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HOW DO FIRMS ADAPT THEIR PORTFOLIOS OF EXTERNAL COLLABORATIONS TO CHANGING INTERNAL ORGANIZATIONAL ATTRIBUTES? THE MODERATING ROLE OF FIRM AGE

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Farid Mammadaliyev: Contextualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Original, Revision and editing, Viewing, Project management. **Victor Gilsing:** Contextualization, Methodology, Validation, Resources, Data curation, Revision and editing, Supervision, Obtaining funding. **Joris Knoben**: Contextualization, Methodology, Software. Validation, Data curation, Revision and editing, Supervision.

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Abstract

Objective of the study: Given the benefits of external collaborations in technology-intensive industries, we explore how firms adapt their portfolios of external collaborations to internal uncertainties. Using the behavioral theory of the firm, this study examines how firms adapt based on innovation performance feedback.

Methodology/approach: We built a panel dataset from three sources. Patent data came from The National Bureau of Economic Research (NBER) paper (Kogan, Papanikolaou, Seru, & Stoffman, 2017), which used extensive name-matching tools to link USPTO patents to firms. External collaborations data were collected from the SDC Platinum Joint Ventures and Alliances database, focusing on R&D agreements. Financial data were sourced from Compustat. After processing, the dataset included nearly 900 publicly listed firms from 12 high-tech industries (1990-2010). We tested our hypotheses using two probit models, each predicting a different dependent variable.

Originality/Relevance: We shift the focus from the traditional dyad perspective, which centers on individual partnerships, to how firms adjust their entire portfolios of external collaborations in response to their internal dynamics, like innovation performance feedback. While real options and transaction cost theories emphasize the need to maximize efficiency in individual partnerships, we explore how firms adapt their broader set of external collaborations to changing internal conditions.

Main results: We find that firms performing above innovation aspirations are more likely to form equity alliances (i.e., joint ventures). However, the magnitude of this effect greatly differs between mature and young firms. Young firms are about four times more likely than their mature counterparts to form equity alliances when they significantly surpass their innovation targets.

Theoretical/methodological contributions: Our study contributes to the research on alliance portfolio adaptation by showing that, beyond external factors like technological change and market uncertainty, firms also adjust their portfolios of external collaborations in response to internal factors, specifically innovation performance feedback. Moreover, our findings also demonstrate that firms' responses to innovation performance relative to aspirations vary based on their lifecycle stage.

Social /management contributions: Our study also has several implications for managers. First, managers of well-performing firms should view exceeding innovation aspirations as a signal to pursue collaborations to scale new technologies and knowledge. Their performance gives them a stronger negotiating position for forming joint ventures, allowing them to secure more favorable terms. Additionally, they should, in this case, seek partnerships to share risks associated with cutting-edge innovation projects rather than solely investing in internal innovation prospects. For young firms, which tend to respond more aggressively when outperforming their innovation aspirations, managers should adopt bold partnership strategies. In contrast, managers in mature firms should focus their resources on internal development, mergers and acquisitions, or partnerships that help maintain the autonomy of these firms.

Keywords: innovation performance, historical aspirations, technological knowledge, inter-firm collaborations,

¿Cómo adaptan las empresas sus carteras de colaboraciones externas a los cambios en los atributos organizativos internos? El papel moderador de la edad de la empresa

Resumen

Objetivo del estudio: Dados los beneficios de las colaboraciones externas en las industrias intensivas en tecnología, exploramos cómo las empresas adaptan sus carteras de colaboraciones externas a las incertidumbres internas. Utilizando la teoría conductista de la empresa, este estudio examina cómo se adaptan las empresas en función de la retroalimentación sobre el rendimiento de la innovación.

Metodología y enfoque: Construimos un conjunto de datos de panel a partir de tres fuentes. Los datos de patentes proceden del trabajo de The National Bureau of Economic Research (NBER) (Kogan, Papanikolaou, Seru, & Stoffman, 2017), que utilizó amplias herramientas de coincidencia de nombres para vincular las patentes de la USPTO con las empresas. Los datos sobre colaboraciones externas se obtuvieron de la base de datos SDC Platinum Joint Ventures and Alliances, centrándose en los acuerdos de I+D. Los datos financieros proceden de Compustat. Tras el procesamiento, el conjunto de datos incluía casi 900 empresas cotizadas en bolsa de 12 industrias de alta tecnología (1990-2010). Probamos nuestras hipótesis utilizando dos modelos probit, cada uno de los cuales predice una variable dependiente diferente.

Originalidad/Relevancia: Cambiamos el enfoque desde la perspectiva tradicional de la díada, que se centra en asociaciones individuales, a cómo las empresas ajustan toda su cartera de colaboraciones externas en respuesta a su dinámica interna, como la retroalimentación del rendimiento de la innovación. Mientras que las teorías de las opciones reales y los costes de transacción enfatizan la necesidad de maximizar la eficiencia en las asociaciones individuales, nosotros exploramos cómo las empresas adaptan su conjunto más amplio de colaboraciones externas a las cambiantes condiciones internas.

Principales resultados: Encontramos que las empresas con un rendimiento superior a sus aspiraciones de innovación son más propensas a formar alianzas de capital (es decir, empresas conjuntas). Sin embargo, la magnitud de este efecto difiere enormemente entre las empresas maduras y las jóvenes. Las empresas jóvenes tienen unas cuatro veces más probabilidades que sus homólogas maduras de formar alianzas de capital cuando superan significativamente sus objetivos de innovación.

Aportaciones teóricas y metodológicas: Nuestro estudio contribuye a la investigación sobre la adaptación de la cartera de alianzas al demostrar que, más allá de factores externos como el cambio tecnológico y la incertidumbre del mercado, las empresas también ajustan sus carteras de colaboraciones externas en respuesta a factores internos, concretamente a la retroalimentación sobre el rendimiento de la innovación. Además, nuestros resultados también demuestran que las

respuestas de las empresas a los resultados de la innovación en relación con sus aspiraciones varían en función de la fase del ciclo de vida en la que se encuentren.
Contribuciones sociales y de gestión: Nuestro estudio también tiene varias implicaciones para los directivos. En primer lugar, los directivos de las empresas que obtienen buenos resultados deberían considerar la superación de las aspiraciones de innovación como una señal para buscar colaboraciones a fin de ampliar nuevas tecnologías y conocimientos. Su rendimiento les da una posición negociadora más fuerte para formar empresas conjuntas, lo que les permite asegurar condiciones más favorables. Además, en este caso, deberían buscar asociaciones para compartir los riesgos asociados a los proyectos de innovación de vanguardia en lugar de invertir únicamente en las perspectivas de innovación.

Palabras clave: desempeño de innovación, aspiraciones históricas, conocimiento tecnológico, colaboraciones entre empresas.

Como é que as empresas adaptam as suas carteiras de colaborações externas às alterações dos atributos organizacionais internos? O papel moderador da idade da empresa

Resumo

Objetivo do estudo: Tendo em conta os benefícios das colaborações externas em indústrias de tecnologia intensiva, exploramos a forma como as empresas adaptam as suas carteiras de colaborações externas às incertezas internas. Usando a teoria comportamental da empresa, este estudo examina como as empresas se adaptam com base no feedback do desempenho da inovação.
Metodologia/abordagem: Construímos um conjunto de dados de painel a partir de três fontes. Os dados de patentes vieram do artigo do National Bureau of Economic Research (NBER) (Kogan, Papanikolaou, Seru, & Stoffman, 2017), que usou ferramentas extensivas de correspondência de nomes para vincular patentes USPTO a empresas. Os dados sobre colaborações externas foram recolhidos da base de dados SDC Platinum Joint Ventures and Alliances, com foco em acordos de I&D. Os dados financeiros foram obtidos da Compustat. Após o processamento, o conjunto de dados incluiu cerca de 900 empresas cotadas em bolsa de 12 sectores de alta tecnologia (1990-2010). Testámos as nossas hipóteses utilizando dois modelos probit, cada um prevendo uma variável dependente diferente.
Originalidade/Relevância: Mudamos o foco da perspetiva tradicional da díade, que se centra em parcerias individuais, para a forma como as empresas ajustam todo o seu portefólio de colaborações externas em resposta à sua dinâmica interna, como o feedback do desempenho da inovação. Enquanto as teorias das opções reais e dos custos de transação enfatizam a necessidade de maximizar a eficiência em parcerias individuais, exploramos a forma como as empresas adaptam o seu conjunto mais vasto de colaborações externas às condições internas em mudança.
Principais resultados: Concluímos que as empresas com um desempenho acima das aspirações de inovação têm maior probabilidade de formar alianças de capital (ou seja, joint ventures). No entanto, a magnitude deste efeito é muito diferente entre empresas maduras e jovens. As empresas

jovens têm cerca de quatro vezes mais probabilidades do que as suas congéneres maduras de formar alianças de capital quando ultrapassam significativamente os seus objectivos de inovação. **Contributos teóricos/metodológicos:** O nosso estudo contribui para a investigação sobre a adaptação da carteira de alianças ao mostrar que, para além de factores externos como a mudança tecnológica e a incerteza do mercado, as empresas também ajustam as suas carteiras de colaborações externas em resposta a factores internos, especificamente o feedback do desempenho da inovação. Além disso, os nossos resultados também demonstram que as respostas das empresas ao desempenho da inovação em relação às aspirações variam consoante a fase do seu ciclo de vida. **Contributos sociais / de gestão:** O nosso estudo também tem várias implicações para os gestores. Em primeiro lugar, os gestores de empresas com bom desempenho devem encarar o facto de excederem as aspirações de inovação como um sinal para procurarem colaborações para expandir novas tecnologias e conhecimentos. O seu desempenho dá-lhes uma posição de negociação mais forte para a formação de joint ventures, permitindo-lhes garantir condições mais favoráveis. Além disso, devem, neste caso, procurar parcerias para partilhar os riscos associados a projectos de inovação de ponta, em vez de investirem apenas em perspectivas de inovação interna. Para as empresas jovens, que tendem a responder de forma mais agressiva quando ultrapassam as suas aspirações de inovação, os gestores devem adotar estratégias de parceria arrojadas. Em contrapartida, os gestores de empresas maduras devem concentrar os seus recursos no desenvolvimento interno, em fusões e aquisições ou em parcerias que ajudem a manter a autonomia dessas empresas.

Palavras-chave: desempenho da inovação, aspirações históricas, conhecimento tecnológico, colaborações entre empresas.

Introduction

In technology-driven industries, external collaborations are common as they enhance innovation (Van de Vrande, 2013). These collaborations help firms gain capabilities that would require time and substantial resources to develop alone (Ahuja, 2000a). By co-developing and in-sourcing external technology, firms can share knowledge, combine skills, achieve economies of scale in research, and share costs and risks (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008; Phelps, 2010; Sabidussi et al., 2014).Research shows that collaboration in technology-intensive industries boosts innovation, which is key for survival (Bos, Faems, & Noseleit, 2017; Hoehn-Weiss, Karim, & Lee, 2017; Lungeanu, Stern, & Zajac, 2016; Van de Vrande, 2013). However, firms must constantly adapt and reconfigure their external collaborations

to keep them beneficial (de Leeuw, Gilsing, & Duysters, 2019). This leads to a broader debate on continuous organizational adaptation (T. Kim & Rhee, 2017). Powell, White, Koput, and Owen-Smith (2005) argue that social, technological, or economic changes push firms to adjust their external collaborations. The newly emerging literature now focuses on how firms adapt their portfolios of these partnerships to external uncertainties, such as technological change (e.g., de Leeuw et al., 2019) or market uncertainty (Beckman, Haunschild, & Phillips, 2004; Ozcan, 2018). Given the benefits of external collaborations in technology-intensive industries, the question remains whether firms also adapt their portfolios of external collaborations to internal uncertainties (Posen, Keil, Kim, & Meissner, 2018). This study addresses that issue.In particular, we rely on the behavioral theory of the firm to examine how firms adjust their portfolios of external collaborations in response to their innovation performance feedback. The rationale behind this is that top managers are viewed as boundedly rational, and thus they base strategic choices on their imperfect anticipation of consequences of future events (Gavetti, Greve, Levinthal, & Ocasio, 2012). Therefore, top managers' evaluation of innovation performance might affect their decisions about alliance formation. Our approach aligns with prior studies by acknowledging that firms adjust their external partnerships based on internal uncertainties, specifically innovation performance feedback (Beckman et al., 2004; Kotiloglu, Chen, & Lechler, 2021). At the same time, our study also diverges from earlier research and makes a significant contribution to this stream of literature.

Our first major contribution is that building upon the behavioral theory of the firm, we define the conditions under which a firm prefers equity or non-equity alliances to include in its alliance portfolio. Previous studies within this tradition have shown that firms' innovation performance relative to their aspirations influences partner and resource diversity in their external collaboration portfolios (Kavusan & Frankort, 2019; Lungeanu et al., 2016; Martínez-Noya & García-Canal, 2021). However, although these studies have advanced our understanding of how firms adapt partner and resource diversity in their portfolios of external collaborations, the question as to why firms prioritize certain types of collaborations in response to their innovation performance feedback remains unanswered. In this study, we address this question by considering risk-taking of firms depending on their innovation performance relative to aspirations and unique characteristics of different types of collaborations. Our second contribution is that we examine the moderating role of firm age in the relationship between

innovation performance feedback and a firm's adaptive behavior. Previous studies have primarily focused on R&D based-measures to explain the heterogeneity in firms' responses to innovation performance feedback, overlooking other internal dynamics that might encapsulate valuable insights (Kotiloglu et al., 2021; Martínez-Noya & García-Canal, 2021). According to organizational theory, a firm's stage in the lifecycle determines the extent to which it maintains the status-quo and builds on its previous innovative activities (Coad, Segarra, & Teruel, 2016; Sørensen & Stuart, 2000). In this study, we address this gap by examining the role of firm age to understand why firms respond heterogeneously to innovation performance feedback.Using a panel dataset of around 900 publicly listed firms from 12 high-tech industries over the period of 1990-2010, we find that performing above innovation aspirations increases the likelihood of forming equity alliances (i.e., joint ventures). However, older firms are less likely to form these alliances when they exceed their innovation goals. We do not find any significant impact on alliance formation when firms fall short of their innovation performance goals.

Theory and Hypotheses

Firms' adaptation of their portfolios of external collaborations

Traditionally, few theories have dominated in explaining how firms adapt their portfolios of external collaborations to changing conditions (Parmigiani & Rivera-Santos, 2011). At the forefront of these theories, real options and transaction cost theories present effective arguments and empirical methodologies for selecting collaboration modes from the perspective of environmental uncertainty and cost efficiency, respectively (Grant & Baden-Fuller, 2004; Van de Vrande, Vanhaverbeke, & Duysters, 2009).

Real options theory

Real options theory has generated a number of predictions regarding the potential value associated with investments. The core idea of the theory is that organizational decisions may create value through the option to defer or delay irreversible investment, also called as "option of waiting" (Leiblein, 2003). This option refers to firms' willingness to maintain their flexibility in making collaboration mode choices under high levels of environmental uncertainty and creates value for them until new information is available to make more sophisticated decisions. Firms that are

willing to avoid the risk of committing irreversible resources to an alliance require flexibility since the future expected value of this investment is uncertain in a dynamic environment (Pateli, 2009). Thus, the central premise of the real options theory is that in the presence of high uncertainty about the future success of the investment, firms prefer less hierarchy-like modes (i.e., non-equity alliances) of external collaboration in their portfolios to assure flexibility and avoid sunk cost of irreversible commitments (Pateli, 2009; Santoro & McGill, 2005).

Transaction cost economics

To date, several authors have studied the selection of a mode of external collaboration from the transaction costs perspective (Chen & Chen, 2003; Geyskens, Steenkamp, & Kumar, 2006; Leiblein & Miller, 2003; Pateli, 2009). The theory argues that when relevant contingencies surrounding an exchange are too unpredictable to be specified ex ante in a contract, environmental uncertainty arises (Geyskens et al., 2006). Uncertainty causes market failure when contractual renegotiation takes place in the presence of transaction-specific assets (Leiblein, 2003; Leiblein & Miller, 2003). Therefore, firms prefer hierarchy-like modes to market-like ones. However, uncertainty without transaction-specific assets still favors market-like modes of collaboration since potential transaction partners are numerous, and thus a new transaction can be easily arranged at low costs if necessary (Geyskens et al., 2006; Williamson, 1975). Thus, from a transactional perspective, the effect of uncertainty on a collaboration mode choice is conditional on asset specificity. Consequently, TCE argues that firms' adaptation of their external collaboration portfolios depends on three factors: uncertainty, asset specificity, and transaction frequency.

The limitations of existing theories

Although studies in real options and transaction cost literature have advanced our understanding of how firms choose different types of external collaborations based on changing conditions, they appear less well-equipped to examine firms' adaptation of their portfolios of external collaborations. Real options theory examines which mode of collaboration is optimal to cooperate with a prospective partner under environmental uncertainty (Van de Vrande et al., 2009). Similarly, TCE focuses on maximizing efficiency in an individual transaction or partnership rather than maximizing the joint efficiency of a set of transactions or partnerships (de Leeuw et al., 2019). Previous studies in TCE have examined the external conditions under which a firm prefers one

particular collaboration form to another with a prospective partner (e.g., Gulati, 1995; Santoro & McGill, 2005; Van de Vrande et al., 2009; Villalonga & McGahan, 2005). However, we consider the fact that firms often rely on a combination of external collaborations (Carayannopoulos & Auster, 2010; Keil, Maula, Schildt, & Zahra, 2008). This implies that we should move beyond the dyad perspective, which has been dominant in the literature until now (de Leeuw et al., 2019; Hoehn-Weiss et al., 2017). Consequently, we contribute to the research on adaptation by considering the behavioral antecedents that lead firms to prioritize a certain type of external collaboration. Our research question diverges from previous studies within this tradition that have primarily focused on diversity in firms' portfolios of external collaborations (Kavusan & Frankort, 2019; Martínez-Noya & García-Canal, 2021).

Innovation performance aspirations

We draw upon the behavioral theory of the firm (Cyert & March, 1963; Gavetti et al., 2012) to explain how firms choose certain modes of external collaboration. Firms have goals and expectations that form their aspirations (Lungeanu et al., 2016; Martínez-Noya & García-Canal, 2021). Greve (2003) concludes that performance relative to aspiration levels appears to serve as a "master switch" that affects a firm's willingness to take risks in many organizational behaviors (Baum, Rowley, Shipilov, & Chuang, 2005). This reference point, described as "psychologically neutral" (Kameda & Davis, 1990, p. 56), comes from a decision maker's attempt to simplify performance evaluation by turning it into a clear and discrete measure of success or failure (Greve, 1998). We argue that deviation from these aspiration levels motivates firms to prioritize a certain mode to add to their portfolios of external collaborations.

The behavioral theory of the firm explicitly implies that organizations learn from their past performance and use that knowledge to shape their future strategies (Levitt & March, 1988). Referring to this phenomena, Cyert and March (1963, p. 123) posited that "… organizations exhibit (as do other social institutions) adaptive behaviors over time." However, depending on the difference between the outcomes and aspirations set for those outcomes, a focal unit's adaptive behavior can vary (Levitt & March, 1988). A firm compares its actual performance against two benchmarks: historical aspirations – which compare its current performance to its past and social aspirations – which compare its performance to similar organizations (Baum et al., 2005; Joseph & Gaba, 2015; Moliterno, Beck, Beckman, & Meyer, 2014). The motivation to change the

behavior depends on how far its current performance is from these aspirations (Greve, 1998).Organizations have many goals to achieve (Ethiraj & Levinthal, 2009; Gavetti et al., 2012; Greve, 2008), but most research in the behavioral theory of the firm has primarily looked at financial performance goals to explain why firms partner with others (Audia, Locke, & Smith, 2000; Greve, 2003). Recent studies indicate that firms in science-based industries are more likely to adjust their strategic maneuvers based on how their innovation performance compares to their aspirations (Eggers & Kaul, 2018; Lungeanu et al., 2016). This is because general performance measures, like return on assets, lack specificity (Gaba & Bhattacharya, 2012). Thus, we argue that firms consider the difference between their current innovation performance and aspiration levels set for that performance when choosing different collaboration modes to add to their portfolios.

Firms' adaptation to changing levels of innovation performance

The behavioral theory of the firm has been long used to explore risk preferences (e.g., March & Shapira, 1987) and how organizations search for opportunities (e.g., Levinthal & March, 1981). Drawing upon the behavioral theory of the firm, our contention is that a firm's motivation to choose a certain mode of collaboration depends on how its current innovation performance compares to its set goals (Lungeanu et al., 2016). Specifically, we assume that a firm's aspirations are shaped by comparing itself to similar firms and its own past performance (Baum & Dahlin, 2007; Eggers & Kaul, 2018; Greve, 1998). Moreover, we focus on innovation aspirations and performance because, in high-tech industries, financial goals provide little insight into future success (Lungeanu et al., 2016).

Adaptation when performing below aspirations

Firms often start with less integrated partnerships, like non-equity alliances, to test the waters before committing fully (Das & Rahman, 2010). These alliances create pressure to generate quick results, and if things don't go well, firms or their partners may act selfishly to protect themselves (Das & Rahman, 2010). This can include, but is not limited to, breaking agreements and promises, or withholding resources (Das & Rahman, 2010). Since these partnerships are not equipped with sophisticated monitoring and control mechanisms to punish the misbehavior of a partner, they come with higher risks (Van de Vrande et al., 2009). Firms performing below their innovation goals are more likely to take on these risky solutions (Greve, 2003).

Eggers and Kaul (2018) suggest that when a firm's innovation performance falls below expectations, it may perceive that its existing strategies and knowledge are not enough to achieve desired results, prompting it to explore new solutions. When performance is below target, a firm shifts its potential gains (Greve, 2003; Kahneman & Tversky, 2013). Less integrated modes of collaboration offer flexibility, allowing a firm to try multiple options and quickly withdraw if outcomes are not promising (Van de Vrande et al., 2009).

Poorly-performing firms often lack necessary resources to develop technology internally and compete effectively with their closest rivals. Therefore, they turn to collaborations to source external knowledge and overcome their deficiency (Ahuja, 2000b). However, these firms may not be attractive to potential partners in the market because they don't offer much value. As a result, other firms may hesitate to form costly and deeply integrated partnerships, like joint ventures, with them. To form a collaboration depends on not only a firm's desire, but also its attractiveness to potential partners (Ahuja, 2000b). In this case, collaborating through less integrated, flexible modes might be more appealing to both parties. In this way, the partner is not required to invest large, non-recoverable resources, and the poorly-performing firm can access external knowledge to boost its innovation. This is a "win-win" situation: the struggling firm gains external knowledge to supplement its internal R&D, while its partner experiments without making a big financial commitment. Considering all above-mentioned arguments, we state the following:

H1: Firms performing below innovation aspiration levels are more likely to collaborate through less integrated modes of collaboration (i.e., non-equity alliances) in their organizational adaptation.

Adaptation when performing above aspirations

Firms performing above aspiration levels react to performance feedback differently (Greve, 2003). They tend to satisfice, believing that their current strategies are sufficient (Eggers & Kaul, 2018). Since they rely on their existing strengths and routines, these firms are less concerned about the future and less likely to seek out new, experimental opportunities.

Firms performing above aspiration levels possess two types of valuable knowledge: tacit knowledge, which is deeply rooted in their social context, and codified knowledge, such as patents, copyrights, licenses, design models, and software (Denicolai, Ramirez, & Tidd, 2014). These two

types of knowledge are more at risk if a partner behaves opportunistically. As a result, these firms are more concerned with preserving their knowledge from their partners. More integrated collaborations, like joint ventures, provide a secure platform with strong controls to prevent partner misbehavior. More integrated modes of collaboration prohibit free-ridership as they offer several monitoring tools to reveal and sanction the misbehavior of a partner. Villalonga and McGahan (2005) argue that firms choose these secure partnerships when their technological knowledge capital is highly valuable. For well-performing firms, the real risk is not the cost of the collaboration, but the potential loss of valuable knowledge they have accumulated over time.Forming joint ventures with well-performing firms benefits both parties. These collaborations allow firms to share each other's technological knowledge, with strong monitoring tools in place to ensure mutual consent to the exchange. These tools do not limit the transfer of knowledge, but help firms control what they want to share and protect their valuable tacit and codified knowledge. Well-performing firms are attractive parties because they not only safeguard their knowledge but also have more to share with their partners. Therefore, we predict that firms exceeding their innovation aspirations are more likely to collaborate through less risky partnerships. Thus, we propose:

H2: Firms performing above innovation aspiration levels are more likely to collaborate through more integrated modes of collaboration (i.e., joint ventures) in their organizational adaptation.

The moderating role of firm internal characteristics

In today's fast changing world, especially in high-tech industries, firms constantly look for ways to gain or maintain a competitive edge by forming alliances. While a firm's innovation performance relative to its innovation aspirations is a critical factor in forming alliances, other external (e.g., industry characteristics, geographical proximity, environmental turbulence) and internal factors (e.g., firm size, organizational culture, leadership, and management) also play a role in this complex process. Research has shown that external factors are key in understanding a firm's alliance formation behavior because they can limit how a business operates. For example, Molina-Morales, García-Villaverde, and Parra-Requena (2014) have found that an excess of geographical proximity produces spatial lock-in, restricting a firm's capabilities to access new knowledge. This suggests that firms near each other might approach alliances differently compared

to those farther apart. In the similar vein, Ferreira, Fernandes, and Raposo (2017) have argued that a firm's distance from urban centers impacts its ability to find innovative solutions. Firms located far apart from urban areas might be more eager to form alliances than those closer to cities. Lastly, de Leeuw et al. (2019) have found that firms strategically adjust their innovation search processes in response to technological shifts within their business environments by optimizing their portfolios of interorganizational relations.Internal factors are also important in alliance formation because they reflect a firm's internal dynamics. For example, larger firms might face bureaucratic hurdles that make them slower to react to new opportunities for innovation (Kijkasiwat & Phuensane, 2020). Additionally, internal factors, such as CEO characteristics and management practices, are critical to a firm's pursuit of competitive advantage. CEOs with a focus on research (van de Wal, Boone, Gilsing, & Walrave, 2020) and management practices that encourage open communication and collaborative decision-making (Singh, Gupta, Busso, & Kamboj, 2021) facilitate a firm's search for innovative solutions.

Firm age as a moderator

While the factors mentioned earlier offer valuable insights into the link between innovation performance relative to aspirations and alliance formation, firm age stands out as a particularly influential driver. Unlike other factors, firm age encapsulates a range of several dynamic attributes that change over time. Firm age is a unique moderator in this relationship because it inherently captures a firm's evolution over time, affecting its resources, risk tolerance, reputation, learning capabilities. As firms age, they undergo significant transformations that shape their strategic behaviors, including how they approach alliances. This dimension of firm age provides a comprehensive "black box", continuously recording the challenges a firm has faced, helping explain the interplay between innovation performance relative to aspirations and alliance formation.

According to the systematic review of Coad, Holm, Krafft, and Quatraro (2018), firm age has gained enormous momentum and visibility in the top economics and management journals. In JSTOR, the term "firm age" appeared 214 times in the 1980s, rising to 1,237 mentions in the period between 2010 and 2017. Firm age opens new research opportunities, particularly in studying innovation and interfirm collaborations within high-tech industries, as being new in these industries poses unique opportunities and challenges. Recent studies highlight firm age as key to

understanding innovation, showing that firms born after major industry shifts, such as massive exits or technological turbulence, behave differently from those that lived through these changes (Coad, 2018; Coad et al., 2018; Leyva-De la Hiz & Bolívar-Ramos, 2022). Firms established in post-disruption environments are better positioned to capitalize new market conditions, whereas incumbent firms have to undertake costly restructuring (De Massis, Audretsch, Uhlaner, & Kammerlander, 2018). On the other hand, being a new comer might also pose some challenges if they develop bad habits or inefficient routines that hinder growth (Coad, 2018).In management literature, four key areas explain how firm age influences a firm's behavior in seeking innovative solutions through alliances: resource accumulation and utilization, risk tolerance and strategic orientation, reputation and credibility, and learning and adaptation.

- *Resource accumulation and utilization.* According to Cucculelli (2018), aging simply implies that firms gather more resources and capabilities over time, and firms at different stages of their lifecycle might commit varying amounts of resources to subsequent innovation activities (Belitski, Stettler, Wales, & Martin, 2023; Coad et al., 2016).

- *Risk tolerance and strategic orientation.* Firm age plays a role in shaping risk tolerance and entrepreneurial spirit (Berman, Cano-Kollmann, & Mudambi, 2022; Kücher, Mayr, Mitter, Duller, & Feldbauer-Durstmüller, 2020). As a result, firms of different ages might adopt various strategies for forming alliances, depending on how quickly they need to access new technologies, market, and expertise. In high-tech industries, risk mitigation and cost-sharing are often the main motives for entering alliances (Dhaundiyal & Coughlan, 2020), emphasizing the importance of risk tolerance.

- *Reputation and credibility.* Firms build reputation and credibility over time, which enhances their access to key resources (Coad et al., 2018). For example, mature firms are often viewed as more credible, making them attractive partners for alliances and improving growth prospects. The rationale is that mature firms have already proven themselves to other market players.

- *Learning and adaptation.* Firm age reflects a firm's learning and adaptability, capturing insights from experience. Firms develop knowledge and internal routines that guide their future actions (Argote, Lee, & Park, 2021). As they mature, they adjust to shifts in their

business environments to better align with external demands. However, their adaptability varies across lifecycle stages (Sarta, Durand, & Vergne, 2021; Zhang, You, Tang, & Wen, 2023). Thus, firm age offers valuable insights into a firm's learning and adaptability, aiding our understanding of its behavior in alliance formation.

The studies discussed above underscore the significance of firm age in understanding alliance formation. Neglecting firm age in this research risks missing essential dynamics that affect how firms in high-tech industries form alliances. In the next section, we present findings and hypothesize that young and mature firms might exhibit distinct patterns in alliance formation, particularly in response to innovation performance relative to aspirations.

Hypothesizing the moderating role of firm age

The role of firm age when firms perform below aspirations

We argue that firm age affects the influence of innovation performance feedback on a firm's adaptation behavior. As firms develop specific routines, competencies, and norms over time, R&D and resource allocation processes become increasingly routinized and thus difficult to change (Kapoor & Klueter, 2015). Previous studies have argued that old firms' search for new technological knowledge is therefore limited by their own imprinted processes, cultures, and capabilities (e.g., Sørensen & Stuart, 2000). Organizational learning theories suggest that firms may become less likely to change as they age because they accumulate competence and experience in a particular domain of activity. In one paper, Huergo and Jaumandreu (2004) argue that older firms tend to show lower probabilities of introducing new innovations. In mature firms, organizational routines and actions are path dependent. Routines that are related to success are repeated, while those related to failure are abandoned or adjusted (Ahuja & Lampert, 2001). This ensures that in mature firms, routines are concentrated on very specific outcomes. In a similar vein, Chiu, Chi, Chang, and Chen (2016) argue that established firms usually cannot achieve their innovation goals due to their existing organizational inertia, which can be categorized into three types: bounded searching, insufficient planning and risk-taking, and improper structures and systems. As the bounded rationality of top managers is the central premise in the behavioral theory of the firm (Gavetti et al., 2012), it is important to understand how they react differently to innovation performance feedback when faced with organizational inertia.Top managers in mature

firms might be more reluctant to collaborate via non-equity alliances (i.e., strategic alliances) for the following reasons. Firstly, in mature firms R&D activities are not exploratory, but rather more incremental and developmental (Akcigit & Kerr, 2018; Segarra & Teruel, 2014). Therefore, in case of innovation performance shortfalls, top managers are bounded to certain activities in their search that are not so deviant from their firms' existing routines. In other words, mature firms are less responsive to innovation failure, which impedes their ability to explore new problem-solving approaches (Khanna, Guler, & Nerkar, 2016; J. Kim, 2021). For example, in mature firms decisions to explore new alternative opportunities beyond their existing routines are regarded as risky (Desai, 2008; Hillmann & Guenther, 2021). Secondly, mature firms are argued to have experience and enough market awareness to identify likely failure projects (Coad et al., 2016). Thus, their managers tend to carefully filter market opportunities on the horizon to replenish their firms' innovation performance, engaging only in R&D activities (i.e., strategic alliances) with high potential for expected returns. However, Barron, West, and Hannan (1994) argue that "young firms may benefit from 'a fresh perspective' and spot new market opportunities without being hindered by liabilities of inertia and obsolescence" (Coad et al., 2016, p. 389). These arguments imply that mature firms that fall short of their innovation aspirations are less likely to source new technological knowledge through less integrated modes of collaboration, which are considered riskier.

H3: The positive relationship between below innovation performance aspirations and the likelihood of engaging in less integrated modes of collaboration (i.e., non-equity alliances) will be weakened as a firm gets older.

The role of firm age when firms perform above aspirations

On the other hand, we argue that mature firms that perform above their innovation aspirations are more likely to increase their engagement in more integrated modes of collaboration (i.e., joint ventures). These modes of collaboration are seen as less risky for technological knowledge leakage, and decision-makers prefer them due to the protective mechanisms they offer. The rationale behind this is that top decision-makers rely on the monitoring mechanisms of such collaboration modes that can protect their firms' technological knowledge from any misbehavior. When mature firms exceed their innovation aspirations, their top managers gain confidence

(Martínez-Noya & García-Canal, 2021), but tend to stay within core areas (Hillmann & Guenther, 2021; Khanna et al., 2016). Therefore, they increase their engagement in previously tested modes of collaboration, namely more integrated modes (i.e., joint ventures), to access additional resources at lower costs and risks. Previous studies have argued that this conservatism might even cannibalize mature firms' market share in the long-term (Coad et al., 2016). Additionally, managers in well-performing mature firms have a strong interest in increasing their engagement in more integrated modes of collaboration (i.e., joint ventures) to maintain technical quality (Balasubramanian & Lee, 2008), which is vital for survival in tech-intensive industries (Lungeanu et al., 2016). Therefore, we hypothesize the following:

H4: The positive relationship between above innovation performance aspirations and the likelihood of engaging in more integrated modes of collaboration (i.e., joint ventures) will be strengthened as a firm gets older.

Methods

Sample

In patent studies, management scholars have deployed different sampling approaches to test theoretical arguments. Eggers and Kaul (2018) test their hypothesis in a broad, cross-firm, and cross-industry sample of patents that includes all patents filed in the United States Patent and Trademark Office (USPTO). Similarly, Schilling and Phelps (2007) constructed a large, unbalanced panel of U.S. firms that were part of the alliance networks of 11 high-technology manufacturing industries to test the effect of inter-firm collaborations on firm innovation. Keil et al. (2008) analyze data from publicly traded firms with the revenue above $200 million in 4 ICT industries. Following these studies, we also constructed a large, cross-firm, and cross-industry sample of Compustat firms for the period of 1990-2010 across 12 high-technological industries: aerospace equipment (standard industrial classification code (SIC): 3721, 3724, 3728, 3761, 3764, 3769), automotive bodies and parts (3711, 3713, 3714), chemicals (281-, 282-, 284-, 285-, 286-, 287-, 288-, 289-), computer and office equipment (357-), household audiovisual equipment (3651), medical equipment (3841, 3842, 3843, 3844, 3845), petroleum refining and products (2911, 2951, 2952, 2992, 2999), pharmaceuticals (2833, 2834, 2835, 2836), telecommunications equipment (366-), measuring and controlling devices (382-), electronic components and accessories (367-), computer programming, data processing and other computer related services

(737-). In these industries, firms actively patent their inventions and use alliances in pursuit of their innovation activities (Martínez-Noya & García-Canal, 2021; Schilling & Phelps, 2007).

Data

We used multiple sources in the data collection. Data on firms' external collaborations were collected from the SDC Platinum Joint Ventures and Alliances database. SDC tracks a very wide range of agreement types, including research & development agreements, sales and marketing agreements, banking agreements, manufacturing agreements, supply chain agreements, property development agreements, software development agreements, and licensing pacts (Schilling, 2009). SDC also covers agreements between universities, government organizations, privately held firms, or any combination thereof. However, we excluded agreements involving government organizations[1]. Following prior studies, we retained only those agreements in which technology development or technology sharing was one of the objectives of the alliance (Boone, Lokshin, Guenter, & Belderbos, 2019; de Leeuw et al., 2019; Lungeanu et al., 2016). The problem here is that there is no straightforward approach to define R&D-based contracts in SDC database. Therefore, we developed a new approach to capture the majority of agreements that were aimed at improving or sharing a new technology.

Activity column in SDC reports the objectives of each alliance. The most common alliance objectives are R&D services, manufacturing services, marketing services, licensing services, and supply services. We retained those agreements whose at least one objective was R&D services. However, we did not solely rely on R&D services flag to define R&D-based alliances. Instead, we combined these outcomes with a keyword search. Our initial keyword search included such words/combinations as "development", "improvement", "research", "cross-technology transfer", "cross-technology licensing", "research and development", and "explore". The results showed that these keywords effectively detected the agreements with the purpose of technological knowledge transfer. Nevertheless, we needed to review random selections of the matches based on these keywords and manually exclude false positives. Given the fact that our initial database of all

[1] By so doing, we kept our sample homogeneous because governmental organizations as partners are often characterized by the political nature of their actions (Rangan, Samii, & Van Wassenhove, 2006). In order words, this helped us to keep those alliances in the final sample that were more likely to aim at developing new technologies rather than pursuing political interests.

agreements was huge (nearly 200 thousand agreements), we could not deal with true negatives. This is due to the fact that a true negative observation required us to read its description and decide whether it contained elements of technological knowledge transfer.

We extracted patent data from The National Bureau of Economic Research (NBER) paper (Kogan et al., 2017) in which the authors used extensive name-matching tools to assign USPTO patents to focal firms. However, these firms were classified by a "permno" identifier. Thus, we employed a CRSP/Compustat merged database (linking table) to obtain global identifiers, specifically gvkey and cusip, for each patent. Consequently, we matched our sample firms to their joint venture and alliance data from SDC, their patent data from NBER database and their financial data from Compustat using gvkey and/or cusip.

Dependent variables

We operationalized the dependent variables in a two-step process. First, we calculated the number of non-equity alliances and joint ventures a firm made each year (Van de Vrande, 2013; Van de Vrande et al., 2009). Second, we constructed a non-equity alliance dummy which took 1 if a firm engaged in 1 or more non-equity alliances in a given year, 0 otherwise to test H1. For H2, we created a joint venture dummy which took 1 if a firm formed 1 or more joint ventures in a given year, 0 otherwise. SDC database collects data from the U.S. Security and Exchange Commission (SEC) fillings (and their international counterparts), trade publications, wires and news sources (Schilling, 2009). Therefore, we assumed that a firm did not engage in any alliance activity if there was no record. This assumption set both dependent variables to 0 for unobserved years.

Independent variables

We measured innovation performance as the number of patents granted to a firm or its subsidiaries in a given year (Keil et al., 2008; Lungeanu et al., 2016; Schilling & Phelps, 2007). Following Boone et al. (2019), we used the patent application date as the first indication of inventions. As the protection of technological knowledge has become difficult in high-technological industries, firms tend to patent their inventions (Cohen, Nelson, & Walsh, 2000; van de Wal et al., 2020). Therefore, patent count is a very good and widely used proxy for measuring innovation performance despite its drawbacks (Lungeanu et al., 2016) and has been also used in

the most recent innovation aspiration studies (Kavusan & Frankort, 2019; Martínez-Noya & García-Canal, 2021).

Innovation performance is generally evaluated against two types of aspiration levels: a firm's prior performance (historical aspirations) and performance of similar firms in the industry (social aspirations). The behavioral theory of the firm asserts that the recent performance of comparable firms is a benchmark for a firm. However, the question to which reference group a firm compares its current performance remains unanswered. According to Shapira (2017), a focal firm might choose different reference groups based on size, technology, or strategy, or even compare itself to subgroups in other industries. In general, researchers have faced difficulties in determining an appropriate social reference group (Greve, 2008; Kacperczyk, Beckman, & Moliterno, 2015; Kuusela, Keil, & Maula, 2017). Moreover, managers seldom have two aspiration levels for the same goal (Bromiley & Harris, 2014). Therefore, following Shapira (2017), Tyler and Caner (2016), and Vidal and Mitchell (2015), in this study we focus on comparing a firm performance with its own performance history[2].

There are two widespread approaches to calculate historical aspiration levels. Some authors have assumed that the aspiration level is equal to a firm's performance in the preceding year (Patel & Chrisman, 2014; Shapira, 2017; Souder & Bromiley, 2012). One major drawback of this approach is that a firm with zero patent is supposed to set its aspiration level to zero for the next year, but zero cannot be regarded as an aspiration level for any firm. Therefore, we used another approach and calculated a firm's historical aspiration level using an equation in which inputs were its prior aspiration level and innovation performance, and output was its current aspiration level (Joseph & Gaba, 2015; Lungeanu et al., 2016; Rhee, Ocasio, & Kim, 2019):

$$HA_t = \alpha \times HA_{t-1} + (1 - \alpha) \times P_{t-1}$$

where A is the aspiration level, P is the innovation performance, α is the weight of the most recent aspiration level. The first-year aspiration is the level defined solely by the first year performance in the data (Kuusela et al., 2017). We estimated our models with three α values (0.25, 0.50 and 0.75) and retained the value that best fitted our data (Baum et al., 2005; Kacperczyk et al., 2015; Moliterno et al., 2014). The models predicting the likelihood of undertaking strategic

[2] For an extensive review of organizational aspiration, studies see Shinkle (2012).

alliances and joint ventures retained a value of α equal to 0.75. As we employed a random-effect probit regression to estimate our models, we treated log pseudo-likelihood as a model fit.

To examine the effect of below and above innovation performance separately, we specified a spline function by entering separate variables for *below* and *above aspiration levels* (Greve, 2010). *Below aspiration* equaled 0 when innovative performance was above the aspiration level and equaled innovative performance minus the aspiration level when the performance was below the aspiration level, and *above aspiration* equaled 0 when innovative performance was below the aspiration level and equaled innovative performance minus the aspiration level when the performance was above the aspiration level (Krishnan & Kozhikode, 2015; Lungeanu et al., 2016; Vidal & Mitchell, 2015).

Moderator

To test the effect of firm age on the relationship between innovation performance and a firm's adaptive behavior, we operationalized firm age as the number of years passed since the birth of a firm (Wu, Levitas, & Priem, 2005). We measured firm age as the difference between a firm's Initial Public Offering (IPO) and observation years.

Control variables

We controlled for accumulated numbers of non-equity alliances and joint ventures a firm had because the number of existing alliances might affect the likelihood of making new ones. However, this required us to assume average alliance duration. Consistent with prior research, we assumed that on average alliances lasted three years (Schilling & Phelps, 2007). To compute the total number of *non-equity alliances* a firm had at the time of observation, we summed new non-equity alliances over the three previous years. For the total number of *joint ventures*, we summed new joint ventures over the three previous years (Schilling & Phelps, 2007).

We also accounted for *firm size* measured as the natural logarithm of total assets, which could affect a focal firm's propensity to engage in alliances (Lungeanu et al., 2016). As larger investments in R&D increase a focal firm's capacity to recognize and work with external resources and knowledge (de Leeuw et al., 2019), we included *R&D intensity* in our models (Franzen, Rodgers, & Simin, 2007). *R&D intensity* was calculated as the ratio of R&D to total assets. Lastly, we introduced *year dummies* to capture eventual changes in patent application levels and *industry*

dummies for high-tech industries as different industries might have different propensity to patent. Control, moderator, and independent variables were lagged by one year. We did not lag non-equity alliance and joint venture stock variables because there was a lag in the measurement of these variables. Our final econometric models are described below:

$$\Pr(NAD = 1 \mid X) = \sigma\,(\beta_0 + \beta_1 * Below\ aspiration + \beta_2 * Above\ aspiration + \beta_3 * Below\ aspiration * Firm\ age + \beta_4 * Joint\ venture\ stock + \beta_5 * Non-equity\ alliance\ stock + \beta_6 * Firm\ size + \beta_7 * R\&D\ intensity + \beta_8 * Firm\ age + Year\ dummies + Industry\ dummies + \varepsilon)$$

$$\Pr(JVD = 1 \mid X) = \sigma\,(\beta_0 + \beta_1 * Below\ aspiration + \beta_2 * Above\ aspiration + \beta_3 * Above\ aspiration * Firm\ age + \beta_4 * Joint\ venture\ stock + \beta_5 * Non-equity\ alliance\ stock + \beta_6 * Firm\ size + \beta_7 * R\&D\ intensity + \beta_8 * Firm\ age + Year\ dummies + Industry\ dummies + \varepsilon)$$

where NAD is a non-equity alliance dummy and JVD is a joint venture dummy.

Results

A summary of total patents, average patents, and the number of firms for each industry, averaged over time, is reported in Table 1. There is substantial variation across industries in the number of firms included in the sample and in the average number of patents per year. In contrast to Lungeanu et al. (2016), who argue that the pharmaceutical industry makes much more extensive use of patents than other industries, we found that the pharmaceutical industry was one of the least patenting industries among high-tech industries (per firm). The rationale behind this contradiction might be that we did not apply any selection criteria to include firms above a certain size. This resulted in small pharmaceutical firms with few or no patents remaining in the final sample, significantly lowering the average number of patents per firm[3]. Therefore, in our robustness test, we split the sample into big and small firms, then re-ran all regressions. However, we did not find significant changes in the regression coefficients and significance levels.

[3] We provide more explanation in "Research limitations and future research avenues" section.

Table 1

Descriptive statistics of different industries

Industry Name[4]	Total patents	Total firms	Total observations	Average patents
Electronic components and accessories	130049	115	1093	54
Computer programming and data processing	118684	225	1897	25
Computer and office equipment	54440	51	390	51
Pharmaceuticals	40570	285	2514	7
Telecommunication equipment	37581	50	429	36
Automotive bodies and parts	30165	14	175	103
Chemicals	19710	35	304	27
Measuring and control devices	13397	55	444	12
Aerospace equipment	10065	10	98	48
Medical equipment	6428	71	494	4
Petroleum refining and products	5798	18	178	16
Household audiovisual equipment	1822	4	23	33
Total	**468709**	**933**	**8039**	

Note: Average patents refer to the average number of patents per firm-year in a given industry

In Table 2, the descriptive statistics and correlations between the variables are shown[5]. Joint venture dummy is highly correlated with above aspiration (0.23), suggesting a strong link between

[4] We used the 4-digit SIC codes to assign our sampled patents to different industries.
[5] One should interpret correlation results carefully as correlation does not imply causation.

performing above aspirations and the likelihood of forming joint ventures. As we also control for a firm's existing joint ventures, it would be also interesting to mention the correlation between joint venture dummy and a firm's joint venture stock. The coefficient suggests that the more joint ventures a firm has in its portfolio, the more likely it is to form a joint venture with its prospective partner (0.33). Similarly, non-equity alliance stock in a firm's portfolio is positively associated with forming a joint venture (0.31). Moreover, there is also a strong relationship between joint venture dummy and firm size, suggesting that bigger firms are more likely to form joint ventures (0.25). Furthermore, the correlation between joint venture dummy and firm age is moderate (0.11), which implies that forming a joint venture might be the practice that is more common for older firms. Surprisingly, the table shows a weak, but still negative, correlation between joint venture dummy and R&D intensity (-0.07). This finding implies that as a firm's R&D intensity increases, the likelihood of engaging in joint ventures slightly decreases. The rationale behind this might that firms with higher focus on R&D or more established R&D practices might prefer developing innovations in-house or choosing other types of external collaborations in their quest for new knowledge.

Table 2 also shows how non-equity alliance dummy is correlated with the other variables. Non-equity alliance dummy is weakly correlated with below aspiration (-0.06), suggesting a weak negative link between performing below aspirations and the likelihood of forming non-equity alliances. As we also control for a firm's existing non-equity alliances, it would be worth mentioning the correlation between non-equity alliance dummy and a firm's non-equity alliance stock. The coefficient suggests that the more non-equity alliances a firm has in its portfolio, the more likely it is to form a non-equity alliance with its prospective partner (0.22). In the similar vein, joint venture stock in a firm's portfolio is positively associated with forming a new non-equity alliance (0.15). Moreover, there is also a strong relationship between non-equity alliance dummy and firm size. This means that bigger firms are more likely to form non-equity alliances (0.17). Nevertheless, the correlation between non-equity alliance dummy and firm age is negligible (-0.01). The table also shows a negligible coefficient for the correlation between non-equity alliance dummy and R&D intensity (-0.03).

Table 3 presents the results of the probit regression with non-equity alliance dummy as the dependent variable. The baseline model (Model 1) of Table 3 shows statistically significant and positive effects of joint venture stock, non-equity alliance stock, firm size, and R&D intensity on

the likelihood of forming non-equity alliances. In particular, the results of the Model 1 show that firms with more joint ventures in their alliance portfolios are more likely to form a non-equity alliance ($b=0.091$, $p < 0.01$). This coefficient means that each additional joint venture a firm has in its portfolio increases its z-score by 0.091, which in turn suggests a higher likelihood of forming a non-equity alliance. However, the exact magnitude of this effect cannot be determined because the coefficients in a probit model cannot be directly interpreted as probabilities of the event occurring. Similarly, firms with more non-equity alliances in their alliance portfolios are more likely to form another non-equity alliance ($b=0.100$, $p < 0.01$). Moreover, larger firms are also likely to form a non-equity alliance ($b=0.121$, $p < 0.01$). Furthermore, R&D intensity is also positively associated with the likelihood of forming a non-equity alliance ($b=0.187$, $p < 0.05$). Lastly, mature firms are less likely to form non-equity alliances ($b=-0.067$, $p < 0.01$). The rationale behind this might be that mature firms tend to protect their technological knowledge, and thus they are less likely to collaborate via less integrated forms of external collaborations, namely non-equity alliances.

In Model 2, historical aspiration variables were added to the baseline model. However, the relationship between below historical aspiration and the likelihood of forming non-equity alliances is statistically insignificant. Consequently, H1 claiming that declining innovation performance relative to the aspiration level is positively associated with the likelihood of forming non-equity alliances does not get any support. In Model 3, we examined the effect of firm age together with below historical aspiration. The coefficient of the interaction term is not statistically significant. This implies that firm age does not moderate the relationship between below historical aspiration and the likelihood of forming non-equity alliances. Thus, Hypothesis 3 is not supported.

Table 2

Descriptive statistics and correlations

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9
1	Joint venture dummy	0.09	0.29	0.00	1.00	1.00								
2	Non-equity alliance dummy	0.49	0.50	0.00	1.00	0.11	1.00							
3	Below aspiration	-0.12	0.71	-27.37	0.00	-0.06	-0.07	1.00						
4	Above aspiration	0.20	0.92	0.00	17.64	0.23	0.10	0.04	1.00					
5	Joint venture stock	0.35	1.25	0.00	24.00	0.33	0.15	-0.10	0.46	1.00				
6	Non-equity alliance stock	2.98	7.48	0.00	178.00	0.31	0.22	-0.18	0.51	0.67	1.00			
7	Firm size (ln)	5.99	2.43	-2.55	12.79	0.25	0.17	-0.25	0.28	0.31	0.31	1.00		
8	R&D intensity	0.18	0.31	0.00	14.86	-0.07	-0.03	0.06	-0.08	-0.08	-0.05	-0.47	1.00	
9	Firm age (ln)	2.17	0.98	0.00	3.91	0.11	-0.01	-0.16	0.11	0.17	0.15	0.50	-0.25	1.00

Note: The test showed that all correlations higher than 0.05 were statistically significant

Table 3

Probit regression for non-equity alliance dummy

Non-equity alliance dummy	**(1)**	**(2)**	**(3)**
Intercept	-1.231***	-1.352***	-1.350***
	[0.273]	[0.284]	[0.285]
Joint venture stock	0.091***	0.094***	0.095***
	[0.027]	[0.029]	[0.029]
Non-equity alliance stock	0.100***	0.094***	0.093***
	[0.009]	[0.010]	[0.010]
Firm size	0.121***	0.142***	0.141***
	[0.014]	[0.016]	[0.016]
R&D intensity	0.187**	0.242**	0.240**
	[0.087]	[0.103]	[0.103]
Firm age	-0.067***	-0.078***	-0.076***
	[0.024]	[0.025]	[0.025]
Below aspiration		-0.022	-0.219
		[0.043]	[0.214]
Above aspiration		0.025	0.027

Non-equity alliance dummy	**(1)**	**(2)**	**(3)**
		[0.039]	[0.039]
Below aspiration x firm age			0.059
			[0.058]
Industry dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Number of observations	6,616	5,862	5,862
Number of firms	885	865	865
Log-Likelihood	-3193	-3193	-3192
Pearson chi2	855	869	866

*Robust standard errors in brackets: *** p<0.01, ** p<0.05, * p<0.10*

Table 4 provides the results of our analyses of the likelihood of forming joint ventures. Model 1 is the baseline model consisting of only control variables. The results indicate that non-equity alliance and joint venture stocks, firm size, R&D intensity have a positive impact on the likelihood of engaging in joint venture activities, whereas firm age is negatively associated with such activities. Particularly, the results of the model show that firms with more joint ventures in their alliance portfolios are more likely to form a joint venture ($b=0.095$, $p < 0.01$). In the similar vein, firms with more non-equity alliances in their alliance portfolios are also more likely to form a joint venture ($b=0.028$, $p < 0.01$). Moreover, larger firms are also more inclined to form a joint venture ($b=0.183$, $p < 0.01$). Furthermore, R&D intensity is also positively associated with the likelihood of forming a joint venture ($b=0.342$, $p < 0.01$). Lastly, mature firms are often less inclined to form joint ventures ($b=-0.064$, $p < 0.1$). The rationale behind this finding might be that mature firms tend to prefer internal investments in their innovation prospects rather than pursuing collaboration strategies. Alternatively, they might also prefer other types of external collaborations, such as mergers and acquisitions.

Hypothesis 2 predicted a positive relation between above historical aspiration and the likelihood of forming joint ventures. Model 2 of Table 4 displays the results of this hypothesis test. The coefficient of the relationship between above historical aspiration and joint venture dummy is positive and significant ($b = 0.087$, $p < 0.01$). This result provides a full support for H2, which implies that firms above their historical aspirations are more likely to collaborate through more integrated alliances (i.e., joint ventures). To test our fourth hypothesis, we added an interaction term with firm age. The coefficient of the interaction term is negative and statistically significant ($b = -0.46$, $p < 0.05$), which implies that firm age mitigates the positive relationship between above historical aspiration and the likelihood of forming joint ventures[6]. In other words, older firms tend to be risk averse and build on their existing technological knowledge (Sørensen & Stuart, 2000). Therefore, they become reluctant to source technological knowledge, even via more integrated alliances (i.e., joint ventures), in order to maintain (at a minimum) their competencies. This finding is opposite to what H4 initially predicted.

[6] The effect size of firm age has been discussed in the conclusion section of this paper.

Table 4

Probit regression for joint venture dummy

Joint venture dummy	**(1)**	**(2)**	**(3)**
Intercept	-1.853***	-1.973***	-1.965***
	[0.259]	[0.281]	[0.283]
Joint venture stock	0.095***	0.088***	0.088***
	[0.028]	[0.030]	[0.030]
Non-equity alliance stock	0.028***	0.023***	0.024***
	[0.004]	[0.005]	[0.005]
Firm size	0.183***	0.194***	0.187***
	[0.020]	[0.023]	[0.023]
R&D intensity	0.342***	0.469***	0.459***
	[0.091]	[0.157]	[0.157]
Firm age	-0.064*	-0.071**	-0.053
	[0.033]	[0.036]	[0.037]
Below aspiration		-0.044	-0.042
		[0.038]	[0.038]
Above aspiration		0.087***	0.216***
		[0.026]	[0.052]
Above aspiration x firm age			-0.046**
			[0.019]

Joint venture dummy	**(1)**	**(2)**	**(3)**
Industry dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Number of observations	6,616	5,862	5,862
Number of firms	885	885	885
Log-Likelihood	-1452	-1308	-1306
Pearson chi2	732	726	784

*Robust standard errors in brackets: *** p<0.01, ** p<0.05, * p<0.10*

Robustness check

We ran several complementary analyses to test the robustness of our findings. As the first robustness check, we transformed all control variables to their logarithms because the skewness of the control variables might influence the outcomes of the analyses (Keijl, Gilsing, Knoben, & Duysters, 2016). The signs and significance of the independent variables remained the same.

As the second robustness check, we split up the sample into two subsamples because firms might give different reactions to innovation performance relative to aspiration levels depending on their size (Greve, 2008). After some additional tests, we decided to label firms as "big firms" if their total assets exceeded 100 million in the first year of the sample (1989). Then, we ran all regressions for both subsamples. The results showed that firms' behaviors in choosing collaboration modes were not dependent on their size. We applied the same method using another size measure (the number of employees). The signs and significance of the coefficients remained the same.

As the third test, we changed our firm size measure (i.e., total assets) to a new size measure, which was the logarithm of the number of employees. It did not make remarkable changes in our full models. Nevertheless, we reported models with a size measure that was the logarithm of total assets because it produced a better model fit.

As the last robustness check, we added ROA to our models to ensure that our results were not driven by financial performance of firms. We did not observe significant changes in the coefficients and significance of our main independent variables.

Conclusion

How a firm adapts its portfolio of external collaborations to different sources of uncertainty has long been in strategy and organizational scholars' interest. We have endeavored to contribute to this body of literature by (1) considering the behavioral antecedents that lead a firm to choose non-equity alliances (or equity alliances), (2) moving beyond the dyad perspective that has dominated the literature on inter-firm collaborations until now and (3) examining the role of firm age.

We primarily contribute to the literature on the antecedents of alliance portfolio adaptation. Previous studies have identified technological discontinuity (Asgari, Singh, & Mitchell, 2017), technological change (de Leeuw et al., 2019), and market uncertainty (Ozcan, 2018) as the drivers of alliance portfolio adaptation. A limited number of studies have also pointed at the role of internal contingencies, such as firm-specific uncertainty and business strategy, in moderating the effect of external contingencies (Beckman et al., 2004; Hoffmann, 2007).

In this study, we contribute to the newly emerging stream of literature by showing that alliance portfolio decisions can be traced back to the bounded rationality of top decision-makers (Cyert & March, 1963; Gavetti et al., 2012). Specifically, boundedly rational top managers strive to simplify performance evaluation by converting a continuous measure of performance into a discrete measure of success or failure (Baum & Dahlin, 2007; Baum et al., 2005; Kameda & Davis, 1990). Building on the behavioral theory, in this study we argue that a discrete measure of success (i.e., performing above aspirations) might lead to changes in a firm's behavior in alliance formation.

As far as we know, there is limited evidence in the literature on the relationship between innovation performance feedback and alliance portfolio adaptation. Yet, available studies have mostly focused on explaining how firms change their alliance portfolio diversity (Kavusan & Frankort, 2019; Martínez-Noya & García-Canal, 2021), formation of R&D alliances (Tyler & Caner, 2016), and their technology sourcing vehicles (Lungeanu et al., 2016) in response to innovation performance relative to aspirations. Since we find support for Hypothesis 2, we add to the recent and very scarce literature by showing that when performing above their innovation aspiration levels, firms tend to increase their propensity to engage in more integrated alliances (i.e., joint ventures). The rationale behind this is that when firms exceed their innovation aspirations their tacit knowledge—deeply rooted in their social context—and codified knowledge—capitalized in firms' intellectual properties, such as patents, copyright, design models, licenses, software—become more vulnerable (Denicolai et al., 2014). Therefore, firms above innovation performance aspirations are risk averse because they tend to protect their valuable technological knowledge from leakage through more stable and better-monitored alliances, namely joint ventures (Kotiloglu et al., 2021; Villalonga & McGahan, 2005). Lastly, when firms outperform their aspirations, they can benefit from a stronger negotiating position due to their attractiveness and form new joint ventures with more favorable terms (Ahuja, 2000b; Martínez-Noya & García-

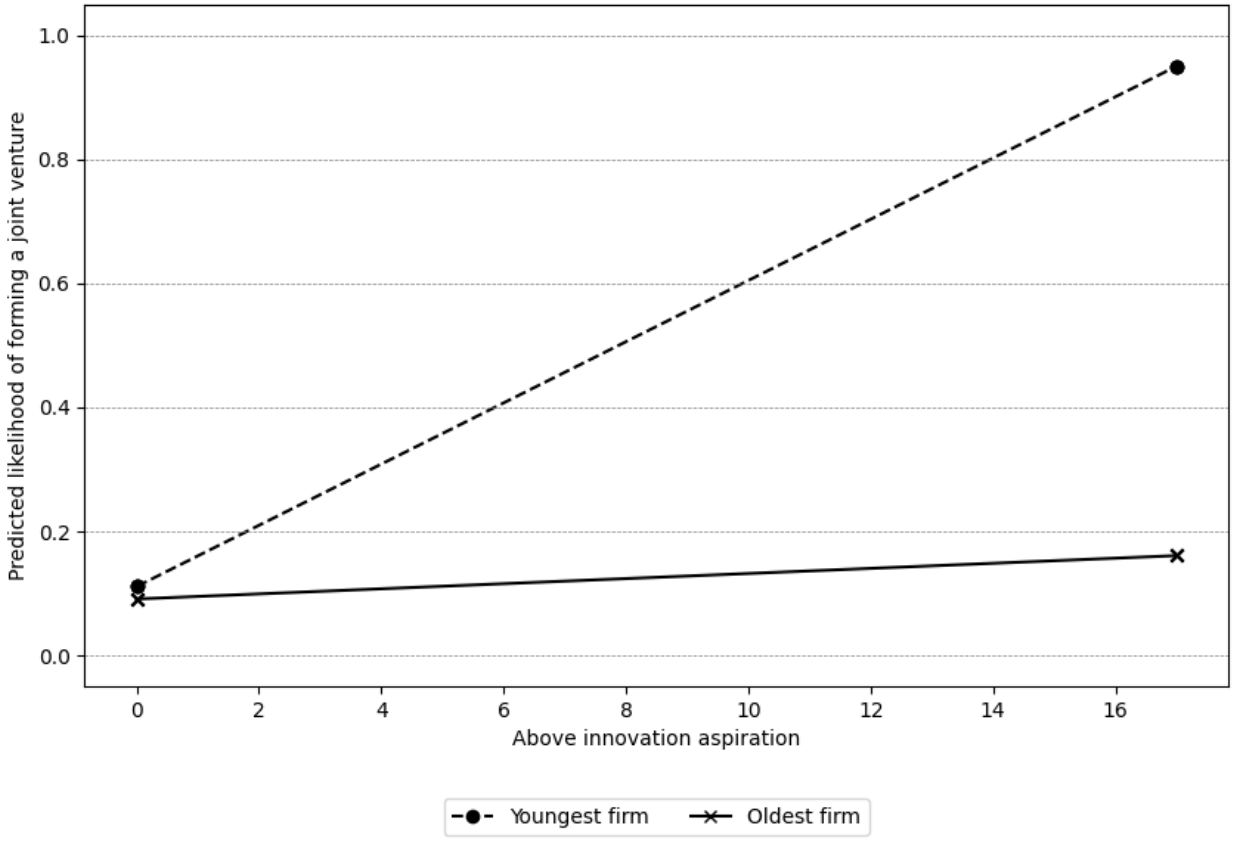
Canal, 2021). By doing so, well-performing firms can also maintain their autonomy to a great extent in their external collaborations.

Our study also contributes to the literature on inter-firm collaborations by shifting away from the dyad perspective (de Leeuw et al., 2019; Hoehn-Weiss et al., 2017). In particular, research has focused on the notion that firms choose a specific collaboration mode with a prospective partner based on the characteristics and eligibility of the partner (Van de Vrande et al., 2009). However, this approach often overlooks the internal uncertainties of firms. This study, on the other hand, adopts a more firm-centered approach, exploring how a firm's own internal attributes, namely innovation performance relative to aspirations, might affect its preferences and behaviors. By taking this step, we argue that firms might engage in external collaborations not only as a response to external partner considerations, but also as a strategic initiative driven by their internal factors. This approach introduces a new dimension to our understanding of alliance formation, enriching our view of how firms navigate in competitive environments where innovation is vital for survival.

We also contribute to the behavioral theory of the firm by examining why firms respond to performance feedback differently (Shinkle, 2012). Previous studies have highlighted the role of financial slack (Lungeanu et al., 2016), absorbed slack (Kavusan & Frankort, 2019; Kotiloglu et al., 2021; Tyler & Caner, 2016), and R&D intensity (Martínez-Noya & García-Canal, 2021) in moderating the relationship between innovation performance feedback and alliance portfolio adaptation. In this paper, we argue that previous studies have overlooked the role of firm age in alliance formation (Hypothesis 4). However, in contrast to our expectations, firm age appears to be a limiting factor that reduces the likelihood of mature firms engaging in joint ventures. To the best of our knowledge, our study is the first to show the moderating role of firm age on the relationship between innovation performance feedback (i.e., above innovation aspiration level) and the likelihood of involving in joint venture formation (Figure 1).

Figure 1

Predictive margins for the moderating role of firm age



Our results suggest that young firms have a stronger positive relationship between innovation performance relative to aspirations and the likelihood of forming a joint venture. As these firms perform better in terms of innovation, exceeding their aspirations, their likelihood of forming joint ventures increases substantially. When innovation performance exceeds aspirations slightly, their likelihood of forming a joint venture rises dramatically. For example, when young firms exceed their aspirations by 4 patents their likelihood of engaging in a joint venture is 0.3. However, this likelihood increases sharply up to 0.9 when these firms exceed their aspirations by 16 patents. This indicates that young firms might view joint ventures as a critical strategy to scale up their innovations and gain access to critical resources, markets, and expertise, which they often lack (Bruneel, Ratinho, Clarysse, & Groen, 2012). This is largely due to young firms' capabilities to innovate by exploiting knowledge generated elsewhere (Narula, 2004).

On the other hand, the results show that mature firms have a much weaker relationship between innovation performance relative to aspirations and the likelihood of forming a joint

venture. As innovation performance increases, the likelihood of forming a joint venture only shows a slight upward trend. This suggests that mature firms are, in general, less likely to form a joint venture even when their innovation performance exceeds aspirations significantly. For example, when mature firms exceed their aspirations by 4 patents, their likelihood of engaging in a joint venture is 0.1. Surprisingly, this likelihood remains largely flat and improves slightly at higher levels of innovation performance relative to aspirations. In particular, the likelihood of engaging in a joint venture increases only up to 0.15 when mature firms exceed their aspirations by 16 patents. This finding is in line with previous studies. Mature firms typically have more established resources, capabilities, and networks, which might result in greater organizational inertia, limiting their innovation search (Mahmood, Zhu, & Zajac, 2011). Mature firms often have established business models and large R&D departments, therefore they might prefer exploiting innovations through various other strategies, including mergers and acquisitions (Dezi, Battisti, Ferraris, & Papa, 2018).

Finally, our study is one of the early studies to examine a firm's adaptation in a cross-industry sample. Previous research has long focused on one-industry samples to understand how firms respond to innovation performance feedback. Among others, the pharmaceutical (Lungeanu et al., 2016), biotechnology (Kavusan & Frankort, 2019), and biopharmaceutical (Tyler & Caner, 2016) industries have been mostly used to test hypotheses in this context. By testing our hypotheses in a unique sample of nearly 900 firms from 12 high-tech industries, we increase the external validity of previous studies and show that firms' reactions to innovation performance feedback are not industry-specific.

Research limitations and future research avenues

Limitations in the sample and innovation measure selection

With respect to the study's limitations, our study can be developed by future research in several ways. Firstly, in this study we rely on a cross-industry sample to test our hypotheses, which allows us to generalize the results. Although, using a cross-industry sample increases the external validity of the paper, this approach also entails certain limitations. In particular, previous studies have mentioned industry-specific differences and shown that propensity to patent might differ

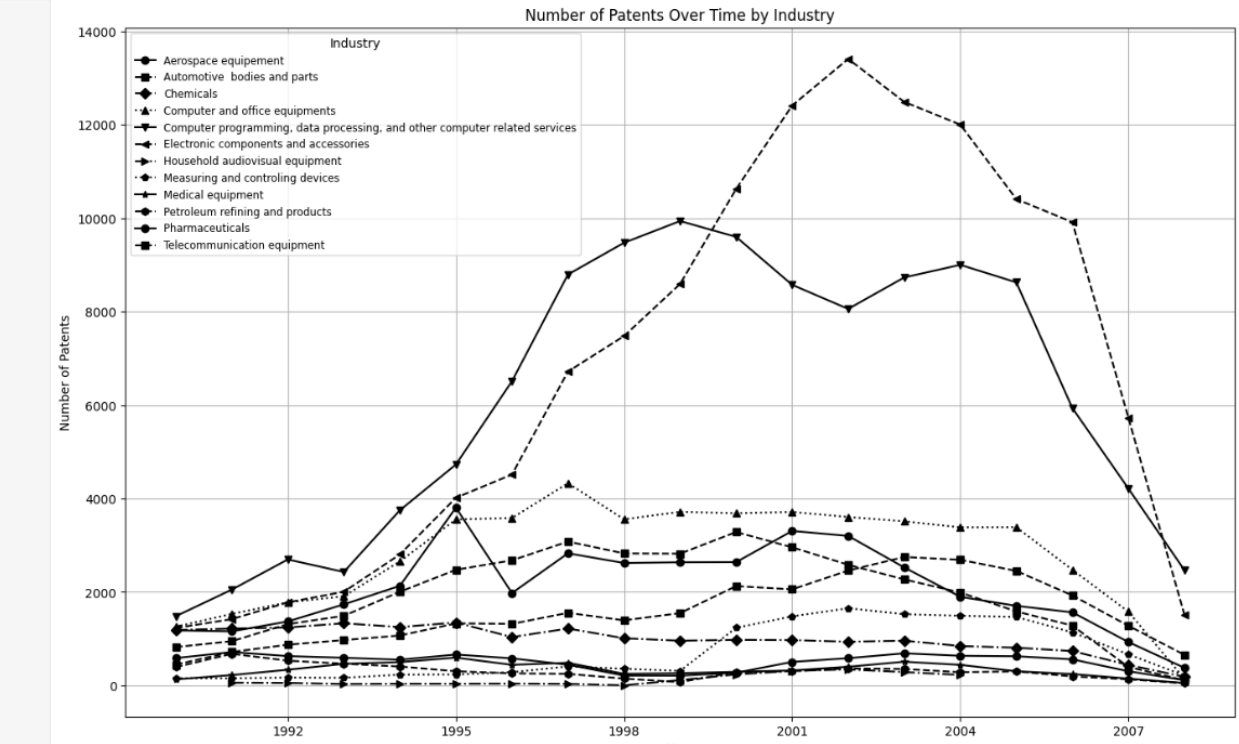
significantly across industries (Guo, Zhang, Dodgson, & Cai, 2017; Hall & Ziedonis, 2001; Noel & Schankerman, 2013), which is in line with the descriptive statistics reported in Table 1. In our sample, automotive bodies and parts industry had the highest number of average patents per firm (i.e., 103 patents), followed by electronic components and accessories industry (i.e., 54 patents), while medical equipment industry recorded, on average, only 4 patents per firm.

Discussing industry-specific variations, Guo et al. (2017) argue that firms are involved in "patent portfolio races" in semiconductor and telecommunication industries. In a similar vein, Noel and Schankerman (2013) argue that medical equipment and software industries contribute most to the growth in aggregate patenting of high-tech industries. Surprisingly, in pharmaceuticals the growth in patenting is slightly smaller than the average growth in patenting in high-tech industries (Noel & Schankerman, 2013). Generally speaking, firms patent their inventions offensively to prevent their competitors from patenting inventions which are similar to what they are developing and intend to introduce to the market (Blind, Cremers, & Mueller, 2009). However, patenting in the pharmaceutical industry has unique characteristics. In particular, in the pharmaceutical industry firms have alternative means of deploying patents, namely licensing contracts (de Leeuw et al., 2019; Khanna, Guler, & Nerkar, 2018; Van de Vrande et al., 2009). This suggests that not all firms need to patent to access and use necessary resources in this industry. Moreover, firms also terminate their patents at early stages if the development of certain drugs requires high costs (Khanna et al., 2018). These ideas also explain why the pharmaceutical industry is the one of the least patenting industries in terms of the number of patents per firm.

Considering all the arguments discussed above, we suggest that future research deploys different and more sophisticated approaches to control for the fundamental differences across industries. Figure 2 shows the total number of patents over time by industry. It can be clearly seen from this graph that two industries received the highest number patents in the period of 2000 and 2002 (i.e., electronic components and accessories, and computer programming, data processing and other computer related services). The rest of the industries largely remained flat over time, receiving similar numbers of patents every year. By showing these variations in patenting trends across industries, we underscore the need for more tailored approaches to control for industry characteristics. For example, future studies could categorize high-tech industries based on their patenting behaviors, while also controlling for critical events within those industries, and examine whether our results hold across all sub-samples.

Figure 2

Number of patents over time by industry



Secondly, future research could extend our work by developing other measures to operationalize innovation performance. Patent-based measures are widely used in empirical research on innovation (Lerner & Seru, 2022; Wagner & Wakeman, 2016) because they are positively associated with a firm's market value (Hall, Jaffe, & Trajtenberg, 2005), future sales (Farre-Mensa, Hegde, & Ljungqvist, 2020), and a speed of product commercialization (Wagner & Wakeman, 2016). Previous research has also employed patent-based measures to predict the likelihood of a receiving new patent (Farre-Mensa et al., 2020). According to Savage, Li, Turner, Hatfield, and Cardinal (2020), there were 146 patent-based studies in the top management journals in the period of 2015-2017, which is roughly 40% higher compared to the period of 2012-2014. The authors have also revealed that empirical studies using patent-based measures have increased by 614% between 2000 and 2017 in the field of management, especially in the leading management journals (Savage et al., 2020). Nevertheless, these measures are often criticized for overlooking the lengthy process from discovery to commercialization. For example, in the pharmaceutical

industry the overall length of the pre-launch period, which covers the period between the first identification of pharmaceutically-active substance and its sale on the market, is, on average, 11.5 years (Sternitzke, 2010). The limitation of this paper is that it conceptualizes patent-based measures as innovation outputs ignoring the causal chain of how patents become commercial products in the market, which are crucial for gaining a competitive advantage over rivals. This is because a firm's innovation performance depends not only on the creation of new technologies, but also on their commercialization. The logical continuation of this research would be opening the "black box" by explaining the long and complex period that follows the first discovery of technologies. Future research could examine whether the internal attributes discussed in this paper are still the key determinants.

Moreover, with regard to the measure of innovation performance, we suggest that future studies construct more advanced measures considering the financial impact of inventions (Hall et al., 2005; Hall, Jaffe, & Trajtenberg, 2000), patent worth (Farre-Mensa et al., 2020), patent quality (Higham, De Rassenfosse, & Jaffe, 2021), or new product introductions (Tyler & Caner, 2016), which could help construct a weighted measure of innovation performance. There already exists a growing body of pioneering studies using the advancements of Artificial Intelligence to analyze patent text (Arts, Hou, & Gomez, 2021; Miric, Jia, & Huang, 2023). This might also yield valuable insights into innovation dynamics within firms and pave the way for future research on innovation performance.

Limitations in the methodology

With respect to the study's methodological limitations, we underscore four main limitations. Firstly, in this study we have chosen to focus on horizontal alliances mainly due to data constraints. Our theoretical justification to focus only on horizontal alliances was that firms might have different approaches in terms of their engagement in horizontal vs. vertical alliances (Dezi et al., 2018). Therefore, future research could examine how firms also adapt their engagement in vertical collaborations (e.g., minority holdings, majority holdings, M&A) or their portfolios of horizontal and vertical collaborations. In particular, firms have different types of inter-firm collaborations at their disposal, and thus they often adjust their portfolios of inter-firm collaborations in response to internal and external attributes instead of focusing on a certain type of collaboration (de Leeuw et al., 2019). Future studies could also focus on the resources (i.e.,

existing or new resources) and partners (i.e., existing or novel partners) involved in a certain collaboration (Kavusan & Frankort, 2019). Types of external collaborations and their interdependence, control, and flexibility are presented in Appendix 1.

Second, future research could also develop a new approach to capture agreements aimed at developing technology. The SDC Platinum Joint Ventures and Alliances database provides a description of each agreement (Schilling, 2009). We specified several keywords to determine whether an agreement was aimed at developing technology. Future research could leverage natural language processing (NLP) techniques to analyze frequently used technology-related terms and focus on agreements where these terms are present. Nowadays, modern AI tools (e.g., Jasper AI, HubSpot, Anyword AI, ChatGPT) can be employed to summarize the description of each agreement, allowing researchers to better understand the true purpose of that agreement. For example, these tools could filter agreements specifically intended for technology development, offering a more tailored and precise method than the keyword search approach we used.

Thirdly, in this study our main focus was historical aspirations since it was challenging to determine a reference group against which a focal firm compares its performance (Kacperczyk et al., 2015; Kuusela et al., 2017). Moreover, the notion of a single reference group proved incompatible with our cross-industry sample approach because firms in various industries tend to be affected by a wide range of reference groups. Future research could extend our findings by developing a better method to operationalize social aspirations.

Finally, due to data constraints, in this study we did not control for external factors, such as technological turbulence, geographical location, or market uncertainty. These factors have been argued to influence firms' behaviors in alliance formation (de Leeuw et al., 2019; Ferreira et al., 2017; Ozcan, 2018; Van de Vrande et al., 2009). For example, Van de Vrande et al. (2009) have argued that when the environment is turbulent, innovating firms place greater value on keeping their options open. Similarly, de Leeuw et al. (2019) have found that when the industry is facing technological changes, innovating firms are more likely to incorporate more integrated modes of collaboration, such as joint ventures, into their portfolios of external collaborations. Therefore, we suggest that future studies control for these external factors in their predictive models.

Managerial implications

This paper also provides several implications and suggestions for top managers and businesses. In high-tech industries, no single firm has all required capabilities and resources to stay competitive. Recent advancements in technology, particularly in Artificial Intelligence (AI), have made survival in these industries increasingly difficult. For example, in sectors such as autonomous vehicles, cloud computing, AI-powered chatbots, and AI-powered diagnostics, it is essential for firms to access critical resources and innovate continuously to survive. Therefore, performing above innovation aspirations could be also perceived as a signal by top managers that it is the right time to form external collaborations to scale new technological ideas and knowledge. Moreover, exceeding innovation aspirations provide top managers a stronger negotiating position in forming new joint ventures because well-performing firms are often attractive to other market players. Therefore, when a firm performs above aspirations, its managers should use this opportunity and negotiate with more favorable terms and conditions. Furthermore, our findings also imply that managers of well-performing firms should actively seek partnerships to mitigate or share the risks of cutting-edge innovation projects instead of investing in internal innovation prospects.

Another important implication of this paper is the following. As exceeding innovation aspirations leads to forming joint ventures and accelerates growth opportunities, managers of well-performing firms could also reinforce a continuous innovation culture within their firms and inspire their teams by emphasizing that “success leads to growth.” Lastly, our paper also suggests that manager of well-performing firms could use joint ventures to access global hubs that are specialized in cutting-edge AI and data knowledge. For example, managers could seek joint venture opportunities with the players of leading AI hubs, such as Silicon Valley, Shenzhen, Beijing, and Toronto. The players of these hubs can provide access to cutting-edge knowledge, technology, and talent, which would be challenging to develop in-house.

As we also show that young and mature firms respond differently to innovation performance above aspirations, there are also several takeaways for managers of both emerging and established firms. Since our model indicates that young firms react more aggressively when they outperform their innovation goals, managers in such firms should focus on more aggressive partnership strategies when their firms exceed previously set innovation aspirations. By so doing,

well-performing young firms could take advantage of their momentum. Moreover, managers in young firms should closely monitor innovation performance and make sure that they are ready to leverage joint ventures when their aspiration goals have been achieved.

On the other hand, managers in mature firms should acknowledge that high innovation performance relative to aspirations might not be the only main driver of forming joint ventures. Therefore, in this case they should also focus on other alternatives to cultivate innovation prospects. Particularly, managers in mature firms could allocate their commitments and resources to internal development, M&As, or different types of partnerships that allow mature firms to maintain their autonomy to a great extent.

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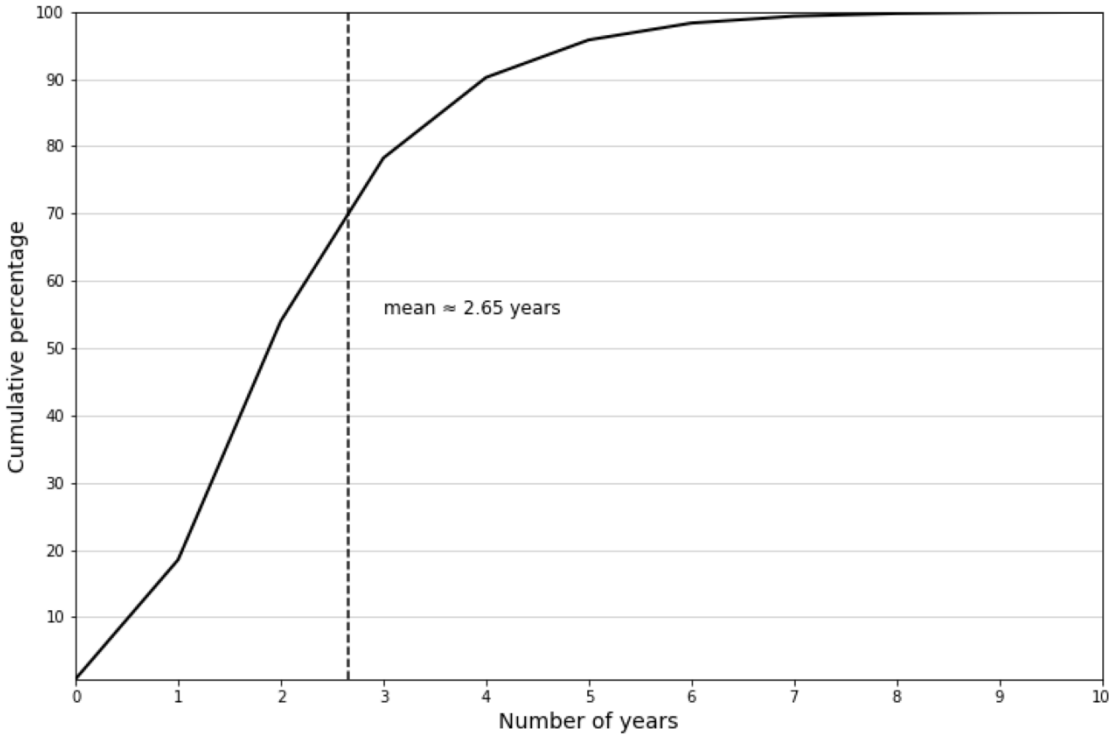
Appendix 1

Types of inter-firm collaborations and their interdependence, control and flexibility (de Leeuw et al., 2019)

Appendix 2

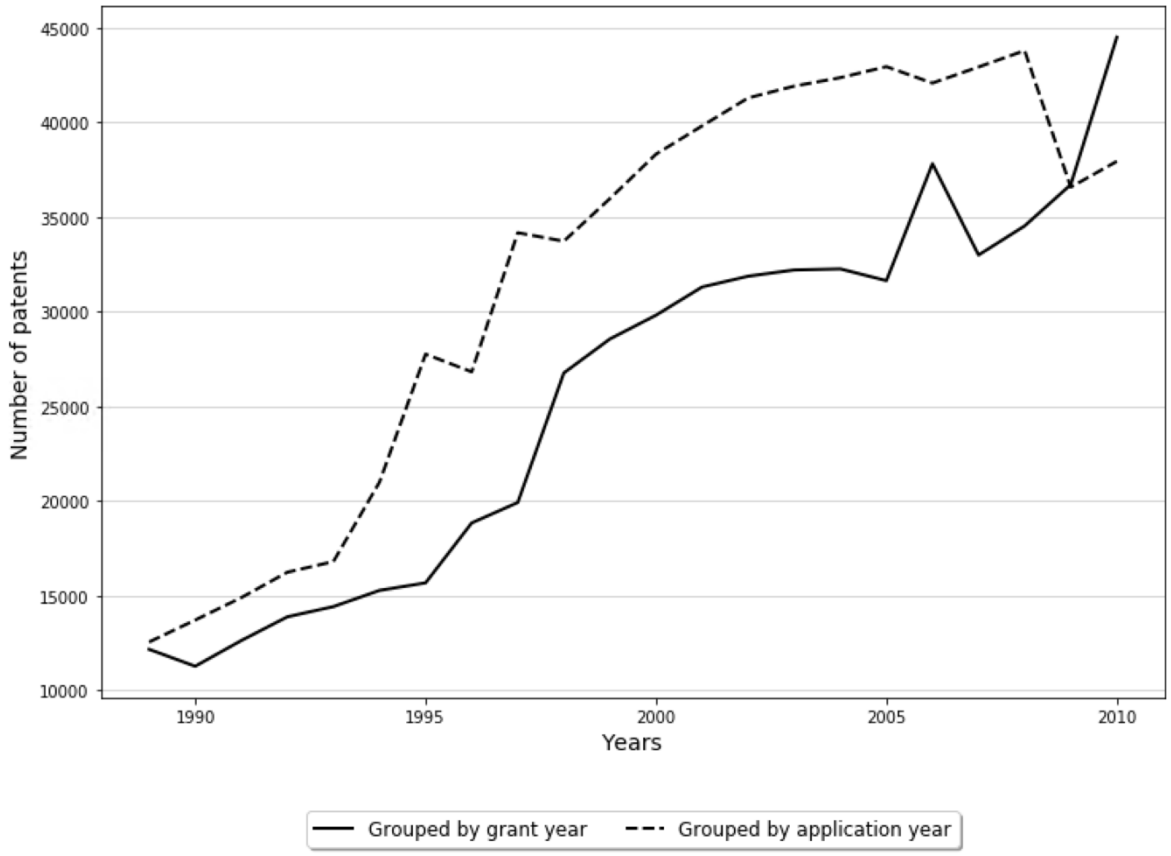
Year difference between application and granted years of the sampled patents[7]



[7] This outcome was generated after updating our sample of granted patents using the most recent patent database constructed by Kelly, Papanikolaou, Seru, and Taddy (2021).

Appendix 3

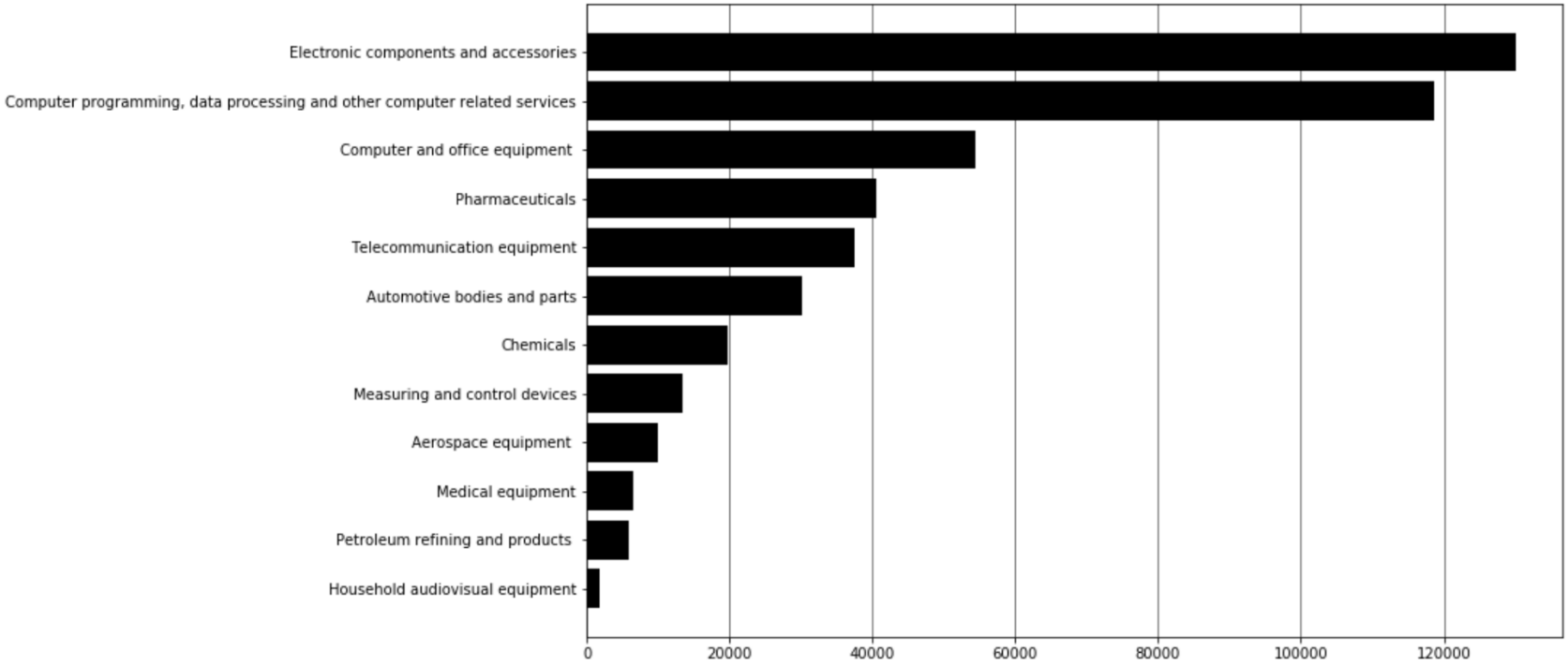
Number of the sampled patents over the period of 1990 – 2010[8]



[8] This outcome was generated after updating our sample of granted patents using the most recent patent database constructed by Kelly et al. (2021).

Appendix 4

Number of the sampled patents per industry (4-digit SIC code)9



[9] In this paper, we define an industry as a collection of several 4-digit SIC codes (see the details in the sample section of the corresponding paper).