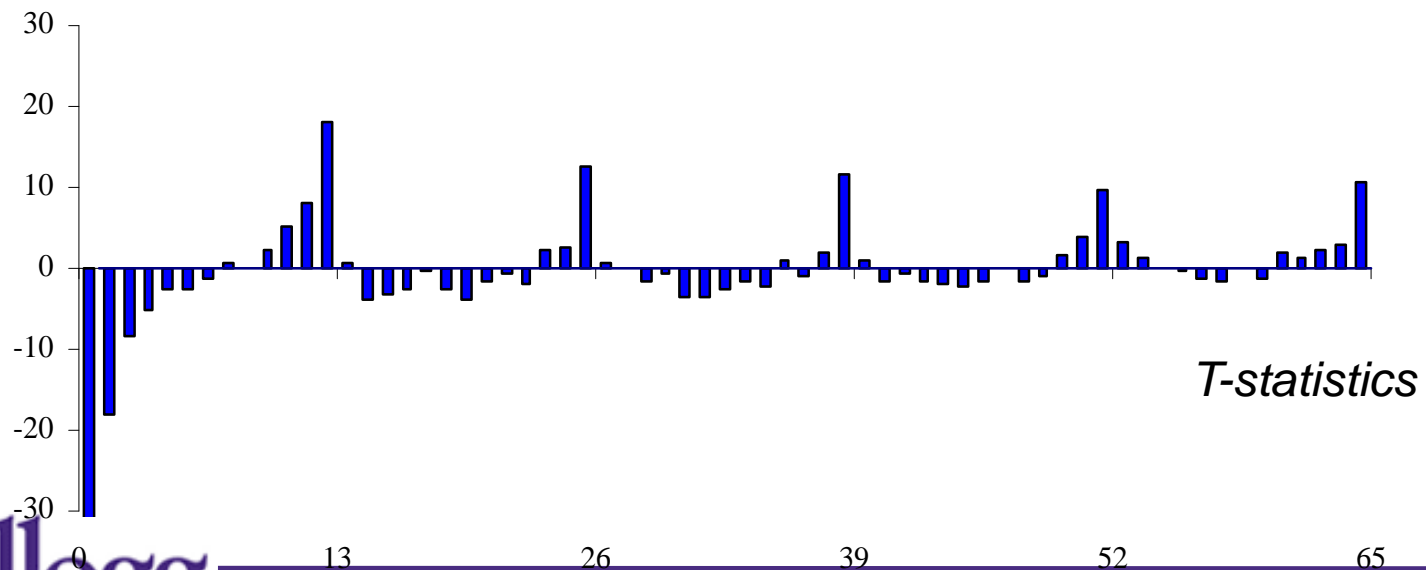
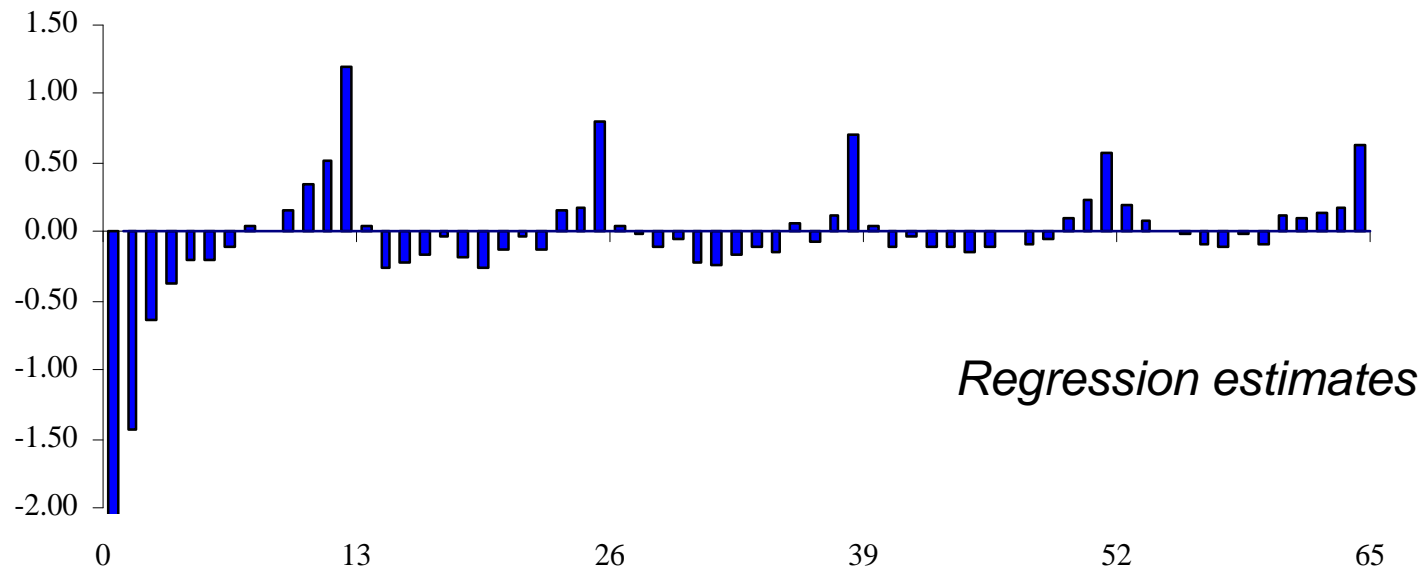
# Methodology

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- Cross-sectional regressions
  - $r_{i,t} = \alpha_{t,k} + \gamma_{t,k}r_{i,t-k} + e_{i,t}$
  - The return responses  $\gamma_{t,k}$  are excess returns
- We also use multiple regression and portfolio sorts

# Cross-Sectional Regressions

## Main Results



# Cross-Sectional Regressions

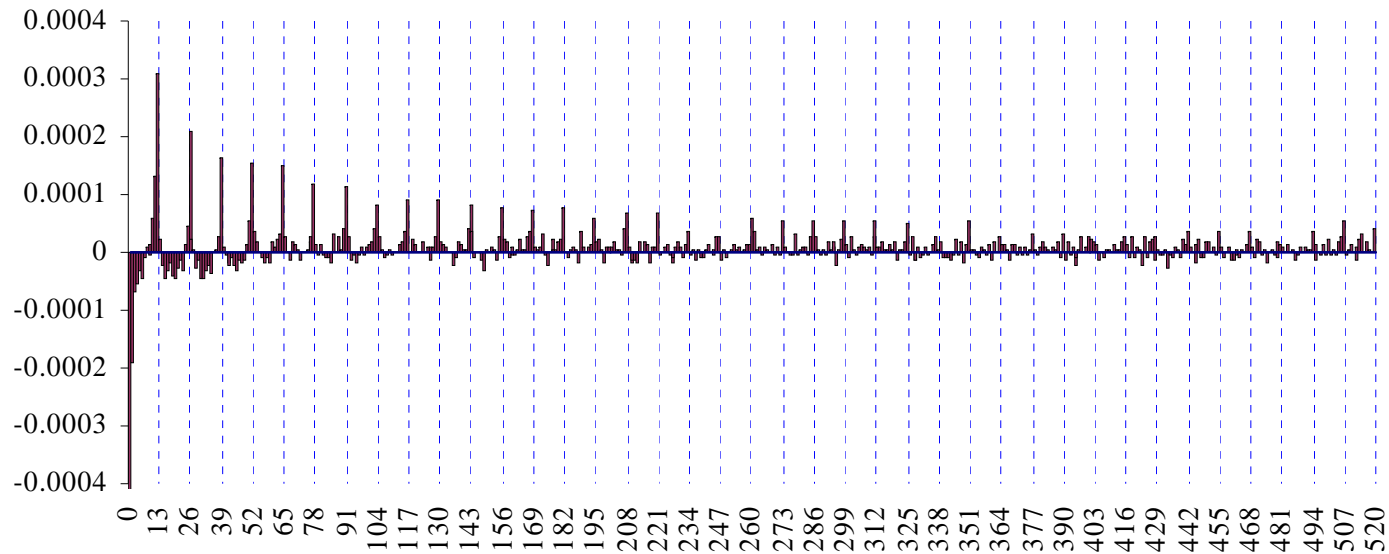
## Main Results

Lag	Estimate	<i>t</i> -statistic	Lag	Estimate	<i>t</i> -statistic	Lag	Estimate	<i>t</i> -statistic	Lag	Estimate	<i>t</i> -statistic	Lag	Estimate	<i>t</i> -statistic
1	-5.35	-59.22	14	0.04	0.60	27	0.05	0.74	40	0.05	0.87	53	0.19	3.13
2	-1.44	-17.96	15	-0.26	-3.97	28	-0.01	-0.11	41	-0.10	-1.65	54	0.08	1.29
3	-0.65	-8.26	16	-0.21	-3.24	29	-0.11	-1.66	42	-0.04	-0.60	55	0.00	0.01
4	-0.38	-5.02	17	-0.17	-2.49	30	-0.05	-0.81	43	-0.11	-1.65	56	-0.02	-0.31
5	-0.21	-2.73	18	-0.03	-0.42	31	-0.23	-3.51	44	-0.12	-1.83	57	-0.09	-1.36
6	-0.20	-2.58	19	-0.18	-2.68	32	-0.24	-3.63	45	-0.15	-2.30	58	-0.11	-1.65
7	-0.11	-1.44	20	-0.27	-3.92	33	-0.17	-2.57	46	-0.10	-1.58	59	-0.01	-0.08
8	0.05	0.68	21	-0.12	-1.75	34	-0.10	-1.55	47	0.01	0.10	60	-0.08	-1.31
9	0.00	-0.01	22	-0.03	-0.51	35	-0.15	-2.29	48	-0.10	-1.50	61	0.12	1.91
10	0.16	2.31	23	-0.13	-2.02	36	0.07	1.03	49	-0.05	-0.86	62	0.09	1.40
11	0.34	5.05	24	0.15	2.41	37	-0.07	-1.07	50	0.09	1.52	63	0.14	2.30
12	0.52	8.10	25	0.17	2.62	38	0.13	2.04	51	0.24	3.96	64	0.18	3.00
13	1.19	18.22	26	0.79	12.45	39	0.70	11.54	52	0.58	9.62	65	0.63	10.57

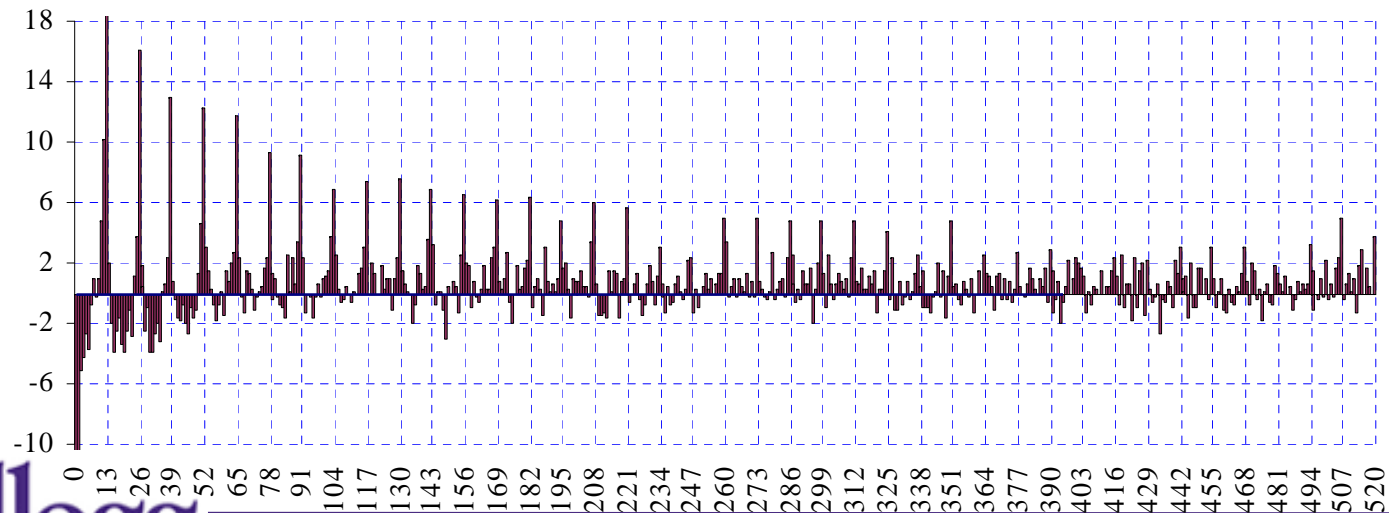
- Continuation at the daily (13 lag) frequency
- Multiple regressions yield similar results

# Decile Portfolio Spreads

*Average portfolio returns*



*T-statistics*



# Long-Run Performance

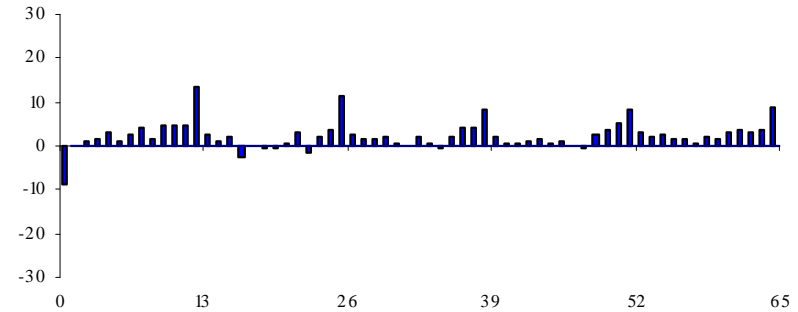
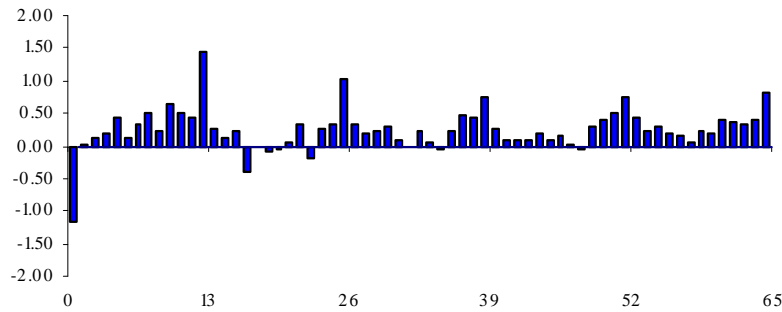
Strategy (lag)	1 (losers)		10 (winners)		10-1	
	Return	<i>t</i> -statistic	Return	<i>t</i> -statistic	Return	<i>t</i> -statistic
13	-1.39	-6.34	1.71	8.18	3.11	22.81
26	-0.98	-4.54	1.13	5.44	2.11	16.10
39	-0.82	-3.83	0.83	3.99	1.65	12.88
52	-0.74	-3.47	0.81	3.87	1.55	12.24
65	-0.66	-3.10	0.83	4.01	1.49	11.77
78	-0.53	-2.51	0.63	3.05	1.16	9.34
91	-0.52	-2.46	0.60	2.89	1.12	9.12
104	-0.32	-1.50	0.51	2.50	0.83	6.81
117	-0.33	-1.54	0.59	2.85	0.91	7.42
130	-0.45	-2.13	0.48	2.33	0.93	7.58
143	-0.35	-1.65	0.49	2.40	0.84	6.95
156	-0.30	-1.44	0.47	2.29	0.77	6.46
169	-0.35	-1.66	0.40	1.95	0.75	6.18
182	-0.31	-1.46	0.47	2.31	0.77	6.38
195	-0.14	-0.68	0.43	2.12	0.58	4.76
208	-0.24	-1.17	0.45	2.23	0.70	5.93
221	-0.26	-1.26	0.40	1.95	0.66	5.60
234	-0.08	-0.41	0.27	1.34	0.36	3.03
247	-0.06	-0.27	0.22	1.08	0.28	2.34
260	-0.30	-1.43	0.29	1.43	0.59	4.99

# Strategies Based on Past Performance

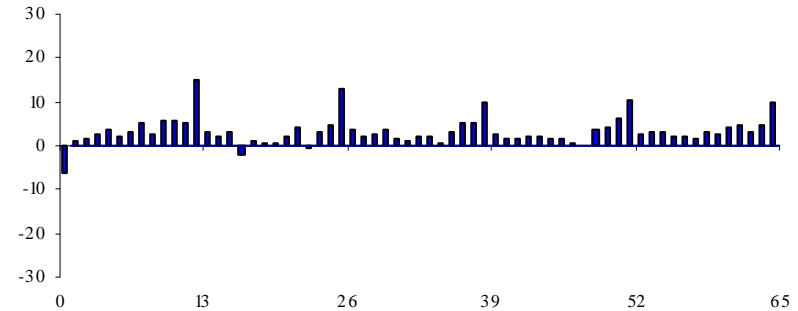
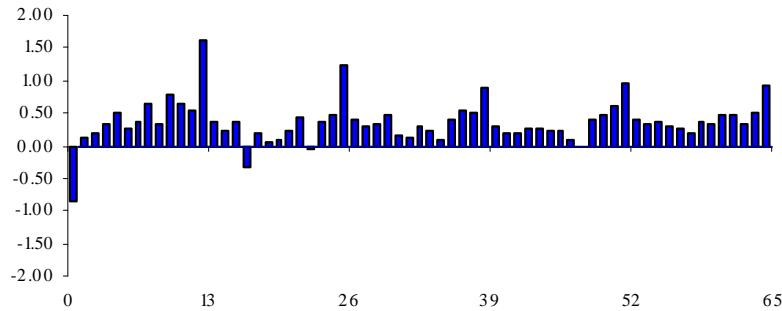
Strategy	1 (losers)	2	3	4	5	6	7	8	9	10 (winners)	10-1
Day 1											
Nondaily	3.16 [13.64]	0.67 [3.68]	0.27 [1.62]	0.09 [0.57]	-0.02 [-0.13]	-0.17 [-1.09]	-0.15 [-0.98]	-0.24 [-1.48]	-0.59 [-3.40]	-1.51 [-7.16]	-4.67 [-28.16]
Daily	-1.35 [-6.18]	-0.64 [-3.51]	-0.35 [-2.05]	-0.07 [-0.42]	0.06 [0.39]	0.16 [1.03]	0.44 [2.76]	0.63 [3.83]	0.92 [5.22]	1.66 [7.93]	3.01 [22.15]
Day 2											
Nondaily	0.61 [2.78]	0.37 [2.06]	0.22 [1.30]	0.23 [1.42]	0.13 [0.81]	0.18 [1.13]	0.12 [0.77]	0.02 [0.11]	-0.10 [-0.58]	-0.31 [-1.55]	-0.92 [-6.57]
Daily	-0.90 [-4.18]	-0.42 [-2.34]	-0.20 [-1.15]	-0.06 [-0.37]	0.13 [0.80]	0.22 [1.41]	0.37 [2.32]	0.50 [2.99]	0.75 [4.25]	1.07 [5.15]	1.97 [15.01]
Day 3											
Nondaily	0.41 [1.92]	0.25 [1.41]	0.28 [1.70]	0.17 [1.07]	0.19 [1.22]	0.17 [1.09]	0.08 [0.52]	0.05 [0.29]	0.07 [0.40]	-0.21 [-1.04]	-0.62 [-4.62]
Daily	-0.63 [-2.95]	-0.27 [-1.51]	-0.05 [-0.28]	0.03 [0.18]	0.08 [0.52]	0.23 [1.42]	0.31 [1.90]	0.40 [2.44]	0.54 [3.09]	0.73 [3.53]	1.36 [10.75]
Day 4											
Nondaily	0.21 [0.99]	0.20 [1.13]	0.20 [1.18]	0.26 [1.61]	0.25 [1.62]	0.15 [0.98]	0.18 [1.16]	0.02 [0.10]	0.12 [0.69]	-0.13 [-0.64]	-0.34 [-2.60]
Daily	-0.58 [-2.73]	-0.25 [-1.42]	-0.11 [-0.66]	0.05 [0.32]	0.07 [0.44]	0.19 [1.22]	0.21 [1.28]	0.38 [2.26]	0.50 [2.83]	0.68 [3.27]	1.26 [10.01]
Day 5											
Nondaily	0.08 [0.39]	0.12 [0.66]	0.14 [0.86]	0.20 [1.24]	0.10 [0.62]	0.21 [1.32]	0.27 [1.66]	0.13 [0.80]	0.21 [1.20]	0.02 [0.09]	-0.06 [-0.49]
Daily	-0.43 [-2.05]	-0.17 [-0.94]	0.01 [0.07]	-0.04 [-0.26]	0.06 [0.38]	0.22 [1.39]	0.23 [1.44]	0.23 [1.39]	0.47 [2.66]	0.66 [3.19]	1.09 [8.70]

# Ask, Bid, and Midpoint Returns

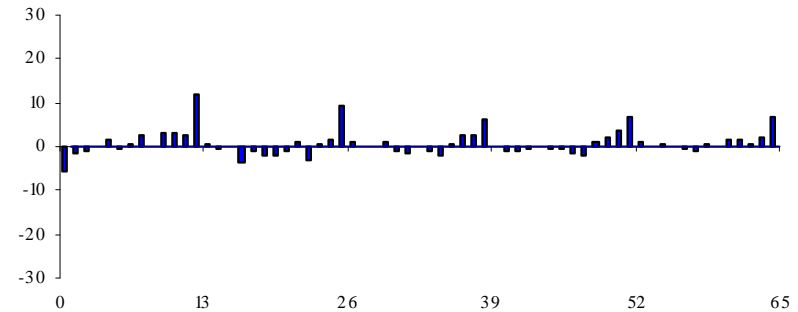
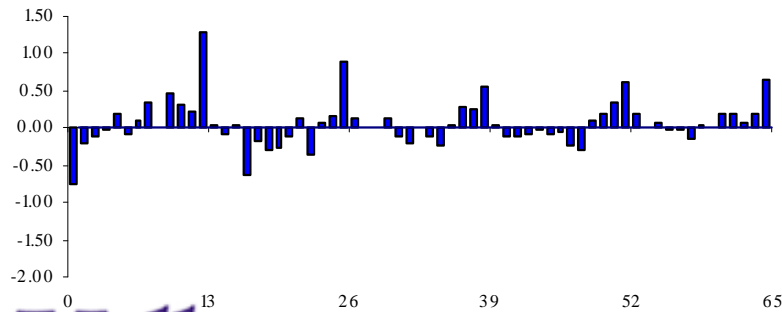
*Ask-to-Ask Returns*



*Bid-to-Bid Returns*



*Midpoint-to-Midpoint Returns*



# Returns during different half-hour intervals of the trading day

Strategy	1 (first) [9:30-10:00]	2 [10:00-10:30]	3 [10:30-11:00]	4 [11:00-11:30]	5 [11:30-12:00]	6 [12:00-12:30]	7 [12:30-13:00]	8 [13:00-13:30]	9 [13:30-14:00]	10 [14:00-14:30]	11 [14:30-15:00]	12 [15:00-15:30]	13 (last) [15:30-16:00]	2-12 [10:00-15:30]
<b>Day 1</b>														
Nondaily	-8.36 [-8.80]	0.62 [0.77]	-1.00 [-1.55]	-2.01 [-3.61]	-1.96 [-3.83]	-2.89 [-5.99]	-4.88 [-10.84]	-2.83 [-6.38]	-3.38 [-7.49]	-8.17 [-16.08]	-5.96 [-12.08]	-8.75 [-17.27]	-11.24 [-18.32]	-3.74 [-22.60]
Daily	11.48 [12.58]	5.02 [7.97]	2.66 [5.01]	1.20 [2.87]	1.38 [3.71]	1.35 [3.92]	1.53 [4.69]	0.76 [2.16]	1.19 [3.72]	0.81 [2.12]	0.89 [2.45]	2.46 [6.48]	8.42 [14.90]	1.75 [14.06]
<b>Day 2</b>														
Nondaily	-2.96 [-3.52]	0.68 [1.04]	0.68 [1.22]	-0.06 [-0.13]	-0.50 [-1.08]	0.05 [0.13]	-0.42 [-1.10]	-0.24 [-0.65]	0.78 [1.99]	-1.94 [-4.88]	-1.75 [-4.30]	-2.58 [-6.03]	-3.79 [-7.25]	-0.48 [-3.44]
Daily	10.48 [12.32]	2.59 [4.22]	1.32 [2.67]	0.51 [1.21]	-0.06 [-0.17]	0.35 [1.08]	0.84 [2.61]	0.06 [0.20]	0.27 [0.80]	0.22 [0.62]	1.35 [3.99]	1.10 [2.91]	6.52 [11.43]	0.78 [6.45]
<b>Day 3</b>														
Nondaily	-4.87 [-6.03]	-0.24 [-0.39]	0.88 [1.59]	-0.07 [-0.15]	0.21 [0.48]	0.04 [0.10]	0.04 [0.09]	0.06 [0.18]	0.19 [0.50]	-1.31 [-3.33]	-1.10 [-2.89]	-0.63 [-1.58]	-1.29 [-2.64]	-0.17 [-1.31]
Daily	6.32 [7.59]	1.55 [2.70]	0.23 [0.46]	0.34 [0.80]	0.40 [1.06]	0.38 [1.14]	0.65 [2.07]	-0.18 [-0.58]	0.57 [1.76]	0.06 [0.17]	1.19 [3.76]	0.56 [1.56]	5.57 [10.46]	0.52 [4.44]
<b>Day 4</b>														
Nondaily	-2.55 [-3.31]	0.31 [0.51]	0.08 [0.15]	-0.89 [-1.94]	0.08 [0.19]	-0.45 [-1.13]	-0.58 [-1.62]	0.34 [0.93]	0.28 [0.74]	0.00 [0.01]	0.27 [0.70]	-0.06 [-0.14]	-1.26 [-2.67]	-0.06 [-0.43]
Daily	5.64 [6.86]	1.52 [2.51]	0.84 [1.67]	0.90 [2.26]	0.25 [0.69]	0.10 [0.31]	0.06 [0.19]	0.04 [0.14]	0.65 [2.06]	0.53 [1.52]	0.95 [2.86]	0.54 [1.56]	4.32 [7.98]	0.58 [4.95]
<b>Day 5</b>														
Nondaily	-0.14 [-0.18]	0.43 [0.72]	-0.43 [-0.77]	-0.81 [-1.76]	-0.28 [-0.66]	-0.22 [-0.57]	0.90 [2.44]	0.89 [2.50]	-0.31 [-0.82]	-0.08 [-0.21]	0.99 [2.66]	-0.49 [-1.24]	-1.29 [-2.83]	0.05 [0.42]
Daily	4.98 [6.13]	1.37 [2.34]	-0.68 [-1.27]	0.89 [2.21]	0.18 [0.46]	0.45 [1.37]	0.34 [1.06]	0.88 [2.75]	0.64 [2.04]	0.62 [1.69]	0.25 [0.72]	0.78 [2.25]	3.50 [6.97]	0.52 [4.35]



# Controlling for Liquidity

Strategy	Stock above 5 dollars (value-weighted returns)	Stocks with at least 10 trades per half hour
Day 1		
Nondaily	-1.77 [-8.07]	-3.17 [-19.44]
Daily	1.93 [10.34]	2.45 [18.44]
Day 2		
Nondaily	-1.28 [-6.45]	-1.21 [-8.65]
Daily	1.25 [7.14]	1.72 [13.38]
Day 3		
Nondaily	-0.75 [-4.01]	-0.56 [-4.26]
Daily	0.99 [5.75]	1.05 [8.54]
Day 4		
Nondaily	-0.48 [-2.57]	-0.20 [-1.58]
Daily	1.06 [6.06]	1.07 [8.74]
Day 5		
Nondaily	0.24 [1.32]	0.09 [0.72]
Daily	0.97 [5.58]	0.94 [7.63]

# Controlling for Market Risk

Strategy	Risk-adjusted returns			
	1-13 (all)	1 (first)	2-12	13 (last)
Day 1				
Nondaily	-4.65 [-28.26]	-8.52 [-8.53]	-3.71 [-22.62]	-10.79 [-16.96]
Daily	3.03 [22.33]	11.64 [12.24]	1.76 [14.17]	8.40 [14.17]
Day 2				
Nondaily	-0.90 [-6.44]	-3.25 [-3.64]	-0.45 [-3.27]	-3.73 [-6.89]
Daily	1.98 [15.14]	10.30 [11.52]	0.79 [6.56]	6.92 [11.53]
Day 3				
Nondaily	-0.61 [-4.57]	-4.82 [-5.69]	-0.17 [-1.26]	-0.85 [-1.66]
Daily	1.38 [10.94]	6.82 [7.80]	0.55 [4.67]	5.96 [10.61]
Day 4				
Nondaily	-0.34 [-2.58]	-3.21 [-3.94]	-0.06 [-0.43]	-0.91 [-1.84]
Daily	1.25 [9.96]	5.96 [6.92]	0.57 [4.86]	4.26 [7.46]
Day 5				
Nondaily	-0.04 [-0.33]	-0.14 [-0.17]	0.07 [0.56]	-0.53 [-1.12]
Daily	1.10 [8.76]	4.84 [5.63]	0.53 [4.42]	3.42 [6.40]

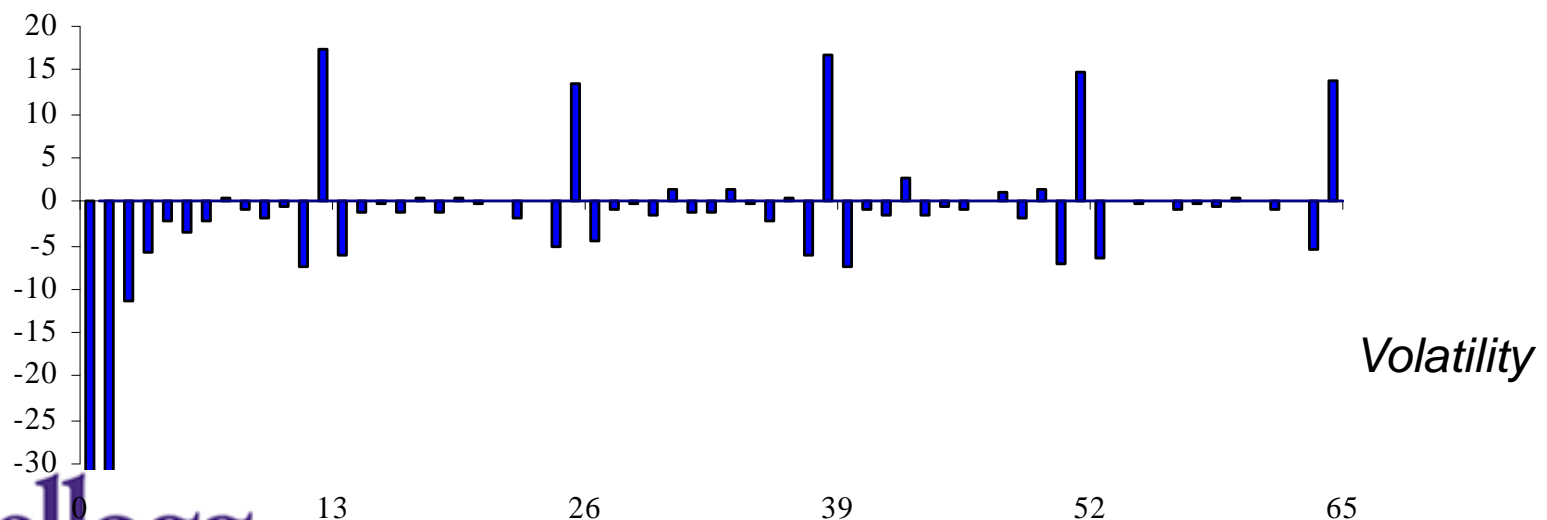
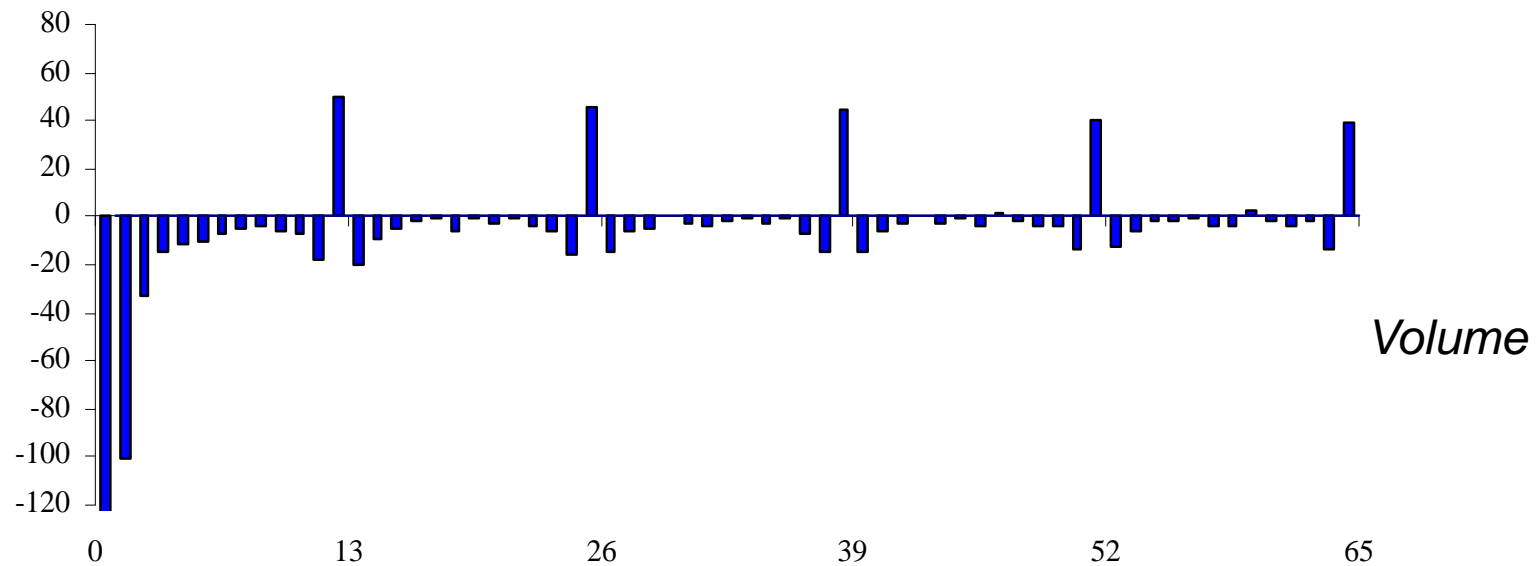
# Controlling for Size

Strategy	Small				Large			
	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)
Day 1								
Nondaily	-9.92 [-30.94]	-10.89 [-6.33]	-8.69 [-26.73]	-22.55 [-18.55]	-1.15 [-6.24]	1.18 [1.03]	-0.94 [-5.08]	-5.88 [-10.77]
Daily	5.16 [16.71]	20.43 [11.90]	3.15 [10.26]	11.98 [9.77]	1.88 [12.43]	6.67 [6.30]	0.86 [5.95]	8.38 [20.58]
Day 2								
Nondaily	-1.04 [-3.64]	-4.55 [-2.95]	-0.20 [-0.70]	-6.82 [-6.12]	-1.28 [-7.78]	-3.70 [-3.37]	-0.91 [-5.66]	-2.91 [-6.19]
Daily	2.87 [9.70]	12.06 [7.52]	1.51 [5.07]	8.70 [7.38]	1.36 [9.55]	7.78 [8.00]	0.29 [2.15]	6.65 [16.80]
Day 3								
Nondaily	-0.89 [-3.15]	-7.69 [-5.03]	0.08 [0.29]	-4.78 [-4.60]	-0.53 [-3.41]	-3.85 [-3.83]	-0.34 [-2.24]	0.80 [1.85]
Daily	2.10 [7.01]	7.26 [4.63]	1.04 [3.41]	8.59 [7.32]	0.88 [6.34]	4.88 [5.15]	0.13 [0.94]	5.14 [14.04]
Day 4								
Nondaily	-0.72 [-2.59]	-4.33 [-3.02]	-0.14 [-0.49]	-3.50 [-3.35]	-0.30 [-1.99]	-0.75 [-0.75]	-0.30 [-2.04]	0.18 [0.42]
Daily	1.67 [5.59]	7.03 [4.20]	0.75 [2.51]	6.41 [5.49]	0.94 [6.60]	5.05 [5.12]	0.28 [2.02]	4.07 [11.22]
Day 5								
Nondaily	-0.19 [-0.70]	0.35 [0.24]	-0.08 [-0.28]	-2.00 [-1.93]	0.20 [1.33]	1.52 [1.58]	0.12 [0.80]	-0.25 [-0.58]
Daily	1.86 [6.24]	6.46 [3.76]	1.13 [3.79]	5.27 [4.70]	0.80 [5.66]	4.06 [4.22]	0.24 [1.79]	3.61 [10.10]

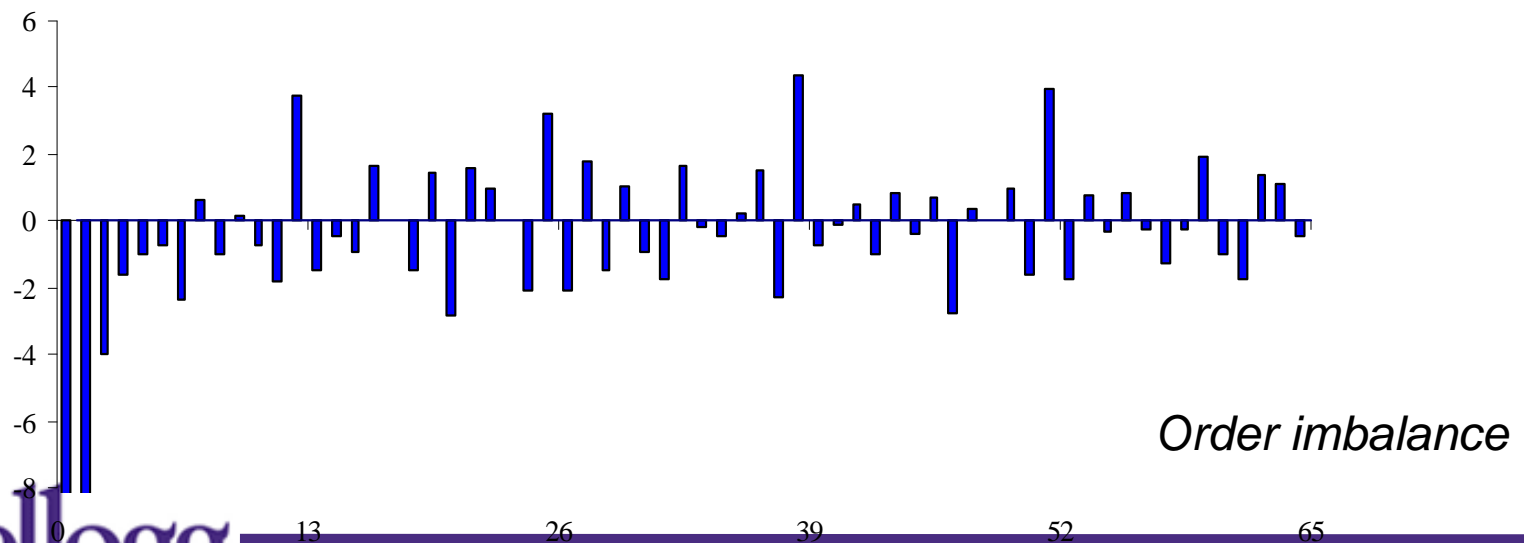
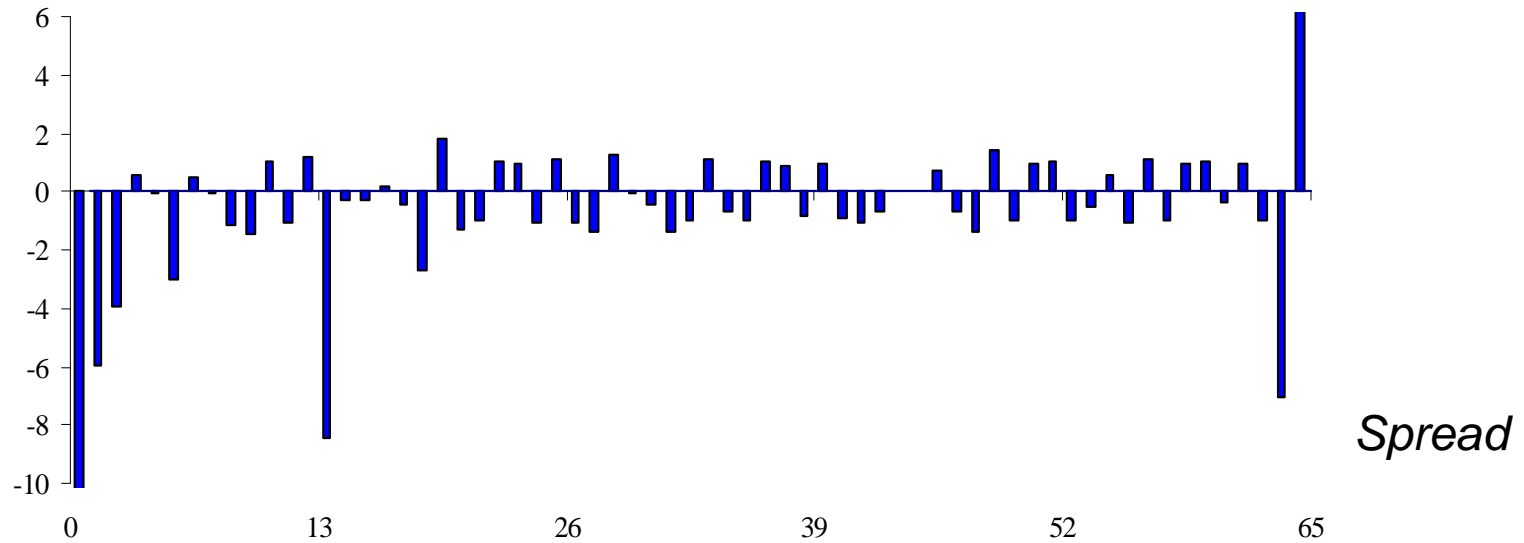
# Controlling for Bid-Ask Spreads

Strategy	Small				Large			
	1-13 (all)	1 (first)	2-12	13 (last)	1-13 (all)	1 (first)	2-12	13 (last)
Day 1								
Nondaily	-25.03 [-27.51]	30.56 [0.90]	-24.91 [-26.05]	-27.41 [-9.54]	-14.77 [-44.97]	-27.92 [-7.92]	-14.24 [-53.48]	-9.74 [-13.03]
Daily	-23.78 [-28.37]	-28.26 [-0.72]	-23.68 [-27.43]	-24.41 [-8.75]	-13.25 [-46.50]	-13.43 [-4.24]	-13.91 [-61.05]	-5.84 [-8.96]
Day 2								
Nondaily	-25.17 [-30.97]	9.90 [0.22]	-24.84 [-29.47]	-29.03 [-10.83]	-12.98 [-33.13]	-6.42 [-1.22]	-13.62 [-56.95]	-11.21 [-16.66]
Daily	-24.49 [-29.41]	-84.59 [-2.89]	-24.31 [-28.20]	-23.41 [-8.37]	-13.46 [-49.00]	-11.02 [-3.61]	-14.07 [-63.68]	-8.79 [-14.60]
Day 3								
Nondaily	-25.26 [-32.59]	-59.52 [-2.51]	-24.99 [-30.75]	-26.72 [-10.54]	-14.40 [-50.33]	-13.72 [-4.44]	-14.33 [-60.54]	-15.72 [-24.69]
Daily	-24.29 [-30.68]	-35.03 [-1.03]	-24.61 [-30.07]	-21.30 [-7.62]	-13.77 [-52.27]	-8.75 [-3.15]	-14.48 [-65.83]	-10.02 [-17.25]
Day 4								
Nondaily	-25.23 [-31.85]	5.24 [0.22]	-25.06 [-30.15]	-28.06 [-11.15]	-14.65 [-54.40]	-15.63 [-5.33]	-14.53 [-65.76]	-15.27 [-23.97]
Daily	-23.77 [-28.87]	-15.34 [-0.46]	-23.44 [-27.75]	-26.96 [-9.26]	-14.13 [-53.48]	-13.56 [-4.85]	-14.50 [-65.71]	-10.52 [-18.27]
Day 5								
Nondaily	-25.31 [-33.95]	-28.62 [-1.40]	-24.94 [-31.87]	-28.27 [-12.15]	-14.92 [-55.45]	-18.84 [-6.65]	-14.72 [-64.02]	-14.09 [-21.71]
Daily	-25.92 [-32.58]	-21.21 [-0.64]	-25.63 [-30.95]	-28.77 [-10.51]	-13.66 [-35.73]	-8.08 [-1.58]	-14.28 [-61.98]	-11.40 [-18.29]

# Cross-Sectional Regressions of Volume and Volatility

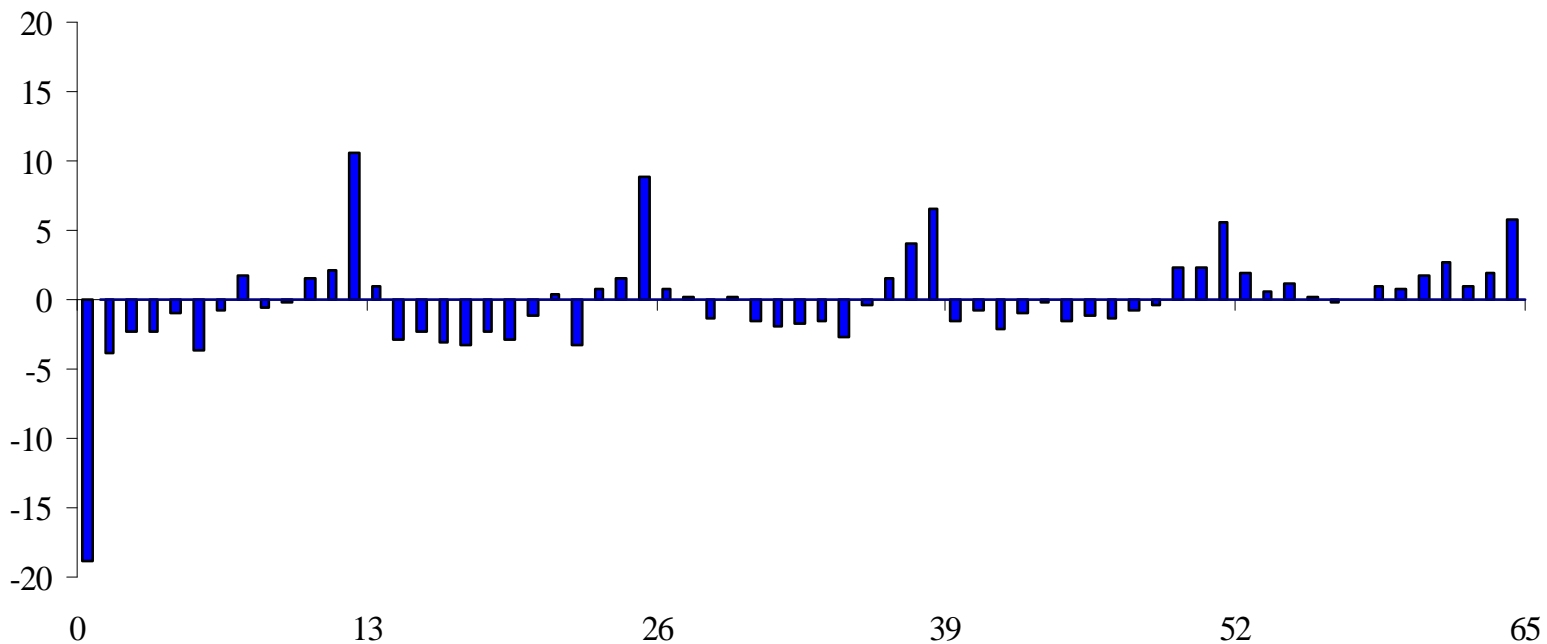


# Cross-Sectional Regressions of Spread and Order Imbalance



# Cross-Sectional Regressions of Returns using Controls

*T-statistics*



# Subperiod Analysis

Panel A. Raw portfolio returns

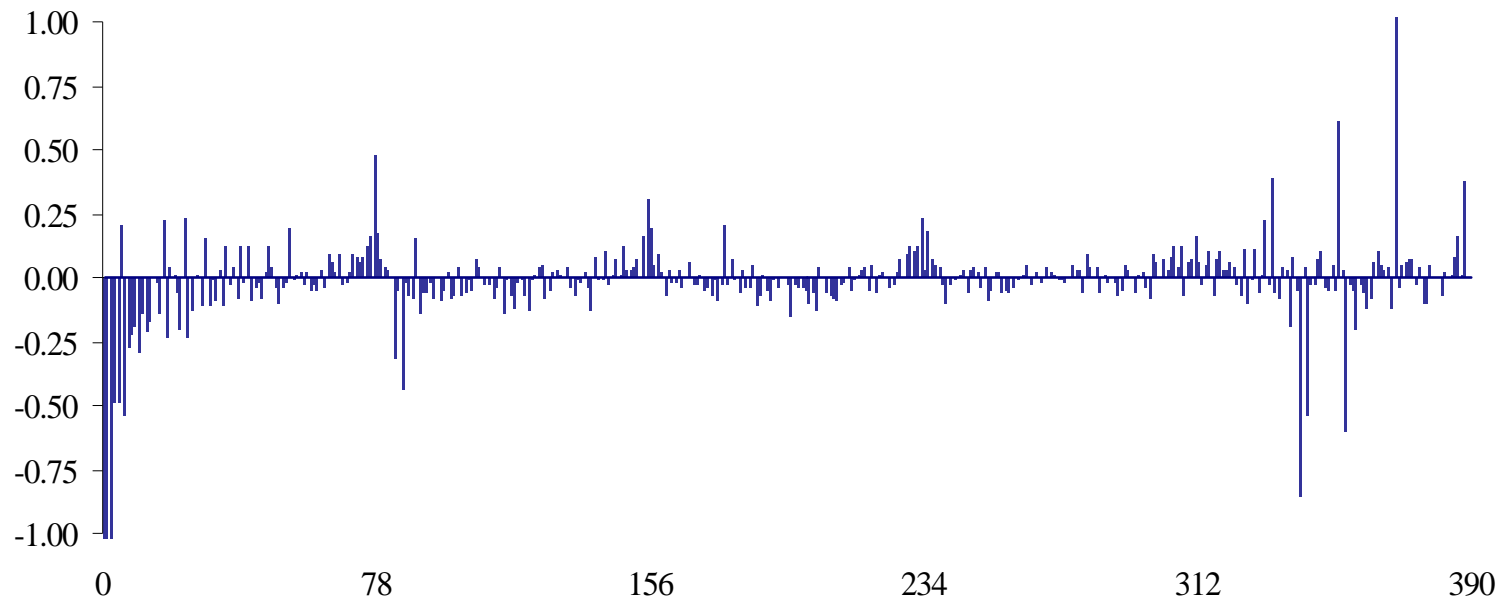
Strategy	January 1, 1993 - June 23, 1997 [14,190 observations)	June 24, 1997 - December 31, 2000 [11,506 observations]	January 1, 2001 - December 31, 2005 [16,261 observations]
Day 1	2.88	-10.30	3.01
[lag 13]	[4.90]	[-0.84]	[22.15]
Day 2	1.00	4.67	1.97
[lag 26]	[6.52]	[3.01]	[15.01]
Day 3	0.84	69.61	1.36
[lag 39]	[5.56]	[1.31]	[10.75]
Day 4	-0.21	-54.00	1.26
[lag 52]	[-0.21]	[-1.02]	[10.01]
Day 5	0.68	-15.15	1.09
[lag 65]	[4.44]	[-1.00]	[8.70]

Panel B. Winsorized portfolio returns (top and bottom 1%)

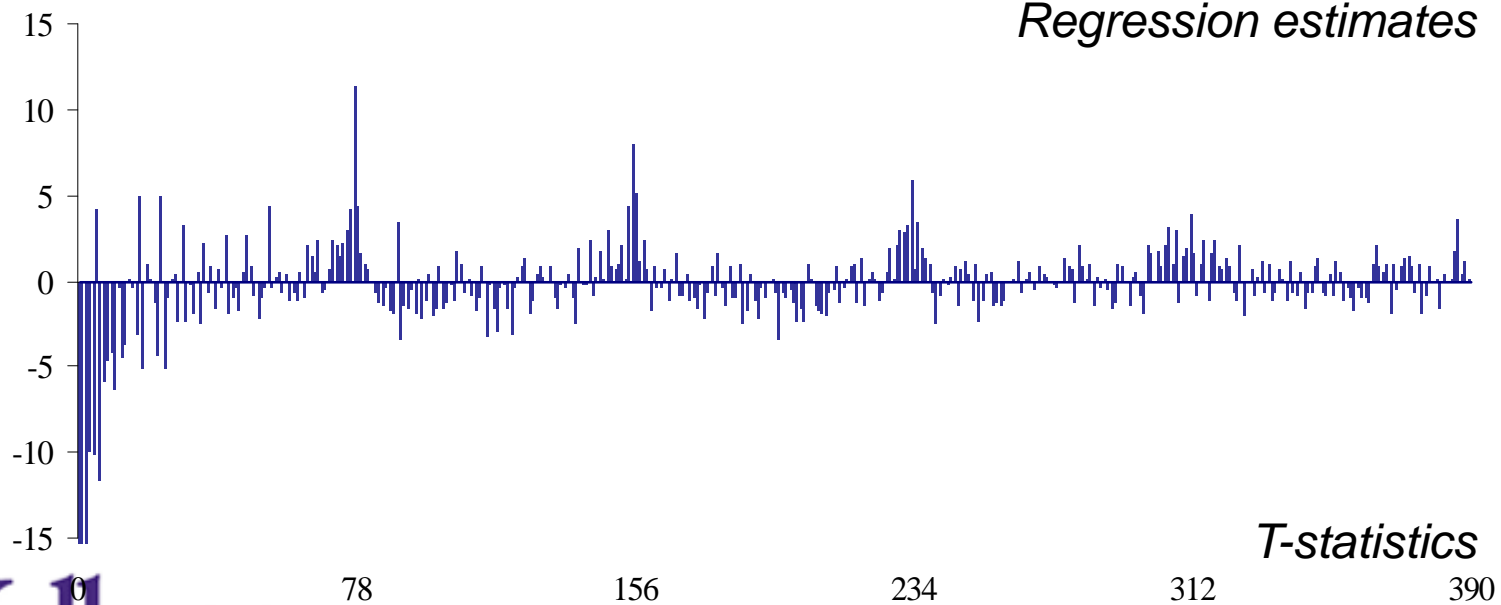
Strategy	January 1, 1993 - June 23, 1997 [14,190 observations)	June 24, 1997 - December 31, 2000 [11,506 observations]	January 1, 2001 - December 31, 2005 [16,261 observations]
Day 1	2.28	3.43	2.90
[lag 13]	[15.22]	[18.27]	[22.89]
Day 2	0.98	2.07	1.89
[lag 26]	[6.69]	[11.39]	[15.34]
Day 3	0.86	1.61	1.38
[lag 39]	[5.88]	[8.95]	[11.56]
Day 4	0.72	1.57	1.26
[lag 52]	[4.90]	[8.80]	[10.52]
Day 5	0.69	1.12	1.13
[lag 65]	[4.72]	[6.29]	[9.58]



# Five-Minute Returns



*Regression estimates*



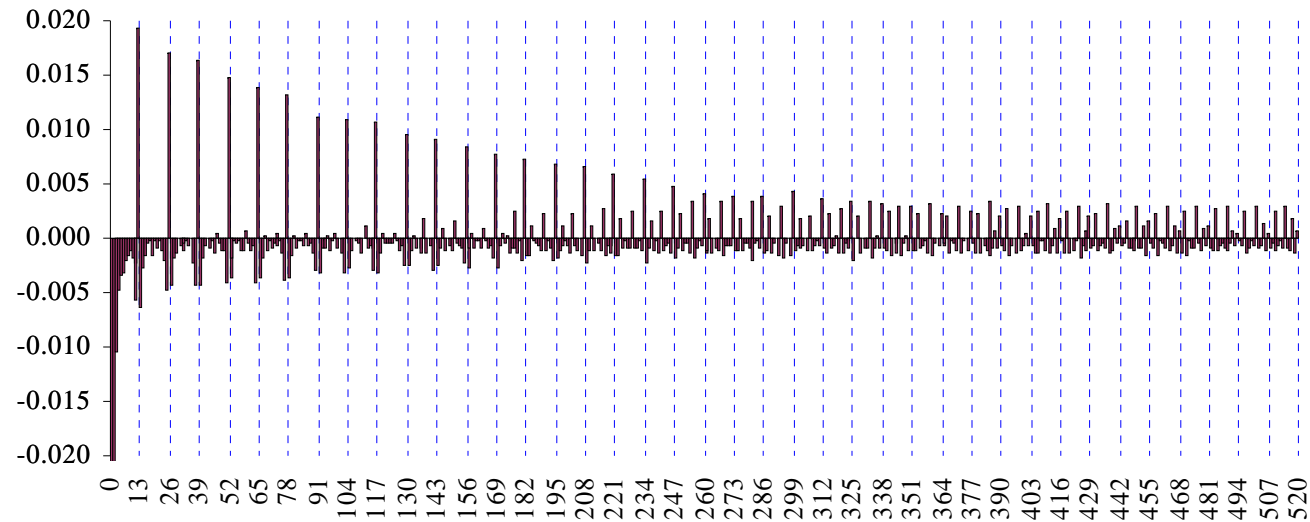
*T-statistics*

# Conclusions

- Pattern in intraday stock returns
  - Continuation at the daily frequency
  - Intraday reversal at other times
- Volume and volatility have similar patterns, but do not explain return pattern
- Robustness
  - size, risk, index membership, day-of-week, turn-of-month, bid-bid, ask-ask, midpoint-midpoint
- Profits are smaller than bid-ask spread
  - This is likely not an arbitrage, but represents a demand for immediacy
  - Why don't traders adjust timing by 30 minutes?!

# Cross-Sectional Regressions of Volume, Long-Run Analysis

*Regression estimates (Panel A)*



*T-statistics (Panel B)*

