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Insights to technological alliances and financial resources as antecedents of high-tech firms' innovative performance

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High-tech firms are triggered to externally acquire and combine additional supplementary and complementary resources to develop innovative capabilities and generate new knowledge, products, and business ideas. Firms may rely on cooperation, alliances, and other interfirm ties as well as on the external acquisition of the stock of resources and capabilities to foster their innovativeness and support their patent activity. This contribution develops and tests a conceptual framework for assessing external sources of a firm's innovative performance in high-tech industries. By simultaneously evaluating the explanatory power of technological alliances and financial resources in shaping a firm's innovative performance, measured as new patents registered, the paper provides some original outcomes from both conceptual and methodological perspectives. Research hypotheses are tested performing ordinary least squares (OLS) regression models on 90 European-listed firms operating in the aerospace and defence industry, engaging over 1,300 technological alliances within the 2007–2011 timeframe. The findings demonstrate that high-tech firms leverage on technological supplementary alliances to innovate and to create new knowledge embodied in artifacts such as patents. In addition, financial slack is proved to be a prerequisite for a successful patent activity in high-tech industries. Empirical outcomes, discriminating between small and large firms, bring valuable insights both for academics and practitioners.

1. Introduction

In highly competitive business environments, characterized by profound technological innovations, novel knowledge creation acquires a critical role in ensuring a firm's competitive advantage (Das and Teng, 2000). As innovation and cutting-edge technologies development become preconditions for surviving, standing-alone strategy no longer constitutes a viable option for high-tech firms (Hagedoorn and

Duysters, 2002). In this context, firms rely on cooperation, alliances, networks, communities, and interfirm ties in undertaking innovation activities (Baum et al., 2000), as well as on the external acquisition of the necessary stock of resources and capabilities (Patzelt et al., 2008).

This contribution focuses on technological alliances and financial resources as predictors of firms' innovative performance and patent activity in high-tech industries. Extant literature recognized the dominant role of technological alliances in supporting a firm's innovative performance (Baum et al., 2000). Technological agreements enhance the development of knowledge and new capabilities (Hagedoorn and Duysters, 2002), ensure organizational flexibility (Doz, 1988), share costs, and moderate risks originating from highly uncertain research and development (R&D) projects and innovation activities (Jiang et al., 2010). In addition, several scholars argue that financial resources endowment does influence a firm's attitude toward innovation by increasing managerial discretion and opportunities for developing nonfinancial capabilities (George, 2005; Patzelt et al., 2008). Despite the attention awarded by practitioners and academics to the predicting role of technological alliances in shaping a firm's innovative performance (Ahuja, 2000), the dimensions of technological alliances, which impact on innovation, still remain under-explored (Schilling and Phelps, 2007).

The paper aims to fill-up existing academic gaps, and adds to extant literature. It addresses technological alliances for supplementary and complementary resources, cooperation agreements with universities, and other research centers as well as the 'industrial variety of technological alliances portfolio' (VTA). In addition, only a few contributions empirically test the role of the financial resources on a firm's innovation outputs (Bond and Van Reenen, 2007; Brown et al., 2009). By focusing on 'financial slack' (FIS) and 'institutional investors' ownership' (INV), this contribution investigates the impact of financial resources on a firm's patent activity as a proxy of firms' innovative performance, and provides a sound empirical ground for further studies.

Research hypotheses are tested by performing OLS regression models on 90 firms listed on major European Stock Exchanges and operating in the aerospace and defence (A&D) industry. These firms engaged over 1,300 technological alliances within the 2007–2011 period. Empirical outcomes bring valuable insights for academics and practitioners.

The paper is structured as follows: Section 2 provides the conceptual framework and develops research hypotheses. Section 3 focuses on the sampling frame and the operationalization of variables. Section 4 provides main empirical outcomes and explores alternative specifications. Section 5 discusses major academic and managerial implications, before concluding.

2. Literature review and hypotheses development

2.1. *Technological alliances and innovative performance*

High-tech industries, where technology, innovation, and time to market are key success factors, experienced an impressive growth in the number of technological alliances, i.e. interfirm cooperation agreements implying joint innovative activity and/or exchange of technology (Gulati et al., 2000). Technology-based alliances include, among others, transfers for property rights ('technology for cash'), licensing agreements, R&D contracts, and joint R&D.

Technological agreements, providing firms with access to external information and know-how, increase a firm's innovative performance, both supporting new patents application and products development (Baum et al., 2000; Hagedoorn and Duysters, 2002; Schilling and Phelps, 2007).

Academics and practitioners questioned the explanatory power of technological alliances on innovative performance in high-tech industries, debating on several theoretical perspectives for investigating the phenomenon. Transaction cost economics (Williamson, 2002), resource-based view (RBV) and dynamic capabilities approach (Eisenhardt and Martin, 2000), network theory, and embeddedness perspective (Ahuja, 2000; Arya and Lin, 2007; Lavie, 2007) emerge as dominant theories. Nevertheless, the dimensions of technological alliances affecting innovation in high-tech industries still remain under-explored by academics (Schilling and Phelps, 2007), and a solid empirical base is needed (Hagedoorn and Duysters, 2002). In this context, RBV appears appropriate as it recognizes the relevance of unique resources and relationships in enhancing a firm's innovative performance, as well as the centrality of technological alliances for accessing and retaining knowledge, resources and capabilities out of a firm's boundaries (Hagedoorn and Duysters, 2002).

2.1.1. *Supplementary resources*

As resources shared and exchanged may be similar or dissimilar, two dichotomist forms of alignments are commonly defined in literature, i.e. supplementary and complementary (Das and Teng, 2000; Dussauge et al., 2000; Schilling and Phelps, 2007). Resource similarity among partners is traditionally defined as the degree to which parties share resources comparable in terms of type and amount (Chen, 1996). Within technological alliances, supplementary (or 'scale') alliances are interfirm agreements devoted to share and exchange similar resources (Mitchell et al., 2002). These alliances ensure to high-tech firms risk sharing as well as economies of scale and scope in operational areas such as R&D activities (Arranz and Fdes de Arroyabe, 2008). Proximity in technology and resources supports alliance outcomes because of the more intensive and deeper interactions among partners (Baum et al., 2000), and increases the efficiency and speed of cooperation (Gilsing et al., 2008).

In high-tech industries, although technological and R&D cooperation may determine involuntary 'outgoing spill-overs' to partners when they are also rivals, firms find incentives to share and exchange technology and know-how with other parties, in order to establish new standards (Dussauge and Garrette, 1995). As resource similarity is expected to foster innovative output, we hypothesize that:

H1.1: *Technological supplementary alliances positively affect firm's innovative performance.*

2.1.2. Complementary resources

The role of complementary resources in assessing partnership outcomes is recognized by contributions addressing alliances in a RBV perspective (Eisenhardt and Martin, 2000). Complementarity refers to multifaceted aspects of the resources involved in interfirm agreements, such as resources' type and nature (Helfat, 1997). Das and Teng (2000) suggest that complementary alliances have to pave on dissimilarity and compatibility of shared resources.

By enhancing the combination of diverse resources whose matching provides firms with enormous synergies, 'link' alliances are expected to be reliable predictors of a firm's innovative performance (Dussauge et al., 2000). Dissimilar resources (i.e. unique to a given partner) pooled together facilitate the creation of new capabilities, stimulate technological innovation, and favor collaborative relations among partners because of their nonoverlapping nature (Das and Teng, 2000; Sà and Lee, 2012). Relatedly, Doz (1988) prompts that technological complementarity may positively affect innovative output. In high-tech industries, due to the pace of technological change, these alliances permit firms to expand knowledge and manage technological convergence within the R&D processes (Arora and Gambardella, 1990; Miotti and Sachwald, 2003; Arranz and Fdes de Arroyabe, 2008). Therefore, we hypothesize that:

H1.2: *Technological complementary alliances positively affect a firm's innovative performance.*

2.1.3. Universities and other research institutes

Recent empirical evidences demonstrate that high-tech firms are eager to cooperate with universities, laboratories, and research centers, also participating in research consortia (Arranz and Fdes de Arroyabe, 2008).

These cooperation agreements provide firms with an external source for quickly accessing new scientific and technical knowledge (Belderbos et al., 2004). By collaborating with these entities, firms face lower commercial risks and outgoing spillover threats. In fact, universities and public research institutions pursue predominantly noncommercial objectives (Miotti and Sachwald, 2003). Technological alliances with universities and research centers are supported by public funding (Hagedoorn et al., 2000), and thus represent cheap, or even inexpensive, external sources of knowledge (Belderbos et al., 2004).

Some scholars have empirically tested the impact of technological cooperation with universities and other research institutes on firms' innovative performance. George et al. (2002) analyze 2,457 alliances undertaken by 147 biotechnology firms and find that those firms engaging relational linkages with universities sustain lower R&D expenses and reach higher levels of innovative output. Belderbos et al. (2004), by addressing Dutch firms, discover that R&D cooperation with universities strengthen a firm's propensity to introduce new successful products into the market. Finally, Baba et al. (2009), addressing 455 firms operating in the advanced materials, demonstrate that R&D collaborations with universities empower a firm's innovative performance measured as the number of registered patents. Therefore, we expect that:

H1.3: *Technological alliances with universities and other research institutes positively affect a firm's innovative performance*.

2.1.4. VTA

Partner characteristics affect the type and nature of resources and external knowledge accessed by the firm. Therefore, partner selection becomes a critical antecedent of alliances performance (Doz, 1988).

Hagedoorn and Schakenraad (1994) demonstrate that partner peculiarities influence the firm's performance more profoundly than the sole number of alliances, whereas Goerzen and Beamish (2005) find that industry and country diversity of alliance partners unveil a U-shaped relationship with firm performance. Other scholars question the role of partner industrial diversity in shaping firms' capacity to acquire additional knowledge and competences (Belderbos et al., 2004). Cohen and Levinthal (1990) argue that partners from the same industry show higher absorptive capacities, as they share common knowledge and technological bases.

Conversely, a stream of literature suggests that a diversified partners' portfolio provides a firm with valuable capability development opportunities, as it enhances the access to mixed pools of resources (Jiang et al., 2010). Therefore, although absorptive capacity is expected to decline as technological distance among partners increases, a positive association between innovation and partners' diversity is suggested (Gilsing et al., 2008).

In high-tech industries, where 'technological convergence' triggers to share and exchange knowledge and diverse resources (Rothaermel and Thursby, 2007), VTA may enhance unexpected learning and resource access benefits (Jiang et al., 2010). By managing a heterogeneous portfolio of technological alliances, high-tech firms come in touch with new ideas and routines that favor resources recombination, creativeness, and novel approaches to the business, fostering firms' innovative output and, specifically patent activity (Schilling and Phelps, 2007). Therefore, we expect that:

H1.4: *The industrial variety of technological alliances portfolio engaged by the firm positively affects its innovative performance.*

2.2. Financial resources and innovative performance

The role of financial resources as a predictor of firms' investment decisions concerning innovation activities has been widely debated by scholars (Hubbard, 1998). With respect to fixed capital investments, in fact, the financing of innovative and R&D-intensive projects become more problematic because of critical information asymmetries (Carpenter and Petersen, 2002), the intangible nature of innovation outputs (Ughetto, 2008), and the difficulty in estimating future cash flows (Lev, 2001). This matter appears even more challenging in high-tech industries, which require enormous investments for acquiring additional equipment, research facilities, skilled staff, licenses, and technologies by third parties (Gulati et al., 2000; Patzelt et al., 2008).

Academic literature distinguishes between internal (i.e., cash flows) and external (i.e., debt or external equity) financial resources and assesses their diverse impact on R&D investments and innovation (Ughetto, 2008).

Although both retained earnings and the availability of new debt or equity exert an impact on a firm's investment decisions, R&D projects and innovative activities are preferably financed by internally generated cash flows (Himmelberg and Petersen, 1994). Many reasons lie behind that: first, in high-tech industries, innovative projects determine smooth investment patterns over time, are subject to a high degree of uncertainty, and have low probability of success (Ughetto, 2008); second, several frictions concerning risks perception may originate from asymmetric information between entrepreneurs and outsiders (Carpenter and Petersen, 2002); third, innovation outputs are often intangible assets, not usable as collaterals to secure a firm's borrowing (Lev, 2001).

In this vein, academics debate on the impact of internal and external financial resources on R&D activities (Himmelberg and Petersen, 1994; Mulkay et al., 2001), propensity toward innovation (Kochhar and David, 1996; Patzelt et al., 2008), and new product development (Svensson, 2007) in high-tech businesses. Although prior researches find that financial resources have a positive impact on R&D activities in high-tech industries (Mulkay et al., 2001), only a few empirical contributions address the role of the financial resources on a firm's patent activity (Bond and Van Reenen, 2007; Brown et al., 2009). Therefore, further investigation is required (Kochhar and David, 1996).

2.2.1. FIS

Internal financial resources play a relevant role in fostering a firm's patent activity (Martinsson and Loof, 2009) and new product developments (Mishina et al., 2004). FIS, i.e. cash and receivables available, increases managerial discretion, facilitates the development of nonfinancial capabilities, and enables a faster firm's adaptation to instable business environments (Patzelt et al., 2008).

In highly technological environments, where innovation and R&D activities are expensive and time-consuming (Kellog and Charnes, 2000), FIS permits to quickly acquire missing competences externally or to build new internal capabilities (George, 2005). Internal financial resources reduce a firm dependence from external capital markets and allow undertaking

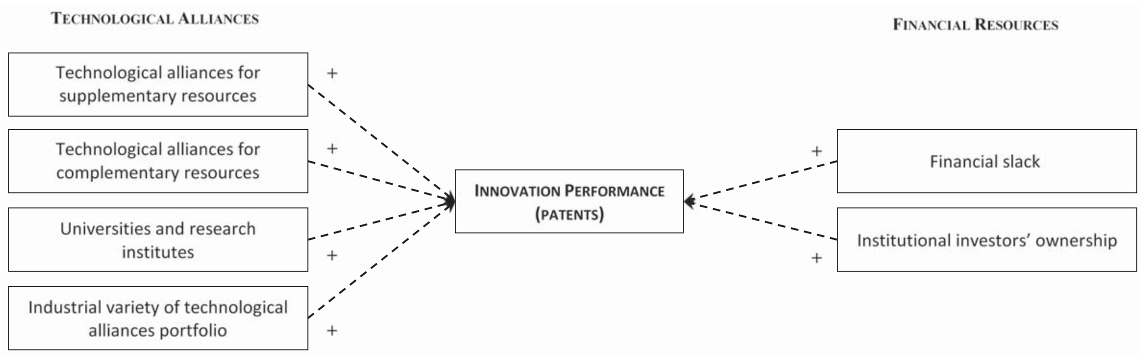

Figure 1. Conceptual framework and hypothesis development.
Sources: authors' own elaboration.

long-term investments dedicated to innovation also during bearish financial cycles (Audretsch and Lehmann, 2004). FIS also supports innovative performance, providing high-tech firms with the opportunity to start-up incremental innovation processes without sacrificing current R&D projects (Rothaermel and Deeds, 2004).

Empirical research demonstrates that the availability of internal financial resources constitutes a prerequisite for a successful patent activity and the development of new products (Mishina et al., 2004). Besides, firm innovative performance is strengthened by a higher managerial discretion in the acquisition of additional investment, such as research facilities, equipment, skilled human resources, licenses, or other intangible capabilities (Zucker et al., 2002). Finally, as the defence of intellectual property is complex and expensive, especially in high-tech industries, FIS provides firms with proper tool for protecting patents and sustaining the costs of litigations that originate from the infringements of intellectual property (Patzelt et al., 2008). Therefore:

H2.1: *The availability of financial slack positively affects a firm's innovative performance.*

2.2.2. INV

Concerning the explanatory role of external financial resources in shaping a firm's innovative performance, some arguments are raised against the reliance on bank lending (Audretsch and Lehmann, 2004). In particular, debt is not well suited for risky projects and presents characteristics adequate for financing innovation embodied in physical capital rather than intangible assets (Ughetto, 2008).

Conversely, stock markets contribute to foster a firm's patent activity, directly funding innovation (Martinsson and Loof, 2009). Moreover, the presence of institutional investors in a firm's ownership is attracting the attention of scholars as potential predictors of innovative performance (Czarnitzki and Kraft, 2004). Institutional investors are expected to drive firms to innovate rather than simply invest in firms that act as innovators (Ussem, 1993). Nonspeculative institutional investors are eager to support investments in innovative projects, whose expenditures are supposed to improve firm value in the long term (Kochhar and David, 1996). Some studies demonstrate the existence of a positive relation between INV and firms' R&D attitude (Baysinger et al., 1991). Institutional investors evaluate investment alternatives carefully and select successful innovative ventures (Aoki, 1984). Besides, they increase managerial incentives to innovate by reducing the career risk of uncertain projects (Kochhar and David, 1996).

As INV positively influences patent activity providing firms with additional financial resources and managerial discretion (Kochhar and David, 1996), we expect that:

H2.2: *Institutional investors' ownership positively affects a firm's innovative performance.*

The overall conceptual framework discussed in this section is outlined in Figure 1.

3. Data and method

3.1. Sampling frame

Research hypotheses are tested on cross-sectional data concerning firms that operate in the A&D industry, i.e. one of the most competitive and knowledge-intensive sector among high-tech industries. This business represents an ideal site for investigating the relationship between a firm's innovative performance and external source of innovation for several reasons. First, in this sector, patents are widely exploited in securing intellectual property rights, and therefore constitute a raw, yet appropriate, indicator of a firm's innovative performance (Levin et al., 1987; Guillou et al., 2009). Second, in the A&D industry, 53% of the firms cooperate to innovate: that is twice as high as the average for all manufacturing sectors (Europe Innova, 2012). Finally, due to the wide array of enabling technologies involved in innovation activities, A&D firms face significant investments and need an enormous amount of financial resources (Dussauge and Garrette, 1995).

Empirical analysis addresses European-listed firms operating in the A&D industry within the 2007–2011 timeframe. Data have been gathered in March 2013 from the S&P Capital I-Q database, which provides reliable and timely financial information, and from the European Patent Register (from the European Patent Office, EPO), containing data publicly available on European patent applications passed through the grant procedure.

The sampling process includes four steps. First, firms operating in A&D industry, listed on primary European Stock Exchanges are screened (stage I) from the S&P Capital I-Q database. As a result, 110 companies are sampled, and corporate data as well as economic and financial information for the 2007–2011 period are gathered. To complete missing value, data are cross-checked with information disclosed by firms in corporate annual reports and financial statements. Eleven firms that entered the market after 2007 or went bankrupt before 2011 are excluded from the analysis to ensure data homogeneity and consistency (stage II). Thus, the sample is narrowed down to 99 companies. For these firms, all data on patent applications in the 2007–2011 period are collected from the European Patent Register (stage III): nine firms did not apply for any patent in the selected timeframe and are removed from the sample. The final sample is made up of 90 companies and provides a sound representation of the European A&D industry, due to its fairly concentrated nature.

For each of these 90 companies, a new extraction from the S&P Capital I-Q database is performed to investigate the technological alliances engaged in the sample timeframe (stage IV). Technological alliances are defined as alliance agreements explicitly established for the pursuit of joint R&D, technology licensing, and cross-technology transfer (Schilling and Phelps, 2007). A dataset of 1,309 strategic technological alliances involving at least one of the sample firms is realized. For each alliance, relevant data are collected (e.g., partners' primary industry, country of origin and size, the key goals of the agreement, etc.). Aiming to assess the nature of the resources shared in each of the collaborative agreements, information from S&P Capital I-Q database are validated, consulting reliable sources, such as specialized technology journals and academic contributions.

3.2. Variables

3.2.1. Dependent variable

The firm's innovative performance, i.e. the dependent variable, is operationalized as a firm's patent activity. The number of patents is recognized as a meaningful indicator of innovativeness, because its attitude to reflect the *locus* of a firm's technology and capability development (Griliches, 1990). In fact, the innovation process drives to new knowledge embodied in artifacts such as patents and new products (Schilling and Phelps, 2007). Patents enhance to measure the amount of new inventions externally validated through the examination process (Griliches, 1990). Patents also confer property rights to the assignee and ensure a valuable economic impact (Ahuja, 2000; Maskus, 2000). In high-tech industries, patent count as a proxy for innovativeness has to be preferred as opposed to alternative measures such as patent citation. Patent citations occur over time and this provokes a bias in regard to elder patents (DeCarolis and Deeds, 1999).

We modeled a firm's innovative performance as a firm's patent activity. This choice grounds on prior research arguing that a firm's patent count is highly correlated with patents quality (Stuart, 2000) and fits with the launch of new product (Basberg, 1987). Although a variety of indicators can be used to assess the innovative performance of firms (R&D inputs, patent counts, patent citations, new products, etc.) the statistical overlap between these metrics is strong enough to justify the usage of a single indicator instead of a combination of them (Hagedoorn and Cloodt, 2003). Patent activity represents a raw, yet reasonable, approximation of a firm's innovative output in high-tech industries. In fact, in those industries where the costs of copying an innovation is significantly lower than the costs originating from innovation activities (e.g. pharmaceuticals, chemicals, A&D, etc.), patents enable the capture of a firm's innovativeness in respect to alternative measures (Arundel and Kabla, 1998; Ahuja, 2000).

For the purpose of this study, a firm's patent activity is measured as the number of patents assigned to each firm in the 2007–2011 period, consistent with prior studies (Nadeau, 2011). A 5-year time window is an appropriate range for assessing the technological impact of new inventions (Ahuja, 2000; Gilsing et al., 2008). The variable is transformed into a more usable form by applying the natural logarithm of the number of patents.

3.2.2. *Independent variables*

External sources of firms' innovative performance assessed in this contribution include both technological alliances and financial resources. The former refers to the supplementary and complementary resources shared in cooperative agreements, the collaborations with universities and other research institutes, as well as the industrial variety of the technological alliances portfolio (Miotti and Sachwald, 2003; Arranz and Fdes de Arroyabe, 2008; Gilsing et al., 2008) (Table 1).

The variable 'technological supplementary alliances' (TSA) takes into account a firm's attitude to join alliances aiming to raise supplementary resources. It is operationalized as the number of technological scale alliances entered in the sample period (Santangelo, 2000; Mitchell et al., 2002). Analogously, the variable 'technological complementary alliances' (TCA) reflects a firm's attitude to enter new alliances for complementary resources and is measured as the number of technological link agreements contracted in the same timeframe (Santangelo, 2000; Mitchell et al., 2002). To measure a firm's capacity to collaborate with universities and research institutes, a count variable is introduced, i.e. URI ('collaborations with universities and other research institutions'). It is defined as the number of collaborative agreements with universities and research institutions to develop new knowledge and/or technologies.

An *ad hoc* synthetic index, i.e. VTA, is developed to assess the diversity of the partners each firm collaborates with. This indicator provides information about the heterogeneity of resources captured through technological alliances. Consistent with previous studies (Gilsing et al., 2008; Jiang et al., 2010), we investigate the primary industry of each partner engaged in the 1,309 sample technological alliances, by applying the standard industrial classification (SIC) at the four-digit level. As a result, 91 codes are identified in the sample. Focusing on the 90 selected A&D firms, we calculate the Herfindahl index (H^j) related to the share of partners belonging to each SIC code, as shown in equation (1):

$$H^j = \sum_{i=1}^{n} \left(\frac{A_i^j}{AT^j} \right)^2 \qquad (1)$$

A_i^j = number of technological alliances engaged by the *j*th sample firm with partners whose primary industry is the *i*th sector; $AT^j = \sum_{i=1}^{n} (A_i^j)$, i.e. number of technological alliances engaged by the *j*th sample firm; '*j*' ranges from 1 to '*m*', with '*m*' = 90, i.e. the number of sample A&D firms; '*i*' ranges from 1 to '*n*', with '*n*' = 91, i.e. the number of SIC codes to which at least one partner belongs to.

Finally, for each A&D firm the VTA is calculated as in the equation (2):

$$VTA^j = 1 - H^j \qquad (2)$$

VTA^j measures the variety of interorganizational relationships and technological alliances joined by the *j*th firm in the 2007–2011 period: the higher the value, the higher the variety. It ranges from 1 to $1 - \left(\frac{1}{n} \right)$.

The role of financial resources as predictor of firms' patent activity is evaluated by introducing two variables. The variable FIS investigates to which extent internal free monetary resources contribute to the acquisition and development of nonfinancial capabilities (Patzelt et al., 2008). It measures the amount of financial resources internally available within the sample timeframe. The variable INV brings information on the firm access to additional financial and managerial resources (Kochhar and David, 1996; Czarnitzki and Kraft, 2004). It is operationalized as a dichotomous dummy variable, taking value 1 if the share owned by institutional investors on a firm's total capitalization is over 10.00%, and 0 otherwise.

3.2.3. *Control variables*

Consistent with extant literature, some control variables are introduced to contemplate their impact on a firm's innovative performance and patent activity. First, a firm's 'market capitalization' is tested, as large firms are expected to apply for more patents than small, all else equal (Scellato, 2007; Holgersson, 2013). Large firms may aggressively invest money for innovating because of their monopolistic power in the market, which allows them to generate additional profits and therefore held an innovation advantage with respect to small firms (Rothwell and Dodgson, 1991).

Consistent with prior empirical investigations (Mulkay et al., 2001; Brown et al., 2009), we consider a firm's 'research and development expenses' (RDE). Several scholars support the positive effect of R&D expenses on a firm's innovative performance in high-tech industries (Mowery et al., 1996).

Table 1. Description and operationalization of dependent, independent and control variables

Code	Variable	Definition and operationalization	Hypothesis	Predicted sign
Dependent variable				
PAT	Patent	Reflects firm's innovative performance. Measured as the number of annual patents assigned to each firm in the 2007–2011 period (source: European Patent Office). The variable has been transformed into a more usable form by applying the natural logarithm of the number of patents.	–	–
Independent variables				
TSA	Technological supplementary alliances	Reflects the propensity of each firm to engage technological alliances with partners in order to obtain supplementary resources. Measured as the number of technological supplementary alliances entered by each firm in the selected timeframe (source: Author' own elaborations from S&P Capital I-Q, corporate disclosure documents and websites).	*H1.1*	+
TCA	Technological complementary alliances	Reflects the propensity of each firm to enter technological alliances with partners in order to obtain complementary resources. Measured as the number of technological complementary alliances engaged by each firm in the selected timeframe (source: Author' own elaborations from S&P Capital I-Q, corporate disclosure documents and websites).	*H1.2*	+
URI	Universities and research institutes	Reflects the propensity of each firm to collaborate with universities and other research institutions to improve the firm's innovative performance. Measured as the number of strategic alliances and collaborations with universities and other research centers in the selected timeframe (source: Author' own elaborations from S&P Capital I-Q, corporate disclosure documents and websites).	*H1.3*	+
VTA	Industrial variety of technological alliances portfolio	The variable measures the variety of interorganizational relationships and alliances entered by each firms within the selected timeframe. It has been calculated as shown in equation (1) through an *ad hoc* entropy measure.	*H1.4*	+
FIS	Financial slack	The variable measures firms' financial slack. It reflects the total amount of internal financial resources available for each firm. measured as the mean of cash and equivalent assets hold by the firm within the 2007–2011 period. Consistent with Kang and Kim (2012), cash and equivalent data have been transformed into a more usable form by using the natural logarithm of cash and equivalent data (source: S&P Capital I-Q).	*H2.1*	+
INV	Institutional investors' ownership	The variable provides relevant information about firms' access to additional external financial and managerial resources. It refers to the presence of institutional investors (e.g. public pension funds, mutual funds, insurance companies, banks, etc.) as relevant shareholders in the company. The variable takes value 1 if % share owned by institutional investor on total capitalization exceeds 10%, and 0 otherwise (source: S&P Capital I-Q).	*H2.2*	+
Control variables				
CAP	Market capitalization	The variable refers to firm's market capitalization within the selected timeframe. It represents a good proxy of firm's size, as market capitalization may be presented as a function of revenue, earnings, book value, and total assets of the firm (Bowen et al., 2002). Measured as the average market capitalization in the 2007–2011 period. Data are expressed in € millions (source: S&P Capital I-Q).	–	–
RDE	Research and development expenses	It reflects the total amount of expenses for research and development including all expenses on creative work undertaken systematically to increase knowledge and the use of knowledge for new applications. RDE covers basic research, applied research, and experimental development. The variable has been measured as cumulated R&D expenses during the selected timeframe (2007–2011). Data are expressed in € millions (source: S&P Capital I-Q, corporate annual reports and firm's institutional website).	–	–
KEI	Knowledge Economy Index	The variable refers to the Knowledge Economy Index (KEI) of the firm's country of origin, developed by the World Bank. KEI takes into account whether the environment is conducive for knowledge to be used effectively for economic development. It is an aggregate index that represents the overall level of development of a country towards innovation and knowledge, and grounds on four pillars, i.e., economic incentive and institutional regime, education and human resources, the innovation system and information and communication technology.	–	–

Sources: authors' own elaboration from S&P Capital I-Q (2007–2011), World Bank (2012) and corporate disclosure documents and websites.

Nevertheless, after a certain threshold of R&D expenses, some diseconomies may emerge and the positive impact on a firm's innovativeness is expected to decline because of absorptive capabilities associated with research activities (Griffith et al., 2004). Therefore, the quadratic function of the RDE variable (RDE^2) is tested in the study.

Finally, as the normative and institutional environment (e.g., patent-related governmental grants, R&D tax incentives, etc.) influences a firm's attitude towards innovation (Czarnitzki and Kraft, 2004), 'Knowledge Economy Index' (KEI) of a firm's country of origin (World Bank, 2012) is introduced. It shows to what extent environmental conditions are conducive for knowledge and innovation.

4. Empirical results

4.1. OLS regression analysis

Before performing the OLS regression analysis, the correlations among dependent, independent, and control variables are calculated. Table 2 provides the descriptive statistics and the correlation matrix. As a number of variables are founded to be mutually correlated, further diagnostics are required. Indeed, tests unveil that multicollinearity does not constitute a threat to the OLS results. Tolerance and variance inflation factors (VIF) are largely within the accepted range (Hair et al., 1995), being higher than 0.1 and lower than 10, respectively (Table 3). Descriptive statistics give interesting insights about the patent activity of the sample firms as well as the external sources of innovative performance. During the 2007–2011 period, the sample A&D firms have registered 8,059 patents (89.51 per firm on average). Moreover, 340 technological scale alliances and 813 technological link alliances are contracted (3.77 and 9.03 on average, respectively). In addition, 156 cooperative technological agreements involving at least one university/research institution are engaged. Finally, the VTA assumes values between 0 and 0.93 (0.41 on average).

To assess the role of technological alliances and financial resources as predictors of innovative performance of high-tech firms, four OLS regression models are performed (Models 1–4), including six independent variables and three control variables. Table 3 shows regression analysis outcomes. All models are highly significant (P-value < 0.01).

Model 1 includes only control variables and tests the appropriateness of their selection: two out of three control variables influence a firm's patent activity. Model 2 exhibits the effect of variables related to

Table 2. Descriptive statistics and correlation matrix

	Mean	SD	Min	Max	PAT	TSA	TCA	URI	VTA	FIS	INV	CAP	RDE	KEI
PAT	2.62	1.87	0.69	7.05	1	–	–	–	–	–	–	–	–	–
TSA	3.78	9.21	0.00	52.00	0.6566**	1	–	–	–	–	–	–	–	–
TCA	9.03	16.26	0.00	88.00	0.5515**	0.5803**	1	–	–	–	–	–	–	–
URI	1.73	3.32	0.00	15.00	0.6444**	0.7234**	0.4509**	1	–	–	–	–	–	–
VTA	0.41	0.36	0.00	0.93	0.6164**	0.3873**	0.4565**	0.4796**	1	–	–	–	–	–
FIS	1.32	1.38	–3.00	3.71	0.7111**	0.4794**	0.5226**	0.4925**	0.5415**	1	–	–	–	–
INV	0.69	0.47	0.00	1.00	0.3664**	0.1960	0.2582	0.2146	0.1669	0.3735*	1	–	–	–
CAP	1,529.10	3,169.96	2.19	15,544.55	0.7114**	0.7294**	0.5867**	0.5159**	0.4479**	0.5624**	0.2709	1	–	–
RDE	710.90	2,186.11	0.00	14,343.00	0.5936**	0.9023*	0.5442**	0.6188**	0.3353*	0.4391**	0.2002	0.7891*	1	–
KEI	8.64	0.46	7.51	9.43	0.1358	–0.0016	0.0898	–0.0078	0.0740	–0.1087	0.2246	0.1815	0.0659	1

CAP, market capitalization; FIS, financial slack; INV, institutional investors' ownership; KEI, Knowledge Economy Index; PAT, patent; RDE, research and development expenses; SD, standard deviation; TCA, technological complementary alliances; TSA, technological supplementary alliances; URI, universities and research institutes; VTA, industrial variety of technological alliances portfolio.
*$P < 0.01$.
**$P < 0.001$.

Table 3. OLS regression models

	Model 1	Model 2	Model 3	Model 4	Collinearity diagnostics	
					Tolerance	VIF
Intercept	0.8330	–0.6404	–2.8664	–2.8114	–	–
	2.5768	*2.2061*	2.3212	2.1538	–	–
Independent variables						
TSA	–	0.0471	–	0.0516*	0.1463	6.8350
	–	*0.0339*	–	*0.0309*		
TCA	–	0.0082	–	–3.70E-04	0.5846	1.7105
	–	*0.0094*	–	*8.76E-03*		
URI	–	0.1192**	–	0.0841*	0.4508	2.2184
	–	*0.0529*	–	*0.0488*		
VTA	–	1.2591***	–	0.8723***	0.6488	1.5413
	–	*0.3994*	–	*0.3803*		
FIS	–	–	0.6018***	0.4149***	0.4893	2.0437
	–	–	*0.1094*	*0.1124*		
INV	–	–	0.1877	0.2508	0.8609	1.1615
	–	–	*0.2731*	*0.2521*		
Control variables						
CAP	2.78E-04***	2.09E-04***	1.23E-04*	1.34E-04**	0.2734	3.6576
	7.70E-05	*6.93E-05*	*6.96E-05*	*6.57E-05*		
RDE	7.62E-04***	2.18E-04	6.34E-04***	1.99E-04	0.1564	6.3938
	2.35E-04	*2.47E-04*	*1.99E-04*	*2.25E-04*		
RDE^2	–5.33E-08***	–3.21E-08***	–4.16E-08***	–2.76E-08**	0.1046	9.5616
	1.65E-08	*1.45E-08*	*1.40E-08*	*1.34E-08*		
KEI	0.1267	0.2287	0.4791*	0.4413*	0.8752	1.1425
	2.99E-01	*0.2558*	*0.2707*	*0.2522*		
Number of observations	90	90	90	90	–	–
Multiple R	0.7500	0.8382	0.8359	0.8718	–	–
R-squared	0.5625	0.7026	0.6987	0.7599	–	–
Adjusted R-squared	0.5419	0.6732	0.6769	0.7296	–	–
F-statistic	27.322***	23.9214***	32.0843***	25.0148***	–	–
P-value	*1.37E-14*	*2.14E-18*	*1.09E-19*	*1.47E-20*	–	–

Standard errors are in italics. CAP, market capitalization; FIS, financial slack; INV, institutional investors' ownership; KEI, Knowledge Economy Index; OLS, ordinary least squares; RDE, research and development expenses; RDE^2, quadratic function of the RDE variable; TCA, technological complementary alliances; TSA, technological supplementary alliances; URI, universities and research institutes; VIF, variance inflation factors; VTA, industrial variety of technological alliances portfolio.
*$P < 0.10$.
**$P < 0.05$.
***$P < 0.01$.

technological alliances (i.e., TSA, TCA, URI, and VTA) on the dependent variable (PAT). Model 3 focuses on financial resources, testing the impact of FIS and INV on patenting. Finally, Model 4 includes all independent and control variables. Model 4 is highly significant (*F*-statistic 25.0148, *P*-value < 0.01) and presents a valuable adjusted r-squared (0.7296), higher than previous models (Model 1–3). In Model 4, four out of six independent variables are statistically significant and correctly signed. In particular, TSA, URI, VTA, and FIS positively influence a firm's innovative performance, supporting H1.1, H1.3, H1.4, and H2.1, respectively. Conversely, the coefficients of TCA and INV are not significant and H1.2 and H2.2 are not supported. The results of Model 4 are further tested to verify their robustness and consistency. The Breusch–Pagan (BP) test unveils the absence of heteroscedasticity (BP = 12.48, $P = 0.2539$). We also check the normality of residuals. The Kolmogorov–Smirnov test shows that residuals are normally distributed (D = 0.09; P-value = 0.096).

TSA, technological alliances with universities and other research institutes, the VTA, and the availability of FIS are proven to positively affect a firm's innovative performance, measured as number of patents registered. Conversely, the impact of TCA and INV on a firm's patent activity is statistically inconsistent.

4.2. Alternative specifications and robustness checks

To further validate the empirical results and test their consistency, a number of robustness checks are performed and a set of alternative specifications is explored (Table 4).

We basically proceed in two directions. First, as firm size may shape strategic behavior and a firm's

Table 4. Robustness checks and alternative specifications

	Firm size (no. of employees)		Firm primary industry	
	Model 5a (small firms)	Model 5b (large firms)	Model 6a (A&D industry)	Model 6b (other industry)
Intercept	−3.1715	−2.1627	0.3229	−1.1898
	2.6955	*2.6890*	3.3895	2.7330
Independent variables				
TSA	−0.5214**	0.0549*	0.0197	0.1523*
	0.2211	*0.0323*	*0.0363*	*0.0830*
TCA	0.7222***	−0.0035	−0.0206	−1.49E-03
	0.1399	*0.0093*	*0.0328*	*1.19E-02*
URI	−0.1764	0.0809*	0.1212**	0.0632
	0.2019	*0.0513*	*0.0540*	*0.0774*
VTA	2.0040**	0.4663	2.0121***	0.2782
	0.9336	*0.4592*	*0.6908*	*0.4775*
FIS	0.2016	0.4559**	0.1120	0.3789**
	0.1448	*0.2042*	*0.1444*	*0.1748*
INV	−0.4000	0.7068**	0.7953**	0.0111
	0.2462	*0.3396*	*0.3597*	*0.3212*
Control variables				
CAP	−1.96E-03**	1.35E-04*	1.72E-04**	2.04E-03
	8.04E-04	*7.00E-0.5*	*6.13E-05*	*1.68E-04*
RDE	−3.98E-02	1.73E-04	3.62E-04*	2.04E-03*
	5.57E-02	*2.32E-04*	*2.36E-04*	*1.24E-03*
RDE^2	1.50E-03	−2.612E-08*	−2.71E-08**	−3.47E-07**
	1.81E-03	*1.39E-08*	*1.23E-08*	*1.49E-07*
KEI	0.4907*	0.3507	0.0102	0.2760
	0.3226	*0.3198*	*0.3946*	*0.3205*
Number of observations	27	63	29	61
Multiple R	0.9228	0.8627	0.9793	0.8189
R-squared	0.8516	0.7443	0.9415	0.6707
Adjusted R-squared	0.7589	0.6951	0.9090	0.6048
F-statistic	9.1855***	15.1349***	28.9582***	10.1852***
P-value	*6.6062E-05*	*3.5329E-12*	*4.6365E-09*	*4.5074E-09*

Standard errors are in italics. Standard errors are in italics. A&D, aerospace and defence; CAP, market capitalization; FIS, financial slack; INV, institutional investors' ownership; KEI, Knowledge Economy Index; RDE, research and development expenses; RDE^2, quadratic function of the RDE variable; TCA, technological complementary alliances; TSA, technological supplementary alliances; URI, universities and research institutes; VTA, industrial variety of technological alliances portfolio.
*$P < 0.10$.
**$P < 0.05$.
***$P < 0.01$.

sources of innovation (Cohen and Klepper, 1996), we test how technological alliances and financial resources in small and large firms may influence firms' patent activity in a different manner. We adopt a two-population approach, by constructing two separate subsamples. We consider the total number of employees and take 500 workers as threshold, consistent with analogous academic contributions (Perks, 2006). Model 5a focuses on small firms and Model 5b on large firms. For both subsamples, OLS regression models are highly significant (Model 5a: F-statistic = 9.1855, P-value < 0.001; Model 5b: F-statistic = 15.1349, P-value < 0.001).

The model concerning small firms (Model 5a) confirms the explanatory power of TSA and VTA as antecedents of a firm's innovative performance, whereas URI loses its significance. Contrary to Model 4, the coefficient of TCA is correctly signed respect to H1.2 and assumes a strong statistical significance (P-value < 0.01). The variables associated to financial resources (FIS and INV), instead, do not provide any statistical support. Concerning large firms, Model 5b shows that only TSA and URI are predictors of a firm's innovative performance among the variables related to technological alliances. Also, FIS and INV positively influence firms' patent activity. Although these results partially confirm the outcomes of Model 4, they suggest the opportunity to develop a more sophisticated conceptual framework capturing the existence of diverse external sources of innovations for small and large firms, respectively (see Section 5).

Second, as diverse industries are characterized by different technological regimes (Colombo et al., 2006), we remove any bias arising from sectorial differences by rerunning the regression analysis on two narrower subsamples of firms (Models 6a and 6b). Model 6a includes firms whose primary business is the A&D industry, whereas Model 6b focuses on other companies. Both models are highly significant (P-value < 0.001), and outcomes are partially in line with previous findings. Model 6a confirms that URI and VTA significantly contribute to foster the innovativeness of firms primarily operating in the A&D industry. Among financial variables, the role of institutional investors appears predominant respect to internal FIS. Conversely, TSA and FIS are critical predictors of firms' patent activity in other high-tech businesses, as demonstrated in Model 6b.

5. Academic and managerial implications

The results provide a number of valuable insights for scholars and practitioners. The manuscript adds to academic literature in different ways. First, the study explores a knowledge-intensive and technology-driven high-tech industry and addresses an under-researched area, i.e. the external sources of a firm's innovative performance by assessing the impact of technological alliances and financial resources on a firm's patent activity.

Empirical findings demonstrate that high-tech firms leverage on TSA to integrate similar resources, to generate innovation hard to develop internally (Das and Teng, 2000), and to codify new knowledge by registering additional patents. Grounding on technological commonalities, scale technological alliances facilitate high-tech firms in generating and exploiting new knowledge, and boost firm patent activity (Schilling and Phelps, 2007). Conversely, the outcomes related to technological alliances for complementary resources are not statistically significant for the whole sample. In high-tech industries, the combination of complementary resources is a dominant force that shapes the formation of exploitative commercial alliances (commercialization of new products) rather than explorative technological alliances devoted to realize new patents (Colombo et al., 2006). In this vein, some bias may originate from the operationalization of a firm's innovative performance applied in this study, i.e. the number of patents registered, which does not consider patent commercialization and new products development.

The outcomes of Models 2 and 4 validate the assumption that the industrial variety of the partners involved in innovation activities constitutes a more reliable predictor of patent activity in respect to the simple count of the technological link alliances (Jiang et al., 2010). In high-tech industries, firms are required to join heterogeneous networks of partners and resources to strengthen their innovative output (Schilling and Phelps, 2007). As breakthrough innovations are triggered by the combination of basic scientific principles with applied research and their translation into new patents, products, and processes (Klevorick et al., 1995), cooperation agreements with universities constitute an ideal source of specialist knowledge and exert a positive impact on a firm's patent activity (Belderbos et al., 2004).

Concerning financial resources, the models disclose mixed results. FIS is demonstrated to be a prerequisite for a successful patent activity in high-tech industries. Cash and receivables internally available facilitate the development of nonfinancial capabilities and the rapid acquisition of missing competences externally (George, 2005). Conversely, the presence of institutional investors has not been proved to be a key determinant of a firm's patent activity. This could derive from the measure of

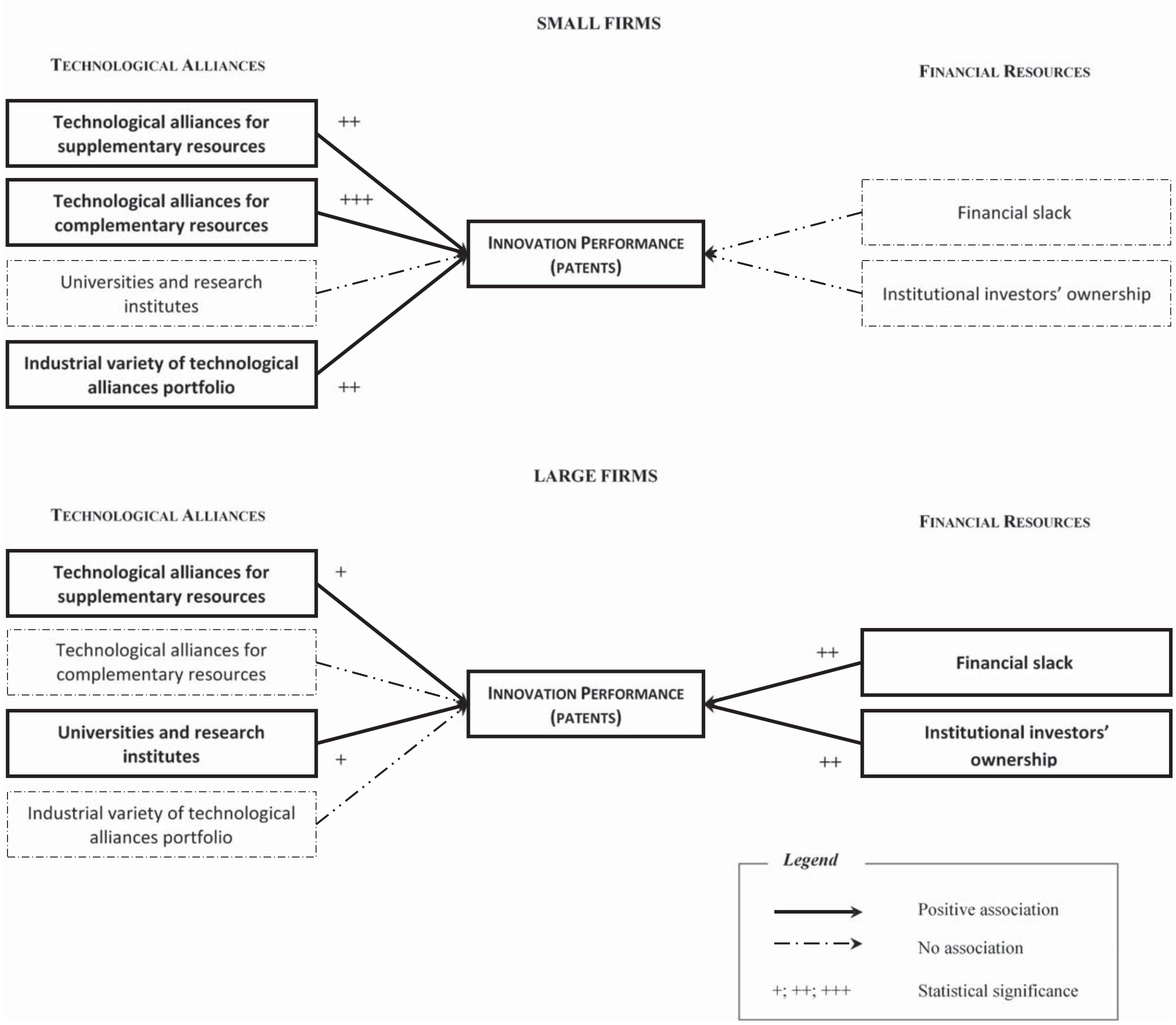

Figure 2. Technological alliances and financial resources as predictors of innovative performance: small vs large firms.
Sources: authors' own elaboration.

innovative performance selected in this study, i.e. the number of patents registered, which neglects the impact exerted by institutional investors in other phases of innovation, such as patent commercialization and new products development (Kochhar and David, 1996).

Second, the alternative specifications further add to extant literature, suggesting to develop a more advanced conceptual framework, able to capture the diverse explanatory role of external sources of innovative performance in small and large firms (Figure 2). The outcomes show that in high-tech industries, small firms strongly rely on technological alliances to boost their patent activity, whereas financial resources do not constitute a reliable predictor of innovative performance.

Commonly, small high-tech firms internally develop specialized core competencies and leverage on technological alliances to attain additional resources, reaching beyond their dimensional limits. By accessing supplementary and complementary external resources, small firms enlarge their stock of knowledge and manage technological convergence within R&D processes (Arranz and Fdes de Arroyabe, 2008). Finally, stretching the industrial diversity of their alliances portfolio, small firms find new opportunities to gather heterogeneous pools of resources and capabilities (Jiang et al., 2010).

Large firms present an articulated approach toward external sources of innovation, through the exploitation of both technological alliances and financial resources (Granstrand et al., 1992). Their patent activity is supported through the collection of exogenous supplementary resources and the resort to collaborative agreements with universities and research institutions as cheap external sources of knowledge (Belderbos et al., 2004). FIS and INV positively influence the patent activity of large firms. In high-tech industries, where large firms deal with expensive and time-consuming processes for patenting, the deployment of internal cash and receivables sustains innovation strategy (Kellog and Charnes, 2000). Nonspeculative institutional investors positively affect large firms' patent activity by supporting their investments in long-lasting innovative ventures and increasing managerial commitment toward innovation reducing career risks (Kochhar and David, 1996).

Third, the study provides a solid empirical base for further investigations, assessing the impact of technological alliances and financial resources on firms' patent activity.

Finally, an *ad hoc* synthetic index (VTA) is proposed to appreciate the industrial variety of the technological alliances portfolio. It provides a useful methodological tool for measuring the heterogeneity of resources shared by partners.

Empirical evidence gives a number of managerial implications for practitioners. High-tech firms are suggested to structure a mixed portfolio of technological alliances to foster innovative performance (Schilling and Phelps, 2007; Petruzzelli, 2011). A heterogeneous pool of knowledge and capabilities (VTA) is expected to support a firm's attitude to develop cutting-edge technological components and/or scientific know-how. Managers are invited to build-up wide networks of alliances involving companies that operate in diverse sectors, such as electronics, informatics, chemistry, etc. Alliance management capability, i.e. a firm's capacity to manage multiple alliances (Rothaermel and Deeds, 2006), is becoming a critical source of success in innovation activities for high-tech firms. Firms are requested to manage different types of partners and different combinations of knowledge. Trying to simultaneously manage a number of alliances, managers risk experiencing information-processing overload (Hitt et al., 1997). To handle this threat, managers are invited to establish a dedicated alliance function or to create an *ad hoc* organizational unit responsible for accumulating experience from prior alliances (Kale et al., 2002). This suggestion appears even more valuable for small high-tech ventures, as the VTA deeply affects their patent activity. Because small firms cope with resource constraints, available resources should be dedicated to create a specialized team for coordinating activities related to technological alliances. Both the establishment of a dedicated alliance function and the development of an *ad hoc* organizational unit/team are expected to support a firm's learning process and to boost the impact of technological alliances on a firm's innovative output.

High-tech firms moving along the technological frontier need to be prone to long-running formal and informal ties with leading universities and research institutes (Miotti and Sachwald, 2003). This type of alliances is notably characterized by high uncertainty and implies the transfer of tacit knowledge and noncodifiable know-how (Rothaermel and Deeds, 2006). Managers have to play attention in managing these technological alliances over time, from the selection of the partner to the decision of exiting or revitalizing the alliance. The way by which the alliance is managed becomes crucial for understanding its impact on firms' innovative output. Consequently, high-tech firms are invited to model their relationship with university partners by leveraging on various viable cooperative agreements in line with their objectives, including research support, cooperative research, knowledge transfer, and technology transfer (Elmuti et al., 2005).

In addition, empirical outcomes suggest managers to cautiously select R&D investments in high-tech businesses. After a certain threshold of R&D expenses, some diseconomies emerge because of the absorptive capacities associated with research activities and the positive effect on a firm's innovative performance declines (Griffith et al., 2004).

Managers are called to deploy FIS to gather additional nonfinancial capabilities and foster innovative performance (Patzelt et al., 2008). Accordingly, nonspeculative institutional investors should be more heavily involved in the high-tech firms' ownership structure, as they may provide firms with additional financial assets and managerial discretion.

6. Conclusion and limitations

The contribution develops and tests a conceptual framework for assessing external sources of innovative performance in high-tech industries. By simultaneously evaluating the explanatory role of technological alliances' dimensions and financial resources in fostering a firm's patent activity, the paper provides some original outcomes from a conceptual and methodological perspective.

Despite the valuable contribution provided, the manuscript presents some inherent limitations, requiring further investigations.

First, being innovative performance measured as the number of patents, the study neglects some alternative dimensions of breakthrough innovation (e.g., new products development). Patent activity differs in the diverse types of innovation, as in process innovation, and patenting tends to be lower than in product innovation (Cohen and Klepper, 1996;

Arundel and Kabla, 1998). Further contributions are called to validate our findings by introducing other proper dependent variables to measure innovative performance.

Second, empirical results may be affected by the operationalization of some independent variables. The measurement of resource-based constructs has been proven to be complex because of the lack of large sources of reliable primary data (Das and Teng, 2000).

Third, the study focuses on the A&D industry and provides insights on this valuable high-tech sector. Future studies are invited to extensively test the conceptual framework proposed on a larger scale to achieve further empirical validation. In this vein, other high-tech industries (e.g., biotechnology, telecommunication, etc.) that are experiencing fast trends of technological convergence and a pivotal role of alliances in shaping the success of business initiatives should be investigated. In addition, some bias in the outcomes may originate from the geographic coverage of the sample, which should be extended reaching beyond European Union (EU) borders, inserting North American and Asian firms.

Further studies are required to investigate the 'intervening variables' (e.g. how the alliance is managed) that might moderate the impact of technological alliances and financial resources on a firm's innovative output. Additional research is invited to theorize about financial resources' influence on the direct link between alliance type and innovative performance by investigating if the moderating role of FIS differs for supplementary versus complementary alliances.

Finally, scholars are encouraged to adopt a longitudinal perspective by monitoring the evolution of technological alliances over time in order to evaluate the development of interfirm ties in high-tech industries.

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