Aggressive R&D investments in pre-IPO years: the signalling explanation

Abstract

Relying upon the signalling theory in the IPO literature, we hypothesize that companies are likely to make an aggressive investment in R&D activities in pre-IPO years to signal future growth potential to the IPO market. We focus on *abnormal* R&D expenditures in pre-IPO years as a proxy for the signal. Based on a sample of IPOs during 1980-2016, we find the following. First, companies invest more aggressively in R&D activities in pre-IPO years. Second, investors price the abnormal R&D spending in pre-IPO years into the IPO first-day market value and post-IPO stock returns. Third, the abnormal R&D activities generate more patents and patents with higher impact, which appear to be a channel through which companies grow in sales and market value in post-IPO years. Collectively, our findings indicate that "good private companies" make aggressive R&D spending in pre-IPO years as a credible signal of a high-growth potential, which successfully generates innovative outputs and sales growth in the post-IPO period. Our evidence sheds light on the real benefits of abnormal R&D activities before going public but contrasts to the view that companies use earnings management opportunistically in the IPO market.

Keywords: Abnormal R&D expenditures; Initial public offerings; Signaling; Innovation; Growth

Data availability: Data are available from sources identified in the text.

1. Introduction

Information differences between companies and investors in the capital market often lead to the information or "lemons" problem (Healy and Palepu 2001). Analyzing the role of signals within the IPO process, Leland and Pyle (1977) show how companies with favorable prospects and higher possibilities of success ("good companies") should always send clear signals to the market when going public to separate themselves from bad ones in the IPO market due to high information asymmetry (for example, the owner keeping control of a significant percentage of the company shares). If no signal is sent to the market, significant asymmetric information will result in adverse selection in the IPO market. To be reliable, a signal should be prohibitively too costly to be mimicked by "bad companies" and rational investors can clearly infer the value of the signal and price it accordingly in the IPO market. The signaling theory helps explain some anomalies in the IPO literature. In particular, Fan (2007) finds that good companies use ownership retention and discretionary accruals as joint signals in the IPO market to distinguish themselves from bad ones.[1] Allen and Faulhaber (1989) design a model showing that better-informed companies use IPO underpricing to signal their quality to investors.

Prior IPO studies show that companies invest more aggressively prior to IPO (Pagano et al. 1998) and primarily use IPO proceeds to repay debt due to the aggressive investments (Leone et al. 2007). Since most R&D expenditures are not allowed to be capitalized under the current GAAP, investing in R&D activities is conceptually costly to IPO companies as it leads to lower reported earnings before going public. This cost can be recouped by companies with favorable prospects ("good companies") in the future when companies experience increased growth and generate more innovation outputs. As such, "good companies" are likely to invest in R&D

[1] Earlier studies examining earnings management of IPOs show that companies are likely to opportunistically manage accruals in the IPO market (e.g., Teoh et al. 1998a, 1998b). Recent studies, however, cast doubt on the opportunism explanation for accruals management in the IPO year and provide corroborating evidence that companies report more conservatively in pre-IPO years (e.g., Fan 2007; Ball and Shivakumar 2008; Cecchini et al. 2012; Armstrong et al. 2016).

activities more aggressively in pre-IPO years, so that the cost is prohibitively too high to be mimicked by "bad companies". With such costly signal, rational investors will realize only "good companies" can bear this cost and thus price the signal accordingly. The literature of IPO valuation provides evidence that investors are likely to price R&D expenditures as an important valuation input during the IPO process (e.g., Hand 2003; Guo et al. 2006; Aggarwal et al. 2009).

The two streams of studies on the signaling and the IPO valuation of R&D investments motivates us to examine the following two research questions. First, relying upon the signalling theory, we examine if private companies engage in abnormally high R&D investments before going public to signal their quality of future growth in the IPO market. Second, we investigate if such aggressive R&D investments credibly signal the IPO market by testing on the first-day market value upon IPOs and post-IPO stock returns as well as future innovation outputs and growth in the post-IPO period.

To test our research questions, we focus on *discretionary* R&D expenditures rather than actual R&D expenditures that prior IPO studies frequently use, because the *discretionary* portion beyond the normal level of R&D expenditures represents managers' incentives for signaling in the IPO market.[2] We refer those firms with positive *discretionary* R&D expenditures to those of making aggressive R&D expenditures for signaling. By linking the discretionary R&D spending of IPO firms to the market pricing and future generation of innovation outputs, we shed additional light on IPO firm managers' incentives to signal their quality, opportunistically mimic other good companies, or opportunistically manage earnings. The abnormal (or discretionary) R&D

[2] While the literature of real earnings management generally adopts discretionary R&D expenditures as one of the measures of real earnings management, prior studies document mixed evidence on the opportunistic use of R&D expenditures by managers. Some provide evidence that companies are likely to cut R&D expenditures to meet the earnings benchmark in the secondary market (See, e.g., Roychowdhury 2006; Cohen and Zarowin 2010; Zang 2012). Others argue that the cut of R&D expenditures to meet the earnings benchmark is not opportunistic but signaling superior future earnings (Gunny 2010) or correcting stock underpricing (Fang and Fu 2018**).** Nevertheless, although several studies have examined the existence of real earnings management (e.g., cutting R&D expenditures) in the secondary market, few pay attention to the IPO setting. Moreover, while prior studies focus on *negative* discretionary R&D expenditures for opportunistic earnings management, in contrast, our study focuses on *positive* discretionary R&D expenditures as a signaling proxy for aggressive R&D investments.

expenditures are calculated as the difference between actual R&D expenditures and the expected (i.e., normal) level of R&D expenditures of IPO firms in pre-IPO years. The expected level of R&D expenditures is calculated from the model in Canace et al. (2018).[3] We compare abnormal R&D expenditures between pre-and post-IPO years and also between IPOs and non-IPO companies matched by earnings performance (Kothari et al. 2005) and a propensity score by firm size, age and sales growth as Armstrong et al. (2016) propose.[4]

It is theoretically unclear whether investors recognize "abnormal" R&D expenditures beyond the normal level of R&D spending in pre-IPO years as a credible signal and price it accordingly. Our study provides empirical evidence on this important query. Our univariate and multivariate analyses indicate that private companies are likely to aggressively invest in R&D activities before going public. In specific, IPO companies have significantly larger amounts of abnormal (discretionary) R&D expenditures in pre-IPO year (Year -1) and the IPO year (Year 0). They are significantly greater than those of the matched non-IPO firms.[5] In contrast, abnormal R&D expenditures in post-IPO years are generally insignificant and decrease monotonically.

Next, we investigate three economic consequences of abnormal R&D spending in pre-IPO years. Firstly, we examine whether the market recognizes the abnormal R&D expenditures as a signal in the IPO process by testing their effects on the IPO first-day market value and post-IPO stock returns. We find that abnormal R&D expenditures in pre-IPO years are significantly and positively associated with the IPO first-day market value and the post-IPO short- and long-run stock returns (from one month to 36 months). The evidence is consistent with the signaling

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[3] While the model in Canace et al. (2018) provides reliable estimation of abnormal R&D expenditure, there is another widely-used model implemented by Roychowdhury (2006) in the literature of real earnings management to estimate abnormal discretionary expenditures. To ensure our inference does not depend on a model choice, we redo the estimation procedure using the Roychowdhury model. The results are qualitatively the same as we discuss in detail in Section 6.1.

[4] We provide another comprehensive measure of abnormal R&D expenditures by adopting a similar propensity score matching by earnings, firm size, age and sales growth. We discuss details in Section 3.

[5] We analyze abnormal R&D expenditures both in Year -1 and Year 0 (the IPO year), as companies are likely to continue investing in R&D activities up to the IPO date. In addition, most prior IPO studies focus on Year 0 due to a small sample size available in Year -1.

explanation of aggressive R&D spending. Investors clearly utilize the abnormal R&D expenditures in pre-IPO years as an "extra" valuation input beyond the normal level of R&D expenditures and price it accordingly upon the IPO and in the post-IPO years.

Secondly, we examine the real effects of aggressive R&D investments on future growth. Following Aggarwal et al. (2009) who argue that R&D investments can proxy for growth opportunities, we predict and test whether abnormal R&D expenditures in pre-IPO years are significantly and positively associated with post-IPO growth. We measure firm growth by sales growth and a price-to-sales ratio in post-IPO years, respectively. Consistent with our prediction, we find that abnormal R&D expenditures in pre-IPO years are significantly and positively associated with future sales growth and the fiscal-year-end price-to-sales ratios for Year 1 through Year 3 after the IPO.

Thirdly, we examine whether the abnormal R&D spending prior to the IPO promotes innovation outputs in the post-IPO years. Prior studies provide evidence that R&D investments are important innovation input activities that lead to future patent output (e.g., Bereskin et al. 2018). We capture the innovation outcomes in terms of the quantity and quality of granted patents and measure them by the number of successfully registered (i.e., approved) patents and the total number of forward citations received by all successful patent registrations, respectively. We expect that high discretionary R&D expenditures before going public increase the total number of registered patents and the total forward citations for Year 1 through Year 3 following the IPO. Consistent with the expectation, we find significantly positive association of abnormal R&D expenditures of Year -1 and Year 0 with the total number of registered patents and the total number of forward citations in Year 1 to Year 3 after the IPO. We consider that innovation outputs are a channel through which IPO companies effectively grow in sales and market values in the post-IPO period. Our results are robust to a choice of estimation models, measurement of abnormal R&D expenditures, matching techniques, and controlling for the normal level of R&D

and capital expenditures. Collectively, our results indicate that "good" private companies make abnormally high R&D spending in pre-IPO years as a credible signal of their quality and it actually generates innovative outputs and helps them grow in the post-IPO period.

Our study makes several contributions to the IPO literature of signalling, real activities management, and innovation. First, it contributes to the signaling literature in the IPO market by providing evidence that "good private companies" with high growth potentials are likely to use abnormally high investments in R&D activities before going public as a credible signal to distinguish themselves from other low-growth companies within the IPO process. The signal of abnormal R&D spending carries value of predicting post-IPO growth opportunities and is accordingly priced by market participants upon the IPO and after the IPOs.

Second, it contributes to the literature of real activities management in the IPO market. Utilizing the important R&D measure of real activities management, we discover the significant magnitudes of discretionary R&D expenditures in pre-IPO years that increase the IPO first-day market value and post-IPO stock returns. Such positive market responses are consistent with our findings that pre-IPO abnormal R&D spending actually promotes innovation outputs and sales growth in post-IPO years. Collectively, these findings contrast to the view that companies are likely to use earnings management opportunistically in the IPO process. This evidence is particularly important as it corroborates recent findings that companies are likely to report earnings more conservatively in the IPO market (e.g., Fan 2007; Ball and Shivakumar 2008; Cecchini et al. 2012; Armstrong et al. 2016).

Third, our study extends the prior studies that document the association between R&D investments and innovation outputs (e.g., Bereskin et al. 2018) to the IPO market. We provide evidence that aggressive R&D expenditures of private companies before going public help generate successful patents outputs and forward citations, and help them grow operational and market performance in the post-IPO years. As such, successful innovation outputs appear to be a channel through which companies grow after the IPO. Our result is in alignment with a recent evidence that private companies with more disruptive technology (e.g., the technological disruptiveness of patent) are more likely to exit through IPOs than via acquisitions (Bowen et al. 2018).

The remainder of this paper is organized as follows. Section 2 reviews the signalling literature in the IPO setting and develops research hypotheses. Section 3 discusses research design and Section 4 describes sample. Section 5 provides empirical results and Section 6 conducts robustness checks. Section 7 concludes the paper.

2. Literature Review and Hypothesis Development

Significant information asymmetries often exist between insiders (e.g., managers) and outside investors in the capital market, which will result in the "lemons" problem (Healy and Palepu 2001). To attempt to solve such a problem, Leland and Pyle (1977) design a model to analyze the signals within the IPO process. The authors argue that when going public, a private company with favourable prospects and higher possibilities of success ("good companies") should send a signal to the market about the value of the firm (for example, retaining part of its equity). They argue that a reliable signal should be prohibitively too costly to be mimicked by "bad companies" and rational investors realize only "good companies" are able to bear this cost and can correctly infer firm value from the signal in the IPO market.

The signalling theory helps explain some anomalies in the IPO literature. For example, Allen and Faulhaber (1989) design a model to explain the anomaly of IPO underpricing. They argue that companies with good future perspectives should signal their quality by underpricing their IPOs, as investors know that only "good companies" can recoup the cost of this signal from subsequent issues. Similarly, Fan (2007) designs a model and provides empirical evidence that "good companies" use discretionary accruals and ownership retention as joint signals to the market to distinguish themselves from bad ones.

In this study, we extend prior studies by exploring the motivation and economic consequences of aggressive R&D investments of private companies before going public as a signal of firm value in the IPO market. Relying upon the signalling literature, we predict that R&D investments of private companies are a reliable signal in the IPO market as follows. First, and perhaps more important, the investment in R&D activities is conceptually costly to private companies before going public. Under the current GAAP in the U.S., companies are not allowed to capitalize most R&D expenditures (SFAS No. 2). Instead, most spending on R&D activities has to be recognized as current expenses in the income statement (FASB 1974).[6] As a result, those companies that invest more aggressively in R&D activities are likely to face earnings decrease and consequentially increase in the cost of capital. Only companies with favourable prospects ("good companies") are likely to recoup this cost in the future when the economic benefits of R&D investment (such as increases in innovation outputs and operational and market growth) start to materialize. In contrast, "bad companies" that invest in R&D activities aggressively to imitate "good companies" in the IPO market are likely to suffer from this cost without the possibility of recouping in the future. To separate themselves from bad ones, "good companies" have an incentive to aggressively invest in R&D activities to a level that the cost is prohibitively too high for "bad companies" to mimic. In equilibrium, rational investors realize that only "good companies" can bear the cost of aggressive R&D investments to such a high level. In this sense, abnormally high R&D expenditures can be viewed as a signal to reduce the adverse selection in the IPO market.

Second, literature provides evidence that investors take R&D investments as an important value driver in the IPO market. For instance, Hand (2003) finds that investors value negative book

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[6] The one exception is software development costs, which can be capitalized under SFAS No. 86.

values in the IPO market as they indicate investments in R&D and other intangibles over the years prior to the IPO. Similarly, Guo et al. (2006) indicate that pre-IPO R&D expenditures are significantly and positively correlated with both initial underpricing and long-term performance. Aggarwal et al. (2009) find that the level of pre-IPO R&D expenditures is significantly and positively correlated with the IPO offer value and the first-day market value as it is priced as growth opportunity in the IPO market. In this sense, investors are likely to infer firm value from R&D investments accordingly in the IPO market. As a result, good private companies will have a strong incentive to invest more aggressively in R&D activities before going public to signal future growth potential to investors in the IPO market. Different from prior studies, the objective of our study is to examine the implications of aggressive R&D expenditures before going public and thus focuses on the discretionary portion of R&D expenditures to measure aggressive R&D investments beyond the normal level.

Since R&D investments are part of the corporate decision procedure, managers often have considerable discretion in deciding the timing and amounts of R&D investments.[7] During the IPO process, it is difficult for investors to judge the appropriateness of the amounts of R&D investments of private companies in pre-IPO years due to the lack of other sources of corroborative information available in the IPO market. As such, we expect that private companies have an exceptional opportunity to invest aggressively in R&D activities to signal their quality in the IPO market. In this sense, we expect that good companies with favourable future perspectives are likely to make aggressive R&D investments in pre-IPO years as a signal for their future growth opportunities and to separate themselves from others in the IPO markets. Thus, we develop our first hypothesis as follows (in an alternative form):

> **H1:** *Ceteris paribus*, companies are likely to invest aggressively in R&D activities in pre-IPO years.

[7] For example, prior studies in the literature of real earnings management provide evidence that companies have discretion to opportunistically reduce R&D investment to avoid reporting losses (e.g., Roychowdhury 2006).

In an equilibrium of signalling, rational investors can realize that only good companies could bear the cost of the signal to a prohibitively high level and value the signal accordingly. Relying upon this theory, we expect that aggressive R&D expenditures in pre-IPO years signal future growth opportunities and, as such, are significantly and positively correlated with the IPO first-day market value and post-IPO stock returns. Prior studies provide some evidence that the level of R&D expenditures in pre-IPO years is significantly and positively associated with the IPO first-day and long-term equity values (e.g., Guo et al. 2006; Aggarwal et al. 2009). Unlike those studies, we focus on abnormal (i.e., discretionary) R&D spending beyond the normal level of R&D expenditures as a proxy for signalling, as we aim to understand the managers' motivation for signalling in the IPO market and its real effects on the IPO markets and on post-IPO performance.

It is theoretically unclear whether investors recognize "abnormal" R&D expenditures beyond the normal level of R&D spending in pre-IPO years as a credible signal and price it accordingly. As such, an examination of the associations between pre-IPO abnormal R&D expenditures and the IPO first-day and long-term equity values can provide corroborating evidence to support our signalling explanation for the aggressive R&D investments in pre-IPO years. While the IPO first-day market value can provide evidence on investors' immediate pricing of abnormal pre-IPO R&D expenditures, post-IPO stock returns will allow us to examine how investors price the value of abnormal R&D investments in pre-IPO years in a longer run following the IPO. Correspondingly, we state our second hypothesis as follows (in an alternative form):

> **H2:** *Ceteris paribus*, abnormal R&D expenditures in pre-IPO years are positively associated with the IPO first-day market value and post-IPO stock returns.

Our third hypothesis is developed to examine the real benefits of abnormal R&D expenditures made before going public. As indicated in the signalling theory, only companies with good future perspectives can bear the cost of signalling in the IPO market. Thus, we postulate that aggressive investment in R&D activities in pre-IPO years can generate significant economic benefits for issuers in post-IPO years. Aggarwal et al. (2009) provide evidence that actual R&D expenditures proxy for company's growth opportunities in the future. Bereskin et al. (2018) find that R&D expenditures are important innovation input activities that can lead to subsequent innovation output such as patent registrations (quantity) and citations (quality). If aggressive R&D expenditures in the pre-IPO years are perceived as a credible signal for the future growth potential in the IPO market, we postulate that the abnormal R&D spending is likely to deliver innovation output and operating and market growth in the post-IPO years. We develop our third hypothesis as follows (in an alternative form):

> **H3a:** *Ceteris paribus*, abnormal R&D expenditures in pre-IPO years are positively associated with post-IPO growth.

> **H3b:** *Ceteris paribus*, abnormal R&D expenditures in pre-IPO years are positively associated with post-IPO patent outputs.

The above three hypotheses complement each other and shed lights on managers' motivation of aggressive R&D investments in pre-IPO year and their economic benefits on equity values and operating performance in the years following the IPO.

3. Research Design

3.1. Abnormal R&D expenditures

We use abnormal R&D expenditures to capture the signalling effect of aggressive R&D investments in pre-IPO years and test Hypothesis 1 (**H1**). The abnormal R&D expenditures (*ARD*) are measured as the difference between R&D expenditures and the expected level of R&D expenditures of IPO firms in pre-IPO years. The expected (i.e., normal) level of R&D expenditures (*NRD*) is estimated from the coefficient estimates of the following model implemented by Canace et al. (2018) on all other non-IPO firms in the same 2-digit SIC industries in the same fiscal year but excluding firms within ±3 years of their IPO offerings: [8]

$$RD = \alpha_0 + \alpha_1 CAPX + \alpha_2 Lag(RD) + \alpha_3 RD\_IND + \alpha_4 LEV + \alpha_5 Lag(CASH) + \alpha_6 SIZE + \alpha_7 SGA + \alpha_8 \Delta SALE + \alpha_9 DIV + \alpha_{10} TSTK + \alpha_{11} ACQ + \varepsilon \quad (1)$$

The dependent variable *RD* is the R&D expenses scaled by average total assets. We deflate all of the following independent variables by average total assets (except *SIZE*). *CAPX* is the capital expenditures. *Lag(RD)* is the lagged R&D expenses. *RD_IND* is the industry average R&D. *LEV* is the total debt. *Lag(CASH)* is the sum of the lagged cash and short-term investments. *SIZE* is the natural logarithm of average total assets. *SGA* is the selling, general and administrative expenses. *ΔSALE* is the year-to-year change in net sales. *DIV* is the total dividends paid. *TSTK* is the amount of stock repurchases. *ACQ* is the amount of acquisitions. All variables in Eq. (1) and data sources are defined in Appendix A.[9]

While the model in Canace et al. (2018) produces reliable estimation of abnormal R&D expenditures in the non-IPO setting, it may possibly produce noisy estimates when applying to the IPO setting if the non-random sample characteristics of IPO firms are not properly addressed. To mitigate this concern, we adjust abnormal R&D expenditures based on a performance-matched approach, as implemented in Kothari et al. (2005). Specifically, we first match each IPO firm in our sample with a non-IPO firm from the same 2-digit SIC industries in the same fiscal year with the closest return on assets (*ROA*) (i.e., earnings before extraordinary items and discontinued operations scaled by average total assets). Then, we estimate abnormal R&D expenditures for both the IPO firm-year observation and its matched counterpart using the Canace et al. model.

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[8] The model in Canace et al. (2018) provides reliable estimation of abnormal R&D expenditures. However, to make sure our inference is not sensitive to alternative model choices, we use another well-known model implemented by Roychowdhury (2006) to estimate abnormal discretionary expenditures. We discuss the results in Section 6.1.

[9] The original model in Canace et al. (2018) includes four additional variables *THRESH*, *MB*, *CFOBRD* and *FINCF*. We drop *THRESH* as our study is not utilizing the opportunistic earnings management explanation. We drop *MB* as it is not applicable to IPO companies since market value doesn't exist prior to the IPO. We drop *CFOBRD* and *FINCF* to make sure our sample period can start from 1980 as cash flow statement data are only available after July 1987. To ensure that our results are not sensitive to missing of these variables, we redo our tests by adding back these variables in the model for the period of 1990 to 2016. Untabulated results show that our inferences are qualitatively similar.

The performance-matched abnormal R&D expenditures (*PM_ARD*) are the differences between the abnormal R&D expenditures of the two matched firms.[10]

Alternate to adjusting abnormal R&D expenditures using earnings performance, Armstrong et al. (2016) propose a propensity score matching by firm size, age and sales growth. Thus, we estimate a propensity score matched abnormal R&D (*SAG_ARD*) following their study. The estimation procedure proceeds as follows: first, we estimate the probability of an IPO from a logistic regression function of firm size, age and sales growth. A predicted probability is derived as a propensity score. Second, we match each IPO company to non-IPOs in the same 2-digit SIC industries in the same fiscal year. Third, one non-IPO is selected per an IPO by minimizing the squared values of the differences of propensity scores in year-industry matched IPOs and non-IPOs. To accommodate both earnings performance, firm size, age and growth characteristics of IPO companies, we provide another comprehensive measure of abnormal R&D expenditures by adopting a similar propensity score matching by earnings, firm size, age and sales growth (*ROA_SAG_ARD*).

While estimating abnormal R&D expenditures of IPO companies from a pool of non-IPO companies can provide direct measures, it can potentially cause biased estimate that leads to biased inference. Ball and Shivakumar (2008) point out that estimation of any measure from non-IPO coefficients to IPO sample might be biased. To mitigate this concern, we implement a multivariate regression model based on the Canace et al. model following Ball and Shivakumar (2008) approach by pooling together IPO and non-IPO companies. The model is presented as follows:

$$RD = \alpha_0 + \alpha_1 CAPX + \alpha_2 Lag(RD) + \alpha_3 RD\_IND + \alpha_4 LEV + \alpha_5 Lag(CASH) + \alpha_6 SIZE + \alpha_7 SGA + \alpha_8 \Delta SALE + \alpha_9 DIV + \alpha_{10} TSTK + \alpha_{11} ACQ + \alpha_{12} IPO + \alpha_{13} IPO \times CAPX + \alpha_{14} IPO \times Lag(RD) + \alpha_{15} IPO \times RD\_IND + \alpha_{16} IPO \times LEV + \alpha_{17} IPO \times Lag(CASH) +$$

[10] While performance-matched approach can reduce the noise of estimating abnormal R&D expenditures from the Canace et al. model in the IPO setting, we note different interpretation of the results: if the estimated performance-matched abnormal R&D expenditures are not different from zero, the implication is not that R&D expenditures are not aggressively invested, but rather that R&D expenditures are not reported any more significantly than in publicly traded firms with similar earnings performance.

$\alpha_{18}IPO\times SIZE + \alpha_{19}IPO\times SGA + \alpha_{20}IPO\times \Delta SALE + \alpha_{21}IPO\times DIV + \alpha_{22}IPO\times TSTK + \alpha_{23}IPO\times ACQ$ + Year and industry fixed effects + ε (2)

The variable of interest is *IPO* which is a dummy variable that equals 1 for IPOs and 0 otherwise. We include year and industry fixed effects. All other variables are the same as in Eq. (1) and defined in Appendix A. Hypothesis 1 (**H1**) predicts that the coefficient of *IPO* (α_{12}) in pre-IPO years is significantly positive.

While pooled OLS regression in Eq. (2) reduces the concern of applying coefficient estimation from non-IPO sample to IPO sample, it may induce another problem. While the IPO sample is based on one-year data, non-IPO sample covers time series. To reduce the potential bias due to sample size differences, we rerun Eq. (2) by using IPOs and their propensity score matched non-IPO counterparts. We expect the coefficient estimated for *IPO* (α_{12}) in pre-IPO years to be significantly positive.

3.2. IPO first-day market value and post-IPO stock returns

To examine **H2** on the association between pre-IPO abnormal R&D expenditures and the IPO first-day market value, we estimate the following equation:

$L(MV) = \alpha_0 + \alpha_1 L(ARD) + \alpha_2 L(NRD) + \alpha_3 L(CAPX) + \alpha_4 L(IBBRD) + \alpha_5 L(IBBRD)\times NegIBBRD + \alpha_6 L(CEQ) + \alpha_7 L(CEQ)\times NegCEQ + \alpha_8 SIZE + \alpha_9 AGE + \alpha_{10} PreUW + \alpha_{11} RETENTION + \alpha_{12} BIGN$[11] $+ \alpha_{13} PriceUpdate$ + Year and industry fixed effects + ε (3)

The dependent variable *L(MV)* is the natural logarithm of MV, which is the IPO first-day closing price multiplied by the number of shares outstanding immediately after the IPO. We use total IPO first-day market value (rather than first-day market price per share) to remove the arbitrary effect of the number of shares issued following Aggarwal et al. (2009), who suggest that underwriters somewhat arbitrarily partition total equity value into price per share and shares

[11] Big N auditors include Arthur Andersen, Ernst & Young, Deloitte & Touche, KPMG and PricewaterhouseCoopers.

offered.[12] Beatty et al. (2000) also indicate that the explanatory power of the IPO valuation model significantly increases when they use total IPO value compared with when they use offer price per share as the dependent variable. We apply natural logarithm (*L*) transformation[13] to both dependent variable and financial statement variables[14] to alleviate the non-normality and heteroskedasticity problems following Aggarwal et al. (2009).

Hypothesis 2 (**H2**) predicts that the coefficient of *L(ARD),* α_1, to be significantly positive. We include *L(NRD)* to control for the normal level of pre-IPO R&D expenditures as they are priced by investors as an important valuation component of IPO first-day market value. Prior studies have found asymmetries in the relations between IPO equity value and positive and negative earnings. In particular, Aggarwal et al. (2009) find that positive earnings are positively associated with IPO equity value and negative earnings are negatively associated with IPO equity value, suggesting that negative earnings are a proxy for growth opportunities and that such growth options are a significant component of IPO firm value. We therefore break up earnings before R&D expenditures (*IBBRD*) into positive and negative (*NegIBBRD*) components using a dummy variable. Prior research also finds that negative book values of equity may have different valuation implications from positive book values. Negative book values may indicate investments in R&D and other intangibles over the years prior to the IPO and thus may be valued by the stock

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[12] In general, prior studies use several different dependent variables in IPO valuation. For example, Kim and Ritter (1999) and Purnanandam and Swaninathan (2004) recommend using the offer price or first-day closing price per share deflated by earnings per share as dependent variables. Klein (1996) and Bartov et al. (2002) recommend using the offer price or first-day closing price per share as dependent variables. As Aggarwal et al. (2009) argue, however, all candidates for dependent variables in the specification of an IPO valuation model in the literature have their own limitations. For example, the offer price or first-day closing price per share deflated by earnings per share leads to the elimination of firms with negative earnings and reduces the generalizability of the findings. The offer price or first-day closing price per share is deficient on theoretical and empirical grounds given the fact that the true economic variable being priced in the IPO process is total value of equity. Underwriters somewhat arbitrarily partition total equity value into price per share and shares offered.

[13] $L(MV) = \log_e(1 + MV)$ when $MV \geq 0$ and $L(MV) = -\log_e(1 - MV)$ when $MV < 0$.

[14] As *ARD* and *NRD* are estimated from Eq. (1) with the scaling treatment of average total assets, to be consistent with other financial statement variables in Eq. (3), we multiple these two variables by average total assets before applying the natural logarithm transformation.

market (Hand 2003). Therefore, similar to the treatment of earnings, we separate positive book value of equity (*CEQ*) from negative ones using a dummy variable *NegCEQ*.

Following prior studies, we control for capital expenditures (*CAPX*), as companies are likely to shift between R&D expenditures and capital expenditures (see, for example, Canace et al. 2018) and firm size (*SIZE*) (see, for example, Beatty et al. 2000). We also include three nonfinancial variables – underwriter prestige[15] (*PreUW*), ownership retention (*RETENTION*), and auditor type (*BIGN*) – as additional control variables. Prior studies find that these variables serve as signals of an IPO's quality and are important determinants of the IPO's realized value (see, for example, Leland and Pyle 1977; Beatty and Ritter 1986; Klein 1996; Carter et al. 1998; Fan 2007; Aggarwal et al. 2009). Finally, we control for *PriceUpdate*, measuring the position of the final offer price relative to the expected price at the time the prospectus was filed. Prior studies find that this variable is an important predictor for IPOs' first-day stock price performance (see, for example, Benveniste and Spindt 1989; Hanley 1993). Other variables are defined as before. Detailed definitions of variables are given in Appendix A.

Next, we examine the associations between pre-IPO abnormal R&D expenditures and post-IPO stock returns for the short-run and the long-run windows. If investors are rational to price the signaling of abnormal R&D expenditures made in pre-IPO years, they value the company accordingly. As such, we expect abnormal R&D expenditures are positively associated with post-IPO stock returns. We estimate various post-IPO short-run and long-run abnormal returns using a calendar regression approach, as implemented in Armstrong et al. (2016). This approach has two

[15] Following Aggarwal et al. (2009), we define prestigious underwriters as underwriters whose reputation rank is greater or equal to 8, where underwriter reputation rank is obtained from Jay Ritter's website (http://bear.warrington.ufl.edu/ritter/ipodata.htm). We acknowledge that the sign of prestigious underwriter variable may change across different time periods, especially given the adverse impact of the 2008 financial crisis on the prestige of investment banks in the U.S. To address this concern, we construct a dummy variable *CRISIS* that equals 1 if the IPO offer date is between January 2008 and December 2016, and 0 otherwise and include it as well as its interaction term with *PreUW* in Eq. (3) to redo the test. Untabulated result provides no significant evidence that the association between underwriter prestige and the IPO first-day market value differs between the pre- and post-2008 financial crisis periods.

advantages. First, it avoids problems inherent in using long run buy-and-hold returns. For example, the severe skewness of the distribution of buy-and-hold returns is no longer an issue, as this approach uses monthly returns (Fama 1998). Furthermore, the test statistics will have more desirable statistical properties (Mitchell and Stafford 2000). Second, it adjusts for risk in a more comprehensive manner (relative to an explicit asset-pricing model) than does simply subtracting the return of a benchmark index. In specific, we estimate the following model:

$$(R_{i,t} - R_{f,t}) = \alpha_0 + \alpha_1 ARD + \alpha_2 SIZE + \alpha_3 AGE + \alpha_4 PreUW + \alpha_5 RETENTION + \alpha_6 BIGN + \alpha_7 IR + \alpha_8 (R_{m,t} - R_{f,t}) + \alpha_9 SMB + \alpha_{10} HML + \alpha_{11} UMD + \text{Year and industry fixed effects} + \varepsilon \quad (4)$$

where $R_{i,t} - R_{f,t}$ is monthly risk-free excess returns over the subsequent 1-, 3-, 6-, 12-, 24-, and 36-month period starting from the month following the IPO month. We implement firm specific risk factors as in Eq. (3) and Fama and French (1993) three factors ($R_{m,t} - R_{f,t}$, *SMB* and *HML*) and a momentum factor (*UMD*) to control for risk associated premiums. We also control for initial return (*IR*), measuring the position of the first-day closing price relative to the offer price, as prior studies find that IPOs with higher initial returns are generally associated with lower long-term stock returns (IPO anomalies) (e.g., Loughran and Ritter 1995). Hypothesis 2 (**H2**) predicts the coefficient of *ARD,* α_1, to be significantly positive.

3.3. *The real benefits of pre-IPO abnormal R&D expenditures*

To test Hypothesis **H3a**, we first examine the association between pre-IPO abnormal R&D expenditures and post-IPO growth measures by estimating the following equation:

$$FSGR/FPS = \alpha_0 + \alpha_1 ARD + \alpha_2 NRD + \text{Year and industry fixed effects} + \varepsilon \quad (5)$$

The dependent variable *FSGR* is post-IPO sales growth. The alternative dependent variable *FPS* is post-IPO fiscal year-end price-to-sales ratio. All variables are defined in Appendix A. **H3a** predicts α_1 to be significantly positive.

To test Hypothesis **H3b**, we examine the association between pre-IPO abnormal R&D expenditures and post-IPO patent output by estimating the following equation:

$$L(COUNTS/CITES) = \alpha_0 + \alpha_1 L(ARD) + \alpha_2 L(NRD) + \alpha_3 L(CAPX) + \text{Year and industry fixed effects} + \varepsilon \quad (6)$$

Following Bereskin et al. (2018), we construct two measures for post-IPO patent output, including patent counts (*COUNTS*), defined as the number of successful (i.e., approved) patent applications for Year 1 – Year 3, and patent citations (*CITES*), defined as the total number of forward citations received by all successful patent applications for Year 1 – Year 3. We control for the normal level of R&D expenditures (*NRD*) and capital expenditures (*CAPX)* following Canace et al. (2018). We apply natural logarithm transformation to both dependent and independent variables to alleviate the non-normality and heteroskedasticity problems. All variables are defined in Appendix A. To support **H3b**, we expect α_1 to be significantly positive.

4. Sample and Data

The initial sample includes U.S. IPOs that are extracted from the Securities Data Corporation (SDC) database from 1980 to 2016. Following prior literature, we exclude IPOs (1) that are unavailable in the Centre for Research on Security Prices (CRSP) database, (2) that are non-ordinary or common shares,[16] and (3) that are filed by regulated utility firms (SIC codes in the range 4900-4999) and financial services, insurance and real estate firms (SIC codes in the range 6000-6999). This selection procedure leads to a final sample of 6,706 IPOs. Table 1 summarizes the effects of the sample-selection criteria on the sample size.

(INSERT TABLE 1 ABOUT HERE)

Table 2 reports distribution statistics of our final IPO sample. Panel A shows the distribution of IPOs over issuing years. Consistent with prior IPO studies, we observe a cluster of IPOs during

[16] We do not rely on SDC classification alone for identifying IPOs of ordinary shares, because SDC occasionally identifies ADRs as ordinary shares. We independently verify the share type using CRSP share code (not equal to 11).

the 1990s. In specific, 3,737 firms (or 56%) of our total sample issued IPOs during 1990–1999. This is not surprising given that the stock market roared during this period. As the stock market value dropped significantly in early 2000, so did the number of IPOs. IPO activities somewhat resumed in 2004 before another recession hit the market in late 2007 due to the subprime mortgage crisis. IPO activities came back again after 2013.

Panel B reports the distribution of IPOs across industries classified by two-digit SIC codes. We find that IPOs take place across different industries. The prime industry is business services, which accounts for about 21% of our sample, followed by chemicals and allied products; electronic and other electrical equipment and components; measuring, analysing, and controlling instruments, photographic, medical and optical goods, and watches and clocks; Industrial and commercial machinery and computer equipment. These industries, taken together, comprise more than 50% of our sample.

(INSERT TABLE 2 ABOUT HERE)

We collect IPO offer price, preliminary filing price range, primary and secondary shares offered in the IPOs and the name of the leading underwriter(s) from SDC[17] or hand collect them from IPO prospectuses available on SEC's website.[18] We obtain IPO founding dates and underwriters' reputation rankings from Jay Ritter's website.[19] We extract the post-IPO stock price, returns and the number of shares outstanding following the IPO from CRSP. We rely on COMPUSTAT for financial statement data. We retrieve the patent records of all U.S. public firms from the NBER patent database originally developed by Hall et al. (2005) and updated by Lai et al. (2011).[20] The data set includes information on filing and grant dates, patents and associated

[17] We also correct for some SDC errors based on the file from Jay Ritter's website on https://site.warrington.ufl.edu/ritter/files/2015/04/SDC_corrections.pdf
[18] https://www.sec.gov/edgar/searchedgar/companysearch.html.
[19] http://bear.warrington.ufl.edu/ritter/ipodata.htm.
[20] The original NBER patent database covers patent data for 1976-2006 and is available from the following website https://sites.google.com/site/patentdataproject/Home. The updated patent database covers patent data for 1975-2010 and is available from the following website https://dataverse.harvard.edu/dataverse/patent.

assignees (i.e., companies), COMPUSTAT-matched identifiers (GVKEY) and the citations made and received by each patent until the end of 2010, for all patents approved (granted) by the USPTO from 1975 to 2010.

5. Empirical results

5.1. Abnormal R&D expenditures

We start univariate analyses by examining the magnitudes of abnormal R&D expenditures (*ARD*) estimated in Eq. (1) from Year -1 to Year 3 around the IPO year (Year 0) to provide a complete picture of annual changes of *ARD* from pre- to post-IPO years. We concentrate on Year -1, because this is the most recent year prior to the IPO that *ARD* can signal company quality to the market.[21] Similarly, it is expected that companies continue to signal until the IPO date and, as such, we are also interested in *ARD* in Year 0 (together with Year -1 as pre-IPO years). This also helps make our results directly comparable to prior IPO studies as they analyze the IPO year (Year 0) due to the lack of data availability in pre-IPO years.

In Panel A of Table 3, to mitigate the effect of outliers, we report the medians of *ARD* and use the Wilcoxon test to examine whether they are statistically different from zero. It indicates that the results are qualitatively consistent across various measures of unmatched *ARD* and matched *ARD* (*PM_ARD, SAG_ARD, ROA_SAG_ARD*). The unmatched *ARD* are significantly positive in Year -1 and Year 0 with the largest magnitudes (1.4% of total assets) in Year -1 and decrease monotonically from Year -1 to Year 3. Similarly, all of the matched *ARD* are significantly positive in Year -1 and Year 0 again with the largest magnitudes in Year -1 (2.0% of total assets for the case of *PM_ARD* and 1.9% for both *SAG_ARD* and *ROA_SAG_ARD*). However, they are mostly insignificant in Year 1 and Year 2 and are significantly negative in

[21] Ideally, we hope to track the annual changes of abnormal R&D expenditures from Year -3 to Year 3, as private companies are likely to use abnormal R&D expenditures as the signal earlier than Year -1 (e.g., Year -3 and Year -2). However, financial statement data for years prior to Year -1 are always missing in COMPUSTAT.

Year 3. In sum, the results of univariate analyses are consistent with our hypothesis that companies invest *aggressively* in R&D activities in pre-IPO years (**H1**). Panel B of Table 3 exhibits correlation coefficients among *ARD* measures in Year -1. Our variable of interest, *ARD*, is positively correlated with R&D expenditures (Pearson correlation coef. = 0.776 and Spearman's correlation coef. = 0.556) but has low correlation coefficients with *NRD* (0.228 and 0.237 respectively). The Pearson correlation coefficient between *ROA_SAG_ARD* and *RD* is only 0.385, suggesting that our matched *ARD* measures do not simply capture actual R&D expenditures that prior studies frequently use.

(INSERT TABLE 3 ABOUT HERE)

Next, we conduct multivariate regression analysis using Eq. (2) to compare abnormal R&D expenditures of the IPOs with those of non-IPOs for Year -1 through Year 3 on an unmatched pool basis. Following Ball and Shivakumar (2008), we implement our analysis based on the Canace et al. model and pooling IPO and non-IPO companies together. Table 4 reports the results.[22] The variable of interest is *IPO*. The coefficients of *IPO* in Year -1 and Year 0 are both significantly positive ($P < 0.01$) with the magnitude in Year -1 (0.092) which is more than three times that in Year 0 (0.028). In contrast, the coefficients of *IPO* in the post-IPO years (Year 1 to Year 3) are all negative and insignificant. Thus, the results are consistent with the univariate test results reported in Table 3, supporting **H1**.

In terms of control variables, all control variables are significantly associated with R&D expenditures and the signs are consistent with Canace et al. (2018). We find that *CAPX*, *Lag(RD)*, *RD_IND*, *Lag(CASH), SIZE*, *SGA*, *ΔSALE*, and *ACQ* are all significantly and positively associated with R&D expenditures. We also find that *LEV*, *DIV*, and *TSTK* are significantly and negatively correlated with R&D expenditures. Adjusted R^2 across all test years are consistently high (around

[22] For brevity, estimated coefficients of interaction terms of *IPO* and other variables in Eq. (2) are not presented in Tables 4 and 5.

80%), suggesting that the Canace et al. (2018) model provides a powerful estimation of abnormal R&D expenditures.

(INSERT TABLE 4 ABOUT HERE)

Table 5 presents the results of running multivariate analysis in Eq. (2) to compare abnormal R&D expenditures of the IPOs with PSM matched non-IPOs by earnings, size, age and sales growth in the same 2-digit SIC industries for Year -1 to Year 3. The results are qualitatively similar to those in Table 4. The coefficients of *IPO* in Year -1 and Year 0 are significantly positive ($P < 0.05$ and $P < 0.01$, respectively) with the magnitude in Year -1 (0.045) more than double that in Year 0 (0.021). In contrast, the coefficients of *IPO* in Year 1 and Year 2 are insignificant, and the coefficient of *IPO* in Year 3 is significantly negative at the 10% level. The results on control variables are generally similar to those reported in Table 4. Adjusted R^2 across all test years are consistently high (79% to 82%) although sample size is smaller. In sum, both univariate and multivariate analyses in Tables 3 - 5 provide corroborating evidence that companies are likely to invest aggressively in R&D activities in pre-IPO years. In the next section, we examine whether abnormal R&D spending in pre-IPO years serves as a credible signal in the IPO market in the first-day and post-IPO years.

(INSERT TABLE 5 ABOUT HERE)

5.2. *The Effect of abnormal R&D expenditures on IPO first-day market value and post-IPO stock returns*

We first examine the association between *ARD* in Year -1 and the IPO first-day market value as in Eq. (3). Table 6 presents the results. Column (1) reports the results only with abnormal and normal R&D variables, *L(ARD)* and *L(NRD).* Column (2) reports the results after controlling for capital expenditure (*L(CAPX)*). Column (3) reports the results after further controlling for earnings (*L(IBBRD)* and *L(IBBRD)*×*NegIBBRD*) and book value of equity (*L(CEQ)* and

L(CEQ)×NegCEQ). Column (4) reports the results with additional controls on firm size (*SIZE*), auditor type (*BIGN*), underwriter prestige (*PreUW*) and ownership retention (*RETENTION*). Column (5) adds *PriceUpdate* as an additional control.

The coefficients of *L(ARD)* are significantly positive across all five specifications ($p < 0.01$), which are consistent with the signaling explanation of aggressive R&D spending in the first-day market value and supportive of **H2**. Next turning to control variables, the coefficients on positive and negative earnings and book value of equity are all statistically significant with the predicted signs. The coefficients of the normal R&D expenditures (*L(NRD)*), capital expenditures (*L(CAPX)*), firm size (*SIZE*), underwriter prestige (*PreUW*), ownership retention (*RETENTION*), auditor type (*BIGN*) and *PriceUpdate* are all significantly and positively associated with IPO first-day market value, whereas firm age (*AGE*) is significantly negative. Our findings of the associations between control variables and the IPO first-day market value are consistent with prior studies.

(INSERT TABLE 6 ABOUT HERE)

Next, we examine the associations between abnormal R&D expenditures and post-IPO stock returns covering various short- and long-windows from one month up to three years (1-, 3-, 6-, 12-, 24-, and 36 months) following the IPO month as in Eq. (4). Columns (1) – (6) of Table 7 report the results across different windows, respectively. We find consistently and significantly positive associations between *ARD* in Year -1 and post-IPO stock returns across various windows up to three years.[23] Collectively, the results indicate that investors value IPO firms according to pre-IPO abnormal R&D expenditures in post-IPO years, consistent with our signalling explanation and supporting **H2**.

[23] We also examine the association between *ARD* in Year 0 and future stock returns across various windows beginning at the end of the fourth month following the fiscal year-end of Year 0. The result is qualitatively similar.

Among the control variables, there are positive and significant coefficients of *PreUW* across all regression models, suggesting that prestigious underwriters play an important role in supporting post-IPO stock returns. We also find a significantly negative coefficient of *IR*, suggesting that IPOs with higher initial returns are generally associated with lower long-term stock returns (IPO anomalies) (e.g., Loughran and Ritter 1995). All Fama-French factors and the momentum factor are statistically significant, as expected. Finally, the intercept, or alpha, is negative across all regression models, indicating that, on average, newly public companies earn negative abnormal returns in the 36 months following their IPOs, consistent with the IPO underperformance literature.

(INSERT TABLE 7 ABOUT HERE)

Taken together, Tables 6 and 7 present the results of examining the consequences of pre-IPO R&D investments on the IPO first-day pricing and post-IPO stock returns. They provide systematic evidence of investors pricing the aggressive R&D investments in pre-IPO years. This evidence is consistent with the signaling theory that managers send a credible signal to the market through pre-IPO R&D investments and investors recognize it as an important value driver, leading to higher IPO first-day price and long-term equity values. It would be possible that the aggressive R&D expenditures made in pre-IPO year successfully generate innovation products and sales growth in the post-IPO years, which contributes to the higher long-term equity value. The next section investigates this possibility.

5.3. Economic benefits of aggressive R&D investments in pre-IPO years

We first examine the real effects of aggressive R&D investment in pre-IPO years on operational and market performance in the post-IPO years. We measure the performance based on sales growth and price-to-sales ratios and implement Eq. (5). Panel A of Table 8 reports the results of post-IPO sales growth. Columns (1) – (4) report the results of the associations between abnormal R&D expenditure in Year -1 and sales growth for each of Year 1 to Year 3 relative to Year -1 (*FSGR_Y1, FSGR_Y2, FSGR_Y3*). Columns (5) – (8) report the results of the associations between abnormal R&D expenditures in Year 0 and sales growth for each of Year 1 to Year 3 relative to Year 0. They provide systematic evidence that abnormal R&D expenditures in pre-IPO years are significantly and positively associated with post-IPO sales growth in each of the three years following the IPO, supporting **H3a**. The coefficients of the normal level of R&D expenditures (*NRD*) are significantly positive in most periods.

Panel B of Table 8 reports the results of post-IPO price-to-sales ratios. We utilize post-IPO fiscal year-end price-to-sales ratios to proxy for company's growth opportunities. Columns (1) – (3) report the associations between abnormal R&D expenditures in Year -1 and the price-to-sales ratio at the fiscal year end of Year 1 – Year 3 (*FPS_Y1, FPS_Y2, FPS_Y3*). Columns (4) – (6) report the results for abnormal R&D expenditures in Year 0. They indicate that abnormal pre-IPO R&D expenditures are significantly and positively correlated with post-IPO price-to-sales ratios in five of six specifications, supporting **H3a**. The coefficients of *NRD* remain significantly positive across all models.

(INSERT TABLE 8 ABOUT HERE)

It would be plausible that the aggressive R&D investments in pre-IPO period successfully generate patents after IPOs, which help companies to grow in the post-IPO period. As such, we consider that innovation outputs are a channel through which IPOs grow in sales and market values in the post-IPO period. In this section, we examine the associations between pre-IPO abnormal R&D expenditures and future patent outputs after IPOs, as in Eq. (6). Table 9 reports the results. In Columns (1) – (4), we report the results on the association between the total number of patents registered from Year 1 to Year 3 (*L(COUNTS)*) and abnormal R&D expenditures in Year -1 and Year 0, respectively. We report the results based on total patent citations (*L(CITES)*) in Columns (5) – (8). We find that, after controlling for the normal level of R&D expenditures, abnormal R&D expenditures are significantly and positively associated with both the quantity and quality of patents in post-IPO years in seven of the eight regressions, supporting **H3b**. We also find that capital expenditures (*L(CAPX)*) are significantly and positively correlated with the total patent number (*L(COUNTS)*) and the total patent citations (*L(CITES)*), suggesting that capital expenditures are also predictive of future patent outputs.

(INSERT TABLE 9 ABOUT HERE)

6. Robustness Checks

6.1. Comparing future growth measures between IPO companies and PSM matched non-IPO companies by performance (ROA), size, age and sales growth

In this section, we compare future growth measures between IPO companies and PSM matched non-IPO companies by performance (*ROA*), size, age and sales growth and test whether pre-IPO abnormal R&D expenditures of IPO companies "signal" greater than those of PSM matched control companies. Specifically, we estimate the following equation:

$$FSGR/FPS = \alpha_0 + \alpha_1 IPO + \alpha_2 IPO\times ARD + \alpha_3 IPO\times NRD + \alpha_4 ARD + \alpha_5 NRD + \text{Year and industry fixed effects} + \varepsilon \quad (7)$$

The dependent variables include sales growth (*FSGR*) and price-to-sales (*FPS*) ratios. To be consistent with the signaling theory, we expect that α_2 is significantly positive. Table 10 reports the results from estimating Eq. (7). Columns (1) – (6) estimate by pooling together the IPO companies of Year -1 and their PSM matched control companies. Columns (7) – (12) estimate for IPO companies of Year 0 and their PSM matched control companies. They show that the coefficients on *IPO* are significantly positive across ten out of twelve columns ($p < 0.01$), indicating that IPO companies are associated with significantly higher growth than the PSM matched non-IPO companies after controlling for R&D expenditures. More importantly, the coefficients on *IPO×ARD* are significantly positive for eight of twelve cases after controlling for the normal level of R&D expenditures. In contrast, the coefficients for non-IPO counterparts

(*ARD*) are significantly positive only for two cases. These results are consistent with our expectation that abnormal R&D expenditures in pre-IPO period credibly "signal" future growth opportunities, to a greater extent, relative to the PSM matched non-IPO companies.

(INSERT TABLE 10 ABOUT HERE)

6.2. *Comparing future patent outputs between IPO companies and PSM matched non-IPO companies by performance (ROA), size, age and sales growth*

In this section, we compare future patent outputs between IPO companies and PSM matched non-IPO companies by performance (*ROA*), size, age and sales growth and test whether pre-IPO abnormal R&D expenditures of IPO companies "signal" greater than those of PSM matched control companies. Specifically, we estimate the following equation:

$$L(COUNTS/CITES) = \alpha_0 + \alpha_1 IPO + \alpha_2 IPO\times L(ARD) + \alpha_3 IPO\times L(NRD) + \alpha_4 IPO\times L(CAPX) + \alpha_5 L(ARD) + \alpha_6 L(NRD) + \alpha_7 L(CAPX) + \text{Year and industry fixed effects} + \varepsilon \quad (8)$$

To be consistent with the signaling theory, we expect that α_2 is significantly positive. Table 10 reports the results. Columns (1) and (2) estimate Eq. (8) by pooling together the IPO companies of Year -1 and their PSM matched control companies. Columns (3) and (4) estimate Eq. (7) for IPO companies of Year 0. They show that the coefficients on *IPO* are significantly positive across all four columns ($p < 0.01$), suggesting that IPO companies are associated with significantly more patent quantity and higher patent quality than the PSM matched non-IPO companies, after controlling for R&D and capital expenditures. Furthermore, the coefficients on $IPO\times L(ARD)$ are significantly positive for Year -1 in the first two columns and positive but insignificant for Year 0 in the last two columns, after controlling for the normal level of R&D and capital expenditures. Overall, these results are consistent with our expectation that abnormal R&D expenditures in pre-IPO period are "signaling" greater of future patent number and citations for IPO companies than for the PSM matched non-IPO companies.

(INSERT TABLE 11 ABOUT HERE)

6.3. *Estimating abnormal R&D expenditures using the model in Roychowdbury (2006)*

In the literature of real earnings management, Roychowdhury (2006) implements a model to estimate abnormal discretionary expenditures (including R&D expenditures) by regressing discretionary expenditures on lagged sales. To make sure our main findings are not sensitive to the choice of the estimation model, we re-estimate abnormal R&D expenditures using the model in Roychowdhury (2006) and repeat our empirical tests. The multivariate regression model by pooling together IPO and non-IPO companies is presented as follows:

$$RD = \alpha_0 + \alpha_1 Lag(SALE) + \alpha_2 IPO + \alpha_3 IPO \times Lag(SALE) + \text{Year and industry fixed effects} + \varepsilon \quad (9)$$

Table 12 reports the univariate and multivariate analyses of the magnitudes of abnormal R&D expenditures across the five years around the IPO. Panel A shows that abnormal R&D expenditures are significantly positive in pre-IPO years and the magnitudes decrease monotonically from Year -1 to Year 3 (0.085 to 0.023 for the performance-matched *ARD*), consistent with our main results in Table 3. However, the Roychowdhury model produces significantly non-negative abnormal R&D expenditures even for post-IPO years but with significantly smaller magnitudes. Panel B of Table 12 replicates the tests in Table 5 by using Eq. (9) and produces consistent results, indicating that that IPO companies invest more aggressively in R&D activities in pre-IPO years relative to control companies. It is interesting to note that the explanatory powers of regressions using the Roychowdhury model in Panel B of Table 12 (less than 15% of adjusted R^2) are substantially lower than those of our main estimation models in Table 5 (about 80% of adjusted R^2). It might suggest that the power of different estimation models for abnormal R&D expenditures varies between IPO firms and non-IPO firms.

(INSERT TABLE 12 ABOUT HERE)

7. Conclusions

The signaling theory in the IPO literature indicates that “good companies” with favorable prospects are likely to send signals to the market within the process of IPO to separate themselves from bad ones. Signaling can help reduce adverse selection in the IPO market where information asymmetry is high. To be reliable, the signal should be potentially too costly to be imitated by “bad companies” and rational investors can readily infer value inputs from these signals in the market. In this paper, we argue that private companies with high growth potential are likely to use aggressive R&D investments in pre-IPO years as a signal of their quality in the IPO market. We use abnormal R&D expenditures in pre-IPO years (Year -1 and Year 0) as a proxy for the signal and implement various tests to examine the magnitudes of abnormal R&D expenditures for companies across years around the IPO. We also test the effects of abnormal R&D expenditures in pre-IPO years on the IPO first-day pricing and the post-IPO stock returns. Finally, we examine the economic benefits of abnormal R&D expenditures in pre-IPO years by linking them to future growth and patent outputs after IPOs.

The results from these tests are consistently strong and support our hypothesis of signaling for IPO firms. We report the following evidence. First, private companies invest more aggressively in R&D activities than their non-IPO counterparts before going public. Second, investors price pre-IPO abnormal R&D expenditure accordingly in valuing IPOs at the issuance as well as in post-IPO stock returns. Third, abnormal R&D expenditures in pre-IPO years generate significant economic benefits for issuers in the post-IPO years. Specifically, companies that invest more aggressively in pre-IPO R&D activities experience higher growth in sales and market values and more patent outputs and citations in the post-IPO years. We consider that effective innovation outputs of those IPO companies are a channel through which IPOs enjoy growth in operation and market valuation in the post-IPO years. Our results are robust to alternative measure of abnormal R&D expenditures, various matching techniques, and a series of tests on managers’ decisions on

R&D expenditures, market pricing, innovation outputs, and future growth. Collectively, our study provides consistent and corroborating empirical evidence that companies effectively use aggressive R&D investments in pre-IPO years to signal their high quality in the IPO market.

Our findings are important to the literature. Contributing to the literature of signaling, we provide reliable evidence on the use of abnormal R&D expenditures beyond the normal level as a credible signal of high quality to separate themselves from low-growth companies in the IPO market where information asymmetry is high. Contributing to the literature on real activities management of IPOs, we provide evidence that companies more aggressively invest in R&D activities in pre-IPO years which help generate innovation outputs and grow after the IPO. These results contrast the opportunism view of earnings management through cutting R&D expenditures around IPOs in some of earlier studies, but are consistent with more recent findings that IPO companies report earnings more conservatively in pre-IPO years (e.g., Fan 2007; Ball and Shivakumar 2008; Cecchini et al. 2012; Armstrong et al. 2016). Our findings are in alignment with a recent evidence that private companies with more technological disruptiveness of patent exit through IPOs than via acquisitions (Bowen et al. 2018). Lastly, our study adds to the literate of innovation by providing evidence that abnormal R&D investments in pre-IPO years credibly signal future innovative products and growth opportunities.

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APPENDIX A: Variable Definition

ATA	Average total assets (COMPUSTAT item AT).
RD	Research and development expense (COMPUSTAT item XRD) scaled by *ATA*.
CAPX	Capital expenditures (COMPUSTAT item CAPX) scaled by *ATA*.
Lag(RD)	Lag of research and development expense (COMPUSTAT item XRD) scaled by *ATA*.
RD_IND	Industry average *RD* (industry is defined at the two-digit SIC code level).
LEV	Sum of book value of short-term debt (COMPUSTAT item DLC) and long-term debt (COMPUSTAT item DLTT) scaled by *ATA*.
Lag(CASH)	Lag of the sum of cash and short-term investments (COMPUSTAT item CHE) scaled by *ATA*.
SIZE	The natural logarithm of *ATA*.
SGA	Selling, general and administrative expense (COMPUSTAT item XSGA) (net of R&D expense) scaled by *ATA*.
ΔSALE	Year-to-year change in net sales (COMPUSTAT item SALE) scaled by *ATA*.
DIV	Total dividends paid (COMPUSTAT item DIV) scaled by *ATA*.
TSTK	The dollar amount of stock which has been reacquired and placed into treasury (COMPUSTAT item TSTK) scaled by *ATA*.
ACQ	The dollar amount of acquisitions (COMPUSTAT item ACQ) scaled by *ATA*.
AGE	The natural logarithm of 1 plus the difference between the founding year of the company and the IPO year. Founding years are obtained from Jay Ritter's website (http://bear.warrington.ufl.edu/ritter/ipodata.htm).
ARD	Abnormal level of *RD*.
NRD	Estimated normal level of *RD*.
ROA	Earnings before extraordinary items and discontinued operations (COMPUSTAT item IB) scaled by *ATA*.
PM_ARD	Performance matched *ARD*.
SAG_ARD	Size, age and sales growth matched *ARD*.
ROA_SAG_ARD	*ROA*, size, age and sales growth matched *ARD*.
L(MV)	The natural logarithm of (IPO first-day closing price × number of shares outstanding immediately after the IPO).
L(ARD)	The natural logarithm of (*ARD* × *ATA*).
L(NRD)	The natural logarithm of (*NRD* × *ATA*).
L(CAPX)	The natural logarithm of (*CAPX* × *ATA*).
L(IBBRD)	The natural logarithm of net income before R&D expenditures, calculated as the sum of earnings before extraordinary items and discontinued operations (COMPUSTAT item IB) and R&D expenditures (COMPUSTAT item XRD).
NegIBBRD	1 if *L(IBBRD)* is negative and 0 otherwise.
L(CEQ)	The natural logarithm of book value of equity (COMPUSTAT item CEQ).
NegCEQ	1 if *L(CEQ)* is negative and 0 otherwise.
PreUW	1 if the underwriter reputation rank is greater or equal to 8, and 0 otherwise. Underwriter reputation rank is obtained from Jay Ritter's website (http://bear.warrington.ufl.edu/ritter/ipodata.htm).
RETENTION	(Number of shares outstanding immediately after IPO – number of primary & secondary shares offered in IPO) / number of shares outstanding

	immediately after IPO.
BIGN	1 if the auditor is a Big N auditing firm and 0 otherwise.
PriceUpdate	(IPO offer price – median value of IPO filing price range) / median value of IPO filing price range.
IR	(IPO first-day market price – IPO offer price) / IPO offer price.
R_i	Monthly return on IPO firm i.
R_f	Monthly 30-day T-bill yield.
R_m	Monthly return on the value-weighted CRSP index.
SMB	Monthly return on small firms minus the monthly return on large firms.
HML	Monthly return on high book-to-market stocks minus the monthly return on low book-to-market stocks.
UMD	Monthly return on high prior return portfolios minus the monthly return on low prior return portfolios.
FSGR	Sales growth for Year 1 – Year 3 relative to Year -1 or Year 0.
FPS	Fiscal year-end price-to-sales ratio for Year 1 – Year 3.
L(COUNTS)	The natural logarithm of number of successful (i.e., approved) patent applications for Year 1 – Year 3.
L(CITES)	The natural logarithm of number of forward citations received by all successful patent applications for Year 1 – Year 3.

Table 1
Sample Selection Process

Total number of IPOs during 1980-2016 in the U.S. market		9,983
Less:		
No matching firms in CRSP database	(41)	
Non-ordinary or common shares	(1,898)	
Regulated utilities, Financial services, insurance, and real estate firms	(1,338)	
Domestic IPOs by non-regulated and non-financial firms listed on NYSE, NASDAQ, or AMEX		6,706

This table presents the sample selection process for IPOs during 1980-2016. Regulated firms are firms with SIC codes in the range 4900-4999. Financial services, insurance, and real estate firms are firms with SIC codes in the range 6000-6999. Non-ordinary/common shares issues are identified based on CRSP share code (not equal to 11).

Table 2
Distribution of IPOs by Year and Industry

Panel A: Distribution by issuing-year

Issuing Year	Number of IPOs	Percent (%)
1980	37	0.6
1981	77	1.1
1982	39	0.6
1983	231	3.4
1984	93	1.4
1985	124	1.8
1986	270	4.0
1987	222	3.3
1988	102	1.5
1989	103	1.5
1990	104	1.6
1991	265	4.0
1992	385	5.7
1993	495	7.4
1994	412	6.1
1995	449	6.7
1996	597	8.9
1997	395	5.9
1998	227	3.4
1999	408	6.1
2000	316	4.7
2001	61	0.9
2002	52	0.8
2003	50	0.7
2004	134	2.0
2005	122	1.8
2006	116	1.7
2007	122	1.8
2008	15	0.2
2009	37	0.6
2010	68	1.0
2011	63	0.9
2012	80	1.2
2013	119	1.8
2014	158	2.4
2015	91	1.4
2016	67	1.0
Total	**6,706**	**100.0**

Table 2 (Continued)
Distribution of IPOs by Year and Industry

Panel B: Distribution by industry (SIC code)

Industry	Two-digit SIC code	Number of IPOs	Percent (%)
Business services	73	1,395	20.8
Chemicals and allied products	28	729	10.9
Electronic and other electrical equipment and components, except computer equipment	36	552	8.2
Measuring, analyzing, and controlling instruments; Photographic, medical and optical goods; Watches and clocks	38	486	7.2
Industrial and commercial machinery and computer equipment	35	459	6.8
Communications	48	265	4.0
Engineering, accounting, research, management, and related services	87	218	3.3
Health services	80	215	3.2
Miscellaneous retail	59	210	3.1
Wholesale trade-durable goods	50	197	2.9
Eating and drinking places	58	153	2.3
Oil and gas extraction	13	147	2.2
Transportation equipment	37	106	1.6
Food and kindred products	20	104	1.6
Miscellaneous manufacturing industries	39	89	1.3
Wholesale trade-non-durable goods	51	86	1.3
Printing, Publishing, and Allied Industries	27	75	1.1
Apparel and other finished products made from fabrics and similar materials	23	75	1.1
Primary metal industries	33	70	1.0
Apparel and accessory stores	56	70	1.0
Motion pictures	78	68	1.0
Amusement and recreation services	79	68	1.0
Others (each one < 1% of total IPO sample)		869	13.0
Total		**6,706**	**100**

This table presents the distribution of IPOs from 1980 to 2016 by year and industry. Panel A presents the time distribution. Panel B presents the industry distribution.

Table 3
Univariate analysis of abnormal R&D expenditures from Year -1 to Year 3 around IPO

Panel A: Median values of abnormal R&D expenditures from Year -1 to Year 3

Year	-1	0	1	2	3
N	1,194	2,769	2,766	2,528	2,262
ARD	0.014***	0.010***	-0.002***	-0.003***	-0.005***
PM_ARD	0.020***	0.015***	0.002***	0.001	-0.003***
SAG_ARD	0.019***	0.016***	0.000	0.002	-0.003**
ROA_SAG_ARD	0.019***	0.016***	0.001	0.002	-0.003***

Panel B: Correlation matrix (Pearson above and Spearman below) among R&D expenditure measures for Year -1

	RD	*NRD*	*ARD*	*PM_ARD*	*SAG_ARD*	*ROA_SAG_ARD*
RD		0.776***	0.791***	0.702***	0.384***	0.385***
NRD	0.909***		0.228***	0.210***	0.086***	0.086***
ARD	0.556***	0.237***		0.879***	0.683***	0.683***
PM_ARD	0.456***	0.208***	0.743***		0.507***	0.507***
SAG_ARD	0.468***	0.199***	0.795***	0.594***		1.000***
ROA_SAG_ARD	0.469***	0.199***	0.796***	0.593***	0.997***	

This table presents univariate analysis of abnormal R&D expenditures from Year -1 to Year 3 around IPOs. Panel A presents the median values of abnormal R&D expenditures for the period from Year -1 to Year 3 around IPOs. Panel B presents the correlation matrix among R&D expenditures, normal R&D expenditures and abnormal R&D expenditures for Year -1. *ARD* is the abnormal R&D expenditures estimated from the model in Canace et al. (2018). *PM_ARD* is the performance (ROA) matched abnormal R&D expenditures calculated following the approach in Kothari et al. (2005). *SAG_ARD* is the size, age and sales growth matched abnormal R&D expenditures using the propensity score matching procedure as in Armstrong et al. (2016). *ROA_SAG_ARD* is the performance (ROA), size, age and sales growth matched abnormal R&D expenditures using the propensity score matching procedure as in Armstrong et al. (2016). Detailed variable definitions can be found in Appendix A. Wilcoxon test is used to examine whether the median value is statistically different from zero. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

Table 4
Multivariate analysis of comparing R&D expenditures of IPO companies and non-IPO companies from Year -1 to Year 3 around IPO (test for H1)

Year	-1	0	1	2	3
Intercept	-0.017	-0.014	-0.014	-0.014	-0.015
	(-1.63)	(-1.45)	(-1.45)	(-1.37)	(-1.46)
IPO	**0.092**	**0.028**	**-0.008**	**-0.011**	**-0.011**
	(4.61)***	**(2.89)*****	**(-0.85)**	**(-1.13)**	**(-1.19)**
CAPX	0.127	0.125	0.126	0.126	0.126
	(12.01)***	(12.16)***	(12.20)***	(12.21)***	(12.21)***
Lag(RD)	0.606	0.609	0.608	0.602	0.606
	(56.52)***	(58.17)***	(58.16)***	(57.80)***	(57.94)***
RD_IND	0.014	0.013	0.013	0.013	0.013
	(5.22)***	(5.10)***	(5.20)***	(5.08)***	(5.29)***
LEV	-0.013	-0.013	-0.013	-0.014	-0.014
	(-5.18)***	(-5.47)***	(-5.45)***	(-5.57)***	(-5.46)***
Lag(CASH)	0.065	0.064	0.064	0.064	0.064
	(21.69)***	(22.00)***	(21.95)***	(22.12)***	(22.05)***
SIZE	0.002	0.002	0.002	0.002	0.002
	(8.70)***	(8.31)***	(8.44)***	(8.12)***	(8.32)***
SGA	0.093	0.090	0.090	0.090	0.090
	(23.62)***	(23.78)***	(23.79)***	(23.74)***	(23.75)***
ΔSALE	0.012	0.012	0.012	0.012	0.012
	(6.91)***	(7.34)***	(7.37)***	(7.29)***	(7.34)***
DIV	-0.084	-0.082	-0.089	-0.088	-0.087
	(-3.96)***	(-4.05)***	(-4.26)***	(-4.24)***	(-4.19)***
TSTK	-0.025	-0.025	-0.025	-0.025	-0.025
	(-6.27)***	(-6.36)***	(-6.31)***	(-6.31)***	(-6.30)***
ACQ	0.044	0.043	0.043	0.043	0.043
	(7.94)***	(7.99)***	(7.98)***	(7.89)***	(7.91)***
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
N	77,725	79,376	79,371	79,127	78,838
Adj. R^2	0.7847	0.7799	0.7793	0.7789	0.8203

This table presents the multivariate OLS regression results of R&D expenditures on a set of variables in the model of Canace et al. (2018) by pooling together all IPO companies and non-IPO companies from 1980 to 2016, as proposed and implemented in Ball and Shivakumar (2008). *IPO* is a dummy variable that equals 1 for IPO companies and 0 otherwise. Detailed definitions for other variables can be found in Appendix A. For brevity, estimated coefficients of interaction terms of *IPO* and other variables in Eq. (2) are not presented in the table. T-statistics appear in parentheses and are calculated based on standard errors clustered by companies. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 5
Multivariate analysis of comparing R&D expenditures between IPO companies and PSM matched non-IPO companies by performance (ROA), size, age and sales growth from Year -1 to Year 3 around IPO (test for H1)

Year	-1	0	1	2	3
Intercept	-0.022	-0.024	-0.016	-0.022	-0.007
	(-0.28)	(-3.01)***	(-0.33)	(-1.56)	(-0.40)
IPO	**0.045**	**0.021**	**0.002**	**0.003**	**-0.020**
	(2.25)**	**(2.92)*****	**(0.29)**	**(0.27)**	**(-1.75)***
CAPX	0.330	-0.048	-0.002	-0.036	0.016
	(4.09)***	(-2.02)**	(-0.06)	(-1.07)	(0.34)
Lag(RD)	0.701	0.649	0.673	0.494	0.470
	(25.92)***	(53.22)***	(52.83)***	(39.04)***	(32.93)***
RD_IND	-0.024	-0.032	0.003	-0.021	0.002
	(-1.67)*	(-2.62)***	(0.21)	(-1.51)	(0.06)
LEV	0.011	0.007	-0.007	-0.004	-0.012
	(1.77)*	(1.76)*	(-1.88)*	(-0.88)	(-2.88)***
Lag(CASH)	0.036	0.028	0.038	0.044	-0.054
	(1.66)*	(3.09)***	(4.66)***	(4.65)***	(-4.04)***
SIZE	0.001	0.002	0.002	0.004	0.002
	(0.73)	(2.99)***	(3.78)***	(4.94)***	(1.67)
SGA	0.095	0.086	0.098	0.138	0.148
	(9.22)***	(19.22)***	(21.53)***	(28.10)***	(34.78)***
ΔSALE	0.033	0.016	0.005	0.007	0.003
	(5.31)***	(6.15)***	(1.37)	(1.71)*	(0.58)
DIV	-0.408	-0.005	-0.069	-0.137	0.008
	(-7.79)***	(-0.26)	(-1.88)*	(-2.93)***	(0.12)
TSTK	0.061	0.001	-0.004	-0.010	0.058
	(2.05)**	(0.04)	(-0.32)	(-0.67)	(3.07)***
ACQ	0.175	0.081	0.056	0.016	0.000
	(3.02)***	(2.57)**	(1.89)*	(0.46)	(0.00)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
N	2,168	5,296	5,418	5,048	4,566
Adj. R^2	0.8225	0.7956	0.8048	0.7943	0.8129

This table presents the multivariate OLS regression results of R&D expenditures on a set of variables in the model of Canace et al. (2018) by pooling together all IPO companies and their matched non-IPO companies from 1980 to 2016 by performance (ROA), size, age and sales growth using a propensity score matching procedure as proposed and implemented in Armstrong et al. (2016). *IPO* is a dummy variable that equals 1 for IPO companies and 0 otherwise. Detailed definitions for other variables can be found in Appendix A. For brevity, estimated coefficients for interaction terms of *IPO* and other variables in Eq. (2) are not presented in the table. T-statistics appear in parentheses. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 6
Abnormal R&D expenditures of Year -1 and IPO first-day market value (test for H2)

Variables	(1)	(2)	(3)	(4)	(5)
Intercept	3.824	3.271	2.844	2.784	2.826
	(15.22)***	(15.51)***	(11.82)***	(14.23)***	(14.04)***
L(ARD)	**0.067**	**0.065**	**0.050**	**0.031**	**0.028**
	(3.25)***	**(3.42)*****	**(2.74)*****	**(2.03)****	**(2.22)****
L(NRD)	0.421	0.231	0.139	0.063	0.068
	(9.25)***	(5.86)***	(3.71)***	(2.55)**	(3.31)***
L(CAPX)		0.391	0.269	0.171	0.140
		(12.06)***	(8.95)***	(5.06)***	(4.41)***
L(IBBRD)			0.131	0.102	0.094
			(4.30)***	(3.96)***	(4.31)***
L(IBBRD)×NegIBBRD			-0.283	-0.191	-0.172
			(-4.81)***	(-3.82)***	(-3.85)***
L(CEQ)			0.132	0.029	0.011
			(4.51)***	(1.15)	(0.53)
L(CEQ)×NegCEQ			-0.260	-0.056	-0.029
			(-4.78)***	(-1.22)	(-0.78)
SIZE				0.199	0.233
				(6.60)***	(8.40)***
AGE				-0.158	-0.107
				(-5.19)***	(-4.00)***
PreUW				0.457	0.394
				(7.56)***	(7.32)***
RETENTION				2.034	1.973
				(14.93)***	(14.95)***
BIGN				0.414	0.377
				(4.66)***	(4.93)***
PriceUpdate					1.552
					(17.29)***
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
N	1,156	1,156	1,156	1,156	1,156
Adj. R^2	0.4177	0.5101	0.5334	0.6944	0.7859

This table presents results from estimating Eq. (3). Detailed variable definitions can be found in Appendix A. T-statistics appear in parentheses and are calculated based on standard errors clustered by IPO year-quarter. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 7
Abnormal R&D expenditures of Year -1 and Post-IPO short- and long-window returns (test for H2)

Variables	(1) *RET_1M*	(2) *RET_3M*	(3) *RET_6M*	(4) *RET_12M*	(5) *RET_24M*	(6) *RET_36M*
Intercept	-0.251	-0.082	-0.103	-0.054	-0.014	-0.021
	(-3.96)***	(-1.93)*	(-3.89)***	(-3.56)***	(-1.41)	(-2.14)**
ARD	**0.083**	**0.092**	**0.063**	**0.029**	**0.020**	**0.018**
	(1.77)*	**(3.33)*****	**(3.29)*****	**(2.18)****	**(2.08)****	**(2.15)****
SIZE	0.000	-0.005	-0.002	-0.000	-0.002	-0.001
	(0.05)	(-1.30)	(-0.93)	(-0.12)	(-1.30)	(-1.25)
AGE	0.016	0.008	0.007	0.006	0.006	0.004
	(1.53)	(1.30)	(1.80)*	(2.33)**	(2.69)***	(1.91)*
PreUW	0.056	0.041	0.021	0.016	0.015	0.013
	(2.31)**	(3.04)***	(2.72)***	(3.25)***	(3.61)***	(3.89)***
RETENTION	0.042	0.029	0.034	0.021	-0.001	0.002
	(1.29)	(1.33)	(2.17)**	(2.08)**	(-0.10)	(0.27)
BIGN	0.042	0.021	0.001	0.001	0.003	0.010
	(2.08)**	(1.53)	(0.08)	(0.14)	(0.51)	(2.20)**
IR	-0.053	-0.019	-0.015	-0.011	-0.010	-0.010
	(-2.74)***	(-1.61)	(-2.61)***	(-2.00)**	(-3.02)***	(-3.94)***
$R_{m,t} - R_{f,t}$	1.315	1.412	1.325	1.385	1.384	1.369
	(6.94)***	(11.89)***	(13.40)***	(19.18)***	(22.39)***	(26.56)***
SMB	1.015	1.221	1.127	1.015	1.117	1.142
	(3.27)***	(5.65)***	(6.90)***	(6.87)***	(13.12)***	(19.22)***
HML	-1.845	-1.333	-1.036	-1.041	-1.008	-0.945
	(-4.25)***	(-6.66)***	(-8.01)***	(-10.20)***	(-12.86)***	(-13.34)***
UMD	0.051	0.008	0.062	-0.118	-0.295	-0.393
	(0.19)	(0.06)	(0.64)	(-1.63)	(-6.07)***	(-11.60)***
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1,138	3,468	6,935	13,818	26,762	37,844
Adj. R^2	0.2055	0.2069	0.1800	0.1874	0.1745	0.1642

This table presents results from estimating Eq. (4). Columns (1)-(6) present results for post-IPO stock returns covering different windows of 1 month (*RET_1M*), 3 months (*RET_3M*), 6 months (*RET_6M*), 12 months (*RET_12M*), 24 months (*RET_24M*), and 36 months (*RET_36M*). Detailed variable definitions can be found in Appendix A. T-statistics appear in parentheses and are calculated based on standard errors clustered by IPO year-quarter. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 8
Abnormal R&D expenditures of Year -1 (Year 0) and Sales Growth and Price-to-Sales ratios of post-IPO years (test for H3a)

Panel A: Future sales growth

Variables	(1) *FSGR_Y1*	(2) *FSGR_Y2*	(3) *FSGR_Y3*	(4) *FSGR_Y1*	(5) *FSGR_Y2*	(6) *FSGR_Y3*
Intercept	-0.916	-1.506	-1.729	0.491	0.843	1.206
	(-1.00)	(-1.27)	(-1.31)	(2.34)**	(2.36)**	(2.39)**
ARD_Year -1	**7.390**	**8.377**	**7.772**			
	(2.54)**	**(2.03)****	**(1.80)***			
ARD_Year 0				**1.627**	**2.415**	**3.282**
				(2.62)***	**(2.50)****	**(2.44)****
NRD	3.731	6.306	7.866	0.482	1.184	2.338
	(1.76)*	(1.84)*	(2.00)**	(1.12)	(1.73)*	(2.41)**
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	733	733	733	1,966	1,966	1,966
Adj. R^2	0.1159	0.0722	0.0421	0.0979	0.0517	0.0333

Table 8 (Continued)
Abnormal R&D expenditures of Year -1 (Year 0) and Sales Growth and Price-to-Sales ratios of post-IPO years

Panel B: Future price-to-sales ratio

Variables	(1) *FPS_Y1*	(2) *FPS_Y2*	(3) *FPS_Y3*	(4) *FPS_Y1*	(5) *FPS_Y2*	(6) *FPS_Y3*
Intercept	3.684	4.024	5.784	12.823	10.783	13.113
	(0.80)	(1.49)	(2.93)***	(2.48)**	(3.21)***	(3.79)***
ARD_Year -1	**3.846**	**8.236**	**6.120**			
	(0.53)	**(1.86)***	**(1.73)***			
ARD_Year 0				**28.359**	**19.126**	**16.039**
				(3.49)***	**(3.82)*****	**(3.44)*****
NRD	19.489	8.024	6.374	29.490	11.242	7.183
	(3.76)***	(2.87)***	(3.04)***	(3.56)***	(2.76)***	(2.31)**
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	733	733	733	1,966	1,966	1,966
Adj. R^2	0.0791	0.0916	0.1279	0.0965	0.1178	0.1033

This table presents results from estimating Eq. (5). Panel A presents results for future sales growth. Columns (1)-(3) present results for the associations between abnormal R&D expenditures of Year -1 and post-IPO sales growth. Columns (4)-(6) present results for the associations between abnormal R&D expenditures of Year 0 and post-IPO sales growth. Panel B presents results for future price-to-sales ratios. Column (1)-(3) present results for the associations between abnormal R&D expenditures of Year -1 and post-IPO fiscal year end price-to-sales ratios. Column (4)-(6) present results for the associations between abnormal R&D expenditures of Year 0 and post-IPO fiscal year end price-to-sales ratios. Detailed variable definitions can be found in Appendix A. T-statistics appear in parentheses and are calculated based on standard errors clustered by IPO year-quarter. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 9
Abnormal R&D expenditures of Year -1 (Year 0) and patent output of post-IPO years (test for H3b)

Variables	(1) *L(COUNTS)*	(2) *L(COUNTS)*	(3) *L(COUNTS)*	(4) *L(COUNTS)*	(5) *L(CITES)*	(6) *L(CITES)*	(7) *L(CITES)*	(8) *L(CITES)*
Intercept	-0.778	-1.252	-0.109	-0.706	-0.165	-0.618	-0.881	1.222
	(-1.45)	(-2.25)**	(-0.35)	(-2.19)**	(-0.22)	(-0.75)	(-1.89)*	(2.90)***
L(ARD)_Year -1	**0.094**	**0.100**			**0.099**	**0.113**		
	(1.93)*	**(1.85)***			**(1.54)**	**(1.88)***		
L(ARD)_Year 0			**0.163**	**0.172**			**0.182**	**0.194**
			(5.08)***	**(5.46)*****			**(4.07)*****	**(4.24)*****
L(NRD)	0.380	0.074	0.535	0.320	0.430	0.089	0.601	0.307
	(5.19)***	(1.15)	(11.43)***	(5.72)***	(5.10)***	(0.94)	(8.15)***	(3.55)***
L(CAPX)		0.435		0.276		0.467		0.354
		(6.16)***		(6.15)***		(4.42)***		(5.55)***
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	335	335	1,147	1,147	380	380	1,206	1,206
Adj. R-Sq	0.2321	0.3002	0.2309	0.2582	0.2063	0.2426	0.1419	0.1509

This table presents results from estimating Eq. (6). Columns (1)-(4) present results for the associations between abnormal R&D expenditures of Year -1 (Year 0) and total number of patents registered from Year 1 to Year 3. Columns (5)-(8) present results or the associations between abnormal R&D expenditures of Year -1 (Year 0) and total patent citations from Year 1 to Year 3. Detailed variable definitions can be found in Appendix A. T-statistics appear in parentheses and are calculated based on standard errors clustered by IPO year-quarter. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 10

Sensitivity Test: Multivariate analysis of comparing Sales Growth and Price-to-Sales ratios of post-IPO years between IPO companies and PSM matched non-IPO companies by performance (ROA), size, age and sales growth of Year -1 and Year 0

Variables	(1) *FSGR_Y1*	(2) *FSGR_Y2*	(3) *FSGR_Y3*	(4) *FPS_Y1*	(5) *FPS_Y2*	(6) *FPS_Y3*	(7) *FSGR_Y1*	(8) *FSGR_Y2*	(9) *FSGR_Y3*	(10) *FPS_Y1*	(11) *FPS_Y2*	(12) *FPS_Y3*
Intercept	-0.493	-1.024	-1.530	3.353	3.542	1.908	0.340	0.057	-0.047	-0.009	2.334	3.043
	(-0.59)	(-0.59)	(-0.60)	(0.26)	(0.83)	(0.84)	(0.47)	(0.56)	(-0.36)	(-0.01)	(1.32)	(3.11)***
IPO	0.694	1.028	1.300	3.378	-2.231	2.463	0.415	0.598	0.752	2.633	0.422	1.715
	(9.27)***	(6.62)***	(5.78)***	(2.98)***	(-1.91)*	(3.66)***	(13.54)***	(13.64)***	(13.46)***	(6.84)***	(0.71)	(4.30)***
IPO×ARD_Year -1	**2.495**	**4.204**	**3.783**	**-10.966**	**-83.756**	**6.962**						
	(3.08)***	**(2.50)****	**(1.59)**	**(-0.87)**	**(-6.68)*****	**(0.87)**						
IPO×ARD_Year 0							**1.397**	**2.126**	**2.253**	**16.043**	**25.069**	**23.332**
							(3.65)***	**(3.89)*****	**(3.23)*****	**(3.36)*****	**(3.33)*****	**(4.63)*****
IPO×NRD	0.692	1.995	2.747	8.525	-9.611	-18.048	0.087	0.166	0.279	1.712	-0.161	-3.485
	(2.02)**	(2.81)***	(2.67)***	(1.60)	(-1.82)*	(-5.68)***	(0.45)	(0.60)	(0.79)	(0.71)	(-0.04)	(-1.34)
ARD	-0.959	-0.808	-0.709	45.648	94.202	5.140	-0.417	-0.884	-0.892	5.363	-12.122	-8.293
	(-1.33)	(-0.54)	(-0.34)	(4.05)***	(8.42)***	(0.71)	(-1.39)	(-2.07)**	(-1.64)	(1.44)	(-2.03)**	(-2.10)**
NRD	0.500	0.686	0.803	23.941	25.082	25.810	0.163	0.283	0.340	10.297	10.755	12.807
	(1.81)*	(1.20)	(0.97)	(5.57)***	(5.93)***	(10.08)***	(1.34)	(1.64)	(1.54)	(6.80)***	(4.48)***	(7.86)***
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1,973	1,976	1,977	1,957	1,824	1,615	4,700	4,705	4,707	4,592	4,175	3,762
Adj. R^2	0.2468	0.1958	0.1504	0.2054	0.1822	0.1407	0.1514	0.1248	0.1119	0.1049	0.1175	0.0802

This table presents the multivariate OLS regression results from estimating Eq. (7) by pooling together all IPO companies and their matched non-IPO companies from 1980 to 2016 by performance (ROA), size, age and sales growth using a propensity score matching procedure as proposed and implemented in Armstrong et al. (2016). *IPO* is a dummy variable that equals 1 for IPO companies and 0 otherwise. The dependent variables include sales growth (*FSGR*) and price-to-sales (*FPS*) ratios. Detailed definitions for other variables can be found in Appendix A. T-statistics appear in parentheses. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 11
Sensitivity Test: Multivariate analysis of comparing patent output of post-IPO years between IPO companies and PSM matched non-IPO companies by performance (ROA), size, age and sales growth of Year -1 and Year 0

Variables	(1) *L(COUNTS)*	(2) *L(CITES)*	(3) *L(COUNTS)*	(4) *L(CITES)*
Intercept	-2.107	-1.608	-0.845	-1.895
	(-3.63)***	(-2.49)**	(-0.66)	(-1.10)
IPO	0.562	1.023	0.264	1.081
	(2.88)***	(3.77)***	(2.95)***	(8.11)***
IPO×L(ARD)_Year -1	**0.144**	**0.243**		
	(2.60)* **	**(3.23)*** **		
IPO×L(ARD)_Year 0			**0.036**	**0.065**
			(1.08)	**(1.31)**
IPO×L(NRD)	-0.271	-0.282	-0.156	-0.262
	(-4.13)***	(-3.13)***	(-4.04)***	(-4.60)***
L(ARD)	-0.032	-0.114	0.148	0.158
	(-0.99)	(-2.54)**	(7.49)***	(5.11)***
L(NRD)	0.229	0.139	0.293	0.363
	(5.18)***	(2.22)**	(11.44)***	(9.34)***
L(CAPX)	0.620	0.797	0.516	0.609
	(13.90)***	(12.92)***	(20.78)***	(16.14)***
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
N	546	595	1,756	1,809
Adj. R^2	0.6897	0.5863	0.5953	0.4308

This table presents the multivariate OLS regression results from estimating Eq. (8) by pooling together all IPO companies and their matched non-IPO companies from 1980 to 2016 by performance (ROA), size, age and sales growth using a propensity score matching procedure as proposed and implemented in Armstrong et al. (2016). *IPO* is a dummy variable that equals 1 for IPO companies and 0 otherwise. Detailed definitions for other variables can be found in Appendix A. T-statistics appear in parentheses. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).

Table 12
Alternative measure of abnormal R&D expenditures using the model in Roychowdhury (2006): Univariate and Multivariate analyses for years around IPO

Panel A: Univariate analysis

Year	-1	0	1	2	3
N	1,274	1,262	1,178	1,032	879
ARD	0.150***	0.094***	0.072***	0.066***	0.058***
PM_ARD	0.085***	0.053***	0.037***	0.035***	0.023***
SAG_ARD	0.252***	0.158***	0.114***	0.116***	0.107***
ROA_SAG_ARD	0.252***	0.165***	0.117***	0.119***	0.110***

Panel B: Multivariate analysis by pooling together all IPO companies and their PSM matched non-IPO counterparts by performance (ROA), size, age and sales growth

Year	-1	0	1	2	3
Intercept	-0.019	0.117	0.123	0.127	0.158
	(-0.11)	(8.98)***	(1.19)	(4.66)***	(4.62)***
IPO	**0.255**	**0.096**	**0.088**	**0.070**	**0.062**
	(13.07)* **	**(12.59)*** **	**(10.79)*** **	**(7.36)*** **	**(4.89)*** **
Lag(SALE)	0.074	0.034	0.050	0.038	0.065
	(7.14)***	(8.61)***	(11.38)***	(7.48)***	(10.21)***
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes
N	2,168	5,296	5,418	5,048	4,566
Adj. R-Sq	0.1441	0.1254	0.1169	0.0991	0.1179

This table presents results from estimating abnormal R&D expenditures using the model proposed by Roychowdhury (2006). Panel A presents the magnitudes of estimated unmatched and matched abnormal R&D expenditures for years around IPO. Panel B presents the multivariate OLS regression results from estimating Eq. (9) by pooling together all IPO companies and their non-IPO counterparts matched by performance (ROA), size, age and sales growth using the propensity score matching technique as implemented in Armstrong et al. (2016). Detailed variable definitions can be found in Appendix A. For brevity, estimated coefficient of the interaction term *IPO×Lag(SALE)* is not presented in the table. T-statistics appear in parentheses. Year fixed effect and industry fixed effect based on 2-digit SIC code are included but not reported. *, **, and *** represent significance levels of 0.10, 0.05, and 0.01 respectively (two-tailed).