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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 volatility reflects informed 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 a risk-adjusted alpha of 1.78% per month over the 1996–2011 period, while a simple momentum strategy fails to perform during the same period. Moreover, Fama–MacBeth regression shows that the return spread is attributed to the interaction of the momentum effect and the correct identification of information diffusion speed with implied volatility growth.

Our results are robust to a battery of alternatives. First, although it is well-known that options are more actively traded before earnings announcements, we find that the informativeness of implied volatility growth is not limited to earnings announcements month. Second, the profitability of the enhanced momentum strategy is robust in consideration of transaction costs. Third, we show that the good performance is not driven by industry momentum (Moskowitz and Grinblatt, 1999) or several stock-level characteristics (Bandarchuk and Hilscher, 2013). Fourth, the portfolio return remains significant if we use implied volatility growth of options that have time-to-maturity equal to the holding period but with smaller magnitude. Finally, our results also hold if we use out-of-the-money options, control for the persistency of implied volatility, and use value-weighting in the portfolio construction.

Our paper adds to the momentum literature. Numerous papers have shown the existence of price momentum across asset classes, sample periods, and geographic markets.[1] Our paper, to the best of our knowledge, is the first to explain momentum profits using information from options markets. Although previous studies find that momentum is stronger when uncertainty is higher (Bandarchuk and Hilscher, 2013), our finding is different from this uncertainty explanation. We show that the high momentum profit is not driven by a mechanically finer sorting on more volatile stocks, but it is attributed to the selection of stocks with slow information diffusion speed.

Our paper is also related to the growing research that studies implications of options markets on equity returns. Our empirical approach is similar to An et al. (2014), who find that increase in call option implied volatility predicts positive underlying stocks' returns. They use a theoretical model to rationalize informed traders' choice across options markets and stock market, and explain the delayed stock price adjustment with the presence of noise traders. We take the insight of their paper and focus on the interaction between the predictive effect of option implied volatility and the momentum effect. Our finding complements their paper by showing that the momentum effect could be enhanced through selecting stocks with slow price adjustment to information. While the predictability suggested in An et al. (2014) is important, the interaction between past performance and implied volatility growth also contributes significantly to this enhancement. Besides An et al. (2014), many researchers have studied the predictive relationship between options markets and equity returns. Bali and Hovakimian (2009) find that realized volatility and implied volatility spread predicts lower future returns, whereas call and put implied volatility spread predicts higher future returns. Xing et al. (2010) find that volatility smirk has strong predictive power for future returns. Cremers and Weinbaum (2010) find that deviation from put-call parity predicts future stock returns. Atilgan et al. (2015) find that volatility spreads and expected returns are negatively correlated at the aggregate market level, suggesting information in the options markets leads that in the stock market.[2]

The remainder of the paper is organized as follows. In Section 2 we describe the data. Section 3 presents the identification of slow information diffusion stocks and the main empirical findings. We conduct a battery of robustness tests in Section 4. Section 5 concludes.

2. Data

Our data primarily come from two sources: CRSP and OptionMatrics Implied Volatility Surface. We include all common stocks that are traded on NYSE, Amex, and Nasdaq. To ensure liquidity, we exclude stocks with market capitalization that are below the 10% NYSE cutoff or have price less than five dollars at the end of formation month. After merging stocks' return data with implied volatility data from OptionMatrics, our final sample is from January 1996 to December 2011.

Panel A of Table 1 presents the descriptive statistics of common stocks and common stocks with options. The average number of stocks in CRSP that satisfies the liquidity restriction is 2762 across all years from 1996 to 2011. The average market capitalization and median market capitalization are 4702 and 887 (million USD), respectively. The CRSP-OptionMetrics-merged data set contains 1536 stocks on average, covering more than half of the listed common stocks. The average size in the merged data set is 6741 million, which is about one and a half times larger than the average size of stocks in CRSP. Note that the fraction of stocks with option contracts has expanded over time: only 15.8% CRSP stocks do not have options in 2011, whereas this number is 73.8% in 1996.

We use implied volatilities of call options with a delta of 0.5 and time-to-maturity from one to six months. Options with a delta of 0.5 are the closest to at-the-money and liquid with large trading volume. In the robustness test, we also use implied volatility

[1] Papers documenting momentum effect include Jegadeesh and Titman (1993), Jegadeesh and Titman (2001), Jegadeesh and Titman (2012), Carhart (1997), Chui et al. (2010), Asness (2011), Novy-Marx (2012), Israel and Moskowitz (2013), and Asness et al. (2013). Many papers implement double sorting on firm-level characteristics to strengthen momentum profit (Hong et al., 2000; Lee and Swaminathan, 2000; Zhang, 2006; Da et al., 2014), and (Hillert et al., 2014)). Papers that try to explain momentum effect include Daniel et al. (1998), Johnson (2002), and Sagi and Seasholes (2007).

[2] Other papers that study the role of options markets include Bhattacharya (1987), Anthony (1988), Easley et al. (1998), Cao et al. (2005), Pan and Poteshman (2006), Acharya and Johnson (2007), Cremers et al. (2008), Goyal and Saretto (2009), Roll et al. (2009), Bali et al. (2011), Roll et al. (2010), Yan (2011), Baltussen et al. (2012), Johnson and So (2012), Vilkov and Xiao (2012), Bali and Murray (2013), Muravyev et al. (2013), Stein and Stone (2013), Hu (2014), Chan et al. (2015), Kehrle and Puhan (2015), Lin and Lu (2015), Bali et al. (2016b), and Ge et al. (2016).

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 2
Momentum Profits for the 1996–2011 Period.
This table presents momentum strategy profits during the 1996–2011 period. Stocks are sorted into ten deciles according to their past J (= 3, 6, 9, 12) months' cumulative returns. We form equal-weighted portfolios for K (= 1, 3, 6, 12) months after skipping $S = 1$ month upon portfolio formation. P10 indicates the winner portfolio, P1 indicates the loser portfolio, and P10-P1 indicates the hedged winner-minus-loser portfolio. We exclude stocks with market capitalization less than the 10% NYSE cutoff or a share price less than \$5 at the formation month to ensure liquidity. Panel A reports monthly portfolio returns with associated t-statistics in parentheses using all stocks. Panel B reports monthly portfolio returns with associated t-statistics in parentheses for stocks that also have listed option contracts.

		Panel A: All stocks				Panel B: Stocks with options			
		K = 1	K = 3	K = 6	K = 12	K = 1	K = 3	K = 6	K = 12
J = 3	P1	0.56	0.49	0.45	0.67	0.48	0.31	0.33	0.58
		(0.78)	(0.70)	(0.64)	(0.98)	(0.64)	(0.43)	(0.46)	(0.87)
	P10	1.17	1.10	1.13	1.00	0.72	0.76	0.86	0.79
		(1.99)	(1.81)	(1.89)	(1.67)	(1.20)	(1.26)	(1.45)	(1.35)
	P10-P1	0.61	0.62	0.68	0.33	0.23	0.45	0.54	0.21
		(1.11)	(1.23)	(1.48)	(1.00)	(0.39)	(0.87)	(1.18)	(0.65)
J = 6	P1	0.34	0.37	0.46	0.72	0.20	0.27	0.42	0.70
		(0.47)	(0.50)	(0.63)	(1.03)	(0.26)	(0.35)	(0.57)	(1.01)
	P10	1.46	1.35	1.27	1.05	1.14	1.02	1.02	0.83
		(2.33)	(2.15)	(2.07)	(1.71)	(1.86)	(1.66)	(1.71)	(1.40)
	P10-P1	1.12	0.98	0.80	0.33	0.94	0.75	0.60	0.12
		(1.78)	(1.62)	(1.45)	(0.82)	(1.37)	(1.19)	(1.09)	(0.30)
J = 9	P1	0.48	0.49	0.61	0.87	0.45	0.44	0.59	0.89
		(0.66)	(0.67)	(0.85)	(1.27)	(0.57)	(0.57)	(0.80)	(1.28)
	P10	1.36	1.29	1.10	0.92	1.04	1.05	0.93	0.75
		(2.15)	(2.03)	(1.76)	(1.48)	(1.7)	(1.72)	(1.54)	(1.26)
	P10-P1	0.87	0.80	0.50	0.05	0.59	0.61	0.34	-0.13
		(1.36)	(1.31)	(0.92)	(0.12)	(0.86)	(0.94)	(0.60)	(-0.30)
J = 12	P1	0.53	0.61	0.76	0.99	0.41	0.55	0.73	0.98
		(0.75)	(0.87)	(1.09)	(1.46)	(0.54)	(0.74)	(1.01)	(1.43)
	P10	1.05	1.01	0.93	0.82	0.76	0.77	0.74	0.65
		(1.66)	(1.58)	(1.46)	(1.31)	(1.24)	(1.25)	(1.21)	(1.08)
	P10-P1	0.53	0.40	0.16	-0.17	0.34	0.21	0.01	-0.33
		(0.86)	(0.70)	(0.31)	(-0.38)	(0.51)	(0.34)	(0.02)	(-0.72)

The simple momentum strategy is only marginally profitable for the 1996–2011 period. Panel A shows that the returns of various momentum portfolios formed using common stocks are almost always insignificant. The return is only marginally significant when a combination of $(J = 6,\ K = 1)$ is used for portfolio formation and holding. In addition, monthly returns of most hedged momentum portfolios are smaller than 1% per month. In Panel B, we report the results based on stocks with listed options: none of the hedged momentum strategies deliver a significant return and all monthly returns are below 1% per month. Overall, a simple momentum strategy does not perform well over the two decades, and its performance is even worse for those stocks with options.

This finding is in contradiction with common wisdom about momentum. A couple of reasons may explain the disappearance of momentum profits. First, our sample period contains market crises that lead to volatile momentum performance. Jegadeesh and Titman (2012) find that the raw return of the momentum strategy is −36.50% in 2009 when the market rebounded from the financial crisis. Daniel and Moskowitz (2016) also find that the momentum strategy could have a sharp performance decline as the market rebounds. Second, stocks with options are relatively large that could have small momentum returns. The lack of profitability in momentum portfolios constructed over optionable stocks is consistent with Hong et al. (2000), who find that the profitability of momentum strategies declines with firm size.

3.2. Identification of stocks' information diffusion speed using implied volatility growth

Hong and Stein (1999) propose a theoretical explanation for momentum. According to their model, stock prices first experience under-reaction as fundamental-driven newswatchers slowly adjust to firms' gradually diffused information. Stock prices then experience over-reaction as price-driven momentum traders start trading. One empirical implication of their model is that stocks with slower information diffusion should exhibit more pronounced momentum. Various pieces of news associated with different stocks and across different time are heterogeneous in terms of their information diffusion speed. Specifically, not only the speed of stock price movement that reflects the diffusion of firm specific information can vary from one stock to another, it can also vary from one piece of information to another even for the very same stock. Therefore, momentum traders can benefit if they construct the portfolio with stocks whose prices have not fully incorporated the relevant information.

Compared to stocks' static characteristics such as size or analyst coverage (Hong et al., 2000), options provide a more timely and precise identification for stocks' information diffusion. A number of advantages of options attract informed investors to realize their superior information in the options markets instead of the stock market. If sophisticated informed investors have positive private news on a stock, they could buy call options. Therefore, call price appreciation might convey informative content about informed traders' view on the information diffusion stage of individual stocks. Consistent with this idea, Billings and Jennings (2011) find that pre earnings announcements option price change is positively related to option traders' view on the sensitivity between the stock price reaction and the earnings announcements. For example, a large increase in call option price implies informed option traders' belief that the stock price will have a large positive reaction to the potential positive earnings announcement, i.e., positive information is going to be diffused into the stock price.

While the study of Billings and Jennings (2011) focuses on earnings announcements, the very same logic can be applied to normal periods. Past cumulative returns could be used to detect stocks' in-

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 implied volatility growth at the beginning of each month throughout the rest of the holding period.

3.3. Empirical results

Table 3 presents average monthly returns for the hedged winner-minus-loser portfolios with holding period $K = 1, 3, 6$ using call option information. V_F, V_M, and V_S represent portfolios constructed by selecting stocks with fast, median, and slow information diffusion, respectively. For $K = 1$, the average excess return for the refined momentum portfolio is 1.55% per month with a t-statistic of 2.16. We also compute the risk-adjusted alphas relative to the CAPM, the Fama-French three-factor model, and a four-factor model of the Fama-French three factors plus the short-term reversal (STR) factor.[4] The four-factor alpha is 1.78% per month with a t-statistic of 2.69, which is similar in magnitude to other risk adjusted alphas. Economically and statistically significant returns remain for longer holding horizons. The four-factor adjusted alphas are 1.52 (t-statistic = 2.61) and 1.25% (t-statistic = 2.38) with a holding period of three and six months, respectively. It is worth emphasizing that almost all the momentum profit comes from the long leg. For the momentum portfolio with one-month holding period, the contribution of long leg is 1.38% per month while the contribution of short leg is only −0.17% per month.

[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%.

[4] Portfolios' beta loadings and adjusted R^2 for the four-factor model are presented in Table IA.1. Beta loadings and adjusted R^2 estimated under the CAPM or the Fama-French three-factor model are available upon request.

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. While our enhanced momentum strategy delivers larger returns than the portfolio single-sorted on call option implied volatility growth (Table IA.6), it is possible that the strong performance merely reflects an additive predictability of momentum and implied volatility growth, without an interactive effect of the two. To examine whether the interaction of the past performance and the option-based identification of slow information diffusion actually contributes to the large profits of the double-sorted momentum portfolio, we implement Fama-MacBeth regressions with the following specifications:

$$R_{i,t+1} = \beta_0 + \beta_1 PastReturn_{i,t} + \beta_2 \Delta IV^C_{i,t} + \beta_3 PastReturn_{i,t} \times \Delta\hat{IV}^C_{i,t} + \beta_4 X_{i,t} + \epsilon_{i,t}, \quad (1)$$

where $\Delta\hat{IV}^C_{i,t} = \Delta IV^C_{i,t}$ for stocks with past returns in the top fifty percentile and $\Delta\hat{IV}^C_{i,t} = -\Delta IV^C_{i,t}$ for stocks with past returns in the bottom fifty percentile. The specification of $\Delta\hat{IV}^C_{i,t}$ is consistent with our stock selection procedure in the portfolio construction. Following previous research Da et al. (2014); An et al. (2014), and Bali et al. (2016a), we choose an array of cross-sectional return determinants $X_{i,t}$, including 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 implied risk-neutral

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 earnings announcements in the holding month. Table 6 presents the monthly portfolio returns with a holding period of one month.[6] We find similar magnitude of returns relative to the

[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.

[6] Results with alternative holding periods are similar and available upon request.

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).

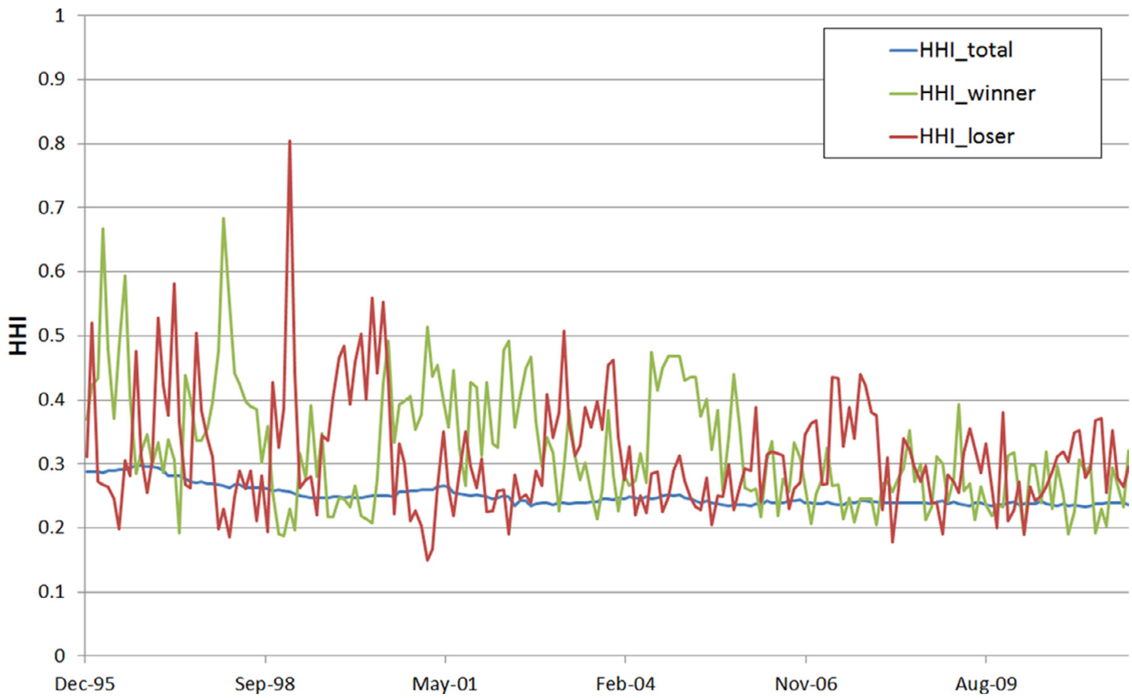

Fig. 1. Industry Concentration of the Enhanced Momentum Portfolios. This figure presents the industry concentration of the enhanced momentum portfolios. Industry concentration is measured by the Herfindahl–Hirschman index (HHI) defined in Eq. (2). The enhanced momentum portfolios are constructed following the procedure described in Section 3.2 where we fix six months for the past cumulative return calculation, skip one month, and hold the portfolio for one month. 30-day to maturity at-the-money call options are used. We exclude stocks with market capitalization less than the 10% NYSE cutoff or with price less than $5 at the end of 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%. The green line indicates the industry HHI for the enhanced winner portfolio; the red line indicates the HHI for the enhanced loser portfolio; and, the blue line indicates the HHI calculated using all stocks that pass the filters. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 8
Monthly Returns for Portfolios Based on Momentum and Call Option Implied Volatility Growth: Option Time-to-maturity Matches with Holding Horizon.
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 (sort stocks based on their price momentum, and then sort them 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 (= 2, 3, 6) months. Momentum ranking for each stock lasts for K months, and option ranking is calculated at the end of the skipping month according to weekly implied volatility growth for call options with a delta of 0.5 and a time to maturity of K months. 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 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 = 2						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	0.53	0.91	0.38	0.60	0.50	0.61	0.35	0.53	0.45	0.55	0.32	0.48	0.48	0.56
	(0.65)	(1.51)	(0.56)	(0.97)	(0.80)	(1.00)	(0.52)	(0.90)	(0.74)	(0.92)	(0.54)	(0.9)	(0.88)	(1.02)
V_M	0.33	1.18	0.85	1.03	0.99	1.11	0.77	0.94	0.90	1.02	0.53	0.66	0.67	0.76
	(0.42)	(1.85)	(1.22)	(1.61)	(1.49)	(1.74)	(1.17)	(1.61)	(1.48)	(1.74)	(0.91)	(1.30)	(1.27)	(1.44)
V_S	−0.14	1.21	1.35	1.51	1.45	1.54	1.03	1.17	1.16	1.26	0.77	0.89	0.93	0.98
	(−0.17)	(1.94)	(2.04)	(2.60)	(2.49)	(2.60)	(1.62)	(2.17)	(2.09)	(2.25)	(1.38)	(1.80)	(1.84)	(1.91)

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

	K=2						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	0.53	−0.14	−0.66	−0.64	−0.67	−0.66	−0.58	−0.56	−0.60	−0.60	−0.28	−0.25	−0.60	−0.26
	(0.65)	(−0.17)	(−3.24)	(−3.18)	(−3.29)	(−3.3)	(−3.69)	(−3.83)	(−4.13)	(−4.16)	(−2.12)	(−2.30)	(−4.13)	(−2.54)
P10	0.91	1.21	0.30	0.28	0.28	0.27	0.10	0.08	0.11	0.10	0.17	0.16	0.11	0.16
	(1.51)	(1.94)	(1.60)	(1.41)	(1.49)	(1.40)	(0.64)	(0.55)	(0.80)	(0.76)	(1.55)	(1.44)	(0.80)	(1.52)
P10-P1	0.38	1.35	0.97	0.92	0.95	0.93	0.68	0.64	0.71	0.70	0.45	0.41	0.71	0.42
	(0.56)	(2.04)	(3.24)	(2.96)	(3.17)	(3.15)	(2.98)	(2.90)	(3.37)	(3.34)	(2.40)	(2.49)	(3.37)	(2.69)

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 0.77% (*t*-statistic = 1.38) for three- and six-month holding horizons, respectively. All risk-adjusted alphas are also statistically significant across different holding horizons. Note that the power of the this lazy updating strategy comes from different sides of winner/loser stocks. Under the benchmark strategy, the marginal contribution of selecting stocks with slow information diffusion speed is similar for winner and loser stocks. Under the lazy updating strategy, the marginal contribution is stronger on the loser side: with a two-month holding period, loser stocks with slow information diffusion (V_S) have a -0.66%/month lower return than those identified to be fast diffusion (V_F), whereas the return difference is 0.30%/month for the winner stocks. Similar findings are found for $K = 3$ and $K = 6$.

We also conduct a number of other robustness tests. To keep the paper succinct, we report and discuss those results in the Internet Appendix.

5. Conclusion

To the best of our knowledge, this is the first paper that empirically investigates the source of price momentum using information from options markets. We provide empirical support for the slow diffusion model of Hong and Stein (1999). We construct a momentum portfolio by selecting stocks with slower information diffusion speed using information from options markets. We show that momentum profit is stronger in stocks with slow information diffusion, and the performance of the enhanced strategy remains strong even during periods when a simple momentum strategy fails to perform.

By double sorting winner and loser stocks using call option implied volatility growth, we find that winner stocks with large growth in call option implied volatility continue to experience strong price appreciation. For loser stocks, those with a sharp decline in call option implied volatility exhibit strong continued price depreciation. An enhanced momentum strategy is able to earn a risk-adjusted alpha of 1.78% per month for the 1996–2011 period. Moreover, the outperformance of our strategy is attributed to the interaction of the momentum effect and the selection of slow information diffusion stocks. Our results indicate that effective identification of information diffusion speed is important in exploiting the under-reaction of price to fundamental information.

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.jbankfin.2016.11.010.

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