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Slow diffusion of information and price momentum in stocks: Evidence from options markets

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abstract

This paper investigates the source of price momentum in the stock market using information from options markets. We provide direct evidence of the gradual information diffusion model in Hong and Stein (1999): momentum profits are larger for stocks whose information diffuses slowly into the stock market. We exploit the options markets to identify stocks with slow information diffusion speed. As informed traders trade options to realize the information that has not been fully incorporated in the stock price, we are able to enhance the momentum strategy by selecting winner/loser stocks with high growth/large drop in call option implied volatility. Our empirical strategy generates a risk-adjusted alpha of 1.8% per month over the 1996–2011 period, during which the simple momentum strategy fails to perform. The results are robust to the impact of earnings announcement, transaction costs, industry concentration, and choice of options' moneyness and time-to-maturity. Finally, our finding is not driven by existing stock- or option-related characteristics that are known to improve momentum.

1. Introduction

The diffusion of information plays a crucial role in explaining price momentum. Researchers attempt to understand momentum from investors' process and reaction to firm-specific information, and how such information is conveyed into stock price. Among them, Hong and Stein (1999) propose a model that shows how slow diffusion of information and interaction of two types of investors, newswatchers and momentum traders, can explain price under-reaction in the short run and over-reaction in the median run. A direct prediction of their model is that momentum should be stronger for stocks with slower information diffusion speed. In this paper, we provide empirical support for their theoretical prediction by identifying stocks' information diffusion speed using options markets. We show that momentum profit concentrates in stocks with slow information diffusion speed. An enhanced momentum strategy that is constructed within such stocks performs well, even during periods when the simple momentum strategy fails to perform.

Although the identification of information diffusion speed is important in explaining momentum, in reality it is easier said than done. Hong et al. (2000) use size and analyst coverage to classify stocks into slow and fast diffusion groups. They find momentum effect is stronger for the slow diffusion group characterized by small size and low analyst coverage. However, size and analyst coverage are static firm-specific characteristics that do not change much over time, while information diffusion speed could be information-specific and time-varying. For example, the manager of a company tends to have a piece of positive information to be perceived by investors fast, but may try to delay the diffusion of another piece of negative information (Kothari et al., 2009). Therefore, our goal is to identify individual stocks' information diffusion speed and construct the momentum portfolio using stocks with continued information diffusion in the holding period.

We take advantage of the options markets to dynamically refine our momentum portfolio selection. Options markets provide an effective channel for price discovery and information diffusion (Manaster and Rendleman, 1982). Previous researchers find that informed traders may prefer options markets to the stock market for various reasons, such as embedded leverage of options (Black, 1975; Frazzini and Pedersen, 2012), investors' short sale constraints (Figlewski and Webb, 1993), transaction costs (Cox et al., 1985), and so forth. Thus, options prices may contain material information that has not been fully reflected in stock prices. Billings and Jennings (2011) find that an increase in uncertainty-adjusted option prices prior to earnings announcements is positively related to the sensitivity between the stock market reaction and earnings announcements. Their finding indicates that option traders prefer

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options of those stocks with slower information diffusion speed regarding earnings announcements. We generalize their argument throughout the course of information diffusion. When the information diffusion speed is slow, upon discovering more information to continue releasing in the stock market, some investors will realize their superior information in the options markets, causing options prices to change. Therefore, within those winner/loser stocks that have started their information diffusion process, trades in options markets allow us to identify those stocks with slower information diffusion speed and thus with further price adjustment. Specifically, for winner stocks, if we also observe prices of call options increase, it indicates that informed option traders believe that not all relevant information has released and there will be further price appreciation. The same logic applies to loser stocks: informed option traders can sell call options if they think that the negative information associated with those loser stocks has not been fully incorporated in the stock prices.

Based on the logic above, we use implied volatility growth of call options to identify stocks' information diffusion speed and construct the enhanced momentum portfolio. A large growth/decline in the call option implied [illegible] rTr formed option traders' buy/sell position and their belief that positive/negative information will continue to convey into stock price. Thus, to enhance the stock selection based on information diffusion speed, we long those winner stocks with the largest growth in call option implied volatility and short those loser stocks with the largest decline in call option implied volatility. Our enhanced momentum strategy generates [redacted] 178% per month over the [illegible]

[illegible]

Table 1
Summary Statistics.
This table presents the summary statistics. Panel A reports the number, the average market capitalization, and the median market capitalization of stocks that are listed on NYSE/NASDAQ/AMEX and the ones with options data. Stocks with market capitalization less than the 10% NYSE cutoff and a share price lower than $5 at the beginning of each month are excluded. Market capitalization is measured in millions of dollars. Panel B reports mean and standard deviation of implied volatility growth in percentage for call options with a delta of 0.5 and maturities of one, three, and six months. The growth is measured between the option implied volatility before the last trading day of a given month divided by that of five trading days earlier.

Panel A: Number of stocks and market capitalization

	CRSP common stocks			CRSP-OptionMetricsmerged		
Year	No. of firms	Mean size	Median size	No. of firms	Mean size	Median size
1996	3564	1894.4	374.6	934	4582.0	1278.0
1997	3565	2413.0	460.3	1124	5094.5	1148.3
1998	3442	3094.9	522.8	1313	5822.0	1131.2
1999	3468	3758.9	499.6	1477	6858.8	1074.0
2000	3539	4382.4	577.3	1484	8500.2	1417.3
2001	2991	4290.1	604.1	1497	7432.9	1359.3
2002	2587	4247.6	695.0	1532	6367.3	1269.3
2003	2505	4206.0	733.2	1526	6195.6	1318.6
2004	2470	5179.1	1005.7	1594	7223.5	1696.3
2005	2443	5681.9	1184.3	1650	7567.8	1806.4
2006	2437	6148.8	1327.7	1710	7856.2	1865.6
2007	2400	6902.7	1441.0	1775	8353.3	2001.5
2008	2285	6020.2	1151.1	1703	7201.1	1612.0
2009	2177	4631.8	877.1	1686	5385.3	1188.4
2010	2192	5649.3	1212.7	1776	6265.2	1520.8
2011	2135	6735.4	1530.6	1797	7148.0	1768.9
Average	2762	4702.3	887.3	1536	6740.9	1466.0

Panel B: Implied volatility growth

	1-month		3-month		6-month	
Year	Mean	SD	Mean	SD	Mean	SD
1996	1.18	15.31	1.10	10.51	0.31	6.62
1997	0.31	13.00	0.91	10.03	0.41	6.38
1998	1.44	14.69	1.78	10.28	1.07	6.98
1999	−0.08	12.92	0.21	10.32	−0.03	7.57
2000	−0.12	14.34	0.42	11.91	0.14	8.67
2001	−1.43	11.43	−0.96	8.61	−0.84	5.84
2002	−0.73	12.01	0.01	10.87	−0.11	7.38
2003	−0.32	11.28	−0.58	8.23	−0.63	5.48
2004	−0.52	12.22	−0.67	9.34	−0.45	7.10
2005	0.66	20.88	0.07	16.38	−0.14	13.13
2006	0.22	32.60	−0.14	21.46	−0.22	13.04
2007	0.91	19.89	1.14	18.58	0.63	11.30
2008	−2.98	14.76	−1.86	11.66	−1.33	9.23
2009	2.10	15.97	0.80	10.97	0.18	8.40
2010	4.72	23.00	3.00	15.67	2.26	12.84
2011	−0.37	24.87	−1.26	19.75	−1.26	13.95
Average	0.31	16.82	0.25	12.78	0.00	8.99

of call options with other combinations of moneyness and time-to-maturity. The variable to measure stocks' information diffusion speed is call option implied volatility growth ΔIV^C. The implied volatility growth is calculated over the five trading days prior to the last trading day of each calendar month. We skip the last trading day to control for the turn-of-the-month short-term reversal. Panel B of Table 1 presents average and standard deviation of call option implied volatility growth. The average implied volatility growth for call options with a delta of 0.5 and maturity of one month is 0.31%. The numbers are 0.25% and 0.00% for three-month and six-month maturity options. Implied volatility growth of options with longer maturity exhibits lower standard deviation (8.99% for six-month options v.s. 16.82% for one-month options), consistent with the fact that long maturity options are less traded.

3. Momentum strategy enhanced by options markets information

3.1. Performance of the traditional momentum strategy for the 1996–2011 period

We first examine the performance of a simple momentum strategy for the 1996–2011 period. Momentum portfolios are constructed following the standard procedure described by Jegadeesh and Titman (1993). Specifically, we assign stocks into ten equal-weighted portfolios according to their past J-month cumulative returns and then hold the winner portfolio and short the loser portfolio for K months. We skip one month between the formation month and the holding month to mitigate the influence of temporary price pressure due to high-frequency phenomena or bid-ask bounce. We construct the momentum portfolio using two groups of stocks: common stocks and common stocks with listed options contracts. Table 2 presents monthly winner-minus-loser returns for various combinations of formation and holding months.

Table 3
Monthly Returns for Portfolios Based on Momentum and Call Option Implied Volatility Growth: Weekly, Dependent Sort.
This table presents monthly returns for momentum and call option implied volatility growth double-sorted portfolios. Panel A reports the results of dependent two-way sorting (first sort stocks based on their past cumulative returns, and then sort based on implied volatility growth), and Panel B presents the marginal contribution of sorting on the implied volatility growth. For the winner portfolio (P10), V_S contains stocks with the largest weekly implied volatility growth. For the loser portfolio (P1), V_S contains stocks with the smallest weekly implied volatility growth. We fix J (= 6) for past cumulative return calculation, skip S (= 1) month, and hold portfolios for K (= 1, 3, 6) months. Momentum ranking lasts for K months, and option ranking is recalculated at the beginning of each holding month based on implied volatility growth of 30-day to maturity at-the-money call options. We exclude stocks with market capitalization less than the 10% NYSE cutoff or a share price less than \$5 in the formation month to ensure liquidity. We also winsorize the data each month by excluding stocks that have implied volatility growth in the top and bottom 1%. We report unadjusted excess returns and risk-adjusted alphas relative to the CAPM, the Fama-French three-factor model, and the Fama-French three-factor plus short-term reversal (STR) factor model. Newey-West four-lag adjusted t-statistics are in parentheses.

Panel A: Monthly returns for momentum and implied volatility growth double-sorting portfolios

	K = 1						K = 3				K = 6			
	P1	P10	Unadj. P10-P1	CAPM P10-P1	FF3F P10-P1	FF3F+STR P10-P1	Unadj. P10-P1	CAPM P10-P1	FF3F P10-P1	FF3F + STR P10-P1	Unadj. P10-P1	CAPM P10-P1	FF3F P10-P1	FF3F + STR P10-P1
V_F	0.47	0.85	0.39	0.64	0.51	0.64	0.00	0.20	0.09	0.20	−0.04	0.13	0.11	0.18
	(0.57)	(1.35)	(0.54)	(1.04)	(0.83)	(1.08)	(0.01)	(0.35)	(0.15)	(0.35)	(−0.06)	(0.25)	(0.21)	(0.35)
V_M	0.33	1.27	0.94	1.14	1.12	1.26	1.02	1.18	1.20	1.33	0.89	1.01	1.06	1.15
	(0.49)	(1.98)	(1.26)	(1.65)	(1.59)	(1.86)	(1.48)	(1.88)	(1.87)	(2.15)	(1.51)	(1.86)	(1.93)	(2.13)
V_S	−0.17	1.38	1.55	1.73	1.68	1.78	1.32	1.47	1.45	1.52	1.04	1.16	1.19	1.25
	(−0.21)	(2.20)	(2.16)	(2.66)	(2.57)	(2.69)	(2.01)	(2.54)	(2.54)	(2.61)	(1.78)	(2.26)	(2.35)	(2.38)

Panel B: Marginal contribution of sorting on the implied volatility growth

	K=1						K=3				K=6			
	V_F	V_S	Unadj. V_S-V_F	CAPM V_S-V_F	FF3F V_S-V_F	FF3F+STR V_S-V_F	Unadj. V_S-V_F	CAPM V_S-V_F	FF3F V_S-V_F	FF3F+STR V_S-V_F	Unadj. V_S-V_F	CAPM V_S-V_F	FF3F V_S-V_F	FF3F+STR V_S-V_F
P1	0.47	−0.17	−0.63	−0.57	−0.60	−0.60	−0.66	−0.62	−0.65	−0.64	−0.52	−0.48	−0.49	−0.49
	(0.57)	(−0.21)	(−2.04)	(−1.97)	(−2.02)	(−2.04)	(−2.28)	(−2.45)	(−2.59)	(−2.64)	(−2.00)	(−2.02)	(−2.13)	(−2.17)
P10	0.85	1.38	0.53	0.51	0.57	0.55	0.66	0.65	0.70	0.69	0.55	0.55	0.59	0.59
	(1.35)	(2.20)	(2.16)	(2.15)	(2.35)	(2.32)	(2.97)	(2.90)	(3.12)	(3.07)	(2.84)	(2.68)	(2.87)	(2.86)
P10-P1	0.39	1.55	1.16	1.09	1.17	1.15	1.32	1.27	1.35	1.33	1.07	1.03	1.08	1.07
	(0.54)	(2.16)	(2.80)	(2.68)	(2.84)	(2.87)	(3.43)	(3.54)	(3.85)	(3.91)	(3.05)	(2.93)	(3.12)	(3.18)

formation diffusion, while they are silent on possible future information diffusion and time-varying diffusion speed. On the other hand, option prices reflect informed investors' view on whether such information diffusion would continue being conveyed into stock prices. Positive past cumulative returns paired with call option price appreciation suggest continued positive information diffusion and thus further stock price increase. The same applies to loser stocks with call price decrease. Since option implied volatility is a monotonic mapping of option price, we identify the sign and magnitude of stocks' information diffusion speed using option implied volatility growth. Notice that we do not exclude the possibility that informed investors could also trade on the stock market. Our assumption here is that option traders are in general more sophisticated with better understanding on whether information diffusion would continue into the stock price.

To construct the enhanced momentum portfolio, we first sort stocks into ten groups based on their cumulative returns over the past six months. We fix the formation period to keep the number of strategies tractable. We skip one month post the formation months. We take positions in a subset of stocks in the winner and loser pools that are more likely to experience continued information diffusion, as suggested by the options markets. Specifically, at the beginning of each month during the holding period, we sort stocks within the winner and loser pools into three groups, namely, slow, median, and fast information diffusion groups, based on implied volatility growth over the most recent trading week.[3] Stocks with slow information diffusion are winners (or loser) stocks that call option traders believe good (bad) news will continue to diffuse into the stock market, and thus the ones with large (small) call option implied volatility growth. Stocks with slow (fast) information diffusion are more (less) likely to experience further price movements. We construct equal-weighted winner-minus-loser momentum portfolio with this double sorting strategy by taking a long position in the refined winner stocks and a short position in the refined loser stocks. We hold the portfolio for one month and re-rank stocks based on

[3] This is the last trading week of the previous month. In addition, to rule out the effect of extreme values, we winsorize the implied volatility growth at 1% and 99%.

Table 4
Fama–MacBeth Cross-Sectional Regressions with Call Options Implied Volatility Growth.
This table presents the results of the Fama–MacBeth regressions. Independent variables include the past six-month cumulative return, option implied volatility growth, their interaction, and an array of firm characteristics. The interaction term $PastCumRet \times \Delta\hat{IV}^C$ is constructed as the product of $PastCumRet$ and ΔIV^C for stocks with cumulative returns above the median, and the product of $PastCumRet$ and $-\Delta IV^C$ for stocks with cumulative returns below the median. Control variables include stock size, stock price, book-to-market ratio, stock trading volume, number of analyst coverage, the maximum daily return, market beta, Amihud illiquidity measure, realized volatility, idiosyncratic volatility, options' open interest growth, options' trading volume change, and option-implied skewness. We exclude stocks with market capitalization less than the 10% NYSE cutoff or a share price less than $5 at the end of formation month to ensure liquidity. We also winsorize the data by excluding stocks that have implied volatility growth in the top and bottom 1%. Regressions are performed on the full sample as well as on stocks classified as the winner and loser based on their past cumulative returns. The average slope coefficients and their Newey-West four-lag adjusted t-statistics are reported in parentheses.

	(1)	(2)	(3)	(4)
$PastCumRet$	0.002		0.000	−0.000
	(0.34)		(0.04)	(−0.05)
ΔIV^C		0.015	0.014	0.005
		(3.53)	(3.41)	(0.48)
$PastCumRet \times \Delta\hat{IV}^C$			0.008	0.017
			(2.56)	(2.25)
Size	−0.000	−0.000	−0.000	−0.000
	(−0.14)	(−0.36)	(−0.33)	(−1.35)
Price	−0.000	−0.000	−0.000	0.000
	(−0.99)	(−0.32)	(−0.95)	(1.14)
BM	−0.001	−0.001	−0.001	0.001
	(−0.73)	(−0.58)	(−0.82)	(0.29)
Stock volume	0.100	0.120	0.094	0.088
	(1.11)	(1.21)	(1.05)	(0.91)
Analyst coverage	−0.000	−0.000	−0.000	0.000
	(−0.30)	(−0.42)	(−0.40)	(0.98)
Maxret	0.007	0.008	0.009	−0.031
	(0.41)	(0.47)	(0.56)	(−1.05)
β_{mkt}	0.003	0.007	0.002	−0.002
	(0.60)	(1.28)	(0.51)	(−0.32)
Amihud	0.246	0.207	0.251	0.500
	(1.28)	(1.11)	(1.31)	(1.66)
Realized vol.	0.014	0.004	0.015	0.059
	(0.33)	(0.08)	(0.35)	(0.90)
Idio. vol.	−0.025	−0.015	−0.030	−0.071
	(−0.63)	(−0.36)	(−0.73)	(−1.18)
Open interest growth	−0.003	−0.003	−0.003	−0.004
	(−3.54)	(−3.32)	(−3.44)	(−0.91)
Options volume change	0.000	0.000	0.000	−0.000
	(1.72)	(1.73)	(1.64)	(−0.84)
Implied skewness	0.004	0.003	0.003	0.007
	(5.41)	(5.15)	(5.08)	(4.40)
Intercept	−0.008	−0.010	−0.007	−0.005
	(−1.69)	(−1.50)	(−1.03)	(−2.15)
Winner and loser				x
Adj. R^2	0.10	0.09	0.10	0.12

Next we assesses the effect of information diffusion speed based stock selection on the performance of momentum strategy. Panel B of Table 3 reports the return difference of two winner/loser portfolios, one is constructed within stocks with slow information diffusion and the other is constructed within stocks with fast information diffusion. Positive and significant return differences highlight the benefit of refining stocks based on their information diffusion. Taking the one-month holding period case as an example, winner stocks with large call option implied volatility growth earn a higher four-factor adjusted alpha of 55 bps per month (t-statistic = 2.32) than winner stocks with small call option implied volatility growth. The monthly return difference for two loser portfolios is 60 bps (t-statistics = 2.04). Together, the hedged winner-minus-loser portfolio earns a four-factor monthly alpha of 1.15% (t-statistic = 2.87) more when it is constructed within those slow diffusion stocks. Similar results are found for longer holding horizons.

An et al. (2014) has showed that an increase in call option implied volatility positively predicts future returns.

Table 5
Characteristics of Portfolios Sorted by Momentum and Implied Volatility Growth.
This table presents the characteristics for momentum and implied volatility growth double-sorted portfolios. Characteristics, measured as the median value across stocks within each portfolio, include: stock size (in million of USD), stock price (in USD), stock trading volume, the average number of analyst coverage, formation period cumulative return, realize volatility, idiosyncratic volatility, the maximum daily return, the open interest growth, and the change in option trading volume. Stocks within each momentum-sorted group are sorted into three equal groups based on their call option implied volatility growth (small, median, large). We fix J (= 6) for past cumulative return calculation, skip S (= 1) month, and hold portfolios for K (= 1) month. We use call options with 30-day to maturity and a delta of 0.5. We exclude stocks with market capitalization less than the 10% NYSE cutoff or a share price less than $5 at the end of formation month to ensure liquidity. We also winsorize the data by excluding stocks that have implied volatility growth in the top and bottom 1%. Portfolios selected as part of the winner-minus-loser momentum portfolio are indicated in bold.

	Size			Price			Stock volume			Analyst coverage			Cumulative return		
	Small	Median	Large	Small	Median	Large	Small	Median	Large	Small	Median	Large	Small	Median	Large
Loser - 1	**741**	822	740	**15**	16	14	**0.012**	0.013	0.012	**7.9**	8.3	7.9	**−0.36**	−0.36	−0.36
2	1222	1471	1326	20	23	21	0.009	0.009	0.009	8.0	8.8	8.4	−0.21	−0.21	−0.21
3	1721	1942	1798	25	27	24	0.007	0.007	0.007	8.7	9.2	8.9	−0.12	−0.12	−0.12
4	2058	2385	2189	28	30	27	0.007	0.007	0.007	9.0	9.7	9.3	−0.06	−0.06	−0.06
5	2239	2653	2515	29	33	30	0.006	0.006	0.006	9.2	10.1	9.6	0.00	0.00	0.00
6	2461	2760	2671	30	34	31	0.006	0.006	0.006	9.2	10.0	9.7	0.06	0.06	0.06
7	2454	2846	2595	32	34	32	0.006	0.007	0.007	9.1	9.9	9.5	0.12	0.12	0.12
8	2357	2759	2507	33	36	32	0.007	0.007	0.007	8.9	9.8	9.5	0.21	0.21	0.20
9	2069	2374	2207	32	35	32	0.008	0.009	0.008	8.5	9.1	8.8	0.33	0.33	0.33
Winner - 10	1530	1698	**1569**	30	33	**30**	0.012	0.012	**0.012**	7.2	7.9	**7.4**	0.63	0.63	**0.62**

	Realized volatility			Idiosyncratic volatility			Max daily return			OI growth			Option volume change		
	Small	Median	Large	Small	Median	Large	Small	Median	Large	Small	Median	Large	Small	Median	Large
Loser - 1	**0.63**	0.64	0.63	**0.54**	0.54	0.54	**0.078**	0.075	0.075	**0.06**	0.05	0.05	**0.26**	−5.41	−0.79
2	0.49	0.48	0.49	0.41	0.40	0.41	0.060	0.059	0.058	0.05	0.05	0.05	−0.67	−3.12	−1.45
3	0.42	0.41	0.42	0.34	0.33	0.35	0.052	0.050	0.050	0.05	0.05	0.05	−0.70	−3.54	−2.02
4	0.38	0.38	0.39	0.31	0.31	0.32	0.046	0.045	0.046	0.05	0.04	0.05	−0.55	−3.01	−1.44
5	0.37	0.36	0.37	0.30	0.29	0.30	0.044	0.043	0.044	0.05	0.04	0.05	−0.49	−2.10	−0.74
6	0.35	0.35	0.36	0.29	0.29	0.29	0.043	0.042	0.043	0.05	0.04	0.05	−0.64	−2.53	−1.24
7	0.36	0.36	0.37	0.30	0.29	0.30	0.044	0.042	0.044	0.05	0.04	0.05	−0.38	−3.34	−0.46
8	0.38	0.38	0.38	0.32	0.31	0.32	0.046	0.044	0.045	0.05	0.04	0.05	−0.83	−2.05	−1.05
9	0.43	0.42	0.42	0.36	0.35	0.35	0.051	0.050	0.049	0.05	0.05	0.05	1.69	−2.71	1.21
Winner - 10	0.54	0.54	**0.54**	0.46	0.45	**0.46**	0.064	0.062	**0.063**	0.06	0.05	**0.06**	−0.32	−4.66	**2.36**

skewness.[5] Results are presented in Table 4. We find that while call option implied volatility growth has a strong predictive power on holding period return (coefficient = 0.015, t-statistic = 3.53), past cumulative return does not (coefficient = 0.002, t-statistic = 0.34). This finding is consistent with the predictive power of options documented in previous studies and the weak performance of a simple momentum strategy in the earlier section. The interaction of momentum and call option implied volatility growth plays an important role: the coefficient estimate on the cross term β_3 is 0.008 with a t-statistic of 2.56. If we conduct the regression within those winner and loser stocks, only the interaction term β_3 is positive and significant (coefficient = 0.017, t-statistic = 2.25). Results of Fama–MacBeth regressions imply that it is indeed the interaction between the momentum and call option implied volatility growth that contributes to the strong performance of our strategy.

To ensure that implied volatility growth is not related to those well-documented stock- or option-specific characteristics that can improve momentum effect, we examine several characteristics for stocks in the double-sorted portfolios. We consider ten characteristics, including stock size, stock price, stock trading volume, stock analyst coverage, past cumulative return, realized volatility, idiosyncratic volatility, maximum daily return, option open interest growth, and option trading volume change. The median value of each characteristic within each double-sorted portfolio is presented in Table 5. Instead of displaying cells in terms of fast, medium, or slow (D_F, D_M, D_S), which involves different implied volatility growth based rankings for winner and loser stocks, we display cells according to the actual implied volatility growth (small, medium, and large). The portfolios that we pick as the long and short legs of the enhanced momentum portfolio are highlighted in bold. We see no obvious pattern in those characteristics across volatility growth sorted portfolios, indicating that stock selection based on implied volatility growth is not equivalent to selecting stocks based on these ten characteristics. In other words, by forming an enhanced momentum portfolio using implied volatility growth, we are not simply implementing a narrower sorting on more extreme winner or loser stocks based on these characteristics above.

4. Robustness analysis

In this section, we present a number of robustness tests. We examine the earnings announcement effect, the impact of transaction cost, the industry concentration of the momentum portfolio, and performance of portfolios that are refined using options with maturity matched with holding horizon. More robustness tests are available in the Internet Appendix.

4.1. Earnings announcement

Option trading and implied volatility increase significantly before earnings announcements. We examine whether the outperformance of the enhanced momentum strategy is driven by informational advantage of options traders around earnings announcements. We construct the momentum portfolio using stocks without

[5] Both the open interest growth and the option trading volume change are computed over the same horizon of which the implied volatility growth is computed. We use the change instead of growth for the option trading volume due to the presence of zero volume. Both open interest and volume are calculated using all call (put) options with maturities between 30 days and 365 days. We exclude short maturity options to avoid the potential mechanical changes near expiration. We thank Frank Liu for sharing his data on the implied risk-neutral skewness.

Table 6
Monthly Returns for Portfolios Based on Momentum and Option Implied Volatility Growth: Stocks without Earnings Announcements.
This table presents monthly returns for momentum and call option implied volatility growth double-sorted portfolios. We exclude stocks that have earning announcements in the holding month. For the winner portfolio (P10), V_S contains stocks with the largest weekly call implied volatility growth. For the loser portfolio (P1), V_S contains stocks with the smallest weekly call implied volatility growth. We fix J (= 6) for past cumulative return calculation, skip S (= 1) month, and hold equal-weighted portfolios for K (= 1) month. Options with 30-day to maturity with a delta of 0.5 are used. We exclude stocks with market capitalization less than the 10% NYSE cutoff or a share price less than \$5 in the formation month to ensure liquidity. We also winsorize the data each month by excluding stocks that have implied volatility growth in the top and bottom 1%. We report unadjusted excess returns and risk-adjusted alphas relative to the CAPM, the Fama-French three-factor model, and the Fama–French three-factor plus short-term reversal (STR) factor model. Newey-West four-lag adjusted t-statistics are in parentheses.

	Unadjusted			CAPM alpha			FF3F alpha			FF3F + STR alpha		
	V_F	V_S	$V_S - V_F$	V_F	V_S	$V_S - V_F$	V_F	V_S	$V_S - V_F$	V_F	V_S	$V_S - V_F$
P1	0.14	−0.41	−0.55	−0.64	−1.14	−0.50	−0.69	−1.23	−0.54	−0.80	−1.32	−0.52
	(0.17)	(−0.51)	(−1.5)	(−1.42)	(−2.61)	(−1.50)	(−1.57)	(−3.04)	(−1.58)	(−1.92)	(−3.27)	(−1.61)
P10	0.77	1.11	0.34	0.25	0.59	0.33	0.11	0.45	0.34	0.17	0.47	0.31
	(1.19)	(1.78)	(1.08)	(0.54)	(1.49)	(1.02)	(0.31)	(1.36)	(1.02)	(0.48)	(1.39)	(0.95)
P10-P1	0.64	1.53	0.89	0.89	1.73	0.84	0.80	1.68	0.88	0.96	1.79	0.83
	(0.82)	(2.01)	(1.73)	(1.36)	(2.72)	(1.62)	(1.22)	(2.59)	(1.68)	(1.57)	(2.73)	(1.67)

Table 7
Monthly Returns for Portfolios Based on Momentum and Implied Volatility Growth: the Impact of Transaction Costs.
This table presents monthly returns for momentum and call option implied volatility growth double-sorted portfolios after taking transaction costs into consideration. A restriction is placed on the fraction of stocks that can be rebalanced every month: for stocks that require rebalancing, only those with market capitalization in the top x (= 80%, 50%, and 20%) percentile can be sold/purchased. We fix J (= 6) for past cumulative return calculation, skip S (= 1) month, and hold equal-weighted/value-weighted portfolios for K (= 1) month. Call options with 30-day-to-maturity with a delta of 0.5 are used. We exclude stocks with market capitalization less than the 10% NYSE cutoff or a share price less than \$5 in the formation month to ensure liquidity. We also winsorize the data each month by excluding stocks that have implied volatility growth in the top and bottom 1%. We report unadjusted excess returns and risk-adjusted alphas relative to the CAPM, the Fama–French three-factor model, and the Fama–French three-factor plus short-term reversal (STR) factor model. Newey-West four-lag adjusted t-statistics are in parentheses.

	Equal-weighted				Value-weighted			
	Unadj. P10-P1	CAPM P10-P1	FF3F P10-P1	FF4F P10-P1	Unadj. P10-P1	CAPM P10-P1	FF3F P10-P1	FF4F P10-P1
80%	1.32	1.49	1.47	1.57	1.49	1.74	1.61	1.72
	(1.99)	(2.56)	(2.54)	(2.64)	(1.73)	(2.15)	(1.99)	(2.09)
50%	0.98	1.13	1.11	1.21	1.42	1.67	1.55	1.65
	(1.77)	(2.39)	(2.35)	(2.58)	(1.72)	(2.16)	(2.00)	(2.11)
20%	0.66	0.74	0.82	0.86	1.06	1.26	1.24	1.31
	(1.65)	(1.89)	(2.08)	(2.15)	(1.49)	(1.83)	(1.82)	(1.90)

ones generated under the full sample in both unadjusted and risk-adjusted terms, suggesting the role of options trading in identifying information diffusion is not limited to earnings announcements period.

4.2. Transaction cost

Momentum strategy usually has high turnover. Such high turnover also applies to our double sorting strategy. Taking the ($J = 6,\ S = 1,\ K = 1$) strategy as an example, only 10% of the stocks do not need to be rebalanced each month. Thus we assess the profitability of the options improved momentum strategy after taking transaction costs into consideration. Due to the lack of data on realized transaction costs, we take an alternative approach by imposing a restriction on portfolio rebalancing. Specifically, each month, we rebalance the largest x% (= 20%, 50%, 80%) stocks that needs rebalancing. Table 7 presents the results. We find that the performance of the option improved momentum strategy is robust to the imposed restriction. When 80% of the stocks are allowed to rebalance, the risk-adjusted alpha is 1.57% per month with a t-statistic of 2.64. When we only allow a turnover of 20%, the alpha is 0.86% with a t-statistic of 2.15. Frazzini et al. (2015) use real-world trading data and find that actual trading costs of major quantitative strategies, including momentum, are much smaller than previous studies suggest and thus sizeable. While we do not have real trading data to precisely examine how implementable the enhanced momentum strategy is, our estimate along with their research suggests that the strategy may still survive with transaction costs.

4.3. Industry concentration

It is possible that the superior performance of our enhanced strategy is a result of selecting stocks concentrated in the winning and losing industries as suggested by Moskowitz and Grinblatt (1999). To address this issue, we examine the correlation between industry concentration of winner/loser portfolios and portfolio returns. Industry concentration is measured using the Herfindahl–Hirschman Index (HHI) as expressed in Eq. (2).

$$HHI_t = \Sigma_{i=1}^{N_t} s_{i,t}^2 \tag{2}$$

The HHI of a portfolio in a given month is computed as the sum of the squared stock share of industry i, $s_{i,t}$, where $s_{i,t}$ is the fraction of stocks that belong to industry i.[7] The HHI takes a positive value from zero to one with a larger number indicating higher concentration.

Panel A of Fig. 1 plots the time series of the HHIs for the winner and loser portfolios constructed using the call option-based benchmark strategy, in comparison to the HHIs of all qualifying stocks. We see that the HHIs for both the winner and the loser portfolios exhibit large time series variation, and such variation is more pronounced in the first half of the sample. Although both

[7] We classify stocks into ten major industry groups based on the first two digits of their SIC code: agriculture, forestry, and fishing (0100–0999), mining (1000–1499), construction (1500–1799), manufacturing (2000–3999), transportation, communications, electric, gas, and sanitary service (4000–4999), wholesale trade (5000–5199), retail trade (5200–5999), finance, insurance, and real estate (6000–6799), service (7000–8999), and public administration (9100–9729).

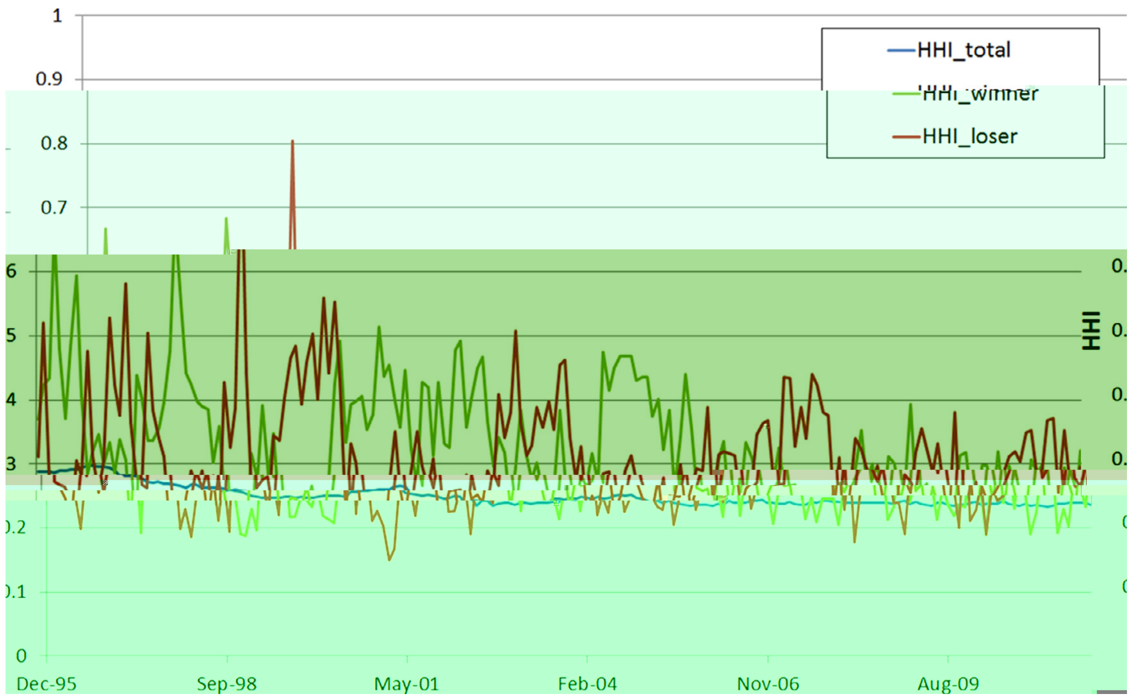

Fig. 1. Industry Concentration of the Enhanced Momentum Portfolios. This figure presents the industry concentration of the enhanced momentum portfolios. Industry concentration is measured by the

portfolios are less “diversified” relative to the all-stock portfolio, their HHIs are at ordinary level: a vast majority of the sample has an HHI smaller than 0.5. Moreover, the correlations between the winner/loser portfolios’ HHIs and the returns of the winner-minus-loser portfolio are 5.9% and 4.5%, respectively; the correlation between the HHIs of the winner/loser portfolios and the returns of the corresponding winner/loser portfolios are 1.7% and 5.9%. Such low correlations suggest that industry concentration is unlikely to be the major driver for the enhanced momentum strategy.

4.4. Lazy updating

In the benchmark strategy, the momentum rank holds constant throughout the holding months, while the option-based information diffusion speed is re-ranked for each holding month. In this section, we match the maturity of options with the holding horizon. Specifically, the implied volatility growth is calculated using options with the time-to-maturity that is equal to the holding horizon and the diffusion speed rank holds constant throughout the holding months. We present the results in Table 8. The monthly raw excess return is 1.35% with a t-statistic of 2.04 for a two-month holding horizon, and the numbers are 1.03% (t-statistic = 1.62) and m 0724 483.957 Tm .0004 Tc (and)Tj /F2 1 Tf 6.3761 0 0 6.376109 8 6.3.957 Tm .0004 Tc (and)Tj /F2 13761 294.1899

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