EFA
Eastern
Finance
Association

The Financial Review 49 (2014) 765–792

The
Financial
Review

R&D Increases and Long-Term Performance of Rivals

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Abstract

We examine how a firm's research and development (R&D) increases affect its intra-industry competitors in the long run. Consistent with the R&D spillover hypothesis, when a firm unexpectedly increases its R&D spending, its intra-industry competitors experience improvements in operating performance and analyst forecast revisions and earn positive abnormal stock returns in the long run. The industry concentration, which is related to the firm's strategic reaction, is crucial in determining the magnitude of the R&D spillover effect.

Keywords: R&D, spillover, intra-industry

JEL Classifications: G30, G31

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This research is supported by a grant from the Taiwan National Science Council (NSC 99-2410-H-035-022).

1. Introduction

Research and development (R&D) spending has attracted increasing attention in the academic literature, and it is no longer considered an expense but is instead seen as a value-enhancing investment. For example, many studies show that R&D investment is a favorable strategy for the investing firm. When a firm increases its R&D outlay, it earns positive abnormal returns both in the short run (Chan, Martin and Kensinger, 1990; Szewczyk, Tsetsekos and Zantout, 1996) and in the long run (Lev and Sougiannis, 1996; Chan, Lakonishok and Sougiannis, 2001; Eberhart, Maxwell and Siddique, 2004, 2008; Hsu, 2009; Li, 2011; Chen, Yu, Su and Lai, 2012).

We explore the impact of R&D investment on rival firms. On one hand, the economic literature suggests the existence of an R&D spillover effect (Levin and Reiss, 1984; Jaffe, 1986; Bernstein and Nadiri, 1989). The R&D spillover effect indicates that an increase in R&D expenditure at a given firm positively affects other companies in the same industry.[1] In this sense the R&D effect on rivals is positive. On the other hand, Zantout and Tsetsekos (1994) find that the rivals of firms that make announcements of increases in R&D expenditures suffer statistically and significantly negative abnormal returns. Sundaram, John and John (1996) also find that the short-run market reaction to competitors varies depending on their competitive strategy measure.[2]

Lev and Sougiannis (1996) and Chan, Lakonishok and Sougiannis (2001) suggest that R&D investment is difficult to realize and to be correctly evaluated over the short run. Moreover, managers seldom announce R&D increases formally. As a result, the market might take time to fully reflect managers' investment decisions. Thus, a long-term approach is more appropriate in capturing the intangible features of R&D investment.

If the market underreacts to the *direct* future benefits of the R&D increases, which is explored by Eberhart, Maxwell and Siddique (2004), then it might also underreact to *indirect* future benefits, or the R&D spillover effect, which a firm's rivals may obtain from the firm's R&D increase. R&D increases provide a natural experiment in examining the long-run market reaction to the R&D spillover effect, a form of indirect intangible information. As a result, we expect to see the long-term abnormal returns of rivals are positive, if rivals do benefit from the knowledge inflow from the spillover effect.

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[1] Researchers explore the intra-industry effect of many types of corporate events. See Brander and Lewis (1986) for leverage; Lang and Stulz (1992) and Brewer and Jackson (2000) for bank failures; Firth (1996), Howe and Shen (1998) and Laux, Starks and Yoon (1998) for dividend changes; Ecbko (1983) and Servaes and Tamayo (2004) for mergers; and Erwin and Miller (1998) and Massa, Rehman and Vermaelen (2007) for share repurchase announcements.

[2] Competitive strategy measure is the impact of a firm's profits on changes in its competitors' revenues. The sign of measure depends on competition style: strategic substitute or complement.

Alternatively, it is possible that a firm with increases in R&D spending may gain unfriendly attention from its rivals. Increasing R&D activity may indicate to rivals that the firm is moving ahead in the race to be the first to innovate and to expand the market shares. Rival firms attempt to meet the competition by increasing their own R&D investments. Specifically, firms respond by expending resources to imitate their rivals' R&D, or to innovate with new and unique R&D investments (Beath, Katsoulacos and Ulph, 1989; Sundaram, John and John, 1996). Massa, Rehman and Vermaelen (2007) suggest that a repurchasing firm conveys a valuable signal about its undervaluation, which threatens competitors. To undo this effect, rival firms mimic the original repurchasing firm and repurchase shares themselves. Using industry concentration to proxy for strategic interaction, they suggest that mimicking behavior is less obvious in a highly competitive environment (a market with fewer strategic interactions) because firms in these industries are not significantly influenced by the actions of their competitors. The repurchase post-event abnormal returns are lower due to the responses of rivals in a concentrated product market. Based on a similar scenario, we argue that because more strategic reaction activities occur in a less competitive product market, the positive R&D spillover effect will be offset by adverse strategic reactions in the industry.[3] As a result, we expect to see the long-term abnormal returns of rivals are higher (lower) when the product market is dispersed (concentrated).

We examine the long-term market valuation of intra-industry competitors when some firms significantly increase R&D investment. Following Eberhart, Maxwell and Siddique (2004), we extract 10,916 significant R&D increases for 3,676 firms during the period 1974–2010.[4] Our findings do not resemble the short-run negative market reaction on rival firms (Zantout and Tsetsekos 1994; Sundaram, John and John 1996). Instead, we find that after a firm increases R&D spending, its rivals experience positive long-run abnormal returns.

The result is consistent with the contention that using the long-term return seems to be a more appropriate method of reflecting the intangible information embedded in R&D investments (Lev and Sougiannis, 1996; Chan, Lakonishok and Sougiannis, 2001). The abnormal returns of the rival portfolio are positively associated with the

[3] One notable example of the R&D spillover and strategic competition is the smart phone market. Apple's iPhone is first announced in 2007. The first generation of iPhones relies on the Symbian system and touch panel, developed in the early 2000s. These technologies spill over to the iPhone and increase its functions and profits. Later, other smart phone companies enter the market, leading to more active strategic reactions among smart phone vendors. This strategic competition lowers the R&D spillover benefit to iPhone, consistent with our argument that the positive R&D spillover effect is offset by adverse strategic reaction activities in the industry.

[4] We define a large R&D-increase firm as a firm that has an R&D level and a change both exceeding 5% in annual financial statements (see details in the Data section). We do not use news retrieval because news does not frequently report the R&D information of firms. For instance, there are only 201 R&D announcements in Sundaram, John and John (1996). When we pursue a long-term study, a larger sample size facilitates the return estimations.

level of R&D spending and the level of market reaction of increasing firms. These results are consistent with the intra-industry R&D spillover hypothesis.

However, these results raise the question of what kind of benefit spills over to the intra-industry rivals is due to an R&D increase. Many economic studies indicate that the R&D investment by a firm reduces its own production cost and, as a result of spillovers, other firms in the same industry also reduce costs (Bernstein and Nadiri, 1988).[5] If spillovers do lower rivals' production costs, we would expect this effect to appear in the operating performance of rivals. To answer the question, we examine whether the changes in operating performance and analysts' forecast revisions of rivals following R&D increases are improved. We find the changes in operating performance and analysts' forecast revisions of rival firms are positively related to the magnitude of R&D spending of increasing firms and the changes in profitability of increasing firms. These findings further align with the intra-industry R&D spillover hypothesis, which means that R&D increases are not only beneficial to the increasers' profitability (Eberhart, Maxwell and Siddique, 2004), but also to their intra-industry rivals (Levin and Reiss, 1984; Jaffe, 1986; Bernstein and Nadiri, 1988).

The industry concentration, which is related to the firm's strategic reaction, could affect the impact of R&D spillover effect. While research documents that managers tend to adopt public announcements as a tool to react to their rivals, it is questionable whether managers also use non-announcement channels, such as R&D investment, to strategically react to their rivals. Consistent with the findings of share repurchase announcements (Massa, Rehman and Vermaelen, 2007) and R&D increase announcements (Sundaram, John and John, 1996), we find that the higher the concentration of the industry and the higher the fraction of firms that significantly increase R&D expense over the past five years in the industry, the more likely it is that the firms in the industry will increase their R&D expense. This result suggests that the decision of corporate R&D investment is influenced by other firms' prior R&D activities in the same industry, and that this influence is more significant for concentrated industries, indicating that strategic interaction becomes stronger as the concentration in the industry increases.

When we partition our sample into groups categorized by industry concentration, the rival portfolio earns significantly positive abnormal returns in less concentrated industries and insignificant returns in concentrated industries. The influence of industry concentration also applies to the results of changes in future operating performance and analysts' forecast revisions. Our findings suggest that an R&D increase does have spillover effects on intra-industry rivals. However, such intra-industry spillover effects are stronger in less concentrated industries.

[5] For example, Levin and Reiss (1984) document that a 1% increase in the R&D spillover caused average cost to decline by 0.05%. Bernstein and Nadiri (1988) show that average cost declined by 0.2% in response to a 1% growth in R&D spillovers. Exploring profitability, Jaffe (1986) shows that a 1% increase in spillovers causes a 0.3% increase in profits.

The contribution of this paper is twofold. First, while we know much about the initial market reaction to industry competitors, no study examines the long-term stock return on industry competitors. Using the factor model technique, our paper is the first to calculate the long-run market reaction to industry competitors for R&D increase cases. Second, our paper explores how R&D spillover flows from the R&D investment. R&D benefits the investing firm and adds value to its industrial competitors.[6] In addition, strategic interaction behavior occurs in concentrated industries. This strategic interaction offsets the benefits of R&D spillover. While the R&D spillover is well documented in the economic literature, few papers investigate the R&D spillover issue in the finance literature. We fill the gap between these two areas of R&D studies.

2. Sample selection

2.1. Data

The sample includes listed stocks in NYSE/Amex/NASDAQ during the period 1974–2010.[7] Data on stock price and number of shares outstanding to compute the market value of equity (*MV*) are obtained from the CRSP database. Following Eberhart, Maxwell and Siddique (2004), stocks that unexpectedly increase R&D must jointly satisfy the following criteria: (1) R&D intensity measured by the ratio of R&D-to-assets (*RDA*, XRD/AT) and R&D-to-sales (*RDS*, XRD/SALE) of at least 5%; (2) increase in dollar R&D by at least 5% (R&D growth rate, or *RDI*); and (3) increase in ratio of R&D-to-assets (*RDAI*) by at least 5%. When we do not have detailed product price or input cost information, similar to Eberhart, Maxwell and Siddique (2004), we use the R&D increase in nominal term only.

Furthermore, we exclude noncommon stock American Depositary Receipts, Shares of Beneficial Interest, unit trusts, closed-end funds, Real Estate Investment Trusts, and financial firms, following Fama and French (1992, 1993). Sample stocks are excluded if they have the following restrictions: (1) nonpositive book equity; (2) without sales, operating income before depreciation (OIBDP), earnings before interest and taxes (OIADP), total assets (AT), or market value; (3) without industry concentration measures; (4) the firm has not appeared in COMPUSTAT for more than two years (Banz and Breen, 1986); or (5) without rival firms in a four-digit Standard Industrial Classification (SIC) industry. The final sample consists of 10,916 firm-year

[6] One recent paper by Chen, Chen, Liang and Wang (2013) also studies the stock performance of R&D firms. Our paper differs from Chen, Chen, Liang and Wang (2013) in two ways. They focus on the stock performance of R&D investing firms, while our focus is on the stock performance of rival firms of R&D investing firms. In addition, we study the R&D competition effect while they do not.

[7] Following Eberhart, Maxwell and Siddique (2004), we start our R&D sample collection from 1974 because the requirement to report R&D expenditures became effective that year (see Statement of Financial Accounting Standards No. 2). We do not exclude any specific industry.

observations, among which include 3,676 R&D increasing firms and 346 four-digits SIC industries.[8]

2.2. Definition of industry rivals

Throughout the paper, we use the four-digit CRSP SIC classification to define industry membership and to measure the industry concentration by the Herfindahl–Hirschman Index (HHI). For each sample firm, we construct its corresponding industry rival portfolio (industry portfolio, thereafter) as all firms, except the sample firm itself, are in the same four-digit SIC industry. Since we have 10,916 firm-year observations (sample firms), 10,916 matching industry portfolios are obtained. The returns on each industry portfolio are equally- and value-weighted by the lagged one-month market value. We take lagged market value as the weight because it is the latest market information available to investors.

HHI is a commonly accepted measure of product market concentration. The HHI of a given industry is the sum of the squared market share of all member firms in a four-digit SIC industry. Market share is defined as the total sales of the firm in a given year divided by the total sales of the industry in that year. The HHI is an equally-weighted moving average over the past three years. For each year, we form three groups based on HHI, where the low-concentration group contains the 30% of the industries with the lowest HHI, and the high-concentration group contains the 30% of industries with the highest HHI, and the medium-concentration group contains the remaining 40% of industries.

2.3. Summary statistics

Table 1 shows the summary statistics for R&D increasing sample firms and for their industry rivals. Panel A shows the statistics for R&D increasing sample stocks. The average (median) book value of assets of the sample firms is 875.17 (56.30) million and the average (median) sales is 712.58 (40.05) million. The average (median) market value of assets to book value of assets ratio is 2.899 (1.973) and the average (median) market value is 1,416.06 (86.85) million. The summary statistics reported here are very similar to the ratios presented in Eberhart, Maxwell and Siddique (2004). The average (median) HHI is 0.237 (0.164), suggesting that most sample firms are in less concentrated industries. Because of extreme outliers, the average *RDS* and *RDI* are over 100%.

Panel B presents the statistics for industry portfolios. The R&D-to-assets ratio, R&D-to-sales ratio, R&D growth rate, and change in R&D intensity are lower than those of R&D increasing sample firms. Finally, the average (median) number of rival firms in each industry portfolio is around 80 (48). The maximum (minimum)

[8] An interesting issue about the sample selection is why sample firms increase R&D, meaning that R&D is an endogenously determined choice. The R&D literature offers a number of studies of this issue (Himmelberg and Petersen, 1994; Ryan and Wiggins, 2002; López, 2008).

Table 1

Summary statistics

This table provides summary statistics for the sample of 10,916 R&D increases for 3,676 firms during the sample period from 1974 to 2010. *MV* is market value of equity (in million). *VA* (Tobin's *Q*) is the ratio of market value of assets to book value of assets. *RDA* is the ratio of R&D expense divided by assets. *RDS* is the ratio of R&D expense divided by sales. *RDI* is the R&D growth rate that equals the increase in R&D expense divided by R&D in beginning year. *RDAI* is the increase in *RDA*. *HHI* is the past three-year moving average HHI. Panel A provides summary statistics for significantly R&D-increase sample firms. Panel B presents statistics for sample firms' corresponding industry portfolios. Panel C reports correlation coefficients for characteristics of industry portfolios. For each sample firm, we form an equally-weighted portfolio for all rival firms, excluding itself, in a four-digit SIC industry. Panel D shows the distribution of sample firms and rival firms by 12 industry classifications identified by Fama and French (i.e., from Kenneth French's website: http://mba.tuck.dartmouth.edu/pages/faculty/ken.french). 1. Consumer nondurables: food, tobacco, textiles, apparel, leather, toys. 2. Consumer durables: cars, TVs, furniture, household appliances. 3. Manufacturing: machinery, trucks, planes, off furn, paper, com printing. 4. Energy: oil, gas, and coal extraction and products. 5. Chemicals and Allied Products. 6. Business equipment—computers, software, and electronic equipment. 7. Telephone and television transmission. 8. Utilities. 9. Wholesale, retail, and some services (laundries, repair shops). 10. Healthcare, medical equipment, and drugs. 11. Finance. 12. Other: everything else.

	Mean	Median	Std.	Min	Max	Q1	Q3
Panel A: Average firm-specific characteristic of sample firms							
Asset	875.17	56.30	4,934.64	0.30	138,898.00	17.82	186.58
Sales	712.58	40.05	3,991.80	0.00	135,592.00	10.86	147.31
MV	1,416.06	86.85	9,199.26	0.04	310,218.71	25.16	326.97
VA	2.899	1.973	3.196	0.194	51.761	1.298	3.272
RDA	0.192	0.131	0.201	0.050	5.760	0.088	0.215
RDS	7.368	0.153	260.805	0.050	25,684.400	0.092	0.331
RDI	1.120	0.374	9.881	0.050	720.739	0.198	0.754
RDAI	0.881	0.339	4.511	0.050	233.177	0.162	0.742
HHI	0.237	0.164	0.207	0.020	1.000	0.080	0.345
Panel B: Equally-weighted industry portfolios with average firm-specific characteristic							
Asset	977.79	396.16	2,758.42	1.26	96,590.89	134.96	1,057.03
Sales	729.28	280.34	1,974.96	0.00	74,312.83	123.82	852.38
MV	1,345.50	549.95	2,237.37	1.51	71,362.63	173.08	1,743.06
VA	2.939	2.752	1.611	0.469	47.546	1.939	3.684
RDA	0.140	0.126	0.100	0.000	1.506	0.078	0.170
RDS	4.432	0.233	15.249	−7.608	153.536	0.101	0.976

(Continued)

Table 1 (*Continued*)

Summary statistics

Panel B: Equally-weighted industry portfolios with average firm-specific characteristic

	Mean	Median	Std	Min	Max	Q1	Q3
RDI	0.415	0.267	1.105	−1.000	30.013	0.115	0.466
RDAI	0.285	0.148	1.134	−1.000	26.188	0.021	0.321
No. of rivals in each industry portfolio	80	48	85	2	376	21	113

Panel C: Correlation coefficients of characteristics for industry portfolios

	Asset	*Sales*	*MV*	*VA*	*RDA*	*RDS*	*RDI*	*RDAI*	*HHI*
Asset	1.00	0.90	0.52	−0.05	0.02	0.11	−0.03	−0.02	0.06
Sales		1.00	0.52	−0.07	−0.02	0.07	−0.02	−0.02	0.12
MV			1.00	0.13	0.20	0.23	−0.02	−0.03	−0.14
VA				1.00	0.43	0.18	0.08	0.03	−0.30
RDA					1.00	0.53	0.15	0.07	−0.44
RDS						1.00	0.04	0.03	−0.16
RDI							1.00	0.16	−0.15
RDAI								1.00	−0.11
HHI									1.00

Panel D: Distribution of the sample firms and rival firms by industry

	Total	1	2	3	4	5	6	7	8	9	10	11	12
Sample firms													
Observation	10,916	74	175	733	17	141	6,240	73	0	78	2,953	135	297
Percentage	100	0.68	1.60	6.71	0.16	1.29	57.16	0.67	0	0.71	27.05	1.24	2.72
Rival firms													
Observation	165,586	10,578	5,106	22,345	9,227	4,510	30,881	5,014	5,859	17,346	15,573	16,662	22,485
Percentage	100	6.39	3.08	13.49	5.57	2.72	18.65	3.03	3.54	10.48	9.40	10.06	13.58

number of rival firms in each industry portfolio is 376 (2). Panel C shows the Pearson correlation coefficients of the variables shown in Panel B. Asset is highly correlated with sales and market value. The correlation between *RDI* and *RDAI* is low. The correlation between HHI and *RDI* (*RDAI*) is −0.15 (−0.11) at the 1% (10%) significant level, suggesting that there is a negative relation between industry concentration and the magnitude of R&D increases. Panel D shows the distribution of sample firms across 12 industry codes identified by Fama and French. Consistent with Eberhart, Maxwell and Siddique (2004), most of our sample firms are in the two industries (#6 [Business equipment] and # 10 [Healthcare]). Panel D also provides a distribution of rival firms for 12 industry codes. The results suggest that we have rival firms in each industry, and that the distribution is close to uniform.

3. Empirical results

3.1. Long-run abnormal returns

We begin by examining stock market reactions through long-term return methods. The five-factor model that includes the Fama and French (1993) factors, the Carhart (1997) momentum factor, and the Pastor and Stambaugh (2003) liquidity factor are adopted as our main method for investigating the long-term stock return, as suggested in previous papers (Titman, Wei and Wie, 2004; Cooper, Gulen and Schill, 2008; Chan, Ikenberry, Lee and Wang, 2010; Chen and Wang, 2012). Since an R&D increase event is based on accounting data, we examine the long-run abnormal returns by measuring these returns at the beginning of the fourth month following the fiscal year-end in which the firm increases its R&D. That is, a three-month lag is defined to allow the market to be informed of the accounting data.

For each calendar month, we form equally- and value-weighted monthly portfolios (called "sample portfolio") of all firms that increase R&D investments by large amounts in any of the previous 60 months. Similarly, we compute the "rival portfolio" return by including industry portfolios that correspond to the sample firms in the sample portfolio. The returns on industry portfolio are equally and value weighted. The returns on the rival portfolio are equally averaged across industry portfolios. A rival portfolio return is composed of many industry portfolios, in which the industry portfolio is composed of the corresponding rival firms, except sample firm itself, in the same industry. For example, if there are N sample firms in month t, then we will have N corresponding industry portfolios, and use these N industry portfolios to form an equally-weighted rival portfolio in month t.

We estimate the intercept of a five-factor model that includes the Fama and French (1993) factors, the Carhart (1997) momentum factor, and the Pastor and Stambaugh (2003) liquidity factor for long-term abnormal stock returns:

$$r_{p,t} - r_{f,t} = \alpha + b(r_{m,t} - r_{f,t}) + sSMB_t + hHML_t + mUMD_t + qLIQ_t + \varepsilon_{p,t}, \quad (1)$$

where $r_{p,t}$ are the equally- or value-weighted portfolio (p) returns on sample firms and industry portfolios in calendar month t.[9] $r_{f,t}$ is the one-month T-bill return. $r_{m,t}$ is the CRSP value-weighted market index return. SMB_t is the return on a portfolio of small stocks minus the return on a portfolio of large stocks. HML_t is the return on a portfolio of stocks with high book-to-market (*BM*) ratios minus the return on a portfolio of stocks with low *BM* ratios. UMD_t is the return on high momentum stocks minus the return on low momentum stocks. *LIQ* is the Pastor and Stambaugh (2003) liquidity factor.[10] The intercept α in Equation (1) is the monthly abnormal returns.[11]

Since the risk level of a stock may change in response to R&D changes (Chan, Lakonishok and Sougiannis, 2001; Nam, Otto and Thorton, 2003; Berk, Green and Naik, 2004), following Eberhart, Maxwell and Siddique (2004), we use the rolling-over method to control for any potential time-varying risk in Equation (1). We use the first 60 monthly returns (i.e., from April 1975 to March 1980) of the portfolio to estimate its factor loadings, and calculate the expected portfolio return in month 61 (i.e., April 1980) based on the factor loadings estimated over the previous 60 months multiplied by their corresponding factor returns in month 61. The abnormal return in month 61 is the difference between the actual portfolio return and expected portfolio return. This step is repeated every month with rolling-over of factor loadings. The average monthly abnormal returns across time and the significance test based on time series standard errors are calculated.

Table 2 presents the intercepts (i.e., the monthly abnormal returns) of a five-factor model, including the Fama and French (1993) factors, the Carhart (1997) momentum factor, and the Pastor and Stambaugh (2003) liquidity factor. Consistent with Eberhart, Maxwell and Siddique (2004), the results show that both equally- and value-weighted long-run abnormal returns on sample stocks are significantly positive. The abnormal returns are 0.78% and 0.35% (0.68% and 0.24% for time-varying regressions) for the equally- and value-weighted methods, respectively. The abnormal returns are significant at the 1% level. The magnitudes of abnormal returns are close to those found by Eberhart, Maxwell and Siddique (2004), who find that the equally- and value-weighted alphas with the four-factor model are 0.74% and 0.53%.

In particular, the second column of Table 2 shows that the abnormal returns for the rival portfolio are significantly positive. The firm increasing R&D expenditures not only experiences positive long-run abnormal returns but also positively affects

[9] The rival portfolio is equally averaged across industry portfolios. However, the industry portfolios are equally- and value-weighted across all firms, except the sample firm itself, in the same industry. Here, a "value-weighted" rival portfolio refers to a rival portfolio composed of many industry portfolios in which rival firms in those industry portfolios are value weighted.

[10] We thank Kenneth French for his kindness in making these factor data available on his website: http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/. We also thank Pastor and Stambaugh for making their liquidity factors available on Wharton Research Data Services (WRDS).

[11] We compute abnormal returns using the Fama and French (1993) three-factor model but not tabulating the results, to save space. The empirical findings are quantitatively similar to those of the five-factor model.

Table 2

Long-term abnormal returns for significantly R&D-increasing firms and for their rivals

This table presents the five-year long run abnormal returns using the five-factor model. For the "Sample" portfolio, the calendar-time monthly portfolio return ($r_{p,t}$) is formed with stocks that have been classified as a significantly R&D-increase sample firm in any of five years. For the "All rival" portfolio, $r_{p,t}$ is formed by including industry portfolios that corresponds to sample firms in the sample portfolio. Additionally, for each sample firm, we construct its corresponding industry portfolio as all stocks, excluding the sample firm itself, in the four-digit SIC industry. The returns on industry portfolio are equally and value weighted. For "No-RD rival" portfolio, $r_{p,t}$ is formed with industry portfolios that contain only firms without expensing on R&D in following five years after the return formation month. The abnormal return is the intercept of a five-factor model that includes the Fama-French (1993) factors, the Carhart (1997) momentum factor, and the Pastor and Stambaugh (2003) liquidity factor.

$$r_{p,t} - r_{f,t} = \alpha + \beta(r_{m,t} - r_{f,t}) + sSMB_t + hHML_t + wUMD_t + qLIQ_t + e_t,$$

where $r_{p,t}$ are the equally- or value-weighted portfolio (p) returns on sample firms and rival portfolios in calendar month t. $r_{f,t}$ is the one-month T-bill return. $r_{m,t}$ is the CRSP value-weighted market index return. SMB_t is the return on a portfolio of small stocks minus the return on a portfolio of large stocks. HML_t is the return on a portfolio of stocks with high *BM* ratios minus the return on a portfolio of stocks with low *BM* ratios. UMD_t is the return on high momentum stocks minus the return on low momentum stocks. *LIQ* is the Pastor and Stambaugh (2003) liquidity factor. Numbers in parentheses are *t*-statistics.

Weighting scheme	*Sample portfolio*	*All rival portfolio*	*No-RD rival portfolio*
Panel A: Five-factor model			
Equally weighted	0.780***	0.635***	0.581***
	(4.71)	(4.94)	(2.89)
Value weighted	0.352***	0.309***	0.457***
	(2.88)	(3.30)	(2.94)
Panel B: Rolling regression			
Equally weighted	0.684***	0.556***	0.255
	(4.31)	(3.83)	(1.24)
Value weighted	0.244**	0.214**	0.083
	(2.39)	(2.26)	(0.57)

***, **, * indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

the stock prices of the other competing firms in the same industry. For all rival firms, the monthly abnormal returns are 0.64% and 0.31% based on equally- and value-weighted method,[12] which is consistent with the spillover hypothesis over a long horizon. Panel B of Table 2 shows that even if one controls the time-variant risk, the rival portfolio still shows positive abnormal returns of 0.56% and 0.21% for equally- and value-weighted method.

[12] The extent of the return of the rival portfolio is comparable with the abnormal returns on the sample firm, since the rival portfolio is also likely to contain stocks which unexpectedly increase R&D expense.

One may argue that the rival portfolio earns positive abnormal returns because rivals also invest in R&D. To address this concern, we construct a "no-RD rival" portfolio, in which industry portfolios contain only rival firms with zero expenses on R&D in the five years following the return formation month. When we control for such R&D investment levels, the abnormal returns fall further, as shown in the third column of Table 2. However, we still find significantly positive abnormal returns (0.58% and 0.46% for equally- and value-weighted, respectively). Even after controlling for R&D-investing activities by intra-industry rivals, the R&D spillover effect remains.

3.2. The influence of strategic reaction

We investigate whether the R&D spillover effect is conditional on the product market structure. First, we examine how the extent of the strategic reaction in an industry influences a firm's decision on the increase in the R&D expense. We use a Probit regression to study whether the competition or the strategic reaction affects the R&D increase decision.

The dependent variable is an indicator that equals 1 if the firm that has R&D intensity (measured by the ratio of R&D-to-assets (*RDA*, XRD/AT) and R&D-to-sales (*RDS*, XRD/SALE) of at least 5% significantly increases dollar R&D by at least 5% (*RDI*) and increases its ratio of R&D-to-assets (*RDAI*) by at least 5%. The *R&D increase wave* term is computed as the ratio of total number of firms that significantly increase R&D expense (i.e., their *RDAI* and *RDI* by at least 5% and their *RDA* and *RDS* by at least 5%) over the past five years in the four-digit industry to the total number of firms in that industry. We use an interaction term *Concentration* × *R&D increase wave* to capture the strategic behavior in which a firm might increase R&D to respond to its rivals' R&D investment in a given competition environment.

Table 3 presents the average Probit regression coefficient from annual regressions with significance tests based on Fama-MacBeth *t*-statistics adjusted by the Newey–West method. The results of Model 1 suggest that the probability of increasing R&D is significantly and negatively determined by the level of industry concentration (*Concentration*), profitability (*ROA*), and the firm's own *MV* and *BM* ratio, and positively affected by investment opportunity (Tobin's *Q*). Model 2 of Table 3 indicates the probability of increasing R&D is positively associated with R&D activities of other firms in the same industry over the past five years (*R&D increase wave*). More importantly, the coefficient of the *Concentration* × *R&D increase wave* term is 4.19 (Model 3), which is significant at the 1% level. This result indicates that the higher the concentration of the industry and the higher the total number of firms that significantly increase R&D expense over the past five years in the industry, the more likely it is the firms located in that industry increase their R&D expense. As these findings are based on public announcement data (Sundaram, John and John, 1996; Massa, Rehman and Vermaelen, 2007), the accounting data (non-announcement data) also shows that firms use R&D increases as a means

Table 3

Probit regression of indicator for large increases in R&D

This table presents the average Probit regression coefficient from annual regressions with significance tests based on Fama–MacBeth *t*-statistics which is adjusted by Newey–West method. The dependent variable is defined as the indicator that equals 1 if the firm that has R&D intensity (measured by the ratio of R&D-to-assets [*RDA*, XRD/AT] and R&D-to-sales [*RDS*, XRD/SALE] of at least 5% significantly increases in dollar R&D by at least 5% [RDI] and increases in ratio of R&D-to-assets [RDAI] by at least 5%). The *R&D increase wave* term is computed as the ratio of total number of firms that significantly increase R&D expense (i.e., their *RDAI* and *RDI* by at least 5%) over past five years in the four-digit industry to the total number of firms in that industry. *MV* is logarithm of market value of equity (in million). *BM* is defined as logarithm of ratio of book to market equity. *ROA* is measured as operating income before depreciation (OIBDP) scaled by asset (AT). The remaining variables are defined as in Table 1. The industry dummies are based on the four-digit SIC code. We winsorize all variables at top-bottom 1% in distribution. Numbers in parentheses are *t*-values.

Model	1	2	3
Intercept	−1.1670***	−2.0360***	−1.2963***
	(−19.99)	(−36.25)	(−11.70)
Concentration	−0.8578***		−2.3650***
	(−11.26)		(−21.46)
R&D increase wave		1.9768***	
		(14.52)	
Concentration × R&D increase wave			4.1913***
			(14.36)
Logarithm of MV	−0.0155**	−0.0139**	−0.0198***
	(−2.24)	(−2.35)	(−3.20)
Logarithm of BM	−0.1604***	−0.1254***	−0.1408***
	(−12.66)	(−10.28)	(−11.64)
ROA	−0.5170***	−0.4166***	−0.4555***
	(−11.68)	(−10.33)	(−10.96)
Tobin's Q	0.0064*	0.0031	0.0044
	(1.84)	(0.98)	(1.33)
Industries dummies	Yes	Yes	Yes
N	130,594	130,594	130,594

***, **, * indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

of strategic interaction, especially firms in concentrated industries. Furthermore, Table 3 also indicates that firms with smaller market capitalization and lower *BM* ratio (growth firms) are more likely to increase their R&D expense. However, profitability is negatively related to the likelihood of increasing R&D expense.

Next, we use the degree of industry concentration to proxy for the extent of strategic interaction. We partition our sample into three subsamples based on industry concentration measured by HHI. Sample stocks with high (low) industry concentration are identified by sorting all sample stocks within each year on HHI and selecting those falling in the top (bottom) 30% of the sample.

Table 4

Long-term abnormal returns for rival portfolios sorted by industry concentration

This table presents the five-year long run abnormal returns of rival portfolio sorted by industry concentration and estimating the intercept of a five-factor model that includes the Fama-French (1993) factors, the Carhart (1997) momentum factor, and the Pastor and Stambaugh (2003) liquidity factor. The rival portfolio is equally averaged across industry portfolios. However, the industry portfolios are equally and value weighted across all firms, except sample firm itself, in the same four-digit CRSP SIC industry. Hence, an equally-weighted (value-weighted) rival portfolio here refers to a rival portfolio composed of many industry portfolios in which rival firms in those industry portfolios are equally (value) weighted. Industry concentration is measured by HHI. Each year, we sort rival portfolios into *Low HHI*, *Medium HHI*, and *High HHI* categories based on a 30–40–30 partition on *HHI*. Numbers in parentheses are *t*-statistics.

Weighting scheme	*Low HHI*	*Medium HHI*	*High HHI*
Panel A: Five-factor model			
Equally weighted	0.673***	0.474***	0.275
	(5.01)	(3.36)	(1.55)
Value weighted	0.337***	0.216**	−0.042
	(3.15)	(1.96)	(−0.36)
Panel B: Rolling regression			
Equally weighted	0.601***	0.392**	0.223
	(3.99)	(2.56)	(1.43)
Value weighted	0.264***	0.062	−0.053
	(2.60)	(0.56)	(−0.42)

***, **, * indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

The strategic reaction hypothesis predicts that the long-term abnormal returns of rivals should be smaller in a concentrated industry. Panel A of Table 4 shows significantly positive abnormal returns for the rival portfolio in less concentrated industries. The monthly abnormal returns over five years post-event are 0.67% and 0.34% of equally- and value-weighted returns, respectively. Instead, in concentrated industries, the abnormal returns for the rival portfolios are not significant. The result is consistent with the argument that because of the strategic reaction behavior, R&D spillover effect is significantly influenced by product market competition. The implications are clear: in a more competitive product market, since firms are not significantly influenced by the actions of their competitors, the strategic reactions are less serious. As a result, spillovers cause significantly positive abnormal returns for the rival portfolio. Instead, when aggressive strategic reactions exist in a less competitive market, the positive effect of spillovers might be offset by negative impact of strategic reactions, making long run abnormal returns ambiguous.

For robustness checks, Table 5 shows the results of Ibbotson's return across time and security (RATS) combined with the five-factor model for rival portfolios with different industry concentrations. Following Peyer and Vermaelen (2008), using the

Table 5

Long-term cumulative abnormal returns for rival portfolios

This table shows the average cumulative abnormal returns of the rival portfolios in percent using Ibbotson's return across time and security (RATS) method combined with a five-factor model that includes the Fama-French (1993) factors, the Carhart (1997) momentum factor, and the Pastor and Stambaugh (2003) liquidity factor. The following regression is run each event month *j*:

$$r_{p,t} - r_{f,t} = \alpha + \beta(r_{m,t} - r_{f,t}) + sSMB_t + hHML_t + wUMD_t + qLIQ_t + e_t,$$

where $r_{i,t}$ are the equally-weighted portfolio returns on industry portfolios in calendar month t that corresponds to the event month j, with $j = 0$ being the month of the beginning of the fourth month following fiscal year-end in which sample firm significantly increase its R&D. The rival portfolio is equally averaged across industry portfolios. However, the industry portfolios are equally and value weighted across all firms, except sample firm itself, in the same four-digit CRSP SIC industry. Hence, an equally-weighted (value-weighted) rival portfolio here refers to a rival portfolio composed of many industry portfolios in which rival firms in those industry portfolios are equally (value) weighted. $r_{f,t}$ is the one-month T-bill return. $r_{m,t}$ is the CRSP value-weighted market index return. SMB_t is the return on a portfolio of small stocks minus the return on a portfolio of large stocks. HML_t is the return on a portfolio of stocks with high *BM* ratios minus the return on a portfolio of stocks with low *BM* ratios. UMD_t is the return on high momentum stocks minus the return on low momentum stocks. *LIQ* is the Pastor and Stambaugh (2003) liquidity factor. The number reported are the sums of the intercepts α_j of cross-sectional regressions over the relevant event periods expressed in percentage term. The standard error (denominator of the *t*-ratio) for a window is the square root of the sum of the squares of the monthly standard errors. Abnormal returns are reported for full and subsamples based on industry concentration. Industry concentration is measured by *HHI*. For each year, we sort rival portfolio into *Low HHI*, *Medium HHI*, and *High HHI* categories based on a 30–40–30 partition on *HHI*.

		Full sample	*Low HHI*	*Medium HHI*	*High HHI*
(+1,+12)	*Equally weighted*	7.97***	8.88***	4.71***	4.45
		(33.38)	(37.92)	(6.91)	(1.47)
	Value weighted	4.13***	5.29***	−0.25	1.08
		(15.67)	(19.97)	(−0.33)	(0.58)
(+1,+24)	*Equally weighted*	16.99***	19.30***	9.31***	5.17
		(49.84)	(57.97)	(9.54)	(1.57)
	Value weighted	8.49***	10.75***	1.12	−1.96
		(22.63)	(28.33)	(1.03)	(−0.77)
(+1,+36)	*Equally weighted*	26.13***	29.74***	15.57***	5.57
		(61.84)	(72.94)	(12.35)	(1.63)
	Value weighted	12.77***	15.85***	4.36***	−9.08***
		(27.56)	(33.91)	(3.20)	(−2.92)
(+1,+48)	*Equally weighted*	34.03***	38.78***	20.96***	2.32
		(69.65)	(83.50)	(14.04)	(0.59)
	Value weighted	16.02***	19.65***	7.62***	−17.15***
		(29.77)	(36.49)	(4.74)	(−4.67)
(+1,+60)	*Equally weighted*	41.49***	47.33***	27.56***	−5.19
		(75.91)	(92.07)	(16.36)	(−1.16)
	Value weighted	18.80***	23.17***	11.18***	−29.35***
		(31.19)	(38.64)	(6.20)	(−6.96)

***indicates statistical significance at the 0.01 level.

RATS approach, stock excess returns are regressed on the five-factor for each month in event time, and the estimated intercept represents the monthly average abnormal returns for each event month. The long-run abnormal returns between one month and 60 months (*j*) after a large increase in R&D at a sample firm are adopted. The following regression is run each event month *j*:

$$r_{i,t} - r_{f,t} = \alpha_j + b_j(r_{m,t} - r_{f,t}) + s_j SMB_t + h_j HML_t + m_j UMD_t + qLIQ_t + \varepsilon_{i,t}, \quad (2)$$

where $r_{i,t}$ are the equally- and value-weighted portfolio returns on industry portfolios in calendar month t that corresponds to the event month j, with $j = 0$ being the month of the beginning of the fourth month following fiscal year-end in which there is a large increase in R&D at a sample firm. The abnormal return α_j is the result of the monthly (in event time j) cross-sectional regression. The cumulative abnormal returns in Table 5 are the sums of the intercepts of cross-sectional regressions over the relevant event periods. The standard error for a window is the square root of the sum of the squares of the monthly standard errors.

Table 5 demonstrates that over 12 (24, 36, 48, 60) months, for the full sample, the cumulative equally-weighted average abnormal returns of 7.97% (16.99%, 26.13%, 34.03%, 41.49%), are all significant at the 1% level. The results of the subsample indicate that for the low industry concentration group, the cumulative abnormal returns are all significant at the 1% level. However, most of the cumulative abnormal returns of the high industry concentration group are nonsignificant. The results of the value-weighted method display a similar pattern. The results are consistent with earlier findings using the factor models. Because of the strategic reaction behavior, the R&D spillover effect is significantly influenced by product market competition where aggressive strategic reactions exist in a less competitive market.

3.3. Cross-sectional regression analysis

We examine the determinants of the long-run abnormal returns of the industry portfolio (rival firms in the same industry). The dependent variable is the 60-month buy-and-hold abnormal returns (*BHAR*) for each industry portfolio, in which the buy-and-hold abnormal returns are controlled for *MV* and *BM* matching portfolio return. Buy-and-hold abnormal returns are calculated using *MV* and *BM* benchmark-adjusted average portfolio returns.[13]

The explanatory variables are as follows. *BHAR of sample firm* is the buy-and-hold abnormal returns of the significantly R&D-increase firm. *RDAI of sample firm* is

[13] To construct the benchmark portfolios, we sort all listed stocks into *MV* and *BM* quintiles based on the cut-off points of the NYSE stock only. This follows the work of Fama and French (1992, 1993). Next, we compute a monthly value-weighted buy-and-hold return for each of the 25 (5 × 5) fractile portfolios. The benchmark portfolios are reconstructed annually at the end of June. The monthly abnormal returns for each stock are the difference between the stock's raw monthly returns and its monthly benchmark portfolio returns.

the one-year increase in R&D-to-assets ratio of the significantly R&D-increase firm. *RDI of sample firm* is the increases in R&D growth of the sample firm, in which R&D growth is the one-year change in R&D dollar amounts scaled by R&D expense in the beginning year. *Concentration* is measured by HHI, which is the sum of squared market shares (using sales as the proxy of output) of a four-digit SIC industry. As an alternative, we use measures of *MV of sample firm*, *BM ratio of sample firm*, *Tobin's Q of sample firm*, industry dummies, and year dummies in the regressions to control for factors that may affect expected returns. *MV of sample firm* is the *MV* of the significantly R&D-increase firm. *BM ratio of sample firm* is the book value of equity divided by *MV* of the significantly R&D-increase firm. *Tobin's Q of sample firm* is the five-year average of market-to-book value of assets for firms with a large increase in R&D.

Table 6 presents the regression results. We specify Models 1 and 2 with different R&D increase variables (*RDAI of sample firm* and *RDI of sample firm*) and set Models 3 and 4 by adding concentration and interaction term to test the strategic reaction effects. Across all models, the positive intercepts suggest that as a whole, the spillover effect exists, a finding consistent with our earlier results. As for the possible determinants of R&D spillover effect, the results of Models 1 and 2 show that the *BHAR of sample firm* term is positive and highly significant across all the models, indicating that the higher the post-formation buy-and-hold abnormal returns to sample firms, the greater the buy-and-hold abnormal returns rival portfolios earn. The long-run abnormal returns of the industry portfolio are positively associated with the level of R&D increases of the sample firm. For example, the coefficients of *RDAI of sample firm* and *RDI of sample firm* are positive at the 10% significance level, at minimum. These results clearly indicate that the R&D expenditure increase has a positive spillover effect on rival firms. More importantly, the coefficient estimate of *Concentration* is significantly negative. Thus, consistent with results shown in Tables 4 and 5, the higher the industry concentration, the lower the long-run abnormal returns to industry portfolios.

When we add interaction terms into the specification, the results are consistent with the notion that the strategic reaction effect exists. For example, the negative coefficients of the interaction term over *RDAI of sample firm* × *Concentration* and the interaction term over *RDI of sample firm* × *Concentration* are negative at the 1% significance level. These results indicate that the higher the concentration of the industry and the higher the post-formation buy-and-hold abnormal returns to sample firms, the lower the subsequent buy-and-hold abnormal returns rival portfolios earn. These findings all show that the long-run performance of the rival portfolio is significantly affected by product market competition.

Table 6

Cross-sectional analysis of long-run abnormal returns to rival portfolios

This table reports cross-sectional regression results of return performance on various explanatory variables. For each sample firm, we form an equally-weighted portfolio for all rival firms, excluding itself, in a four-digit SIC industry. The dependent variable is the 60-month buy-and-hold equally-weighted abnormal returns of industry portfolios controlling for *MV* and *BM* ratio. *BHAR of sample firm* is the 60-month abnormal buy-and-hold returns of sample firms. *RDAI of sample firm* is based on sample stock's increases in its ratio of R&D to assets. *RDI of sample firm* is based on sample stock's increases in its dollar R&D. *MV of sample firm*, *BM ratio of sample firm*, and *Tobin's Q of sample firm* are the market value, *BM* ratio, and five-year average ratio of market asset to book asset of the sample stock, respectively. *Concentration* is based on the *HHI*. *BHAR of sample firm* × *Concentration* is the product of *BHAR of sample firm* and *Concentration*, and the remaining variables are defined similarly. The industry dummies are based on the four-digit SIC code. We winsorize all variables at top-bottom 1% in distribution. The standard errors are adjusted for heteroskedasticity. Numbers in parentheses are *t*-statistics.

Model	1	2	3	4
Intercept	0.4084*	0.4144*	0.3460	0.3489
	(1.74)	(1.85)	(1.28)	(1.45)
BHAR of sample firm	0.0277***	0.0275***	0.0487***	0.0487***
	(4.74)	(4.70)	(5.23)	(5.21)
RDAI of sample firm	0.0180***		0.0653***	
	(2.47)		(7.03)	
RDI of sample firm		0.0078*		0.0450***
		(1.73)		(6.59)
Concentration	−0.6267***	−0.6241***		
	(−10.65)	(−10.61)		
BHAR of sample firm × *Concentration*			−0.1002***	−0.0960***
			(−2.60)	(−2.59)
RDAI of sample firm × *Concentration*			−0.2335***	
			(−7.01)	
RDI of sample firm × *Concentration*				−0.1739***
				(−6.60)
Logarithm of MV of sample firm			−0.0216***	−0.0223***
			(−4.58)	(−4.95)
Logarithm of BM ratio of sample firm			−0.0129	−0.0113
			(−0.91)	(−1.12)
Tobin's Q of sample firm			0.0025	0.0035
			(0.57)	(0.74)
Industries dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
N	7,146	7,146	7,146	7,146
Adj. R^2	0.287	0.264	0.253	0.252
F-statistics	12.77	12.74	11.89	11.84

***, **, * indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

4. Operating performance and analysts' forecast revisions of rival portfolio

4.1. Abnormal changes in operating performance

The R&D investment by a firm reduces its own production costs and those of other firms through spillovers. The reduction of costs might be reflected in the form of increases in future cash inflows and positive market reactions, as observed in Section 3. We measure future cash flow as operating performance following the year in which sample firms unexpectedly increase R&D. If the spillover hypothesis holds, we will observe increases in operating performance for the rival portfolio in the post-event years. Furthermore, the changes in operating performance should be negatively associated with the industry concentration because of the strategic reaction effect.

We use two types of measures of operating performance. Following Barber and Lyon (1996) and Lie (2001), we use return on assets (*ROA*) as our first measure of operating performance, where *ROA* is defined as operating income before depreciation (OIBDP) scaled by assets (AT). We use profit margin (*PM*) as our second measure of operating performance, defined as the earnings before interest and taxes (*EBIT*, OIADP) divided by sales (SALE). Barber and Lyon (1996) recommend the use of changes instead of levels to investigate unexpected performance because tests based on changes are more powerful than those based on levels. To mitigate the concern of systematic comovements, we further define abnormal changes in operating performance of the industry portfolio (rival firms in the same industry) as the deviation of its changes in operating performance from those of the median industry in the economy.

Table 7 presents the regression analysis of the abnormal changes in long-run operating performance for rival portfolios. As in the analysis in Table 6, we examine the post-event long-run operating performance of the industry portfolio and its determinants. The dependent variable is the five-year average post-event abnormal changes in operating performance (*ROA* for Models 1 and 2 and *PM* for Models 3 and 4) of each industry portfolio.

The independent variables are as follows. *Ave. changes in ROA* (*PM*) *of sample firm* is the five-year average abnormal changes in *ROA* (profit margin) for sample stocks after an unexpected increase in a firm's R&D. *MV of sample firm*, *BM ratio of sample firm*, and *Tobin's Q of sample firm* are the market value, *BM* ratio, and five-year average ratio of market assets to book assets of the sample firm, respectively. The remaining independent variables are defined as in Table 6.

First, for the first two columns in Table 7, the intercept indicates that the industry portfolio experiences positive abnormal changes in *ROA* following the R&D increase year. The long-run post-event changes in *ROA* of industry portfolio are positively associated with the level of R&D increases by the sample firm. For example, the coefficients of *RDAI of sample firm* are positive at the 5% significance level. The

Table 7

Cross-sectional analysis of abnormal changes in long-run operating performance of rivals

This table reports cross-sectional regression results of rival's abnormal changes in long-run operating performance (*OP*) on various explanatory variables. For each sample firm, we form an equally-weighted portfolio for all rival firms, excluding itself, in a four-digit SIC industry. The dependent variable is the post-formation five-year average of abnormal changes in *ROA* and *PM* of industry portfolios. *RDAI of sample firm* is based on sample stock's increases in its ratio of R&D to assets. *RDI of sample firm* is based on sample stock's increases in its dollar R&D. *Ave. chg. in ROA (PM) of sample firm* is the five-year average of abnormal changes in *ROA* (*PM*) for sample stock after unexpectedly increasing its R&D. *MV of sample firm*, *BM ratio of sample firm*, and *Tobin's Q of sample firm* are the market value, *BM* ratio, and five-year average ratio of market assets to book assets of the sample stock, respectively. *Concentration* is based on the *HHI*. The industry dummies are based on the four-digit SIC code. We winsorize all variables at top-bottom 1% in distribution. The standard errors are adjusted for heteroskedasticity. Numbers in parentheses are *t*-statistics.

	OP = *ROA*		*OP* = *PM*	
Model	1	2	3	4
Intercept	0.0068**	0.0070**	−0.0560	−0.0634
	(2.22)	(2.28)	(−0.24)	(−0.27)
RDAI of sample firm	0.0004**		0.0269	
	(2.33)		(0.65)	
RDI of sample firm		0.0004		0.0758**
		(1.33)		(2.24)
Concentration	−0.0061**	−0.0060***	−0.2046*	−0.1328
	(−3.85)	(−3.77)	(−1.66)	(−0.99)
Ave. chg. in OP. of sample firm	0.0150***	0.0163***	0.2129**	0.2145***
	(2.75)	(3.38)	(2.49)	(2.64)
RDAI of sample firm × *Concentration*	0.0000		0.0112	
	(−0.03)		(0.11)	
RDI of sample firm × *Concentration*		−0.0001		−0.0836
		(−0.12)		(−0.95)
Ave. chg. OP. of sample firm × *Concentration*	−0.0227*	−0.0229**	−0.1204	−0.1206
	(−1.89)	(−2.46)	(−0.40)	(−0.40)
Logarithm of MV of sample firm	−0.0007***	−0.0007***	0.0148	0.0132
	(−5.38)	(−5.73)	(0.93)	(0.85)
Logarithm of BM ratio of sample firm	−0.0000	0.0000	0.0830	0.0808
	(−0.03)	(−0.04)	(1.31)	(1.28)
Tobin's Q of sample firm	0.0004	0.0004	0.0177	0.0055
	(0.54)	(0.50)	(0.19)	(0.05)
Industries dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
N	7,108	7,108	7,113	7,113
Adj. R^2	0.293	0.293	0.174	0.175
F-statistics	12.92	12.92	6.58	6.61

***, **, * indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

coefficient of *RDAI of sample firm* is 0.0004 of Table 7, which roughly implies that a one unit increase in the *RDAI of sample firm* is associated with a 0.39 million increase (0.0004 times 977.79 million of average book asset) in the abnormal earnings of rivals, after controlling for the industry effect. Since changes in abnormal *ROA* are usually small, expressed in decimals, the effect of *RDAI of sample firm* is economically significant.[14] We argue that R&D investment is not only beneficial to R&D increasers but also to their intra-industry rivals. Thus, if a spillover effect of R&D exists, R&D increasers with higher improvements in post-event profitability will experience higher increases in the future profitability of their rival firms. The positive coefficient of *Ave. changes in ROA of sample firm* shows that the higher the increase in the profitability of sample stocks, the higher the increase in the long-run operating performance of industry portfolios. The result clearly suggests that the R&D increases are beneficial to rivals.

Second, the coefficient estimate of *Concentration* is significantly negative, implying that the higher the concentration of the industry, the lower the long-run operating performances of industry portfolios. Furthermore, when we add interaction terms to the specification, the results are also consistent with the strategic reaction hypothesis. The negative coefficients of interaction term over *Ave. chg. OP. of sample firm* × *Concentration* (around −0.023 in Models 1 and 2) indicate that the higher the profitability of the sample firm and the higher the concentration of the industry, the lower the long-run operating performances of industry portfolios. These findings are consistent with the strategic reaction effect. In Models 3 and 4, we adopt *PM* as the profitability measure. *PM* can sometimes be very volatile and does not consider the cost-saving ability of firms, yet *PM* is still a popular operating performance indicator. We find that the results based on profit margin (*PM*) have the same direction as that of *ROA*. However, these results are weak.

4.2. Analysts' forecast revisions

For robustness, in addition to the post-event operating performance of the rival portfolio, we use changes in analysts' forecast of future *EPS* after the sample firm's R&D increases. We use revisions in forecasts as another measure of abnormal changes in earnings expectation (Grullon and Michaely, 2004). Following Brous and Kini (1993), we define the abnormal revision in *EPS* forecast (AFR_t) in month t as

$$AFR_t = (FR_t - E(FR_t))/PRICE, \tag{3}$$

where FR_t is the median change in analysts' *EPS* forecast from month $t-1$ to t, *PRICE* is the stock price at the beginning of a calendar year of forecast revision, and $E(FR_t)$ is the average change in analysts' *EPS* forecasts during all the months for

[14] For example, the average change in abnormal ROA for period of 1974 to 2001 is 0.08% for R&D increase cases (Eberhart, Maxwell, and Siddique, 2004, Table 7).

Table 8

Cross-sectional analysis of changes in analysts' EPS forecast revisions of rivals

This table reports cross-sectional regression results of rival's long-run analysts' *EPS* forecast revisions on various explanatory variables. For each sample firm, we form an equally-weighted portfolio for all rival firms, except itself, in a four-digit SIC industry. The abnormal *EPS* forecast revision is defined as:

$$AFR_t = (FR_t - E(FR_t))/PRICE,$$

where FR_t is the median change in analysts' *EPS* forecast from month $t-1$ to t, *PRICE* is the stock price at the beginning of a calendar year of forecast revision, and $E(FR_t)$ is the average change in analysts' *EPS* forecasts during all the months for which *EPS* forecasts are available on IBES, excluding the period of the forecasting year. The dependent variable is the post-event 60-month average of abnormal analysts' *EPS* forecast revisions of industry portfolios. The rest of variables are defined as in Table 7. The industry dummies are based on the four-digit SIC code. We winsorize all variables at top-bottom 1% in distribution. The standard errors are adjusted for heteroskedasticity. Numbers in parentheses are *t*-statistics.

Model	1	2	3	4
Intercept	0.00006	0.00007	0.00009	0.00009
	(0.62)	(0.63)	(0.77)	(0.78)
RDAI of sample firm	0.00002*		0.00001*	
	(1.77)		(1.65)	
RDI of sample firm		0.00002**		0.00001*
		(2.49)		(1.72)
Concentration	−0.00006*	−0.00006*		
	(−1.74)	(−1.74)		
Ave. chg. in ROA of sample firm	−0.00005	−0.00002		
	(−0.60)	(−0.28)		
RDAI of sample firm × Concentration			0.00002	
			(1.23)	
RDI of sample firm × Concentration				0.00003
				(1.35)
Ave. chg. ROA of sample firm × Concentration			−0.00014	−0.00011
			(−0.10)	(−0.12)
Logarithm of MV of sample firm			−0.00001	−0.00001
			(−0.94)	(−1.03)
Logarithm of BM ratio of sample firm			−0.00000	−0.00000
			(−0.19)	(−0.10)
Tobin's Q of sample firm			0.00000	0.00000
			(0.79)	(0.80)
Industries dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
N	5,739	5,739	5,739	5,739
Adj. R^2	0.187	0.187	0.187	0.188
F-statistics	6.27	6.29	6.18	6.22

***, **, * indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

which *EPS* forecasts are available on Institutional Brokers Estimate System (IBES), excluding the period of the forecasting year.

Table 8 reports the cross-sectional regressions of abnormal analysts' forecast revisions in *EPS* on various variables. We specify Models 1 and 2 with different R&D increase variables (*RDAI of sample firm* and *RDI of sample firm*) and set Models 3 and 4 by adding concentration and interaction terms to test the strategic reaction effects. The dependent variable is the post-event 60-month average of abnormal analysts' *EPS* forecast revisions of industry portfolios. The remaining independent variables are defined as in previous tables.

The evidence indicates that the long-run averages of abnormal analysts' forecast revisions of industry portfolio are positively associated with the level of R&D increases of sample firms. For example, the coefficients of *RDAI of sample firm* and *RDI of sample firm* are positive and significant at the 10% level, at minimum.[15] The result clearly suggests that the R&D increases have spillover effects on rival firms. On the other hand, the coefficient estimates of *Concentration* are roughly −0.00006 and are statistically significant at the 10% significant level. Thus, the higher the concentration of the industry, the less the long-run profitability industry portfolios earn. Yet, we find there is little effect that interaction variable over concentration and R&D increase relating variable is significant. It is plausible that analysts are slow in responding to the strategic reaction and its impact on firm's EPS.

5. Alternative definitions of rival firms

In some industries rivalry and strategic interaction involves small numbers of competitors with comparable size and market powers (Coke vs. Pepsi, Intel vs. AMD). We examine whether the spillover effect and strategic interaction remains once we control for various characteristics identified in the earlier literature as factors with significant impact on returns.

For each sample firm, we construct its corresponding industry portfolio as matching rival firms, except the sample firm itself, in the same four-digit SIC industry. Within each corresponding industry rival portfolio, the matching rival firms are identified as those firms that match the R&D increasing firms on the basis of the same ranks of characteristics such as *MV*, *BM* ratio, and *ROA*. As before, the returns on the rival portfolio are equally averaged across industry portfolios. The ranks of *MV*/*BM* are based on independent sorting of all stocks into 5 × 5 *MV* and *BM* ratio classifications, and the ranks of *MV*/*BM*/*ROA* are based on independent sorting all stocks into 3 × 3 × 3 *MV*, *BM* ratio, and *ROA* groups. The tests on alternative

[15] Although the coefficient of *RDAI of sample firm* in Model 1 of Table 8 is 0.00002 which looks tiny, the small coefficient could be reasonable. Generally, abnormal forecast revision is usually small, for example, Grullon and Michaely (2004) show that averages of forecast revisions range from −0.04% to −0.1% in repurchase cases. Hence, the small amount of abnormal forecast revision may naturally yield a smaller coefficient.

Table 9

Long-term abnormal returns for matched rivals

This table presents the five-year long run abnormal returns by using the five-factor model. For the rival portfolio, $r_{p,t}$ is formed by including industry portfolios that corresponds to sample firms in the sample portfolio. Additionally, for each sample firm, we construct its corresponding industry portfolio as all stocks, excluding the sample firm itself, in the four-digit SIC industry. Within the corresponding industry portfolio, the matching rival firms are identified as those firms that match the R&D increasing firms on the basis of the same ranks of characteristics, for example, *MV*, *BM* ratio, and *ROA*. The returns on the rival portfolio are equally averaged across industry portfolios. The ranks of *MV*/*BM* are based on independent sorting all stocks into 5 × 5 *MV* and *BM* ratio classifications, and the ranks of *MV*/*BM*/*ROA* depend on independent sorting all stocks into 3 × 3 × 3 *MV*, *BM* ratio, and *ROA* groups. The returns on industry portfolio are equally and value weighted. For No-RD rival portfolio, $r_{p,t}$ is formed with industry portfolios containing only firms without expensing on R&D in following five years after the return formation month. The abnormal return is the intercept of a five-factor model that includes the Fama-French (1993) factors, the Carhart (1997) momentum factor, and the Pastor and Stambaugh (2003) liquidity factor.

$$r_{p,t} - r_{f,t} = \alpha + \beta(r_{m,t} - r_{f,t}) + sSMB_t + hHML_t + wUMD_t + qLIQ_t + e_t,$$

where $r_{p,t}$ are the equally- or value-weighted portfolio (p) returns on sample firms and rival portfolios in calendar month t. $r_{f,t}$ is the one-month T-bill return. $r_{m,t}$ is the CRSP value-weighted market index return. SMB_t is the return on a portfolio of small stocks minus the return on a portfolio of large stocks. HML_t is the return on a portfolio of stocks with high *BM* ratios minus the return on a portfolio of stocks with low *BM* ratios. UMD_t is the return on high momentum stocks minus the return on low momentum stocks. *LIQ* is the Pastor and Stambaugh (2003) liquidity factor. Industry concentration is measured by *HHI*. Each year, we sort rival portfolios into *Low HHI*, *Medium HHI*, and *High HHI* categories based on a 30–40–30 partition on *HHI*. Numbers in parentheses are t-statistics.

Weighting scheme	*All rival*	*No-RD rival*	*Low HHI*	*Med HHI*	*High HHI*
Panel A: Rival firms matched with MV/BM ranks/five-factor model					
Equally weighted	0.688***	0.634***	0.689***	0.596***	0.099
	(4.75)	(3.45)	(4.45)	(3.55)	(0.30)
Value weighted	0.195*	0.394**	0.187	0.269	−0.263
	(1.66)	(2.19)	(1.48)	(1.62)	(−0.83)
Panel B: Rival firms matched with MV/BM ranks/rolling regression					
Equally weighted	0.608***	0.456**	0.643***	0.462**	0.150
	(3.94)	(2.24)	(4.16)	(2.55)	(0.53)
Value weighted	0.110	0.187	0.076	0.196	−0.201
	(0.98)	(1.08)	(0.67)	(1.33)	(−0.75)
Panel C: Rival firms matched with MV/BM/ROA ranks/five-factor model					
Equally weighted	0.664***	0.472*	0.696***	0.532***	0.488
	(4.36)	(1.91)	(4.25)	(2.83)	(1.41)
Value weighted	0.197	0.229	0.211	0.209	0.195
	(1.55)	(0.99)	(1.53)	(1.25)	(0.82)
Panel D: Rival firms matched with MV/BM/ROA ranks/rolling regression					
Equally weighted	0.581***	0.408*	0.622***	0.466**	−0.050
	(3.48)	(1.89)	(3.71)	(2.12)	(−0.10)
Value weighted	0.111	0.155	0.109	0.183	−0.375
	(0.86)	(0.71)	(0.84)	(1.00)	(−0.78)

***, **, * indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

rival portfolio formation provide additional robustness checks to support the major findings of this paper.[16]

Table 9 provides long-term abnormal returns for different types of rival portfolios matched with *MV*, *BM* ratio, and *ROA*. The results of Panels A and C indicate that for the "All rival" portfolio, the monthly equally-weighted abnormal returns are all significantly positive at the 1% level, which is consistent with the spillover hypothesis over a long horizon. The nonsignificant value-weighted results, which are matched with sample firms' characteristics, suggest that spillover effects seem to be driven by firms with small canalizations. The average *MV* rank of R&D increasing firms is about 1.91 (rank 1–5, from smallest to biggest), indicates most R&D increasing firms are small firms. Panels B and D of Table 9 show that even when we control for the time-variant risk, the "All rival" portfolio still shows positive equally-weighted abnormal returns. For the "No-RD rival" portfolio, in which industry portfolios contain only rival firms with zero expense on R&D in the five years following the return formation month, the abnormal returns in third column of Table 9 suggest that there are positive equally-weighted abnormal returns, even after controlling for time-varying risk.

Furthermore, the results of subsamples based on industry concentration measured by HHI are consistent with the strategic reaction hypothesis, which states that because of the strategic reaction behavior, R&D spillover effect is significantly influenced by product market competition. For example, the results of matched rivals indicate that the long-term positive equally-weighted abnormal returns of rivals are smaller in a concentrated industry, and spillover effects are significant in less concentrated industries.

6. Conclusion

Previous studies investigate the long-run stock returns of R&D increases (Eberhart, Maxwell and Siddique, 2004). However, the long-term impact of R&D increases on intra-industry competitors remains a question. Particularly, since the R&D investment is not easily realized and difficult to correctly value over the short run, the results of R&D increase announcements on intra-industry competitors may be misleading. Moreover, managers seldom announce R&D increases formally. Thus, there may be a large time gap between a firm's investment and the market's perception. As a result, the market might take time to fully reflect managers' investment decisions. Therefore, a long-term method is more appropriate for capturing the intangible features of R&D investment.

This paper contributes to the literature by investigating the long-term market valuation of competitors when a firm significantly and unexpectedly spends on R&D. We find that when firms significantly increase their R&D expense, both the firms increasing R&D and their intra-industry competitors experience positive abnormal

[16] We thank the referee for this suggestion.

stock returns in the long run. Industry competitors experience 0.70% and 0.37% abnormal returns per month by equally-weighted and value-weighted five-factor model, respectively. The abnormal returns of the rival portfolio are positively associated with the level of R&D spending by sample firms and the magnitude of market valuation by sample firm. We find consistent evidence that intra-industry competitors experience positive abnormal changes in their operating performance. These results are consistent with the intra-industry R&D spillover effect. Our evidence suggests that the spillover effect is caused by firms that significantly increase R&D expenditures. However, the market is slow to incorporate this intangible information into stock prices, further supporting the argument of Daniel and Titman (2006) that investors misreact to this type of information.

In addition, we find that the higher the concentration of the industry and the higher the ratio of total number of firms that significantly increase R&D expenses over past five years in the industry, the more likely it is that the firms located in that industry will increase their R&D expense. That is, the strategic interaction becomes stronger as the concentration of the industry increases. The long-run abnormal returns are negatively associated with the industry concentration, which is related to the extent of market competitiveness. As a product market becomes more dispersed and prone to be perfectly competitive, the R&D spillover effect becomes stronger, leading to positive abnormal returns of intra-industry competitors. By contrast, the abnormal returns of firms making large R&D increases and of their rival firms is not significant when the product market is less competitive and firms more aggressively react to the product market strategies adopted by other firms. This negative relation between the abnormal returns and the industry concentration is interpreted as support for the strategic reaction effect. Overall, the results of abnormal changes in operating performance and revisions in forecast expectation support the notion that the R&D spillover effect exists. However, the degree of market competition is crucial in determining the magnitude of the R&D spillover effect.

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