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# How do technology ventures signal IPO quality? A configurational approach

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ABSTRACT

This study examines how quality signals sent by technology ventures jointly affect investors' decisions under information asymmetry. We categorize signal contents as concerning technology development, venture officers, or early investors. Because similar information may not much reduce information asymmetry, different signals of the same content substitute for one another in enabling ventures to raise capital in their initial public offerings (IPOs). In contrast, signals of different contents collectively reduce information asymmetry, and thus complement each other. Furthermore, public investors may be more capable of assessing, and therefore give more weight to, signals based on the abilities and commitment of venture officers and early investors than to signals based on the viability and appropriability of technology development. We employ fuzzy set qualitative comparative analysis (fsQCA) and find evidence for these mechanisms from data on 268 IPOs of biotechnology ventures in the United States.

## 1. Introduction

Technology ventures often need to raise large amounts of capital before they can generate stable revenue and income from their products or services. Researchers have widely documented that initial public offering (IPO) is a major financing conduit (Brau & Fawcett, 2006; Ritter & Welch, 2002), but information asymmetry between technology ventures and investors in IPO markets is high. Ventures' advanced and specialized knowledge and technologies are difficult for external stakeholders to understand (Aldrich & Fiol, 1994), and without credible operating records they often lack legitimacy in the eyes of investors (Fisher, Kotha, & Lahiri, 2016).

Signaling theory helps explain how market participants make decisions under information asymmetry (Spence, 1973, 2002). In the IPO context, researchers have examined the signaling effects of intellectual capital (Mousa & Reed, 2013; Singh & Van der Zahn, 2009; Useche, 2014), product development (Deeds, Decarolis, & Coombs, 1997; Guo, Lev, & Zhou, 2005), board directors (Certo, Daily, & Dalton, 2001; Pollock, Chen, Jackson, & Hambrick, 2010), executive officers (Cohen & Dean, 2005), founders' roles and status (Gao & Jain, 2011; Wang & Song, 2016; Williams, Duncan, & Ginter, 2010), and other venture characteristics specified in media and in IPO prospectuses (Gao, Darroch, Mather, & MacGregor, 2008; Mousa, Wales, & Harper, 2015; Pollock & Rindova, 2003).

Although previous studies have extensively examined how these signals individually affect investors' decisions, little is known about whether and how they work jointly. This is an important void, given that investors are unlikely to perceive and evaluate quality signals in isolation. In analyzing mergers and acquisitions (M&As), Campbell, Sirmon, and Schijven (2016, p. 164) posit that "rather than isolating the independent effects of individual factors, market participants [investors] likely perceive and evaluate M&As as complex configurations of interdependent factors." Different signals may have complex relationships among themselves, making it difficult to understand how they collectively affect investors' decisions. Are different quality signals of technology ventures substitutable or complementary? Do investors view quality signals in isolation or look for specific combinations of signals that collectively reflect venture potential?

Some researchers argue that different signals complement each other, so that more signals are better in reducing information asymmetry (Audretsch, Bonte, & Mahagaonkar, 2012; Pollock et al., 2010). Others argue that different signals substitute for each other, so that the utility of one signal diminishes in the presence of other quality signals (Arthurs, Busenitz, Hoskisson, & Johnson, 2009; Higgins, Stephan, & Thursby, 2011; Hsu & Ziedonis, 2013).

There seem to be two major reasons for these conflicting arguments

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and findings. First, management researchers have focused on different venture characteristics that serve as quality signals (e.g., intellectual capital, product development, founders' roles, board directors, executive officers, and early investors) (Connelly, Certo, Ireland, & Reutzel, 2011), but have not clearly distinguished the quality contents being signaled. Whether venture signals complement or substitute for one another may depend on whether the signaled contents are complementary or substitutable in relating to the venture's operations and development.

Second, the majority of management studies adopting signaling theory have not clearly distinguished signaling costs from penalty costs (Bergh, Connelly, Ketchen, & Shannon, 2014). Signaling costs are *ex ante*—sending a signal costs more for low-quality than for high-quality signalers—while penalty costs are *ex post*—the exposure of false signaling imposes more costs on low-quality than on high-quality signalers (Bergh et al., 2014; Connelly et al., 2011). Whether venture signals are complementary to or substitutable for each other may also depend on the cost equilibriums of the signals being studied.

We address these issues by investigating the joint effects of various signals sent out by technology ventures before their IPOs (i.e., pre-market signals). Technology ventures are in essence bundles of complex and firm-specific resources of uncertain value, so investors struggle to assess information about them (Deeds et al., 1997; Wang & Thornhill, 2010). These characteristics make them a fertile ground to study how quality signals affect financial markets' reaction to IPOs. To disentangle the joint effects of different signals on IPO performance, we use a novel technique—fuzzy set qualitative comparative analysis (fsQCA) (Fiss, 2011; Ragin, 2008)—that is particularly useful for disentangling complex relationships among predictors and outcome variables (Fiss, Sharapov, & Cronqvist, 2013).

This study makes several contributions. We advance signaling theory by unraveling the individual and joint impacts of signals with differing *contents* and signals with different *cost equilibriums*. Although researchers have studied a variety of quality signals for technology ventures and have distinguished signaling costs from penalty costs (Bergh et al., 2014), it remains to be seen how different signals *collectively* separate high-quality and low-quality ventures (Connelly et al., 2011). We also contribute to research on venture development by exploring how managers of technology ventures can deploy combinations of different signals that are complementary to rather than substitutable for each other to signal their ventures' potential.

## 2. Venture signals for initial public offerings

Through IPOs, ventures can raise large amounts of capital from public investors (Brau & Fawcett, 2006; Ritter & Welch, 2002). A major challenge for technology firms undertaking IPOs lies in information asymmetry between them and investors in the stock market. Not only are their specialized technologies and cutting-edge knowledge difficult for public investors to understand, but since most of them still lack stable operations, revenue, and cash flow, it is difficult for public investors to estimate their value. As a result, investors need to rely on ventures' quality signals (Cohen & Dean, 2005; Deeds et al., 1997), such as specific characteristics, strategies, decisions, or behaviors that can reflect their potential (Bergh et al., 2014; Connelly et al., 2011).

Because we are interested in understanding how much capital a technology venture can raise from its IPO, we focus on signals that have occurred before the IPO process. Table 1 summarizes the research on these signals.

As Table 1 shows, the literature on signals in IPO markets began by examining credible signals of scientific and engineering capabilities, using measures of intellectual property and product development (Deeds et al., 1997). The literature then incorporated the signaling effects of venture officers, such as top management teams (Cohen & Dean, 2005) and board directors (Certo et al., 2001). More recently, researchers have demonstrated increasing interest in the signaling roles of early investors, including business angels and venture capitalists (Pollock et al., 2010). We categorize quality signals of technology ventures into these three major content types: technology development, venture insiders, and early investors (Table 1, Column 3).

By acknowledging the advancement of this literature, we notice that several issues need further investigation. First, although prior studies have examined how these signals individually affect investors' decisions, little is known about whether and how they work jointly. This is an important void, given that investors are unlikely to perceive and evaluate quality signals in isolation (Bergh et al., 2014; Connelly et al., 2011).

Second, previous studies have not paid much attention to the "separating equilibrium" of venture signals. An effective signal needs to be costly to imitate (Bergh et al., 2014; Connelly et al., 2011). As a consequence, high-quality participants choose to send the signal while low-quality participants choose not to (Spence, 1973, 2002).

Note that a separating equilibrium can be achieved through signaling costs or penalty costs. Signaling costs are the up-front costs of sending the signal (Bergh et al., 2014; Connelly et al., 2011). For example, patent applicants need to pay application, validation, renewal, and attorney fees (De Rassenfosse & van Pottelsberghe de la Potterie, 2013), and product development requires various resources and capabilities (Hoang & Rothaermel, 2010). Penalty costs are the consequence of sending a false signal. For example, a venture's executive officers and board directors will lose money by holding the venture's stocks if the venture cannot succeed (Bell, Moore, & Al-Shammari, 2008; Filatotchev & Bishop, 2002). They may also lose reputation (Ashforth & Mael, 1989). Certo and colleagues point out that "directors would be hesitant to join the board of a low-quality firm, as this might damage their reputation as expert decision agents" (Certo et al., 2001, p. 36). Column 4 of Table 1 summarizes the separating equilibriums of these quality signals.

### 2.1. Signals of technology development and IPO proceeds

A venture's technology development can be reflected in various signals, including the number of product lines (Deeds et al., 1997), the stage of product candidates (Guo et al., 2005), the number of patents applied for or granted (Mousa & Reed, 2013; Useche, 2014), and the number of patent citations (Deeds et al., 1997). In essence, these signals indicate the venture's capabilities in obtaining intellectual property and/or developing new products. For example, obtaining and maintaining a patent entails a variety of costs and fees (De Rassenfosse & van Pottelsberghe de la Potterie, 2013), suggesting that low-quality companies may find it more costly to pursue a broad patenting strategy than do high-quality ones.

Product development also serves as a quality signal (Audretsch et al., 2012; Deeds et al., 1997; Guo et al., 2005). For example, experimental discovery in clinical settings is an important way to develop functional and safe solutions to health problems. Therefore, a biotechnology venture's clinical studies can reflect its abilities to test and improve its products and services (Deeds et al., 1997; Hoang & Rothaermel, 2010). In fact, the U.S. Food and Drug Administration (FDA) provides detailed information about drug development on its official website (U.S. FDA, 2016), and such information is also highlighted in biotechnology ventures' IPO prospectuses. Clinical studies are often costly to conduct (Hoang & Rothaermel, 2010), making them difficult for low-quality ventures to imitate.

We posit that different signals of technology development substitute for one another in enabling ventures to raise capital in their IPOs. From a legitimacy perspective (Aldrich & Fiol, 1994; Fisher et al., 2016), both intellectual property and product development reflect a venture's ability to develop a viable business. A venture's patents suggest that it possesses the necessary scientific and engineering capabilities. Similarly, only capable firms are able to develop a large number of product candidates (Audretsch et al., 2012; Deeds et al., 1997; Guo et al., 2005).

**Table 1**
Sample studies on how ventures signal IPO quality.

| Study | Signal measures | Quality contents | Cost equilibriums |
|---|---|---|---|
| (Deeds et al., 1997) | – Number of product candidates<br>– Citations of a firm's scientists | Technology development | Signaling costs |
| (Certo et al., 2001) | – Board reputation | Venture officers | Penalty costs |
| (Filatotchev & Bishop, 2002) | – Share ownership | Venture officers | Penalty costs |
| (Cohen & Dean, 2005) | – Legitimacy of top management team | Venture officers | Signaling costs |
| (Guo et al., 2005) | – Number of total product candidates<br>– Average stage of product pipelines<br>– Percent of products with patents | Technology development | Signaling costs |
| (Lester et al., 2006) | – TMT education prestige | Venture officers | Penalty costs |
| (Pollock et al., 2010) | – Prestige of executives and directors<br>– Prestige of venture capitalists<br>– Prestige of underwriters | Venture officers, early investors | Penalty costs |
| (Mousa & Reed, 2013) | – Patent intensity | Technology development, venture officers | Signaling costs |
| (Useche, 2014) | – Number of applied patents | Technology development | Signaling costs |
| (Wang & Song, 2016) | – Founder-board ratio | Venture officers | Penalty costs |

Notes: This table provides a sample of premarket signals found to influence IPO outcomes rather than a complete review of the related literatures.

Therefore, either intellectual property or product development will signal to investors that the venture has the technical capabilities to develop a viable business.

**H1.** Different quality signals based on technology development are substitutable for one another in forming sufficient conditions for ventures to raise capital in their IPOs.

### 2.2. Signals of venture officers and IPO proceeds

Venture officers include executive officers and board directors. Executive officers are those holding C-level positions (e.g., chief executive officers, chief operating officers, and chief financial officers), presidents, and vice presidents. These individuals are core members of the top management teams, and have strong power to influence their firms' decisions and operations (Finkelstein, 1992). In technology ventures and entrepreneurial firms, board directors also play significant roles in decision making, talent hunting, fund seeking, and so forth (Garg, 2013; Kroll, Walters, & Le, 2007), and are widely considered venture insiders (Certo et al., 2001; Pollock et al., 2010).

Table 1 summarizes previous studies of the signaling roles of founders (Gao & Jain, 2011; Williams et al., 2010), top management teams (Cohen & Dean, 2005; Lester et al., 2006), and board directors (Certo et al., 2001; Pollock et al., 2010). The importance of a founder to his or her venture has been widely theorized and tested (Wasserman, 2006). Researchers have used different variables to measure founders' roles, such as founder CEO (Gao & Jain, 2011), founder director (Wang & Song, 2016), and founder duality (in which the founder is both the CEO and the chairman of the board) (Williams et al., 2010).

Executive officers and board directors also signal quality, whether they are founders or not. However, information asymmetry between these venture insiders and external stakeholders such as public investors may be high (Jensen & Meckling, 1976). Both economic and emotional bonding can reduce information asymmetry between two parties (Williamson, 1988). Economic bonding—specifically, ownership by executive officers and board directors—reflects the extent to which their benefits are aligned with the residual value of their ventures (Jensen & Meckling, 1976). Social bonding, which aligns the two parties' social images and identities (Ashforth & Mael, 1989), partly explains why prominent executive officers and board directors often try to avoid being associated with failing ventures (Hoenig & Henkel, 2015; Zhang & Yu, 2017). Decision makers become more risk averse as their wealth accumulates (Kahneman & Tversky, 1979). Because the reputation of prominent individuals and organizations is worth more than that of nonprominent individuals and organizations, the former suffer more from reputational penalties than the latter. Furthermore, reputational penalties may occur in a longer horizon than economic penalties. An executive can avoid economic penalties by selling his or her stocks before the venture fails, but his or her reputation will still be damaged (Certo et al., 2001).

Overall, signals based on venture insiders reflect whether a venture's executive officers and board directors have the willingness and abilities to lead the venture successfully. Although prior research has examined a variety of quality signals based on venture officers, the underlying separating system is essentially the same. For example, if a founder of the venture possesses great knowledge and expertise in the business domain, investors in the stock market may not worry too much about whether the venture's board directors possess similar knowledge and expertise. We thus suggest that these signals do not have proportionally cumulative effects on public investors' confidence.

**H2.** Different quality signals based on venture officers are substitutable for one another in forming sufficient conditions that enable ventures to raise capital in their IPOs.

### 2.3. Signals of early investors and IPO proceeds

Early-stage investors are business angels and venture capitalists (Pollock et al., 2010; Williams et al., 2010). Raising a certain amount of capital from these investors before the IPO can also serve as a quality signal. Early-stage investors are often industry experts, who possess more specialized knowledge and skills than do public investors and thus are more capable of evaluating the potential of technology ventures (Brander, Amit, & Antweiler, 2002; Sahlman & Gorman, 1989). They also often assemble an increasingly refined constellation of legal and technology experts, advisory services, analysts, and other trustworthy service providers (Lerner, 1994; Sahlman & Gorman, 1989). Early-stage investors act as specialized agents for the broader investment community. Not only are they good at selecting ventures that have potential to grow, but they also facilitate strategic decisions, talent recruitment, and fund raising (Lerner, 1994). Therefore, public investors in IPO markets, who have rarely developed these capabilities, are likely to view the involvement of early investors as a quality signal (Pollock et al., 2010; Williams et al., 2010).

Early investor prominence is a particularly important signal. As Arthurs et al. (2009, p. 363) note, reputation "impacts the extent to which a VC [venture capitalist] will be able to raise future capital for a venture fund, maintain active ties with prominent underwriters, and establish ties with other VCs in order to syndicate their investments." Prominent early investors are more likely to be able to select promising technologies and provide value-added services for their invested ventures than non-prominent early investors (Busenitz, Fiet, & Moesel,

2004; Sahlman & Gorman, 1989). And prominent early investors will suffer more from reputational losses if their chosen ventures fail (Hoenig & Henkel, 2015; Zhang & Yu, 2017).

In sum, the involvement of early-stage investors may serve as a quality certificate to convince public investors in IPO markets (Megginson & Weiss, 1990). Certainly, researchers have measured this involvement in different ways, such as whether a venture is backed by venture capitalists or has them on its board, the amount of capital raised before the IPO, or the number of prestigious or prominent early-stage investors (Pollock et al., 2010; Williams et al., 2010). Since these signals all reflect early investors' contributions, we expect that their marginal effects on IPO performance decrease.

**H3.** Different quality signals based on early investors are substitutable for one another in forming sufficient conditions that enable ventures to raise capital in their IPOs.

### 2.4. From technology development to venture officers and early investors

Although researchers have separately examined the signaling effects of technology development, venture officers, and early investors, they have not looked at the relative importance of these three types of signals. We expect the signaling effects of venture officers and early investors to be greater than those of technology development. First, although intellectual property and product development indicators can reflect a venture's technological capabilities, various uncertainties may impede its success in the business domain. For example, clinical studies often take a long time. Typical clinical research includes multiple phases of studies, and stricter requirements and criteria apply to later trial phases (U.S. FDA, 2016). On average, 70% of phase I drug candidates successfully move to phase II, while only 33% of drug candidates in phase II successfully move to phase III (U.S. FDA, 2016). Thus, even a venture with many patents and product candidates in its pipeline may still be unable to market a profitable product.

In contrast to the arcane science and technology, what public investors in IPO markets are skilled at assessing is the abilities and commitment of the venture's officers and early investors. Founders possess unique knowledge about their venture's history, successes, failures, strengths, weaknesses, opportunities, and threats (Jain & Tabak, 2008)—knowledge that confers an advantage in both information and judgment (Wasserman, 2006). In a similar vein, Gao and Jain (2011) find that ventures led by founder CEOs achieve higher long-term returns than those led by nonfounder CEOs. As we note above, early investors also possess information advantages over public investors in IPO markets.

Second, signals of technology development mainly involve signaling costs, while signals of venture officers and early investors involve penalty costs (see Table 1). Signaling costs represent an initial belief in the quality of the venture, but do not indicate an ongoing commitment. Moreover, they could have been undertaken before adverse scientific or market indicators were received, or even could have been undertaken to create an image of quality. For example, obtaining a U.S. patent costs about US$35,000 (Hsu & Ziedonis, 2013)—an amount that some low-quality ventures can afford. In contrast, penalty costs remain at risk, in essence hostages to the venture's future. They help deter opportunistic behaviors by managers and ensure the alignment with investors' interests. For example, executive officers and board directors can demonstrate their confidence and commitment by holding a high percentage of the venture's shares (Lester et al., 2006; Pollock et al., 2010). Such signals are likely to be given more weight by investors in IPO markets.

**H4.** Compared with signals based on technology development, signals based on venture officers play a stronger role in enabling technology ventures to raise capital in their IPOs.

**H5.** Compared with signals based on technology development, signals based on early investors play a stronger role in enabling technology ventures to raise capital in their IPOs.

### 2.5. Signals of different contents and IPO proceeds

Finally, we suggest that signals of different contents complement each other. A successful venture needs all three dimensions of quality, so public investors in IPO markets are likely to assess all three kinds of signals. As other researchers have argued (Audretsch et al., 2012; Deeds et al., 1997), technological capabilities do not necessarily mean that the venture's managers are capable of and committed to growing the venture and that they will not pursue their own interests at the investors' expense (Jensen & Meckling, 1976). Therefore, investors in IPO markets pay extra attention to signals about the abilities and commitment of venture officers, including founders, other executive officers, and board directors (Acharya & Pollock, 2012; Guo et al., 2005; Lester et al., 2006). The involvement of early investors such as business angels and venture capitalists may also enhance the confidence of public investors in IPO markets. Of course, sending any signal requires organizational resources and managerial attention. Therefore, instead of asserting that technology ventures need to send all possible signals, we seek to identify the combinations of signals that are *sufficient* to convince investors to buy into the IPO—that is, signal configurations that cover the three content areas (i.e., technology development, venture insiders, and early investors).

**H6.** Quality signals based on different contents (i.e., technology development, venture officers, and early investors) are complementary to each other in forming sufficient conditions for technology ventures to raise capital in their IPOs.

## 3. Data and analyses

### 3.1. Data sources

We used biotechnology ventures, defined by standard industrial classification code 283, to investigate our hypotheses. Biotechnology ventures provide a reasonable context to study signaling theory given the high information asymmetry between them and investors in IPO markets. Biotechnology ventures often adopt industry-specific, cutting-edge technologies that are difficult for external stakeholders to understand (Arthurs et al., 2009; Cohen & Dean, 2005), and that may not be ready for industrial application. Thus investors in IPO markets may not be able evaluate whether a biotechnology venture's technologies can lead to functional and safe products or processes. Furthermore, biotechnology product development requires large amounts of capital and resources (Hoang & Rothaermel, 2010), which normally go beyond the capital commitment of its founders and early investors. As a result, the venture may need to raise capital through an IPO (Cohen & Dean, 2005).

We constructed our sample from Thomas Reuters' Eikon database. We focused on biotechnology ventures undertaking IPOs in the United States, because they represented more than half of all biotechnology ventures in the global IPO markets. We included ventures established in and after 2000, and IPOs with prospectuses submitted to the U.S. Securities and Exchange Commission (SEC). An IPO prospectus, which is required by the U.S. SEC for all companies undertaking IPOs in the U.S. (U.S. SEC, 2016), contains various information that we use to create measures of venture signals.

### 3.2. Variable measures

#### 3.2.1. IPO proceeds

Data on IPO proceeds, or the amount of capital raised (Deeds et al., 1997; Higgins et al., 2011; Ritter & Welch, 2002; Useche, 2014), were

obtained from Thomson Reuters' Eikon database.

Hypotheses 1–3 investigate whether different signals of the same content substitute for one another. We thus need to choose different signal variables to test these hypotheses. Whetten (1989) has provided two criteria to choose the right factors: comprehensiveness and parsimony. For comprehensiveness, we employ at least two signals from each content category. For parsimony, we avoid the use of very similar measures (e.g., applied and granted patents) within each content category. We then turned to the literature to find appropriate signals (see Table 1), and finally derived two signals based on technology development (forward citations of patents and number of product candidates), three signals based on venture officers (founder officers, officer ownership, and officer prominence), and two signals based on early investors (total capital committed and early investor prominence).

#### 3.2.2. Forward citations of patents

From the Patent Full Text and Image Database of the U.S. Patent and Trademark Office (USPTO, 2016), we identified all of the patents that included our sampled ventures as assignees. In examining the signaling function of patents, researchers often study the number of a company's applied or granted patents (Useche, 2014), which however may not reflect the market value of its patents. We thus examined forward citations of a venture's patents (Hoenen, Kolympiris, Schoenmakers, & Kalaitzandonakes, 2014), measured by the total number of times that the firm's patents were cited by other patents before its IPO. A patent's forward citations often serve as an accurate indicator of its market value (Hsu & Ziedonis, 2013). Patent citations also play an essential role in determining competition domains of biotechnology ventures (Petruzzelli, Rotolo, & Albino, 2015), so using forward citations of patents as a quality signal measure fits well with our empirical context.

#### 3.2.3. Number of product candidates

We collected information on drug development through clinical studies by examining the product candidates that our sampled ventures described in their IPO prospectuses. Following other researchers (Deeds et al., 1997; Guo et al., 2005), we used the number of drug candidates to measure a biotechnology venture's product development. The more drug candidates a biotechnology venture has in its product pipeline, the more likely it will succeed with at least one. And since clinical studies are costly to conduct (Hoang & Rothaermel, 2010), the number of product candidates involves signaling costs.

#### 3.2.4. Founder officers

We created a bivariate variable of founder officer, which was assigned a value of 1 if the venture had a founder serving as an executive officer or a board director, and a value of 0 otherwise. Although we did not specifically measure a founder's status as a CEO or a board chairman, a founder generally has an imprinting effect on his or her venture (Gao & Jain, 2011). Certainly, a founder may use an IPO as an exit strategy, but is often precluded from selling a significant stake until 180 days after the IPO and thus takes penalty costs.

#### 3.2.5. Officer ownership

We first obtained stock information from our sampled ventures' IPO prospectuses and then measured officer ownership as the total percent of stocks owned by executive officers and board directors before the IPO date. High ownership exposes officers to potential penalty costs.

#### 3.2.6. Officer prominence

From the IPO prospectuses, we measured educational prominence by the number of executive officers and board directors who had received degrees from premium institutions on Finkelstein's (1992) list, and professional prominence by the number of executive officers and board directors who had been executive officers or board directors of S &P corporations before joining the venture (Acharya & Pollock, 2012). Since these measures differ in meaning and scale, we standardized them and summed the standardized scores as our measure of officer prominence (Diamantopoulos & Winklhofer, 2001). Officer prominence is a signal that entails penalty costs to the officer's reputation.

#### 3.2.7. Total capital committed by early investors

From Thomson Reuter's Private Equity database, we found all the investment records in which our sampled ventures appeared as companies receiving capital from equity investors. We calculated these ventures' accumulated pre-IPO equity financing. Financing expenses are signaling costs associated with total capital committed by early investors.

#### 3.2.8. Early investor prominence

From Thomson Reuter's Private Equity database, we located all of the investment firms that owned at least 5% of any venture in our sample. We then counted the number of each such firm's portfolio companies that undertook IPOs, year by year. For each venture in our sample, we then measured early investor prominence as the total number of IPO ventures backed by its investors during the three-year window preceding the focal venture's IPO date. The more IPO ventures that a venture's early investors had backed during those three years, the more prominent its early investors were (Lee, Pollock, & Jin, 2011). Investor prominence is a signal that entails penalty costs to the investor's reputation.

Table 2 lists the descriptive statistics and bivariate correlations of these variables. The mean value of the sampled ventures' IPO proceeds was US$87.4 million, similar to the mean of IPO proceeds gained by all U.S. technology companies (US$85.9 million) (Ritter, 2018: Table 4a). Before their IPO dates, the sampled ventures on average had received 60.5 forward citations and had two drug candidates. About 59% of the ventures had founders serving as executive officers or board directors, and 42.2% of the ventures' stocks belonged to executive officers and board directors. These ventures on average had raised US$25.75 million from early investors, who had backed 12.74 IPOs during the preceding three years.

**Table 2**
Descriptive statistics and correlations.

| | Mean | SD | Min | Max | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. IPO proceeds | 87.40 | 180.80 | 4.00 | 2574.39 | | | | | | | |
| 2. Forward citations of patents | 60.50 | 179.86 | 0.00 | 1670 | −0.02 | | | | | | |
| 3. Number of product candidates | 2.00 | 1.89 | 0.00 | 22.00 | 0.13 | −0.02 | | | | | |
| 4. Founder officer | 0.59 | 0.49 | 0.00 | 1.00 | −0.12 | 0.10 | −0.04 | | | | |
| 5. Officer ownership | 42.20 | 31.19 | 0.00 | 105.10 | 0.13 | −0.01 | 0.03 | 0.01 | | | |
| 6. Officer prominence | 0.00 | 1.00 | −1.84 | 2.95 | 0.06 | 0.06 | −0.01 | 0.06 | 0.23 | | |
| 7. Total capital committed by early investors | 25.75 | 45.64 | 0.00 | 397.65 | 0.07 | −0.02 | −0.05 | −0.07 | 0.01 | 0.17 | |
| 8. Early investor prominence | 12.74 | 13.94 | 0.00 | 68.00 | −0.06 | −0.01 | −0.09 | −0.05 | 0.23 | 0.21 | 0.12 |

Note: $N = 268$. IPO proceeds and total capital committed by early investors are in millions of U.S. dollars. Correlations with absolute value larger than 0.12 and 0.16 were significant at $p < 0.05$ and $p < 0.01$, respectively.

**Table 3**
Signal configurations for high IPO proceeds (full sample).

| Signal contents | Cost equilibriums | Solutions | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| Technology development | | | | | |
| Forward citations of patents | Signaling costs | | | ● | ● |
| Number of product candidates | Signaling costs | ● | ● | ● | ● |
| Venture officers | | | | | |
| Founder officer | Penalty costs | ● | ● | | ● |
| Officer ownership | Penalty costs | ● | | ● | ⊗ |
| Officer prominence | Penalty costs | | ● | ● | ● |
| Early investors | | | | | |
| Total capital committed | Signaling costs | ● | ● | ● | ● |
| Early investor prominence | Penalty costs | ● | ● | ● | |
| Consistency | | 0.935 | 0.919 | 0.923 | 0.883 |
| Raw coverage | | 0.153 | 0.150 | 0.145 | 0.098 |
| Unique coverage | | 0.035 | 0.012 | 0.055 | 0.027 |
| Overall solution consistency | | 0.907 | | | |
| Overall solution coverage | | 0.266 | | | |

Note: A black circle (●) indicates the presence of a condition, and a circle with cross (⊗) indicates the absence of a condition. Large circles indicate core conditions, and small circles indicate peripheral conditions. A blank space indicates that the condition is irrelevant.

### 3.3. Calibrations and analyses

We used fuzzy set qualitative comparative analysis (fsQCA) to test our hypotheses. Compared with multiple regressions, fsQCA is more versatile in theory development because it disentangles the complex relationships among the predictors and identifies alternative paths to the same outcome (Fiss, 2011; Fiss et al., 2013; Ragin, 2008). Our hypotheses identify combinations of signals that sufficiently lead to high IPO proceeds. Therefore, fsQCA serves as a proper method for us to test our hypotheses.

The initial step in fsQCA is to calibrate the outcome variable and the predictors according to specific values so as to categorize the cases into different member sets (Fiss, 2011; Ragin, 2008). Calibration involves transforming continuous variables into two thresholds that define full nonmembership and full membership (Rihoux & Ragin, 2009). In between the thresholds, cases are "fuzzy," with various probabilities of being nonmembers and members. In the middle of the fuzzy area (i.e., at the crossover point), cases are most ambiguous with respect to their status of membership (Rihoux & Ragin, 2009).

One needs to take into account both theoretical reasons and empirical conditions while calibrating a variable (Ragin, 2008). Fiss (2011) calibrated firm performance (return on assets) by treating firms ranked below the 50th percentile as full members of low performers, firms ranked above the 75th percentile as full members of high performers, and firms ranked at the 62nd percentile as the crossover point. If there are no theoretical reasons to define cutoff points, the 25th, 50th, and 75th percentile of a ranked variable can be used to define nonmembership, crossover point, and full membership, respectively (Misangyi & Acharya, 2014).

In reviewing the studies of technology venture IPOs, we did not find any theoretical cutoffs to define high or low IPO proceeds, forward citations of patents, number of product candidates, officer ownership, officer prominence, total capital committed by early investors, or early investor prominence. Therefore, we used the 25th, 50th, and 75th percentile of these variables to define their nonmembership, crossover, and full membership, respectively (Misangyi & Acharya, 2014). As for founder officer, we calibrated it by treating 0 (i.e., the venture did not have any founder serving as an executive officer or board director) as nonmembership and 1 (i.e., at least one founder was serving as an executive officer or board director) as full membership.

The key rationale of fsQCA is built on a subset relation: "if cases sharing several causally relevant conditions uniformly exhibit the same outcome, then these cases constitute a subset of instances of the outcome" (Rihoux & Ragin, 2009, p. 99). A subset relation can be interpreted as a configuration or combination of the predictors' conditions that consistently leads to the outcome instance. Therefore, an important parameter in fsQCA is consistency, which refers to the extent to which how closely a perfect subset relation is approximated (Ragin, 2008). To ensure the robustness of our results, we adopted a consistency threshold of 0.85.

Another important parameter in fsQCA is the frequency threshold, or the minimum number of observations in a configuration (Rihoux & Ragin, 2009). Although there is not a specific criterion to determine a frequency threshold, it is recommended that one take into account the number of cases in the study (Rihoux & Ragin, 2009). Since our sample consists of only 268 ventures, we reported and interpreted only configurations that contained three or more cases. This frequency threshold setting is comparable to that in previous research. For example, Misangyi and Acharya (2014) had a sample of 1135 firms and set a frequency threshold of three cases per configuration.

We analyzed the variables calibrated above by using the software fsQCA version 3.0. In a robustness test, we replicated our analysis with QCA (R-Package, version 3.2) and found similar results. We distinguished between core and peripheral conditions, which are determined by a counterfactual analysis facilitated by the parsimonious and intermediate solutions produced by the fsQCA 3.0 software (Fiss, 2011; Misangyi & Acharya, 2014). A counterfactual analysis incorporates "remainders"—logically possible configurations for which real cases do not exist in the data. The parsimonious solution incorporates all logical remainders (Rihoux & Ragin, 2009). We denoted conditions produced in the parsimonious solution as core conditions (Fiss, 2011; Misangyi & Acharya, 2014). The intermediate solution incorporates only logical remainders that make theoretical sense (Rihoux & Ragin, 2009). We denoted conditions that were produced by the intermediate solution but were not part of the parsimonious solution as peripheral conditions (Fiss, 2011; Misangyi & Acharya, 2014).

### 3.4. fsQCA results

Table 3 reports the fsQCA results for high IPO proceeds. Following notations commonly used in fsQCA studies (Fiss, 2011; Misangyi & Acharya, 2014), we use black circles and cross-out circles to indicate the presence and the absence of the specified conditions, respectively. Large circles indicate core conditions, and small circles indicate peripheral conditions. Blank spaces indicate that the conditions do not matter.

Our fsQCA resulted in four solutions with acceptable consistency. Hypothesis 1 suggests that different signals of technology development substitute for one another in enabling technology ventures to raise capital in their IPOs. Solutions 1–2 provide evidence for Hypothesis 1, while solutions 3–4 do not. In fact, solutions 1–2 indicate that the number of product candidates is a sufficient signal of technology development that leads to high IPO proceeds. Solutions 3–4 indicate that the two signals complement each other in the sense that they collectively form sufficient conditions for high IPO proceeds. One possible explanation for solutions 3–4 is that the number of products reflects business viability while forward citations of patents indicate appropriability. Both viability and appropriability may be needed for technology ventures to succeed (Audretsch et al., 2012).

Hypothesis 2 implies that different signals of venture officers substitute for one another in enabling technology ventures to raise capital in their IPOs. In all of the four solutions, two out of the three signals of

venture officers form sufficient conditions for high IPO proceeds. More specifically, founder officer and officer ownership substitute for officer prominence (solution 1), founder officer and officer prominence substitute for officer ownership (solution 2), officer ownership and officer prominence substitute for founder officer (solution 3), and founder officer and officer prominence substitute for officer ownership (solution 4). Overall, the four solutions are consistent with Hypothesis 2.

Hypothesis 3 argues that different signals of early investors substitute for one another in enabling technology ventures to raise capital in their IPOs. However, solutions 1–3 indicate that total capital committed by early investors and their prominence complement each other in leading to high IPO proceeds, thus providing no evidence for Hypothesis 3. Solution 4 suggests that total capital committed by early investors forms a sufficient condition for high IPO proceeds. This indicates that total capital committed by early investors substitutes for their prominence, a finding that is consistent with Hypothesis 3.

Hypothesis 4 indicates that signals of venture officers play a stronger role than those of technology development in enabling ventures to raise capital in their IPOs. Solutions 1–4 provide evidence for Hypothesis 4. Core conditions form a strong relationship with the outcome instance and peripheral conditions form a weak one (Fiss, 2011). As Table 3 shows, at least one signal of venture officers forms a core condition, while signals of technology development form peripheral conditions that lead to high IPO proceeds.

Similarly, Hypothesis 5 suggests that signals of early investors play a stronger role than those of technology development in enabling technology ventures to raise capital in their IPOs. In solutions 1–4, total capital committed by early investors forms a core condition that leads to high IPO proceeds, while signals of technology development form peripheral conditions for high IPO proceeds. These patterns support Hypothesis 5.

Hypothesis 6 posits that signals of different content types (i.e., technology development, venture officers, and early investors) complement each other in enabling technology ventures to raise capital in their IPOs. At least one signal from each content category is present in solutions 1–4, thus supporting Hypothesis 6.

### 3.5. Additional analyses and interpretations

Specific meanings of each solution deserve further elaboration. The core conditions in solution 1 were founder officer, officer ownership, capital raised from early investors, and early investor prominence. The combination of founder officer and offer ownership indicates a capable and committed top management team. However, solution 1 suggests that such a team may not be sufficient for a venture to raise a large amount of capital via its IPO. The venture also needs to signal that it has raised a large amount of capital from prominent early-stage investors. The number of product candidates plays a facilitating role in solution 1, suggesting that investors in IPO markets still value product development as a quality signal for technology ventures. However, this effect is weaker when the venture has a capable and committed top management team and board of directors, and has raised a large amount of capital from prominent early investors.

Solutions 2 and 3 share the same core conditions (officer prominence and total capital committed by early investors), but differ in peripheral conditions. Hypothesis 1 predicts that technology ventures need to signal technology development. It is thus not surprising that in solution 2 the number of product candidates facilitates high IPO proceeds. Founder officer and early investor prominence are the other two peripheral conditions in solution 2; the two signals represent different contents and thus collectively help technology ventures raise capital. Forward citations of patents, number of product candidates, officer ownership, and early investor prominence are peripheral conditions in solution 3; they represent different quality contents and collectively allow technology ventures to raise capital.

Solution 4 indicates the situation in which the venture's officers do not have a high ratio of ownership. This is common in the corporate world owing to the separation of ownership and management (Jensen & Meckling, 1976). But when it is the case, the venture needs to show that its founders serve as executive officers or board directors, that its officers are prominent individuals, and that it has raised a large amount of capital from early-stage investors—core conditions that offset the lack. Forward citations of patents and number of product candidates were peripheral conditions in solution 4. As Hypothesis 1 suggests, technology development needs to be signaled, even if peripherally.

**Table 4**
Signal configurations for high IPO proceeds (ventures 8 years old or younger).

| Signal contents | Cost equilibriums | Solutions | | | |
|---|---|---|---|---|---|
| | | 5 | 6 | 7 | 8 |
| Technology development | | | | | |
| Forward citations of patents | Signaling costs | ⊗ | | ⊗ | ● |
| Product development | Signaling costs | ● | ● | ● | ● |
| Venture officers | | | | | |
| Founder officer | Penalty costs | ● | ● | ● | ⊗ |
| Officer ownership | Penalty costs | ● | ● | | ● |
| Officer prominence | Penalty costs | | ● | ● | ⊗ |
| Early investors | | | | | |
| Total capital committed | Signaling costs | ● | ● | ● | ● |
| Early investor prominence | Penalty costs | ● | ● | ● | ● |
| Consistency | | 0.920 | 0.942 | 0.939 | 0.933 |
| Raw coverage | | 0.115 | 0.117 | 0.119 | 0.040 |
| Unique coverage | | 0.020 | 0.022 | 0.024 | 0.040 |
| Overall solution consistency | | | 0.934 | | |
| Overall solution coverage | | | 0.201 | | |

Note: A black circle (●) indicates the presence of a condition, and a circle with cross (⊗) indicates the absence of a condition. Large circles indicate core conditions, and small circles indicate peripheral conditions. A blank space indicates that the condition is irrelevant.

Our sample includes all biotechnology ventures undertaking IPOs in the United States during 2004–2015. However, new technology ventures may suffer more from information asymmetry than do established ones (Fisher et al., 2016; Wang, Thornhill, & De Castro, 2017), so they may need to present different sets of signals in IPO markets. Following prior research (Mousa et al., 2015), we replicated our analyses by focusing on new ventures, defined as eight years old or younger at the time of their IPOs. Since there were only 163 new ventures in the sample, we used a frequency threshold of two in our fsQCA analyses. As Table 4 reports, the overall patterns of the results (the four solutions) are similar to those reported in Table 3, but some differences deserve elaboration.

The *absence* of forward citations of patents became a peripheral condition in solutions 5 and 7. Because the 163 ventures were still young at the time of their IPOs, their patents might have not received many citations from other patented inventions. Meanwhile, because new ventures generally lack the resources and capabilities for patent wars, investors may perceive forward citations of patents as a threat to new ventures. In fact, disclosing information about intellectual property could harm a venture's valuation (Singh & Van der Zahn, 2009).

The *lack* of founder officers and *low* officer prominence became peripheral conditions in solution 8. Wasserman (2003) found that it is common for founders to step down or leave their ventures (voluntarily or involuntarily) within several years after the founding. If a founder leaves, his or her successors will determine whether the venture can succeed. Solution 8 suggests that when a founder steps down, it may be dangerous to replace him or her with a prominent officer who has executive or board experience in established corporations. The mindsets

and skills associated with building and growing a new venture often differ significantly from those needed to run a large corporation.

## 4. Discussion

In sum, our findings suggest that investors in IPO markets take a holistic approach to evaluating quality signals of technology ventures, rewarding those that signal strength in all of the content areas (technology development, venture officers, and early investors). These findings contribute to research on IPOs and technology ventures in several ways.

### 4.1. Theoretical contributions

First, we find that ventures need to signal all three dimensions of quality. Individually each signal type is valuable, but public investors in IPO markets tend to evaluate technology ventures comprehensively, rather than betting on a particular signal. Our fsQCA results from 268 biotechnology ventures demonstrate four solutions, each of which contains signals for all three categories of contents. Therefore, signals of different quality contents complement each other, and collectively enable technology ventures to raise capital via IPOs.

Second, we provide new insights into several quality signals that have been extensively studied. Our results suggest that the importance of technology development signals may have been overstated, at least when other quality contents (venture insiders and early investors) are also signaled. As Table 3 shows, the number of product candidates was only a peripheral condition in solutions 1–4 and forward citations of patents did not matter in solutions 1–2. These results suggest that it is difficult for public investors to evaluate the quality of biotechnology ventures' technologies because the underlying science is complex and the process of moving from the fundamental science to FDA approved drugs is full of uncertainties. We are not alone in this view. For example, Heeley, Matusik, and Jain (2007) find that patents may increase information asymmetry for businesses and that the link between patenting and value appropriation is not transparent.

Compared with signals of technology development, signals based on venture officers and early investors may better indicate the venture's potential. Many of these people have medical degrees, PhDs, or other advanced scientific knowledge. They also have track records of executive and investment experiences, and established reputations that they put at risk. As a result, public investors seem to weight their abilities and commitment more heavily than the direct signals of a venture's scientific and technological capabilities.

Third, the difference between signaling costs and penalty costs offers new insights into why public investors weight factors in this way. Management research adopting signaling theory has largely neglected the difference between signaling costs and penalty costs (Bergh et al., 2014). Because signaling costs are sunk, while penalty costs indicate ongoing commitment, it is reasonable that signals entailing penalty costs for venture officers and early investors may be perceived as especially credible.

### 4.2. Managerial implications

This study has meaningful implications for practitioners. In order to raise large amounts of capital through their IPOs, technology ventures need to present signals that cover all of the three content areas—technology development, venture officers, and early investors—and take both signaling costs and penalty costs. Certainly, there is no fixed formula for sending quality signals. Our analyses demonstrate four different solutions that form sufficient conditions for raising capital through IPOs.

### 4.3. Limitations and future research

Several limitations of this study can be translated into promising directions for future research. We developed Hypotheses 1–6 by reviewing signals that other researchers had found to influence IPO outcomes, but the three content categories may not be exhaustive. Hypotheses 4–5 are partially built on the difference between signals with signaling costs and those with penalty costs, but our data do not allow us to test this difference directly.

We treat premarket signals as constant, without examining their changes over time. But technology ventures may intentionally signal for their IPOs (e.g., window-dressing) (Chen, Hambrick, & Pollock, 2008). We measured quality signals for our sampled firms right before their IPOs, and thus cannot address this window-dressing effect. To overcome these limitations, we encourage researchers to collect data that enable more direct and refined tests for different signal contents, cost equilibriums that can sufficiently separate low-quality and high-quality ventures, and changes in signals before a transitional event such as an IPO.

It is also promising to further analyze the signaling roles of patents. As Tables 3 and 4 show, forward citations of patents do not seem to serve as a strong quality signal. The results may reflect the youth and small size of our sampled ventures. Mehta, Rysman, and Simcoe (2010) find that drug patents are the slowest to be cited and reach their peak citation rate at 8.16 years after the patent is granted. Therefore, forward citations of patents simply may not be a very good proxy for patent value in our sample, given that two-thirds of our ventures were 8 years old or younger (also see Table 4). Young, small technology ventures are often in a disadvantageous position in patent wars because they lack patent portfolios and negotiation power over rivals (Lanjouw & Schankerman, 2004), so patents and patent citations may be questionable indicators of their future performance. Patenting also requires disclosure of key technologies. As a result, investors may worry that forward citations of patents indicate that a venture is at risk of imitation by potential rivals (Singh & Van der Zahn, 2009).

Our focus on biotechnology ventures undertaking IPOs in the United States is reasonable for studying how multiple signals collectively influence investors' decisions under information asymmetry. Nevertheless, we acknowledge the value of testing our hypotheses in other contexts, such as ventures operating in electronic equipment and computer industries (Hall & MacGarvie, 2010; Hsu & Ziedonis, 2013; Somaya, 2003) or other institutional and cultural environments (Bell, Filatotchev, & Aguilera, 2014). It is also promising to examine the effects of signals on other outcomes. For example, Mousa et al. (2015) employ signaling theory to predict strategic positions (entrepreneurial orientation and corporate strategy) communicated in IPO prospectuses, which may affect firm performance in the long run.

## 5. Conclusion

We posit that quality signals of the same content substitute for one another and signals of different contents complement each other in enabling ventures to raise capital in their IPOs. We also posit that signals of venture officers and early investors play a stronger role in affecting decisions of investors in IPO markets than signals of technology development. By analyzing data on 268 biotechnology ventures undertaking IPOs in the United States, we find four different solutions, or combinations of signals, that provide alternative paths to high IPO proceeds. These solutions indicate that in order to raise large amounts of capital via IPOs, technology ventures often need to present signals based on different contents (i.e., technology development, venture officers, and early investors) and take both signaling and penalty costs.

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