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Technological Assets and Top Management Teams: Their Impact on the Capital Raised by Research-Intensive Firms Going Public

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Abstract

The aim of this study is to investigate the influence of specific indicators of technological assets and top management teams on the amount of capital guaranteed from the initial public offering (IPO) of research-intensive companies. We suggest that technological diversity, the value of the firm's patent stock and the heterogeneous experience possessed by the top management team (TMT) can signal to potential investors superior research and innovation competence. We conducted an empirical study of a sample of dedicated biotechnology firms (DBFs) that completed an initial public offering in the United States during 1983-2009. Our findings suggest that technological diversity, the patent stock's value and functional diversity in TMT are positively related to the amount of capital raised through an IPO. Nevertheless, our results indicate that intrapersonal functional diversity in the TMT has not a significant effect on IPO success.

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ABSTRACT

The aim of this study is to investigate the influence of specific indicators of technological assets and top management teams on the amount of capital guaranteed from the initial public offering (IPO) of research-intensive companies. We suggest that technological diversity, the value of the firm's patent stock and the heterogeneous experience possessed by the top management team (TMT) can signal to potential investors superior research and innovation competence. We conducted an empirical study of a sample of dedicated biotechnology firms (DBFs) that completed an initial public offering in the United States during 1983-2009. Our findings suggest that technological diversity, the patent stock's value and functional diversity in TMT are positively related to the amount of capital raised through an IPO. Nevertheless, our results indicate that intrapersonal functional diversity in the TMT has not a significant effect on IPO success.

Key words

Biotechnology firms, dynamic capabilities, technological diversification, patent's citations, TMT's functional diversity

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1. Introduction

An important problem in technology management is the financing of technological development and innovation. There are problems of financing research and development (R&D) activities due to the degree of uncertainty and risk associated with their outputs (Hsu, Shyu and Tzeng, 2005; Levitas and McFadyen, 2009). New entrants and research-based startup firms are more likely to encounter this difficulty than large established firms. The financial rewards of innovation vary dramatically between dominant and nondominant companies. For instance, a study focused on the pharmaceutical industry (Sorescu, Chandy and Prabhu, 2003) shows that dominant firms introduce the large majority of radical innovations, which are highly valued by the financial markets. Incumbent firms are assumed to enjoy experience, economies of scale and scope in both R&D and in marketing and a high level of appropriability of the returns from innovations (Gambardella, 1995). Although entrepreneurial firms preparing for an initial public offering (IPO) often attract investors' attention, this does not always result in investment because those firms have short operating histories, and have higher risk than larger and more established companies (Zimmerman, 2008).

To overcome the asymmetric information problems between investors and entrepreneurial innovative firms, these need to provide information or signals in order to reduce the subjective uncertainty of outside constituencies regarding the productivity and viability of the company. There is little conclusive evidence as to how entrepreneurial firms obtain informational advantages and how those advantages influence the economic value

when they go public (Bach, Judge and Dean, 2008; Zahra and Filatotchev, 2004).

Taking into account that the period of product development is extremely long in some sectors (e.g. biotechnology), patents represent useful mechanisms to signal the value of technological assets and the effectiveness of a firm's R&D program to potential investors. Patents represent the knowledge involved in innovation processes and in the firm's ability to transform research investment into new and potentially valuable knowledge. Although not indicating the development of a marketable product or process, patents demonstrate (Levitas and McFadyen, 2009; Stephan, 1996): the ability to perform knowledge recombination; the possession of potentially valuable technology; and the ability to go beyond basic understanding to produce technology that is not obvious to a person having ordinary skills in the pertinent art. Compared to the exclusive use of R&D expenditure, patents offer richer information on the particular range of technological strengths possessed by a firm (Silverman, 1999). In particular, we focus on the level of technological diversity that can be examined through patents. Among the data available in patents, classification codes identify the type of technology embodied in the invention and can be used to observe indirectly the process of recombinant search and learning (Fleming, 2001) as well as to assess comprehensively a firm's technological diversity resulting from any kind of source (research teams, strategic alliances, etc.). Technological diversity can signal to potential investors superior research competence. Knowledge diversity improves the basis for learning and enables firms to make new combinations. Furthermore, we take into account the patents' usefulness and significance that reflect the economically valuable knowledge accumulation (Trajtenberg, 1990).

Complementary, the characteristics of top management teams (TMT) provide signals about the ability to manage resources and competences to enhance innovation performance. The level of functional diversity of TMT influences the capacity to coordinate the competences needed to foster effective decision-making, exploit market opportunities and

enhance innovation and creativity.

By building on the mainstream literature on dynamic capabilities, the purpose of this study is to explore how technological diversity, patent value as well as the functional diversity of TMT, which are related to research and innovation competences, can attract investment at the moment of IPO.

IPOs have been the focus of large research from many theoretical perspectives including agency theory, resource dependence theory, signaling theory and competence view (Certo, 2003; Daily et al., 2003; Deeds, DeCarolis and Coombs, 1997; Zimmerman, 2008). Scholars have examined a variety of predictors of pricing in the IPO market. However, there are few contributions that examine the influence of patents on the firm value in the market for initial public offerings in spite of the fact that research and patenting activities are potential value creation activities and provide a unique opportunity to examine the role of these activities in IPO pricing (Heely, Matusik and Jain, 2007). Such contributions examine the impact of the number of patents on different measures of IPO success (Chin et al., 2006; Deeds et al., 1997; Heely et al., 2007; Lee and Lee, 2008). Nevertheless, the superior knowledge is reflected not only in the number of patents that a firm has, but also in their usefulness and the technology portfolio that they reflect. One of the contributions of this article is to increase our understanding of the relationship between patent and the ability of research-intensive firms to raise capital in their IPOs by studying two dimensions useful to assess the research capacity of such firms: technological diversity and patent citation.

On the other side, despite the extensive literature on IPOs and evidence that TMT characteristics influence firm performance, there is relatively little research examining the impact of the composite quality of the TMT on IPO performance (Bach et al., 2008; Beckman and Burton, 2008; Cohen and Dean, 2005; Zarutskie, 2010; Zimmerman, 2008). We focus on functional diversity in the TMT, which is an important source of expertise among executives.

Although many scholars have explored the relationship between TMT's functional diversity and organizational performance, few studies examine the effect of such diversity on IPO performance (Beckman, Burton and O'Reilly, 2007; Zimmerman, 2008). We extend this research stream and make a contribution examining two types of diversity: functional diversity of the TMT (heterogeneity in the functional areas in which each TMT member has when the firm goes public) and intrapersonal functional diversity (the within-member breadth of functional experience).

The aim of this paper is to explore a comprehensive set of knowledge that can influence the investors' assessment of research and managerial competences required to perform the innovation process and create value. The structure of this paper is as follows: first, the next section presents the theoretical framework and hypotheses regarding the effects of technological diversity, patent value and functional diversity of TMT on IPO success. This is followed by a description of the research methodology employed and the empirical analysis to test the hypotheses. The final section includes discussion of the results and conclusions.

2. Theory and Hypotheses

The success of an IPO can be determined by the amount of capital that flows into the firm, and this amount depends upon the favorable evaluation of the firm by the financial market. The amount of capital the firm can raise through an IPO involves negotiations between the lead underwriter and the firm. The potential for raising capital is not only based on financial characteristics such as earning, book value, etc., but also on intangible assets (Deeds et al., 1997; Zimmerman, 2008).

For research-intensive firms, knowledge-based capital plays an important role in attracting investors when they go public. Technological diversity and significance of patents are useful dimensions to assess a firm's research competence. Diverse knowledge and

experience possessed by the top management team provide signals to the capital market about potential economic return of ventures. There is little empirical evidence to show how the combination of those dimensions influence the capacity of an entrepreneurial firm to attract the attention and the funds of investors in the IPO process. In the following sections, we develop hypotheses regarding the impact of technological diversity, patent value and functional diversity in TMT on the IPO performance.

2.1. Technological diversity

The range of disciplines relevant to firms' innovative processes is expanding in both breadth (the number of relevant disciplines) and depth (their sophistication and specialization) (Wang and von Tunzelmann, 2000). The complexity of many modern innovations demands an effective management of technological capabilities (Cetindamar, Phaal and Probert, 2009), particularly, a pooling and integration of multiple strands of knowledge (Subramaniam and Youndt, 2005). Technological diversity can be defined as the variety in the knowledge system and principles underlying the nature of products and their methods of production, and it is the result of a range of skills, expertise and perspectives from R&D strategic alliances, teams of researchers and other organizational mechanisms.

Patents disclose technical information that can be used by investors to evaluate the level of technological diversity, especially in industries such as pharmaceutical, chemical and biotechnology where the link between a patent and value appropriation is relatively transparent (Heeley, Matusik and Jain, 2007).

From a theoretical perspective, the dynamic capabilities view (Prahalad and Hamel, 1990; Teece, Pisano and Shuen, 1997) has emphasized that more sustainable competitive advantage relies more heavily on the ability to move beyond local search and to reconfigure its knowledge (Kogut and Zander, 1992; Rosenkopf and Nerkar, 2001; Teece *et al.*, 1997).

Local search means that firms focus on similar technology, and as a result, they become more expert in their current domains (Nelson and Winter, 1982). Specially, in fast-paced environments, enterprises must search the core as well as to the periphery of their central technological base. In this context, technology management must be the capability to improve existing technology and to generate new knowledge and skills in response to the competitive business environment (Jin and Zedtwitz, 2008). Reconfiguration is needed to maintain evolutionary fitness and, if necessary, to try and escape from unfavorable path dependencies and core rigidities (Leonard-Barton, 1992; Teece, 2007).

Thus, the competence view explicitly considers the necessity to enhance variety in a firm's knowledge bases as a continuous process to contribute to firm renewal over time. It is useful to maintain a broad technology base in order to explore and experiment with new technologies for possible deployment in the future and for searching for complementarities that accelerate the pace of technical advance (Granstrand, Patel and Pavitt, 1997). Several empirical contributions support these premises and demonstrate that the ability to integrate knowledge flexibly across disciplinary and technological class boundaries within the organization benefits innovation productivity (Henderson and Cockburn, 1994; Garcia-Vega, 2006; Quintana-Garcia and Benavides-Velasco, 2008). Research programs initiated within a more diverse development effort and technological knowledge is significantly more likely to result in innovations than others initiated within a more narrowly focused effort.

A diversified technology portfolio in the firm might act as renewing dynamic capabilities by generating and renovating technological trajectories and taking advantage of cross-fertilization effects between different technologies (Granstrand, 1998). There is a limit to the number of new ideas that can be created by using the same set of knowledge elements. The exposure to heterogeneous and divergent perspectives and ideas can stimulate novel insights into complex issues. Adding new knowledge and competences to the firm's repertoire

is important for mitigating path dependencies in their development. Distant contexts may offer ideas and insights that can be extremely useful to innovation through knowledge recombination (Rosenkopf and Almeida, 2003). A broader technological knowledge may improve and transform the search process and, thus, shape the evolution of technology and generate useful innovations (Danneels, 2002; Fleming and Sorenson, 2001; McGrath, 2001).

Based on these assumptions, potential investors might consider technological diversity as a driver of high-quality innovative decisions.

Accordingly, we predict the following hypothesis:

Hypothesis 1. The diversity of a firm's technology base is positively related to IPO success.

2.2. *Patent stock's value*

Patents provide signals of the value or effectiveness of a firm's R&D program to potential investors. Patents represent not only an important measure of innovative output, but also are an externally validated measure of technological novelty. Particularly, patents have shown to be closely related with other performance measures such as new product development, profitability, and market value (Henderson and Cockburn, 1994; Rothaermel and Hess, 2007).

For high-technology firms, it is interesting to foster a portfolio of influential inventions that are widely utilized and extended by subsequent inventions. The extent to which a firm's invention resonates with other researchers is an important indicator of its capacity to generate ideas that have both clear utility and wide applicability (DeCarolis and Deeds, 1999; Makri, Lane and Gomez-Mejia, 2006). The fact that other companies' innovation processes build on an idea in a firm's invention reflects an external validation of the value of such an idea. In

addition, external citations provide evidence of the role of the cited patent in the development of successful technologies (Coombs and Bierly, 2006), and they may suggest that the firm will produce commercially valuable inventions in the future. Also, self-citation is relevant because firms citing their own patents may be a reflection of the cumulative nature of innovation and the increasing returns property of knowledge accumulation (Hall, Jafe and Trajtenberg, 2005); besides, it may imply that the firm is gaining a more competitive position in a particular field (Deng, 2007).

Empirical evidence shows that influential inventions create economic value for the firm, and that citations contain information above and beyond simple patent counts on the value of the firm's intangible assets. Several contributions find that the market value (usually measured through Tobin's q) is positively related to a firm's stock of patents adjusted by quality or weighted by citations (Lanjouw and Schankerman, 2004; Hall et al., 2005; Heiens, Leach and McGrath, 2007; Shane and Klock, 1997). By identifying the share of external citations and self-citations out of total citations, some works reveal that both components have a significant and positive effect on market value of firms (Deng, 2007; Hall et al., 2005). Thus, the following hypothesis is suggested:

Hypothesis 2. The value of the firm's patent stock in terms of citations received is positively related to IPO success.

2.3. Functional diversity in the Top Management Teams

Top management team composition can serve as a signal to potential investors of the level of appropriability of the returns from valuable inventions. Expertise possessed by top managers is important as they play a relevant role in deploying resources and determining technology and innovation strategy. Such a role can be particularly relevant in young,

entrepreneurial firms where their simplicity of the organizational structure allows top-level managers to interact with each other and with the firm's resources to influence R&D strategy. In entrepreneurial firms, top managers must constantly interact with those actors who are closer to the core technology so they can select the best alternatives, sponsor potentially productive initiatives, legitimize radical ideas, and identify and commercialize latent capabilities (Day, 1994).

Functional diversity in the top management team refers to representation of various business areas such as marketing, operations and finance. According to the dynamic capabilities perspective, top management teams with functional diversity can be considered as integrative or combinative capabilities (Henderson and Cockburn, 1994; Kogut and Zander, 1992) that encourage coordination and maintain an extensive flow of information across the boundaries of the firm (Teece et al., 1997), and enable the exploration and exploitation of technological and marketing competences (Danneels, 2008; Levinthal and March, 1993; March, 1991).

The functional diversity at the management level can be a result of either the aggregation of executives with different types of functional experience (team functional diversity), or the presence of managers with broad functional background and expertise (intrapersonal functional diversity) (Bunderson and Sutcliffe, 2002).

As the team functional diversity increases, so does the breath of knowledge, perspectives, experience, and capabilities that the overall team can bring to bear in a decision situation (Cannella, Park and Lee, 2008). Innovation requires competences in both idea generation and idea implementation. Designing a heterogeneous TMT in terms of functions can affect how the team performs at all stages of the innovation process. Effective innovation development routines typically involve the participation of cross-functional teams that bring together different sources of expertise. These sources of expertise are essential for superior

products because each addresses a unique aspect of product quality or related production (Eisenhardt and Martin, 2000). Since the team includes research, development, manufacturing and marketing representatives, innovation process is facilitated.

Some studies demonstrate that functional heterogeneity in TMT is a powerful predictor of innovation (Bantel and Jackson, 1989; Fang and Bednar, 2009; Wiersema and Bantel, 1992). In particular, Fang and Bednar (2009) the later contributors find that a TMT with significant R&D and marketing experience benefits firm innovativeness. In fact, it is accepted that the key resources and competences needed to accomplish technological innovation can be classified as market-related and technically-related (Danneels, 2002; Moorman and Slotegraaf, 1999). R&D experience is useful to recognize opportunities in the external environment and more effectively deploy R&D investments to capitalize those opportunities and maximize firm innovativeness (Cohen and Levinthal, 1990). Marketing competences enhance the ability to both leverage R&D investments and exploit existing technologies in additional markets and applications (Danneels, 2002).

Designing a TMT with a high level of functional diversity can provide signals to capital market about their capacity to develop and commercialize valuable innovations. In general, a functional diverse TMT makes a firm more attractive to external investors who may perceive that the management team has the requisite skills and capabilities to make the firm successful, profitable, and thereby a worthwhile investment (Beckman et al., 2007).

Therefore, the following expectation can be stated:

Hypothesis 3. Functional diversity in the top management team is positively related to IPO success.

Information flow, interaction and communication among functional areas are key concepts to innovation. Executives with high intrapersonal functional diversity have a good perception of where the knowledge is and how to tap into it, and they carry potential benefits that promote the coordination of all activities involved in the R&D process and commercialization of innovative outputs. Members of the TMT with high intrapersonal functional diversity tend to be more centrally located in the work flows of their teams and organizations and therefore more influential in decision making (Bunderson, 2003). Such members have shared experience, and are less likely to focus on the problems that reflect their specific functional areas (Cannella et al., 2008). Sharing a common language foundation among all members of the TMT facilitates mutual understanding, a better integration of information and the creation of trust in interpersonal relationships, which is essential for further knowledge sharing. Supporting these arguments, empirical evidence shows that intrapersonal function diversity of the managerial staff fosters innovation and firm performance (Cannella et al., 2008; Yap, Chai and Lemaire, 2005). Thus, potential investors may positively evaluate intrapersonal functional diversity as it enhances the effectiveness of innovation processes based on a suitable coordination and interaction among functional areas.

Hence, the following hypothesis is proposed:

Hypothesis 4. Intrapersonal functional diversity in the top management team is positively related to IPO success.

3. Methods

3.1. Sample and data

The research setting of this paper is provided by dedicated biotechnology firms (DBFs) that completed an initial public offering in the United States during 1983-2009. Some factors

and features justify the importance of technological diversity and continuous innovativeness in this sector. There is a substantial uncertainty surround the commercialization of genetic engineering research (Hsu et al., 2005). Biotechnology itself is a revolutionary technology, and rapid and radical technological innovation within biotechnology threatens to render even current products obsolete within a relatively short time. Therefore, biotechnology firms can sustain a competitive advantage only by continuous research activities that result in valuable and patentable products. Those activities in genetic engineering and biotechnology demand a wide knowledge system and diverse competences (molecular biology, microbiology, enzymology, cell biology, etc.), increasing the importance of the scope economies (Malerba and Orsenigo, 2002; Quintana-García and Benavides-Velasco, 2008). Furthermore, the youth and the entrepreneurial nature of biotechnology companies makes them an excellent venue in which to study the effect of patents and the top management team composition on the perception of potential investors about the effectiveness of R&D strategy.

The research sample was drawn from the Thomson Financial/Venture Economics VentureXpert data set. We used this database to identify biotechnology firms undergoing their IPO of stock and IPO value of each firm during the time period of January 1, 1983 through December 31, 2009. The period of study begins in 1983 because in this year the first IPO undergone by a DBF was identified in VentureXpert database. Searches in this database yielded a list of 308 firms. Data availability constraint (i.e., missing data for one or more of the variables and unavailability of IPO prospectus) limited the sample to 229 companies.

We obtained the information of patents from the United States Patent and Trademark Office (USPTO). A company may have patents granted by other international patent offices; however, the likelihood of this fact is low due to the youth and size of the sample of firms. Nevertheless, using a single patent office as the information source helps to maintain a certain level of consistency and comparability. In our study, the USPTO is found to be suitable in

order to be consistent with the financial market analyzed (IPOs in the United States). Moreover, given the importance and the technological sophistication of the U.S. market, and the “real” patent protection offered by U.S. authorities, it is reasonable to assume that inventions patented in the U.S. have the greatest technological and economic impact and are more valuable by potential investors. Among the data available in patents, we used patent codes to capture the nature and variety of technological knowledge owned by the firm, and the citation received by each patent to estimate the value of the stock of patents.

Information related to TMT was obtained from the IPO prospectus of each firm. The prospectus is the document provided to the Securities and Exchange Commission (SEC) prior to the public offering, and it is also the document circulated by the underwriter to assess demand for the firm’s stock. The SEC requires that firms follow strict guidelines in the format. This fact allows a high level of consistency.

3.2. Measures

3.2.1. Dependent variable

The “IPO success” is the dependent variable of the model. We defined the success of a firm's IPO as the amount of capital from the offering that is actually transferred to the firm and its owners. This variable was calculated by subtracting the underwriter's fees from the total value of the capital raised through the IPO (Deeds et al., 1997). The IPO success is expressed in millions of 2009 constant dollars, and it is not only a measure of IPO performance but also of how the market values a company at the time of its initial offering (Deeds, Mang and Frandsen, 2004). We used a logarithmic transformation of this variable to account for its skewed distribution. This dependent variable was measured using data drawn from the Thomson Financial/Venture Economics VentureXpert data set and the IPO prospectus.

3.2.2. *Independent variables*

To measure the level of “technological diversity” of a firm, we used the Herfindahl index of diversification (Berry, 1975), also known as heterogeneity index (Blau, 1977), which is derived from the Herfindahl-Hirschman Index (HHI). The HHI index is conventionally used to approximate industry concentration, and it is becoming popular to measure technological diversification as well as functional diversity of TMT. The Herfindahl index of diversification can be expressed as follows: $D = 1 - HHI = 1 - \sum_i P_i^2$, where P_i denotes the proportion in a firm of patents in technical field i . The index equals zero when a firm researches only in a single technology, and it is close to one when the firm spreads its research activity over a broad technological knowledge base. Patents are assigned to a number of technology codes. We employed these codes to identify the nature of the technological diversity of a firm. We followed the three-digit USPTO’s classification, which distinguishes over 400 technological classes¹.

The “patent stock’s value” at the moment of IPO represents another independent variable. A patent’s citations contain information on a patent’s value. Citations typically keep coming over the long run, living plenty of time to dissipate the original uncertainty regarding both the technological viability and the commercial worth of the cited innovation. Therefore, if we still observe citations years after the grant of the cited patent, it must be that the latter had indeed proven to be valuable (Hall et al., 2005). We measured the value of a patented invention by counting the number of received citations that come from any subsequent patent, including self-citations by the firm and external citations. We include the number of subsequent citations a patent receives until the date in which the firm undergoes the IPO.

¹ The selection of the USPTO’s classification of technologies is a contribution to literature on technological diversification. Usually, this concept has been measured using patent classifications that distinguish, for example, thirty types (OECD classification), thirty-four technical fields (SPRU taxonomy), thirty-six technological categories (NBER), etc. We consider these taxonomies to be global, quite similar to sectoral subcategories, consequently technological diversity becomes a similar concept to business or market diversification. From an organizational point of view, a more useful study would have to consider a more detailed classification of technologies.

Then, to calculate the “patent stock’s value”, we use the index of weighted patent counts² $WPC = \sum(I+C_i)$ where C_i is the number of citations that the patent i has subsequently received (Trajtenberg, 1990; Wong and Singh, 2010).

The top management team is defined as all inside top-level executives. This definition includes all of the C-level positions, e.g., CEO, chief financial officer, chief operating officer, as well as all executives above the rank of vice presidents and senior vice presidents (Cohen and Dean, 2005). Data on the top managers were obtained from the managers’ biographies presented in the IPO prospectus. In order to measure the two types of functional diversity, we first classified each executive’s function into one of the eleven tracks: management and business development, research (including scientific affairs), development, clinical and medical affairs, production and operations, sales and marketing, finance and accounting, legal, human resource management, quality management, and other. The functions selected for inclusion in this study are based on previous contributions on functional diversity (Michel and Hambrick, 1992; Yap et al., 2005) and adapted to the nature of TMTs of the sector analyzed in this research. “Functional diversity in the TMT” was calculated using Blau’s (1977) heterogeneity index $(1 - \sum S_i^2)$, where S_i is the proportion of a TMT in the i th category. The index can vary between 0 and 1, with values close to 1 indicating higher diversity and values close to 0 indicating that a TMT is dominated by a single category. Following Cannella et al. (2008), to calculate “intrapersonal functional diversity” of a TMT, first we computed an

² Using patent citations to measure the value of a patent stock may have a potential truncation bias (Trajtenberg, 1990), since citations to a given patent typically keep coming over long periods of time, but citations are observed until a specific moment (in this case, the date of the IPO). This problem specially influences the most recent patents. Patents applied for in 2002, for example, will be cited less than patents applied for in 1998. Nevertheless, it is not clear to what extent the market anticipates future citations to evaluate a firm. Moreover, Hall et al. (2005) state that past citations can be used to forecast future ones, and empirically demonstrate that past citations clearly help in forecasting the value of knowledge assets and future returns. Additionally, observing the behavior of citation lags and the number of citations that the patent stocks of the sample have received, the absolute expected number of missing citations is small.

intrapersonal functional diversity score for each member of the TMT (using Blau's heterogeneity index) and then averaged the scores.

3.2.3. *Control variables*

We included several control variables related to the TMT and the firm. "TMT size" might influence the investor's perception of team viability as it may impact on the level of cohesion. TMT size was calculated by counting the number of executives on a team. We control for "firm size" at IPO; this variable was estimated through the number of employees. We also introduce "firm age" at IPO as a control variable. This variable was computed from the date of incorporation to the date of IPO. Firm size and age may increase the market valuation as they are associated with experience, process efficiency and potential higher returns. Factors that vary over time but affect all firms in the industry, such as financial market conditions, were also controlled with dummy variables for each year.

4. **Results**

This section discusses the results of our empirical tests. Table 1 shows the mean, standard deviations, and correlations.

Insert Table 1 about here

Table 2 provides the regression results. To test the significance in predicting the IPO success of the independent variables over the control variables, we used a two-step hierarchical regression analysis. We entered the control variables in the first step (model 1), followed in the second step by the independent variables (model 2).

We tested our data for multicollinearity. The variance inflation factor (VIF) is a measure of the reciprocal of the complement of the intercorrelation among the predictor variables: $VIF = 1/(1 - r^2)$ where r^2 is the multiple correlation between the predictor variable and the other predictors. VIF values greater than 10 indicate possible problems (Cohen et al., 2003). In both regression models (model 1 and 2), the highest VIF score was 2.22, which was within acceptable parameters.

Insert Table 2 about here

Model 1 representing only the control variables was significant with a $R^2 = 0.294$ and an adjusted $R^2 = 0.234$ at $p < 0.001$ ($F = 4.86$). In examining the effect of control variables related to the firm, we found in models 1 and 2 that the effect of size was positive and significant on IPO success, suggesting that perception of investors about a firm's value or viability increases with firm size. As a counterintuitive result, the effect of firm age at IPO was not significant; nevertheless, it can be considered that part of the effect of age will be incorporated into the effect of firm size, as older firms tend to be larger (Heeley et al., 2007).

The independent variables were entered as a block in model 2. The addition of the variables related to the value of the stock patent, technological diversity and the two types of functional diversity of TMT to the equation with the control variables resulted in an improvement in the model. The R^2 was 0.350 and the adjusted R^2 was 0.280 at $p < 0.001$ ($F = 5.03$). The change in R^2 was 0.055 ($p < 0.01$).

Findings strongly support three out of four hypotheses. Hypothesis 1 predicted that the level of technological diversity in a firm's knowledge base is positively related to IPO success. In model 2, the significant positive coefficient of the variable "technological

diversity” supports such a hypothesis. Results also provide support for hypothesis 2. The effect of the “patent stock’s value” in terms of citations received was positive and significant.

Regarding the characteristics of the TMT, hypothesis 3 is supported. “Functional heterogeneity” was positively and significantly related to IPO success. This evidence is consistent with previous research that demonstrates that investors positively value breadth in the functional backgrounds of TMT as an indicator of quality (Beckman et al., 2007; Zimmerman, 2008). However, no support was found for hypothesis 4. “Intrapersonal functional diversity” in the top management team was not significantly related to the capital raised in the IPO market. The control variable “TMT size” influences positively and significantly on IPO success. It is noteworthy that the functional diversity of the TMT has a greater effect on IPO success than information provided by patents. This difference is statistically significant: a Wald test of the equality of the coefficient of “functional diversity of the TMT” ($\beta_1 = 0.933$) and the coefficients of “technological diversity” ($\beta_2 = 0.043$) and “patent’s stock value” ($\beta_2 = 0.037$) yields a F of 4.84 ($p < 0.05$) and 4.90 ($p < 0.05$) respectively with one degree of freedom. A potential explanation is that the top management team is a general indicator of firm quality, which is relatively easy to assess by informed and uninformed investors. Patents reduce information asymmetries related to the value of innovative firms especially with individuals who work in or who have close ties to the firms (i.e., insiders or informed investors) (Heeley et al., 2007); however, the technological content of a patent may not provide usable information to investors without technical knowledge about the sector (uninformed investors).

5. Discussion and Conclusion

The primary objective of the current study is to investigate the influence of specific indicators of technological assets (patents) and top management teams on the amount of

capital guaranteed from IPO. By combining both patents and TMT characteristics in one study, we aim to integrate two relevant dimensions related to innovative competence. An empirical research of a large sample of dedicated biotechnology firms reveals several interesting findings.

Given the relatively short operating history of the research-intensive firms and the asymmetric nature of the knowledge involved, it is usually difficult to guarantee the desired economic value as they go public. For those firms, the potential for raising capital in the IPO market is specially based on intangible assets and knowledge-based capital (Bach et al., 2008). Particularly, their research capabilities are their only valuable assets, as these capabilities represent the firm's potential to develop product innovation (Deeds et al., 1997). Knowledge embedded in patents and top management teams is a reasonable proxy of research and managerial competences required to enhance the complete innovation process.

Our statistical analysis provides support for our argument that technological diversity positively influences IPO success. Investor valuation of IPOs is improved through increasing diversity in a firm's technology portfolio. Innovation processes in high-technology sector usually demand the integration of a wide range of skills and technical disciplines to promote the development of new products. Thus, investors may consider that technological diversity favors the search for complementarities and novel solutions that increase the rate of invention and avoid learning traps. Our results also demonstrate that significance of the firm's stock of patent (in terms of patent citation) benefits IPO valuation. This result is consistent with previous research that shows that patent citations contain significant information that is positively associated with the stock market value of firms (Hall et al., 2005; Heiens, Leach and McGrath, 2007; Lanjouw and Schankerman, 2004; Shane and Klock, 1997). Citations may be used as indicators of the importance of individual patents, introducing a way of measuring the heterogeneity in the value of patents. Patent citation is a proxy for expected

returns, provides signals about superior research competences, and has several advantages such as accessibility, quantifiability and comparability (Hall et al., 2005; Shane and Klock, 1997).

Regarding top management teams, our findings support the idea that designing functionally heterogeneous TMT is positively associated with raising funds through an IPO. This suggests that diverse teams in terms of a representation of various business functions may signal to investors that they can generate more alternatives to solve complex problems, and increase decision effectiveness. This argument is consistent with contributions that report diversity in functional background in TMTs makes a firm more attractive to obtain venture capital and successfully complete an IPO (Beckman et al, 2007; Zimmerman, 2008). Particularly, in high-technology sectors, functionally heterogeneous top management teams can be observed as a combinative capability that impacts on the exchange and integration of distributed knowledge required to develop and commercialize valuable innovations. Furthermore, functional diversity in the TMTs is found to have a stronger effect on IPO success than information related to patents. This implies that, although patents serve as a valuable signal to the financial market, the information asymmetry existing between firms and uninformed investors can be high. Nevertheless, contrary to expectations, our results indicate that intrapersonal functional diversity in the TMT has not a significant effect on IPO success. Intrapersonal functional diversity carries several potential benefits but also has some drawbacks. Shared experience and overlapping knowledge in TMT lead to better integration of available information and to fewer decision biases at the group level (Bunderson and Sutcliffe, 2002). However, the fact that executives have a wide variety of functional experiences also implies that they have few deep commitments to any single functional area, perhaps making it difficult for them to secure strategic support from those in the functional areas (Ouchi, 1980). These two potential results could explain that intrapersonal functional

diversity is not considered a valid signal in the IPO process.

This study has theoretical implications for the dynamic capabilities perspective. The different points of view, backgrounds, and types of training inherent in a diverse technological knowledge base facilitate complex problem solving, the generation of new ideas and novel combinations (Kogut and Zander, 1992). Technological diversity allows the firm to predict the nature and commercial potential of technology advances and to exploit technological opportunities. A valuable stock of patents also provides evidence about the firm's capacity to innovate and discover potential market opportunities. Hence, both dimensions may represent a signal of superior research competence and influence positively on the investors' expectation of higher performance in firms. Moreover, a functionally heterogeneous top management team ensures that the full range of capabilities needed to manage the organization (Beckman and Burton, 2008) and innovation process. Thus, TMT functional diversity can be observed as a combinative capability, which appears to be an important determinant of IPO success.

On the other hand, this study has managerial implications. From the practical perspective, indentifying the effects of technological diversity will allow managers to be more effective in coordinating learning mechanisms of knowledge recombination such as strategic alliances or inventor teams. The empirical link between patent citations and market value may be useful in developing techniques for valuing patent portfolios held by firms, for trading and other purposes. Regarding uninformed investors, managers in research-based firms should pay particular attention to the mechanisms by which they can reduce information asymmetries. Successful mechanisms for reducing these information asymmetries may translate into more capital raised through IPO. TMTs are critical signals to outside investors. In preparing for an IPO, firms should properly design their TMT so as to indicate to investors the breadth of knowledge possessed by the team.

This study has a number of limitations. First, sampling is limited to a single sector of activity, so findings may not generalize to other industries and competitive settings. It would be of interest to extend this research to other technological sectors, and thus to identify differences in the importance of patents and TMT composition to attract investors' attention when firms go public. Another limitation comes from using exclusively secondary sources of information. Combining these sources with information collected through questionnaires, to study the aforementioned question would be interesting. Another subject into which this study can be extended is the examination of how the organization of specific learning mechanisms (e.g. strategic alliances, inventor teams, merger and acquisitions) affects the level of technological diversity and significance of patents to provide valid signals in the IPO process. More dimensions regarding composition, processes and behavior of TMTs such as the level and nature of conflict or demographic factors may provide greater insight into the influence of the TMT on IPO success. Moreover, future research could take into account other measures of performance regarding the value given by the capital market.

Our research contributes to a better understanding of the relationship between specific dimensions related to intangible assets and IPO success of research-based firms. The findings have theoretical and managerial implications. The results provide the motivation to continue the study of some unexplored issues related to sectoral comparisons, specific sources of knowledge diversity and alternative measures of performance which constitute promising streams for future research.

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Table 1
Means, standard deviations, and correlations

Variables	Mean	S.D.	1	2	3	4	5	6	7	8
1. IPO Success (log)	3.6358	0.7622	1.00							
2. Technological diversity	0.2700	0.3472	0.21*	1.00						
3. Patent stock's value	14.1782	67.0098	0.18*	0.27*	1.00					
4. TMT functional diversity	0.7387	0.1140	0.22*	0.14*	0.22*	1.00				
5. TMT intrapersonal functional diversity	0.1316	0.1244	0.01	0.00	0.00	-0.22*	1.00			
6. TMT size	5.6869	2.0146	0.29*	0.22*	0.29*	0.42*	-0.13*	1.00		
7. Firm size	81.6043	114.8147	0.27*	0.20*	0.27*	0.07	-0.06	0.18*	1.00	
8. Firm age	6.1965	4.6661	0.15*	0.29*	0.15*	0.01	-0.02	0.30*	0.53*	1.00

• $p < 0.05$

Table 2

Results of Regression Analysis

	IPO Success (log)			
	Model 1		Model 2	
<i>Independent variables</i>				
Technological diversity			0.043**	(0.010)
Patent stock's value			0.037**	(0.009)
TMT functional diversity			0.933**	(0.404)
TMT intrapersonal functional diversity			0.552	(0.331)
<i>Control variables</i>				
TMT size	0.067**	(0.024)	0.047*	(0.021)
Firm size	0.011*	(0.005)	0.011*	(0.004)
Firm age	-0.004	(0.012)	-0.014	(0.286)
Annual dummies (25 years)	7 years*		6 years*	
Constant	3.239***	(0.162)	2.504***	(0.331)
N (number of firms)	229	229	229	229
R^2	0.294		0.350	
Adjusted R^2	0.234		0.280	
ΔR^2			0.055**	
F	4.86***		5.03***	

^a Standard errors are in parentheses

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$ (two-tailed test)