

Digital Transformation Through Exploratory and Exploitative Internet of Things Innovations: The Impact of Family Management and Technological Diversification*

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This study examines the impact of family management on digital transformation with specific regard to the firm's development of Internet of Things (IoT) innovations. Drawing on the distinctive characteristics of firms with family managers, such as the focus on family-centered noneconomic goals, long tenure, emotional ties to existing assets, and rigid mental models, it hypothesizes that increasing family involvement in the top management team is negatively related to the development of IoT innovations that are distant from a firm's existing technology base (i.e., exploratory IoT innovations) compared to exploitative IoT innovations. Further, the study proposes that the firm's degree of technological diversification, especially in unrelated forms, reinforces this relationship. The longitudinal analysis between 2002 and 2013 on a sample of publicly traded German firms allows us to test our hypotheses from the beginning of the emergence of the IoT concept. Our findings show that due to the particular characteristics of their managers, family-managed firms do not welcome the risks related to exploratory IoT innovations, and the benefit of risk diversification from technological diversification is lower than the cost of abandoning family-centered goals. As our results imply that the involvement of family managers constrains the development of exploratory IoT innovation, the top management team composition in firms that intend to be at the forefront of the digital transformation should be accurately designed by avoiding a high proportion of family members.

Practitioner Points

- The higher the family involvement in the top management team (TMT), the lower the innovative output in terms of exploratory IoT innovations.
- Control/incentive mechanisms that consider and limit the family managers' aversion toward the development of exploratory IoT innovations should be put in place.
- When firms with high family involvement in the TMT pursue a technological diversification strategy,

the development of exploratory IoT innovations is further hindered.

- Especially unrelated forms of technological diversification hamper the development of exploratory IoT innovations.
- The transition toward digital transformation is not straightforward, and technologically diversified family-managed firms face difficulties in this respect, especially when such transition involves the development of digital innovations distant from their current innovation trajectories.

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Introduction

Since its conceptualization, digital transformation has been considered a priority for firms to improve their competitiveness and ensure their survival (Andal-Ancion, Cartwright, and Yip, 2003). Today, such transformation is deemed pivotal and calls for the development and integration of digital innovation into all business areas from products to organizational processes and business models, with the ultimate aim of accelerating organizational learning,

business operations, and creating new ways to deliver value to customers (Lyytinen, Yoo, and Boland, 2016; Nambisan, 2017).

Among the various digital technologies prevalent in the digital transformation of companies (cloud computing, 3D printing, augmented reality, etc.), the Internet of things (IoT)—equipping physical objects with sensors, actuators, and connecting them to the Internet—is considered the cardinal innovation

paradigm (Kim, Lee, and Kwak, 2017). However, the activities to complement a firm's existing technological resources with IoT innovations are still rare or at an initial stage, despite the attempts of academics, executives, and policymakers to promote and sustain investments in IoT in the last decade. The main reasons can be attributed to the technological complexity underlying IoT, for example, the diversity of objects, the immaturity of IoT, the unstructured IoT ecosystems, and the disruptive nature of the related business opportunities (Feki, Kawsar, Boussard, and Trappeniers, 2013; Westerlund, Leminen, and Rajahonka, 2014). In this context, extant research stresses that effective strategic IoT decisions may be largely dependent on the organization's exploratory and exploitative capabilities in the IoT investment process (Li, Hou, Liu, and Liu, 2012; Lo and Campos, 2018). Indeed, IoT “opens up new systematic paths to the exploration and exploitation of business opportunities” (i.e., greater efficiency/reliability of existing businesses or novel, differentiated advantages) (Ehret and Wirtz, 2017, p. 115). However, exploration/exploitation decisions are not easy, especially in the IoT domain, which presents further elements of risk and uncertainty. This leads to the dilemma of what pushes firms to dedicate (scarce) organizational resources to developing exploratory IoT innovations, which is the focus of this paper.

Due to their leadership position, top managers are deemed the most adept at guiding a firm's digital transformation (Singh and Hess, 2017; Westerman, Bonnet, and McAfee, 2014), as TMTs are in charge of strategic change and commitment to innovation (Garms and Engelen, 2019; Hambrick and Mason, 1984), especially in exploration/exploitation decisions (Carmeli and Halevi, 2009). Prior research shows that TMT diversity plays a key role in this regard (Kraiczy, Hack, and Kellermanns, 2014). In particular, the role of family-induced diversity is a relevant and under-researched source of TMT diversity (Ling and Kellermanns, 2010; Minichilli, Corbetta, and MacMillan, 2010) that may affect the firm's exploration/exploitation choices. Distinctive characteristics of family managers (e.g., preferences, social interests, objectives, capabilities) affect strategic choices in general (D'Allura, 2018; Habbershon and Williams, 1999; Sirmon and Hitt, 2003; Stadler, Mayer, Hautz, and Matzler, 2018), and innovation activities in particular (De Massis, Frattini, and Lichtenthaler, 2013; Matzler, Veider, Hautz, and Stadler, 2015). Therefore, this study focuses on top management characteristics

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(i.e., the active involvement of family members in the TMT) to explain a firm's engagement in developing exploitative and/or exploratory IoT innovations.

In specific, this study asks if the distinctive characteristics of firms with family managers, such as their focus on family-centered noneconomic goals, long tenure, emotional ties to existing assets, and rigid mental models, lead to less engagement in the development of IoT innovations that are distant from a firm's existing technology base (i.e., exploratory IoT innovations) compared to exploitative IoT innovations. In addition, it investigates whether this family management-exploratory IoT relationship is influenced by the diversification of the firm's current technology base (Ceipek, Hautz, Mayer, and Matzler, 2019).

Technological diversification is considered as a relevant contingency factor as, on the one hand, IoT solutions require firms to manage diverse technological knowledge domains and their underlying complexities to overcome constraints related to interoperability, standardization, and integrating product-service offerings (Ardito, D'Adda, and Messeni Petruzzelli, 2018; Feki et al., 2013). On the other hand, family-managed firms are more cautious regarding diversification decisions than their nonfamily counterparts, since family managers may be particularly attached to existing assets and innovation trajectories, or fear losing control over the firm (Gomez-Mejia, Makri, and Kintana, 2010). The study further distinguishes between related and unrelated technological diversification to better reflect the actual degree of interrelationship in a firm's technology base (Kim, Lee, and Cho, 2016).

To test our hypotheses, we use a panel data set of publicly traded German firms over the period 2002–2013, a time window that allows us to examine their efforts in developing IoT innovations since the emergence of the IoT concept (Ashton, 2009). The results confirm our hypotheses and show that increasing family involvement in the top management team leads to lower exploratory innovation efforts in the IoT domain. This negative relationship is enforced when firms are technologically diversified, especially in unrelated forms.

Our findings constitute the first attempt to provide empirical evidence of the influence of family management on a firm's transition toward digital transformation. Our main contributions are threefold. First, the study adds to recent research on digital transformation through IoT technologies (Ardito et al., 2018; Krotov,

2017) by offering insights on how companies may differ in their willingness to respond to discontinuities in their business through developing IoT innovations. Second, it provides novel insights into the role of family members in the TMT for innovation decisions by examining their specific influence on exploration and exploitation of (digital) innovation activities (Calabrò et al., 2019; Chrisman, Fang, Kotlar, and De Massis, 2015b). Finally, the results contribute to research focusing on the development of a firm's technology base and its technological diversification (Kim et al., 2016; Leten, Belderbos, and Van Looy, 2007) by highlighting the link to the digital transformation of firms.

Theoretical Framework and Hypotheses

IoT in the Digital Transformation Era

IoT is a fast-evolving, potentially disruptive technological innovation for many industries that expands the scope of conventional internet networks by allowing interactions and information processing among physical objects (Li, Xu, and Zhao, 2015; Manyika et al., 2013). Cisco predicts that there will be 50 billion interconnected smart devices by 2020 thanks to IoT solutions (Evans, 2011), while the McKinsey Global Institute estimates the economic impact of IoT at \$11.1 trillion per year by 2025 (Manyika, 2015). As a result, IoT is considered as one of the main components and drivers of a firm's digital transformation (Pflaum and Gölzer, 2018). As such, IoT is propelling the fourth industrial revolution (Industry 4.0) and opening new ways of rethinking core-business models by enabling changes in the nature of products (Andal-Ancion et al., 2003; Lyytinen et al., 2016; Nambisan, 2017; Schwab, 2017). Some main examples include the possibility to commercialize smart and connected products (e.g., appliances, thermostats, cars, watches, and many others), improve the fit of supply- and demand-focused processes, and adding digital services to physical products (Ardito et al., 2018; Lee and Lee, 2015). Furthermore, IoT is expected to blur the lines between technology and nontechnology firms, with opportunities as well as threats for incumbents and new entrants, hence, changing the overall competitive landscape (Krotov, 2017).

Despite these predictions and expectations, large-scale investments in the IoT domain are risky, and hence, still far from being realized (OECD, 2016). This is especially true when such investments are aimed at

offering innovative IoT products, where monitoring, controlling, and optimization are introduced as new product features and can go hand in hand with innovation in the business model such as servitization (Cenamor, Sjodin, and Pardia, 2017). Indeed, designing businesses based on delivering these IoT innovations is particularly complex due to the number/types of potential connected objects with only modest standardization of interfaces (Ardito et al., 2018; Feki et al., 2013) and the difficulty of predicting how/whether the innovating firm will be part of the evolving IoT and broader Industry 4.0 ecosystem (Westerlund et al., 2014). Therefore, managers struggle to keep pace with the technological evolution of IoT products and planning the related R&D investment decisions (Chen, Xu, Liu, Hu, and Wang, 2014).

This issue is exacerbated as firms are often required to manage the paradox of providing incremental functionalities to the purposes of existing products via IoT (e.g., exploitative innovation activities) versus developing entirely new purposes for existing products (e.g., disruptive business models that replace the traditional product's purpose) or integrated product-service offerings (e.g., exploratory innovation activities) (Bstieler et al., 2018; Ehret and Wirtz, 2017). Such a paradox lies in the fact that IoT innovations are rooted in a firm's knowledge about existing products and in the extent to which firms have to supplement core/established competencies with new technological skills to create value by investing in the IoT domain, while reducing risks and time to market (Saarikko, Westergren, and Blomquist, 2017). Thus, understanding what can effectively support and/or hinder a firm's development of IoT solutions is particularly important and urgent, especially considering that investing and engaging in the development of IoT innovations might lead to tensions between departing from the firm's existing knowledge base and maintaining continuity with current R&D trajectories.

In this context, Li et al. (2012, p. 209) state that “the tendency of whether firms leverage exploitative capability or exploratory capability reflects their investment attitudes, and influences the implementation effectiveness of different IoT strategies.” Often, the TMT primarily affects the attitudes and strategic commitment to (digital) innovation (Garms and Engelen, 2019; Hambrick and Mason, 1984) since an organization is a reflection of its TMT's attributes (Garms and Engelen, 2019; Hambrick and Mason, 1984). However, such attributes have scarcely been

related to the tendency to pursue exploitative and/or exploratory innovation activities in the IoT domain. Prior studies contend that TMT diversity is a crucial TMT attribute (Kraiczy et al., 2014). In particular, while the role of family-induced diversity (i.e., the presence of the family in the TMT) is gaining increasing attention among scholars and policymakers due to the relevance of family-managed firms in today's (digital) economy and the particular characteristics of such firms (Ling and Kellermanns, 2010; Minichilli et al., 2010), it remains an under-researched source of TMT diversity, which this study seeks to consider.

Finally, it is worth noting that knowledge about technologies that are complementary to IoT, such as those relevant in shaping the Industry 4.0 phenomenon (e.g., artificial intelligence, cloud computing, robotics, big data architectures, etc.), must not be neglected. Indeed, the potential of IoT is fully exploited when related products are supported by those solutions (Atzori, Iera, and Morabito, 2010; Xu, He, and Li, 2014). And IoT innovations are more and more deemed to require the simultaneous management of different, complementary technological areas, which are often general purpose in nature (e.g., cloud computing and artificial intelligence) and not always well-established in existing (mature) markets (European Commission, 2016; Li et al., 2015). As a result, in the analysis of the tensions between departing from the firm's existing knowledge base and maintaining continuity with current R&D trajectories, a firm's technological diversification gains increased explanatory power in understanding whether the focus on exploratory/exploitative innovation activities in the IoT domain is fostered/hindered by the TMT. Notably, technological diversification reflects the breadth of a firm's technology base, and so the potential to manage different technological knowledge (Ceipek et al., 2019). Still, it may have downsides that hamper, instead of pushing (e.g., Leten et al., 2007) the TMT intention to engage in innovation activities.

Family Management and Innovation

Family firms—defined as firms whose decisions are influenced by a family involved in the business that has the discretion to direct, allocate, add to, or dispose of a firm's resources in its strategic initiatives aimed at pursuing family-centered goals (De Massis, Kotlar, Chua, and Chrisman, 2014)—are ubiquitous in any world economy (De Massis, Frattini, Majocchi, and

Piscitello, 2018b; Miroshnychenko, De Massis, Miller, and Barontini, forthcoming). Given their relevance, such firms are at the core of current academic and political debates, and particular attention is placed on the complex and articulated effects that family-specific factors exert on innovation activities (Calabrò et al., 2019; Chrisman, Chua, De Massis, Frattini, and Wright, 2015a; Erdogan, Rondi, and De Massis, 2020; Kotlar, De Massis, Frattini, and Kammerlander, 2020; Kraus, Craig, Dibrell, and Märk, 2012). Indeed, family involvement in management, governance, and/or ownership, generates distinct innovation behaviors compared to firms without family involvement (Carnes and Ireland, 2013; Chrisman et al., 2015a; Matzler et al., 2015). Specifically, TMTs represent the upper echelons of a family firm, and their central role is undeniable in the family business literature (e.g., De Massis, Eddleston, and Rovelli, forthcoming), since they represent “the foremost intersection between the family and the business” (D’Allura and Bannò, 2019, p. 750; see also Binacci, Peruffo, Oriani, and Minichilli, 2016). Thus, distinctions are made between firms involving family members in the TMT (i.e., family management) and those without family managers (Sciascia, Nordqvist, Mazzola, and De Massis, 2015), especially in terms of innovation performance, albeit leading to mixed findings (Urbinati, Franzò, De Massis, and Frattini, 2017). On the one hand, some scholars claim that family involvement in the TMT allows firms to draw on rare and unique resources (Ashwin, Krishnan, and George, 2015; De Massis et al., 2013), which in addition to long-term orientation (Llach and Nordqvist, 2010), more intense personal commitment, and stronger managerial attention (Kammerlander and Ganter, 2015), might positively influence the firm’s ability to respond to technological changes, and ultimately increase innovation output (Gomez-Mejia, Haynes, Núñez-Nickel, Jacobson, and Moyano-Fuentes, 2007; Llach and Nordqvist, 2010; Manso, 2011; Matzler, Veider, Hautz, and Stadler, 2015). On the other hand, due to their long history with the firm, family managers view the firm as a part of themselves, and managerial attention is directed to family-centered noneconomic goals (Chrisman, Chua, Pearson, and Barnett, 2012; Kotlar and De Massis, 2013), leading to the propensity to preserve the family’s socioemotional wealth (Gomez-Mejia et al., 2007; Kotlar, Signori, De Massis, and Vismara, 2018). Thus, to protect their socioemotional wealth, family managers tend to adopt conservative strategic behaviors to

avoid risky innovation projects that threaten their socioemotional wealth priorities, such as keeping control in the hands of the family (Brinkerink and Bammens, 2018; Cassia, De Massis, and Pizzurno, 2012; Gomez-Mejia et al., 2007), even if potential economic benefits are offered (König, Kammerlander, and Enders, 2013; Kotlar, De Massis, Frattini, Bianchi, and Fang, 2013).

However, most of these arguments overlook the heterogeneity of innovation guided by family-managed firms (Calabrò et al., 2019), hence, calling for more research on family management and innovation performance. Specifically, the tensions and uncertainties in decisions to pursue exploratory/exploitative innovation activities (Arzubiaga, Maseda, and Iturralde, 2019; Dieleman, 2018) are today exacerbated by the digitalization megatrend, which may be a further source of disruption in firms with family management (KPMG, 2017). In this context, the top management characteristics that help unveil if exploratory/exploitative IoT innovations are developed have yet to be fully investigated. Therefore, in the following, the study examines the relationship between family management and IoT innovation.

Family Management and Innovation in the IoT Domain

Several characteristics of firms with family members in the TMT influence a firm’s decision to develop IoT innovations.

First, family managers tend to pursue family-centered noneconomic goals (e.g., family harmony, family social status), which are less associated with risk taking (Chrisman et al., 2012). Together with concentrated ownership and decision-making authority, this leads to higher risk aversion (Naldi, Nordqvist, Sjöberg, and Wiklund, 2007). As a consequence, family managers are likely to be more cautious and conservative in their investment decisions than managers of firms with widespread ownership (Shleifer and Vishny, 1986). IoT is characterized by high technological complexity in terms of diverse technologies and protocols, variety of devices (Ma, 2011), complementarity with multiple (digital) general purpose technologies, and the involvement of various actors who need to be coordinated. This complexity makes it difficult to assess the state-of-the-art of IoT innovations and develop clear R&D plans (Ardito et al., 2018) or digital business models (Sorescu, 2017). Hence, the development of IoT innovations may be associated with particularly high risks.

As family managers are likely to pursue family-centered noneconomic goals, they tend to be more risk averse, and will prefer exploitation over exploration, since exploitation benefits are more proximate, certain, and immediate (Chrisman et al., 2012, 2015b; Lavie, Stettner, and Tushman, 2010). Second, top managers belonging to a family usually have a longer tenure on the management board, with greater continuity in the firm's innovation trajectory (Calabrò et al., 2019; Lumpkin and Brigham, 2011). Such continuity might hinder IoT exploration, since it requires experimenting novel innovation trajectories, eventually breaking the established innovation routines set in firms with long tenure family members on the TMT. Third, family members have stronger emotional ties to existing assets, as family managers feel more emotionally tied to the prevailing resources and the firm's surrounding ecosystem (König et al., 2013). These ties with existing assets hamper exploration activities in firms with family management. For some firms, such as technology firms active in the software industry, the development of IoT innovations might be exploitative in nature. But for others, especially outside the software sector, engaging in IoT innovations might be an explorative move (Bstieler et al., 2018; Ehret and Wirtz, 2017; Li et al., 2012). IoT innovations may require firms to build new, digital business models and ecosystems to commercialize them (Rong, Hu, Lin, Shi, and Guo, 2015), sometimes making existing assets obsolete. They thus have to rethink “nearly everything they do, from how they conceive, design, and source products; to how they manufacture, operate, and service them; to how they build and secure the necessary IT infrastructure” (Porter and Heppelmann, 2014, p. 5), forcing the question “What business am I in?” (Porter and Heppelmann, 2014, p. 5). Hence, a family manager's emotional ties to existing tangible and intangible assets and ecosystems will reduce their willingness to innovate in exploratory IoT. Fourth, it has been argued that TMTs in family-managed firms become more rigid as family involvement in top management increases (König et al., 2013). These firms are characterized by higher continuity in the TMT (Lumpkin and Brigham, 2011), and tend to become more homogeneous with increasing family involvement (Sirmon and Hitt, 2003). Therefore, mental models become more rigid, and local search is reinforced (König et al., 2013). However, IoT is changing product concepts and related business models, which “stand as cognitive structures providing a theory of how to set boundaries to the firm, how to create value, and how

to organise its internal structure and governance” (Doz and Kosonen, 2010). Hence, business models reflect the mental models or schemas of managers (Martins, Rindova, and Greenbaum, 2015). Consequently, it is expected that more family members in the TMT will be associated with more rigid mental models and local search, hindering the development of IoT innovations that sensibly vary from existing product concepts and business models. Finally, firms with higher family management are less open to outsiders in decision making (Gomez-Mejia et al., 2010). Yet, engaging in IoT innovation activities often changes the allocation of decision-making power both within the organization and along the value chain (Helper, Martins, and Seamans, 2019). Specifically, the more exploratory the IoT innovation project, the higher the likelihood of this event, hence, making family-managed firms disregard exploratory IoT innovation projects. In fact, internally, information asymmetries between family managers and people with digital skills are likely to grow hand in hand with the exploratory nature of the IoT innovation projects, so decisions may be strongly affected by the digital experts (Belkhamza, 2019; Boston Consulting Group, 2017; Forbesinsight, 2017). Externally, due to coordination and standardization issues, as well as the necessity to tap into digital, complementary knowledge possessed by supply chain members, external organizations may have more power to interfere with internal decision-making processes (Ben-Daya, Hassini, and Bahroun, 2019).

These characteristics of family members in the TMT—focus on family-centered noneconomic goals, long tenure, emotional ties to existing assets, decision-making authority, and rigid mental models—will lead firms to avoid innovations that are distant from the firm's current technology base. And we argue that these characteristics of family-managed firms are especially relevant in the context of IoT innovations, as they pose particular challenges. First, IoT has the potential to fundamentally change how the product is designed, offering new ways of creating, delivering (e.g., servitization; see Rymaszewska, Helo, and Gunasekaran, 2017), and capturing value (e.g., pay-peruse, lending/renting/leasing; see Metallo, Agrifoglio, Schiavone, and Mueller, 2018). As highlighted above, IoT leads to more complex ecosystems, as a variety of objects interact and many players and stakeholders are connected in value creation activities (Rong et al., 2015). The emerging IoT ecosystems are typically unstructured, chaotic, and complex

(Westerlund et al., 2014). New relationships have to be established, participants have to be orchestrated, and positions in the ecosystem defined. The emergence of new business models and the creation of complex ecosystems around a new innovative IoT product may make firm assets obsolete or even disrupt long-standing businesses. Firms with increasing levels of family management, as argued above, may face particular challenges with such changes. Second, typical for digital technologies (Brynjolfsson and McAfee, 2014), IoT follows a pattern of exponential growth (Evans, 2011). Third, as a network of interconnected objects (Evans, 2011), IoT offers unprecedented and “virtually endless ways of combining an object, a thing, a business, and a consumer together” (Westerlund et al., 2014, p. 7). In a world of quickly exploding combinatorial possibilities, the challenge is to find the truly valuable opportunities, and processing the options fast enough becomes the biggest constraint (Brynjolfsson and McAfee, 2014). These two patterns that make the speed of adoption critical challenge firms with an increasing level of family management, as such firms are relatively slow at recognizing discontinuous technologies as relevant (König et al., 2013) and are reluctant to experimenting with novel innovation trajectories. Fourth, IoT has been described as an “immature” technology (Westerlund et al., 2014), meaning that IoT solutions are not yet fully standardized or modularized. Objects and devices from different producers often have different technical characteristics and specifications, divergent communication protocols, and use heterogeneous sources of information (Bujari et al., 2018). Lacking interoperability, combined with security and privacy concerns, make investments in IoT innovations difficult and risky, and the typically higher risk aversion characterizing firms with family management is expected to lead to lower engagement in exploratory IoT innovation. Hence, it is argued:

H1: Higher family management decreases the development of exploratory IoT innovations relative to exploitative IoT innovations.

The Moderating Role of Technological Diversification

Technological diversification reflects the choice to diversify a firm’s technological resource base over a broader range of different technological fields and

areas (Ceipek et al., 2019; Granstrand and Oskarsson, 1994). It defines the breadth of a firm’s knowledge system and technological competencies (Lai and Weng, 2014; Quintana-García and Benavides-Velasco, 2008; Piscitello, 2000). Technological diversification influences a firm’s capacity to combine and recombine stock of existing technological knowledge and assimilating new knowledge (Quintana-García and Benavides-Velasco, 2008). Thereby, it impacts a firm’s innovation activities and innovation performance, often resulting in higher R&D intensity and number of patents (Garcia-Vega, 2006; Nesta and Saviotti, 2005). Prior research has also highlighted the important impact of a firm’s level of technological diversification on its exploration and exploitation activities. Access and exposure to a variety of alternative technological knowledge domains influences a firm’s propensity to find new solutions. As technological diversification results in lower exploration costs than a specialization strategy, and earlier identification of new R&D opportunities, its impact on exploratory activities might be stronger than on exploitation (Arvanitis and Woerter, 2015; Quintana-García and Benavides-Velasco, 2008). This may also be true in the context of digital transformation, where IoT solutions require firms to manage diverse technological domains and their underlying complexities, especially with respect to the need to overcome constraints such as interoperability, standardization, and integrating product-service offerings, which might hamper the possibility of realizing effective business models based on IoT solutions (Ardito et al., 2018; Feki et al., 2013).

In firms with high family involvement in the TMT, however, a high level of technological diversification might hamper exploratory innovation activities, also with regard to the IoT domain. First, technological diversification increases R&D costs (Leten et al., 2007), which the family is often unable to cover entirely (Gomez-Mejia et al., 2010; Schulze, Lubatkin, and Dino, 2003). Therefore, family managers are forced to rely on external financial capital against their will (e.g., by floating on the stock market or through bank debt), thereby risking losing control of the firm to banks and/or shareholders (Perri and Peruffo, 2017; Schmid, Ampenberger, Kaserer, and Achleitner, 2015). Second, a high level of technological diversification requires a change in the routines and modus operandi of family-managed firms (George, Kotha, and Zheng, 2008; Lin and Chang, 2015). This may elicit reluctance among family managers, as they

prioritize maintaining the status quo and avoiding significant changes (Gomez-Mejia et al., 2010; Gomez-Mejia, Larraza-Kintana, Moyano-Fuentes, and Firfiray, 2018). Third, technological diversification leads to over-diversification issues, which hinder the recognition of the most valuable ideas while increasing the attention allocation problems for the TMT (Criscuolo, Dahlander, Grohsjean, and Salter, 2017; Ocasio, 1997). This implies that firms should open the doors to new external managerial talent, which might create tension due to the family managers' tendency to exclude outsiders' perspectives in the decision-making processes and protect the family inheritance (Bammens, Voordeckers, and van Gils, 2011; Gomez-Mejia et al., 2007). Such (reinforced) diversification problems tend to be particularly relevant when engaging in exploratory IoT development, since R&D costs of increased technological diversification add to the costs of entering into the IoT domain. The need to reshape the business as a consequence of technological diversification adds to the drastic changes arising from digital transformation, and the inability to screen the best ideas and pay attention to R&D activities is exacerbated by the difficulty of assessing the state-of-the-art of IoT technologies (Ardito et al., 2018; Feki et al., 2013).

To sum up, technological diversification implies diversification risks that are likely to be especially detrimental for family-managed firms because they tend to maintain a strong focus on the firm's core-business (Anderson and Reeb, 2003) and protect the family's socioemotional wealth (Gomez-Mejia et al., 2007), which leads them to innovate "in areas of technology that are adjacent to its existing technology platforms" (Gomez-Mejia et al., 2010). In turn, the desire of family-managed firms to keep control in the hands of the family will be stronger than their inclination to engage in riskier innovation projects (Gomez-Mejia et al., 2007; Jones, Makri, and Gomez-Mejia, 2008). Therefore, if a firm with a high proportion of family members in the TMT already has a high level of technological diversification, the benefit of additional risk diversification (e.g., exploring novel IoT solutions) will be lower than the cost of loss of control. Consequently, the firm will disfavor IoT innovations that are distant from the existing knowledge base. Hence, it is hypothesized:

H2: A firm's level of technological diversification reinforces the negative relationship between

family management and the development of exploratory IoT innovations relative to exploitative IoT innovations.

The Moderating Role of Related and Unrelated Technological Diversification

The previous section identified the risk mechanisms associated with technological diversification enforcing the negative effect of family management on the development of distant IoT innovations. However, prior studies have suggested that these mechanisms associated with the impact of technological diversification might even require a more nuanced approach (Kim et al., 2016; Kim, Lim, and Park, 2009). Following early research on firm scope (Rumelt, 1982; Teece, 1982), work on technological diversification has differentiated between types of diversification by drawing on the notions of "relatedness" and "unrelatedness" (Kim et al., 2009, 2016). Technological diversification is thereby split into two components. Diversification across broad categories of technology is described as broad-field or unrelated technological diversification. Diversification across, and within, narrow categories of technology is labeled as "core-field" or "related technological diversification" (Kim et al., 2016, p. 114).

While so far only limited empirical studies exist on considering such relatedness in technology (Kim et al., 2009, 2016), the following characteristics of unrelated and related technological diversification have been identified. Research has argued that technological development that goes toward unrelated forms of technological diversification is particularly risky (Kim et al., 2009), since the technological uncertainty associated with this strategy is high (Kim et al., 2016). Furthermore, increasingly unrelated technology leads to declining R&D productivity (Seru, 2014) and greater costs. Compared to related technological diversification, the costs of coordination, communication, and integration are substantial for unrelated technological diversification (Kim et al., 2016). In addition, the more unrelated the domains characterizing a firm's technology base are, the more the new managerial and technical talent needs to deal with multiple technology domains (Kim et al., 2016). Moreover, continuous development away from the firm's core over time weakens the focus on knowledge associated with its core technologies (Kim et al., 2016).

These arguments suggest that the negative effect of overall technological diversification on the relationship between family management and investments toward IoT exploratory innovations is mainly driven by unrelated technological diversification. The increased degree of risk, particularly associated with unrelated technological diversification, reduces the willingness to design completely new IoT products (Chrisman et al., 2012). Firms with family managers that begin to diversify their underlying technology into unrelated fields are increasingly in danger of destroying their core-business and related socioemotional wealth (Filser, De Massis, Gast, Kraus, and Niemand, 2018; Gomez-Mejia et al., 2007), thus, further reducing IoT exploration. In addition, the increased demand for new talent in unrelated technological diversification forces the firm to integrate external managerial talent, leading to the risk of losing control over their strategy to preserve the family inheritance (Gomez-Mejia et al., 2007). This, and their preference to avoid (technological) uncertainty (Lavie et al., 2010; Chrisman et al., 2012)—a strong element of unrelated technological diversification (Kim et al., 2016)—are supportive to assume that unrelated technological diversification leads to a negative effect on the development of exploratory digital IoT innovation. Therefore, the following hypothesis is proposed:

H3: The negative moderation effect of technological diversification on the relationship between family management and IoT exploration is driven by unrelated rather than related technological diversification.

Methodology

Sample

The hypotheses were tested on a sample of publicly traded German firms listed on a stock market index (Anderson and Reeb, 2003). The study focused on the German CDAX, a composite index including shares of all domestic companies listed on the Frankfurt Stock Exchange (Deutsche Börse Group, 2018; Matzler et al., 2015). We collected data for those sample firms on our variables from 2002 to 2013. As IoT was first mentioned in 1999 (Ashton, 2009), the time-frame was selected accordingly, allowing us to capture IoT data from the early 2000s. However, the potential

truncation of patent data used to measure IoT does not allow considering more recent years after 2013 (Hall, Jaffe, and Trajtenberg, 2001). German companies have made considerable efforts in leading IoT innovation, “hoping their early entry will secure them vital spots as machines begin communicating with each other to boost efficiency” (Handelsblatt, 2018). Furthermore, family-managed firms are particularly relevant in Germany, with almost half of the 250 largest companies in the hands of one or more families (KPMG, 2015), thus, an ideal context for our study. Indeed, Germany’s economic strength has been tied to the presence of this type of business organization (Berghoff, 2006; De Massis, Audretsch, Uhlaner, and Kammerlander, 2018a), making above-average investments in R&D and accounting for about 40% of exports (Deutsche Bank and Bundesverband der Deutschen Industrien, 2012). Finally, companies in the financial sector, brokers, insurance, and real estate companies (due to missing technology patent data), holdings, investment offices, as well as utilities and foreign subsidiaries (Matzler et al., 2015) were excluded. After excluding firms with missing data, the study arrived at a final sample of 46 firms in our unbalanced panel data set, resulting in 227 firm-year observations.

We collected data by combining multiple data sources. The technology-related variables, such as the IoT exploration index and the technological diversification measures, are based on patent data collected from Thomson Innovation (Stephan, Schmidt, Bening, and Hoffmann, 2017). While patent analysis, of course, has its drawbacks, as not all inventions are or can be patented (Griliches, 1990; Silverman, 1999), it is suitable in our research context. Patenting is a common practice among innovative organizations, are by definition related to inventiveness, and longitudinal patents data are publicly available (Ardito et al., 2018; Hagedoorn and Cloudt, 2003). In addition, in the standardized patent system, the technological domain(s) of patents are clearly recognized by ad hoc standard patent classifications (i.e., IPCs) so that specific types of technology embodied in inventions, such as IoT in this work, can be objectively identified, captured, and traced (Aharonson and Schilling, 2016; Ardito et al., 2018). Despite potential drawbacks, patents are a widely used data source to analyze innovation, technical change, and technology management (e.g., Kim and Lee, 2015; Messeni Petruzzelli, Natalicchio, and Garavelli, 2015; Quintana-García and Benavides-Velasco, 2008). To

construct the family-related variables, we relied on data collected annually from the OSIRIS ownership database provided by Bureau van Dijk (Muñoz-Bullón and Sanchez-Bueno, 2011). These data were complemented and cross-checked with information from annual reports, websites, national directories, and yearbooks (e.g., “Wem gehört die Republik” and “Hoppenstedt Aktienführer”). Annual data on other firm-related control variables were collected from the Worldscope database.

Variables

Dependent variable—IoT exploration index. To capture whether newly developed IoT innovations are close to or distant from an organization’s current innovation trajectories, we constructed a continuous distance measure following Gilsing, Nooteboom, Vanhaverbeke, Duysters, and van den Oord (2008). For every year, we first identified all new IoT patents, and then, determined whether a particular IoT patent is exploratory or exploitative in nature.

To identify IoT patents for a given firm, the classification of Ardito et al. (2018) was employed. This classification scheme was developed through a search strategy based on the International Patent Classification (IPC) codes proposed by the U.K. IP Office (2014). Based on prior literature on IoT and on feedback from experts in the field in terms of clarity, specificity, and representativeness, Ardito et al. (2018) identified IPC codes that best describe the different technologies pertaining to IoT. According to the classification scheme of Ardito et al. (2018), a patent is classified as belonging to the IoT domain

if at least one of its IPC codes is included in one of 10 specific classes defined in Table 1 that fall into the four broad technological categories of network systems technologies (H04L12/28, H04W84/18, and H04W4/00), communication control technologies (H04L29/08, H04L29/06, and G05B19/418), wireless transmission technologies (G08C17/02, H04B7/26, and H04W72/04), and data processing technologies (G06F15/16).

For each identified IoT patent, it was subsequently determined whether it represents an exploratory or exploitative move according to Gilsing et al. (2008). Consistent with our theoretical framework, exploration is defined as the creation of knowledge that is novel to a firm’s extant knowledge base, while exploitative innovation behavior describes the accumulation of experience within an existing knowledge base (Katila and Ahuja, 2002). The more frequently a firm uses and builds on existing knowledge, the more exploitation the firm undertakes. According to Gilsing et al. (2008), research has suggested that a moving window of 5 years is an appropriate time-frame for assessing the technological impact of prior inventions (Ahuja, 2000; Henderson and Cockburn, 1996; Podolny and Stuart, 1995; Stuart and Podolny, 1996). Thus, for every IoT patent within a four-digit IPC class, it was checked whether the firm had received another patent in this respective subordinate four-digit IPC class in the previous 5 years. If the firm had successfully applied for a patent in the previous 5 years in the respective four-digit IPC class, the particular IoT patent was coded as exploitative (Gilsing et al., 2008). If instead the firm had not received a patent in the previous 5 years in the respective four-digit

Table 1. International Patent Classification (IPC) Classes in the IoT Domain (Ardito et al., 2018)

IPC Code	Description
G05B019/418	Total factory control, that is, centrally controlling a plurality of machines, for example, direct or distributed numerical control (DNC), flexible manufacturing systems (FMS), integrated manufacturing systems (IMS), computer integrated manufacturing (CIM)
G06F015/16	Combinations of two or more digital computers each having at least an arithmetic unit, a program unit and a register, for example, for simultaneous processing several programs
G08C017/02	Using a radio link
H04B007/26	At least one of which is mobile
H04L012/28	Characterized by path configuration, for example, LAN [Local Area Networks] or WAN [Wide Area Networks] (wireless communication networks H04W)
H04L029/06	Characterized by a protocol
H04L029/08	Transmission control procedure, for example, data link level control procedure
H04W004/00	Services or facilities specially adapted for wireless communication networks
H04W072/04	Wireless resource allocation
H04W084/18	Self-organizing networks, for example, ad hoc networks or sensor networks

IPC class, the IoT patent was coded as exploratory (Gilsing et al., 2008). Since Gilsing et al. (2008) also argue that knowledge domains remain relatively new and unexplored for a firm immediately after patenting, exploratory IoT patents in our data set maintain their exploratory “status” for three consecutive years (Ahuja and Lampert, 2001). After determining the exploratory or exploitative status of each IoT patent, we summed up the number of exploratory and exploitative IoT patents for each firm year.

In our subsequent analysis, we do not use these numbers of exploratory and exploitative IoT innovations as two separate variables. Rather a continuous index was constructed that sets these two types of IoT innovations in relation to each other, yielding the importance of exploratory IoT innovation relative to total (exploratory and exploitative) IoT innovation:

$$\text{IoT Exploration Index} = \frac{\sum \text{exploratory IoT}}{\sum \text{exploratory IoT} + \sum \text{exploitative IoT}}$$

The sum of exploratory IoT patents is divided by the sum of exploitative IoT patents plus the sum of exploratory IoT patents. This results in a continuous measure that ranges between 0 and 1, where 0 indicates that all IoT patents of a firm in a given year represent exploitative moves close to the current technology base, while 1 indicates that all IoT patents of a firm in a given year are exploratory and more distant from the existing technology base (Gilsing et al., 2008). Hence, the higher a firm scores on this measure, the more distant and exploratory the newly developed IoT technology is from the firm’s existing technology base.

Independent variable—Family management. In contrast to most prior studies, family management was not defined dichotomously depending on whether or not a family member serves in the top management team. Rather, we continuously capture the extent of active family involvement in the TMT by calculating the ratio of the number of family members on the TMT divided by the firm’s total number of top management team positions for each year (Klein, 2000; Matzler et al., 2015). Under German commercial law, all members of the management board are defined as members of the top management team, are legally and collectively responsible for the corporate management, and have to be listed in annual

reports, enabling the consistent identification of the TMT (Hutzschenreuter and Horstkotte, 2013). We cross-checked and complemented the data from the OSIRIS ownership database provided by Bureau van Dijk (Muñoz-Bullón and Sanchez-Bueno, 2011) with information on firm and family histories from annual reports, websites, national directories, and yearbooks (e.g., *Wem gehört die Republik* and *Hoppenstedt Aktienführer*). These additional sources also provided specific top management biographies that allowed identifying family members. To avoid any bias resulting from focusing only on matching surnames, we investigated the family histories over the long run, also taking into account changes in surnames (Amore, Garofalo, and Minichilli, 2014).

Moderator variable—Technological diversification. To capture a firm’s level of breadth in the underlying technology base, the entropy index of diversification was employed (Jacquemin and Berry, 1979; Palepu, 1985). We collected and counted all patent applications and grants at their priority year. The priority year was chosen over the grant or application date, as it is closest to the actual invention date (Ernst, 2001; OECD, 2009). This allowed us to assign each patent through its primary IPC code to hierarchically ordered broader three-digit level classes and corresponding four-digit level narrow classes. Following prior research (Kim et al., 2016), both the overall level of the entropy index, as well as related and unrelated technological diversification were measured. The overall level of technological diversification (TD_{it}) is determined in the following way:

$$TD_{it} = \sum_{k=1}^{639} PS_{ikt} \ln \left(\frac{1}{PS_{ikt}} \right).$$

PS_{ikt} captures the share of patents of firm i in the technology area k . The priority year equals the observation year. $\ln(1/PS_{ikt})$ is a weighted share for each technology area for each year. The smallest value of the index is 0, which indicates technological focus. The higher the value of the index, the more diversified the firm is in its underlying technology.

We then determined both related ($TD_{rel_{it}}$) and unrelated ($TD_{unrel_{it}}$) technological diversification, splitting the overall entropy index into its two

components ($TD_{it} = TD_unrel_{it} + TD_rel_{it}$) (Kim et al., 2016):

$$TD_{it} = \sum_{j=1}^{130} PS_{ijt} \ln \left(\frac{1}{PS_{ijt}} \right) + \sum_{j=1}^{130} PS_{ijt} \left(\sum_{k \in j} PS_{ikt} \ln \left(\frac{1}{PS_{ikt}} \right) \right).$$

PS_{ijt} is the share of patents in the field j for every year t , and can be written as $PS_{ijt} = P_{ijt}/P_{it}$, where P_{ijt} is the number of patents for firm i in technology area j for year t . Further, k describes all the subclasses of technology area j . The first part of the equation is the unrelated component of technological diversification across the 130 broader technology areas, the second part is the related component of technological diversification. This captures the weighted average diversification across the 639 narrow technology areas within the broader 130.

Control variables. In our model, we control for a number of firm and ownership/governance level factors. In line with prior family and innovation research (Matzler et al., 2015; Miller, Minichilli and Corbetta, 2013, we rely on *firm age (log)*, defined by years since establishment (Lee and O'Neill, 2003; Zahra, 2003), to control for the possibility of entrenchment in family firms (Chrisman and Patel, 2012), and as prior research has shown that age plays a role in innovation quality (Balasubramanian and Lee, 2008). Further, *firm performance*—measured by its return on assets (RoA)—is considered to control for its influence on strategic decisions regarding innovation investment (Barker and Mueller, 2002) and the firm's motivation to engage in emerging digital technology (Ceipek, Hautz, Petruzelli, De Massis, and Matzler, 2020). We further consider *firm size (total assets)* since it might not only impact a firm's available capabilities and resources to engage in innovation, but also causes inertia in these innovation activities (Chen and Hambrick, 1995). The model also controls for *firm capital intensity* and *firm leverage*, two variables that control for the financial structure of the firm (Acquaah, 2012; Anderson and Reeb, 2003; Miller et al., 2013; Stadler et al., 2018). Firm capital intensity is determined by the ratio of capital expenditures to total assets (Stadler et al., 2018). According to the literature, family firms show lower debt levels when compared to nonfamily firms (Naldi et al., 2007; Villalonga and Amit, 2006). Thus, firm leverage, defined as a company's total debt divided by its total assets, was

included (Hoskisson and Hitt, 1988; Munoz-Bullon and Sanchez-Bueno, 2011). In addition, we included firm *R&D intensity* as an indicator for the firms' commitment to innovation and research (Grilliches, 1981) and *technology (patent) stock* to control for differences in general technological innovation competence (Fai and Tunzelmann, 2001). Finally, the model controls for *TMT size* as an indicator of the team's ability to process extensive information and to make decisions (Haleblian and Finkelstein, 1993). The active presence of the *founder in the firm* (indicating visionary steadiness), *family ownership* (equity owned by family members), and *family governance* (proportion of family members on the supervisory board) are also controlled for to capture the family's influence on strategic decisions through their equity share and their impact in the second important steering committee in German firms (Matzler et al., 2015; Klein, 2000). We also included year dummies to control for time effects. Given our estimation method capturing firm fixed effect time-invariant unobserved firm attributes (see next section), it was unnecessary to control for factors such as industry or headquarter location (Miller et al., 2013).

Results

To estimate our coefficients, we applied an OLS panel data fixed effects regression model (Greene, 2012; Hohberger, Almeida, and Parada, 2015). The Hausman test revealed that the fixed effects model is preferred over the random effects model (Hausman, 1978). The fixed effects model allows controlling for sources of unobserved firm heterogeneity (Greene, 2012). To control for potential endogeneity, our independent variables were lagged by 2 years, as suggested in previous studies (Kim et al., 2016). As the study deals with strategic decisions and technology outcomes, our lags are also consistent with prior research stressing substantial time lags between strategic changes and measurable impacts (Lamont, Williams, and Hoffman, 1994).

Table 2 reports the descriptive statistics and pairwise correlations, which present values below the .70 critical level, thus, reducing multicollinearity concerns (Cohen, 2003). In Table 3, our regression results are presented. Model 1 shows the results of the base model including only the control variables and their coefficient estimates. The coefficients of control

Table 2. Descriptive Statistics and Correlation Matrix

Variables	Mean	Std Dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 IoT exploration	.313	.436	1																
2 Firm age	79.070	55.067	-.0575	1															
3 Firm age (log)	4.006	.970	-.1002	.9349*	1														
4 Firm performance	5.964	11.761	-.0366	-.0367	.0575	1													
5 Firm size	4.21e+07	7.45e+07	-.3060*	.2254*	.2779*	-.0815	1												
6 Firm capital intensity	6.403	6.651	-.1030	-.1365*	-.1635*	-.1781*	.1909*	1											
7 Firm leverage	.685	.922	-.2372*	.1662*	.2051*	-.1707*	.6288*	.2200*	1										
8 R&D intensity	7.681	11.981	.0614	-.3137*	-.3975*	-.1270	-.1527*	.0214	-.2039*	1									
9 Technology stock	458.652	821.158	-.3524*	.3926*	.2937*	-.0338	.4191*	-.0238	.0776	-.0586	1								
10 Founder in firm	.474	.501	.3134*	-.2962*	-.2921*	-.0538	-.2420*	.0411	-.1023	.1595*	-.2629*	1							
11 Family ownership	.243	.227	-.0068	-.1239	-.0364	.3347*	-.0573	-.0192	-.1061	.0282	-.2055*	-.3117*	1						
12 Family governance	.067	.087	.0082	-.1724*	-.0970	.2050*	-.0813	.0082	-.1648*	.0616	-.1105	-.0047	.5723*	1					
13 TMT size	5.159	2.308	-.3408*	.2128*	.2602*	.0252	.5644*	.1211	.4114*	-.1083	.3061*	-.1356*	-.0218	-.1715*	1				
14 Family management	.036	.095	.1117	-.3873*	-.3799*	.0370	-.2169*	.0860	-.2085*	.1367*	-.1980*	.3152*	.2913*	.1438*	-.1697*	1			
15 Tech. Div.	2.818	1.167	-.2590*	.6699*	.6313*	-.0795	.5134*	.1041	.3781*	-.2947*	.5382*	-.4378*	-.1258	-.2399*	.3804*	-.3308*	1		
16 Unrelated Tech. Div.	2.028	.921	-.1024	.7064*	.6615*	-.0725	.3912*	.0329	.3328*	-.3487*	.4537*	-.3992*	-.1368*	-.2724*	.2676*	-.3235*	.9510*	1	
17 Related Tech. Div.	.790	.407	-.5102*	.3216*	.3125*	-.0630	.5812*	.2226*	.3273*	-.0544	.5159*	-.3525*	-.0508	-.0702	.4848*	-.2133*	.7141*	.4626*	1

* $p < .05$

Table 3. Results of Panel Data Regression

	DV: IoT Exploration Index						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Firm age (log)	.123 (.60)	.050 (.25)	.058 (.30)	.073 (.37)	.103 (.52)	.062 (.31)	.118 (.59)
Firm performance	−.003 (−1.08)	−.003 (−1.10)	−.003 (−1.20)	−.003 (−1.16)	−.003 (−1.26)	−.003 (−1.18)	−.003 (−1.25)
Firm size	.000 (1.54)	.000* (1.90)	.000* (1.81)	.000* (1.89)	.000* (1.79)	.000* (1.87)	.000* (1.79)
Firm capital intensity	−.007 (−1.29)	−.003 (−.54)	−.004 (−.78)	−.002 (−.46)	−.004 (−.75)	−.003 (−.52)	−.004 (−.73)
Firm leverage	−.025 (−.36)	−.030 (−.44)	−.036 (−.53)	−.029 (−.42)	−.032 (−.48)	−.032 (−.46)	−.030 (−.44)
Firm R&D intensity	−.002 (−.54)	−.002 (−.61)	−.003 (−.66)	−.003 (−.72)	−.003 (−.72)	−.003 (−.74)	−.003 (−.70)
Firm technology stock	.000 (.19)	−.000 (−.06)	−.000 (−.15)	.000 (.04)	.000 (.05)	−.000 (−.05)	.000 (.15)
Founder in firm	.056 (.49)	.085 (.77)	.075 (.68)	.081 (.74)	.067 (.61)	.081 (.73)	.065 (.59)
TMT size	.014 (.95)	.013 (.92)	.012 (.82)	.012 (.86)	.011 (.76)	.012 (.84)	.011 (.76)
Family ownership	.018 (.07)	.157 (.60)	.176 (.67)	.170 (.64)	.178 (.68)	.178 (.67)	.171 (.65)
Family governance	−.276 (−.56)	−.961* (−1.85)	−1.073** (−2.07)	−1.031* (−1.96)	−1.121** (−2.15)	−1.061** (−2.00)	−1.104** (−2.11)
Family management		−1.113*** (−3.05)	−.341 (−.62)	−1.169*** (−3.15)	−.193 (−.33)	−1.025** (−2.34)	−.198 (−.34)
Tech. diversification		−.158*** (−2.84)	−.068 (−.93)				
Family management × Tech. diversification			−.492* (−1.89)				
Unrelated Tech. diversification				−.115 (−1.56)	−.007 (−.08)	−.105 (−1.39)	−.002 (−.02)
Related Tech. diversification				−.249** (−1.26)	−.193 (−1.62)	−.191 (−2.11)	−.243 (−1.60)
Family management × Unrelated Tech. diversification					−.810** (−2.18)		−.923** (−2.15)
Family Management × Related Tech. diversification						−.367 (−.61)	.361 (.53)
Observations	227	227	227	227	227	227	227
No. of firms	46	46	46	46	46	46	46
R-squared (within)	.134	.214	.232	.218	.241	.220	.243

Note: *t* statistics in parentheses, time dummies excluded, 2-year lag between dependent and independent variables.

p* < .10, *p* < .05, ****p* < .01.

variables across our models indicate that increased firm size is positively related to IoT exploration. This might be explained by the greater potential of large firms to recombine existing technologies in the exploration of digital technology (Carnabuci and Operti, 2013). Contrary to prior research emphasizing the effect of technology stock on technological innovation (Fai, 2003; Fai and Tunzelmann, 2001), no significant effect was found. While a positive effect for firm size in general is observed, the mere size of the

technology stock shows no significant effect, suggesting that noncodified knowledge present in large firms might support IoT exploration. Against our expectations, also R&D intensity as a relative measure of innovation commitment has no significant effect on IoT exploration. This might be because innovation in explorative digital technology requires R&D investment specifically in those areas, which we potentially do not capture with the broad R&D intensity measure. In line with our hypothesis 1, our control for

more family members in the supervisory board has a significant negative effect supporting the assumption that family influence not only in the top management team, but also in the supervisory board leads to a negative impact on explorative behavior in the context of digital technology. Finally, also our age control variable is not significant, rejecting the assumption that younger firms are better at exploring distant digital technologies.

Model 2 adds family management to analyze its impact on IoT exploration. With a negative significant impact of family management ($\beta = -1.113$, $p = .003$) on IoT exploration, we find support for H1. Hence, a higher proportion of family members in the TMT leads to less engagement in the development of IoT innovations that are distant from the existing technology base. Conversely, increasing focus is placed on exploitative IoT innovations. To investigate the moderating effect of the overall level of technological diversification on the relationship between family management and IoT exploration, the interaction term in Model 3 was added. Our findings provide support for H2, as we find a significant negative interaction term between family management and overall technological diversification ($\beta = -.492$, $p = .060$). Hence, the negative impact of family involvement on IoT exploration is reinforced in firms with a broader technological portfolio. This indicates that the broader the technology portfolio in terms of diversification across different technology classes, the more firms with a higher proportion of family managers are reluctant to engage in exploratory IoT innovation development. In Model 4, the related and unrelated technological diversification components were introduced. Models 5–7 add the interaction terms between unrelated technological diversification and family management and between related technological diversification and family management separately (Models 5–6) and jointly (Model 7). According to these models, support is established for H3. While the coefficient for the interaction term with unrelated technological diversification is negative and significant (Model 7, $\beta = -.923$, $p = .033$), the interaction with related technological diversification is not significant. This suggests that especially unrelated forms of technological diversification reinforce the negative effect of family management on the exploration of distant IoT technologies.

To further support our moderation findings, we conducted a simple slope analysis for our significant interaction effects. Both for overall and unrelated

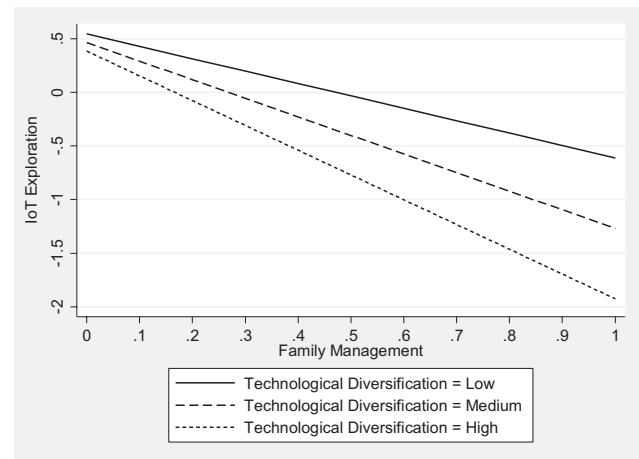


Figure 1. The Moderating Effect of Technological Diversification

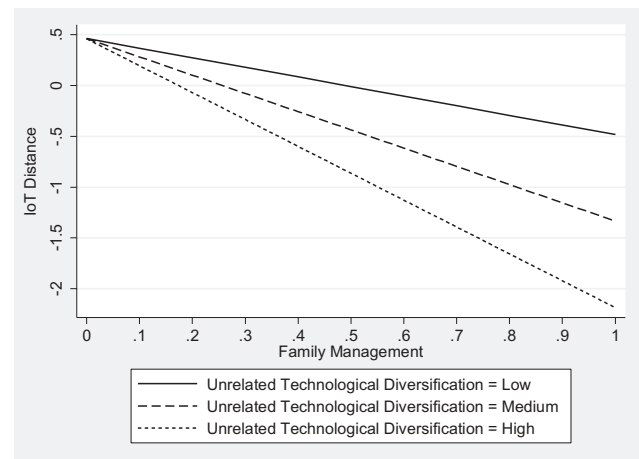


Figure 2. The Moderating Effect of Unrelated Technological Diversification

technological diversification, two levels of technological diversification were considered—low (one standard deviation below the mean) and high (one standard deviation above the mean)—estimating the effect of family management on IoT exploration for both levels. Figures 1 and 2 show the estimations, confirming that at high levels of overall and especially unrelated technological diversification, the negative effect of family management on IoT exploration is more pronounced.

Robustness Tests

We performed a series of robustness test to ensure the validity of our results. First, the robustness of our IoT exploration index measure was tested. We used the share of exploratory IoT patents and the

share of exploitative IoT patents as two separate dependent variables instead of the IoT exploration index. Our results are supported, as we find a significant negative effect of family management on the share of exploratory IoT patents, and a significant positive effect of family management on the share of exploitative IoT patents. Second, alternative measures to account for family involvement were used. We captured active family involvement in management and governance simultaneously by summing-up the proportion of family members in the TMT and in the supervisory board, accounting for the cumulative influence of the family in steering committees. In addition, we captured family involvement in management with a dummy indicating whether the founder is the CEO. In both cases, the results of Model 2 are confirmed.

To check the robustness of the technological diversification moderation variable, we ran several models measuring technological diversification with entropies on different IPC patent hierarchy levels, for example, IPC one- and three-digit level (Kim et al., 2016) or the World Intellectual Property Organization's (WIPO) 35-classes classification (Schmoch, 2008). Furthermore, our entropy measure was replaced with an inverse Herfindahl–Hirschman index (HHI) of diversification, another commonly used measure to determine technological breadth (Corradini, Demirel, and Battisti, 2016). Our results concerning the negative moderation effects of technological diversification remain robust across all models. In addition, when running interactions between family governance and technological diversification, the effect remains unchanged.

To check robustness concerning the moderating effect of related and unrelated technological diversification, we took the HHI core- and broad-field technological diversification measure to replace our entropy measures (Kim et al., 2009; Lin, Chen, and Wu, 2006). Broad-field diversification is technological diversification measured over all classes on the IPC one-digit level. Core-field diversification is the HHI on the three-digit level in the firm's core technology class, the category where the firm has the most patents. While we find a strong negative moderating effect of broad-field diversification, there is also a slight negative effect of core-field diversification. Hence, while we again find a strong negative moderation effect of unrelated (broad) forms of diversification, we also find that even diversification

within the firm's core patent class increases the negative main effect.

Discussion

IoT is a potentially disruptive technology for many industries and firms. In this paper, we have investigated the effect of top management characteristics on a firm's development of IoT innovations. Specifically, we have studied whether firms with family members in the TMT tend to develop IoT innovations that are closer to their technological core (i.e., exploitative) or more distant from their existing knowledge base (i.e., exploratory). It is argued that the specific characteristics of firms with family management in terms of family-centered noneconomic goals (Chrisman et al., 2012), long TMT tenure (Lumpkin and Brigham, 2011), stronger emotional ties to tangible and intangible assets, decision-making authority, and rigid mental models (König et al., 2013) lead to lower investments in IoT innovations of an exploratory nature as family involvement in management increases. Furthermore, we assessed whether and how the diversification of the existing technology base influences decisions to develop more exploratory versus exploitative IoT innovations (Quintana-García and Benavides-Velasco, 2008). The results reveal that technological diversification, especially in unrelated forms, further reinforces the relationship between family management and the development of exploratory IoT versus exploitative IoT innovations. This is ascribed to theories suggesting that family-managed firms are less inclined to add diversification risks (Gomez-Mejia et al., 2010; Schulze et al., 2003), such as those associated with innovation in IoT, when they already pursue unrelated technological diversification strategies.

These findings offer a number of theoretical and managerial implications to the emerging literature on digital transformation, to the literature on the role of TMT, particularly in family businesses, and to technological diversification literature. From a theoretical standpoint, the study contributes to the debate on how the transition toward digital transformation is organized and governed, since it creates more complex innovation dynamics (Nambisan, 2017), as in the case of the IoT context (Ardito et al., 2018). It has been argued that “there are too many possibilities and uncertainties in business models and application scenarios for IoT” (Chen et al., 2014, p. 357; see also

Saarikko et al., 2017). This complexity coupled with the scale, the scope, and the speed associated with digital transformation (Vial, 2019) poses considerable challenges in explaining why, how, and to what extent companies engage in digital transformation. Previous studies have taken different approaches to explain digital transformation. Some studies proposed maturity models to explain differences in digital transformation (e.g., Mittal, Khan, Romero, and Wuest, 2018). Others discuss the role of external drivers of digital transformation (e.g., digital technology, digital competition, digital customer behavior) and the required resources, structures, strategies, and metrics (Verhoef et al., 2019). In an extensive review of the digital transformation literature, Vial (2019) proposes a research agenda to understand digital transformation and highlights the role of organizational dynamic capabilities as a theoretical foundation to explain a company's engagement in digital transformation. The three main mechanisms *sensing*, *seizing*, *transforming* (Teece, 2007) are seen as the enablers for digital transformation. While being conceptualized as organizational capabilities, they are shaped by dynamic managerial capabilities (Helfat and Martin, 2015) and Vial (2019) argues that understanding how digital transformation unfolds in practice requires a micro-foundational perspective on these capabilities: "The literature on DT [digital transformation] highlights changes to an organization's leadership structure as an important enabler of new business models" (p. 134). Our study contributes to this literature by showing how TMT composition (i.e., family involvement in management) influences innovation activities in the IoT domain (e.g., Sia, Soh, and Weill, 2016; Vial, 2019; Weill and Woerner, 2018). The results show that the increasing involvement of family members in the top management team leads to less development of exploratory IoT innovations but increases the focus on exploitative IoT innovations. We thereby highlight which companies are more capable of proposing discontinuities in their business by developing exploratory IoT. Furthermore, we add to research on IoT in general, and to the body of knowledge on the determinants of IoT innovation development in organizations in particular, as we extend prior IoT research focused predominantly on the micro-technology (Feki et al., 2013) and macrocountry level (Ardito et al., 2018). In turn, our study contributes to the literature on the role of TMT composition in strategic decision making in firms in general by adding family management as an important driver, and to

the family business literature in particular by showing how family involvement in the TMT influences exploration and exploitation decisions (Goel and Jones, 2016), particularly in the context of IoT.

Relatedly, this study complements prior research examining innovation in family firms (Arzubiaga, Kotlar, De Massis, Maseda, and Iturralde, 2018; Chrisman et al., 2015a; De Massis et al., 2013; Muñoz-Bullon, Sanchez-Bueno, and De Massis, forthcoming), which is still characterized by mixed evidence, especially in relation to innovation outputs such as patents (De Massis et al., 2013). Indeed, our study refers to a specific type of innovation (IoT innovations), distinguishing between its exploratory and exploitative nature, and focuses on family involvement in the TMT to unearth certain aspects of the heterogeneity of family firm innovation (Calabrò et al., 2019). Our findings especially regarding exploratory IoT innovations are of particular interest to the literature that investigates the adoption of discontinuous technologies of family firms (Kammerlander and Ganter, 2015; König et al., 2013). While there is increasing interest in understanding innovation in family firms and much progress has been made in explaining heterogeneity in innovation input and output (e.g., Chrisman et al., 2015a; Duran, Kammerlander, Van Essen, and Zellweger, 2016; Matzler et al., 2015), the context of discontinuous technologies has been largely neglected by empirical work (Kammerlander and Ganter, 2015). Furthermore, a recent literature review on family firm innovation concludes that "the important issue of TMT and board of director composition, which has been shown to have direct and additive effects on innovation inputs" (Calabrò et al., 2019) is largely overlooked. The authors explicitly call for studying the effect of the proportion of family and nonfamily members on innovation. Our study contributes to closing this gap.

Finally, this study also contributes to the technological diversification literature. Prior research has found that technological diversification exposes firms to a variety of knowledge domains, supporting their exploration efforts (Quintana-García and Benavides-Velasco, 2008). However, in the case of family management and (IoT) digitalization, our study shows contradicting results. In fact, increased technological diversification, especially in unrelated forms (Kim et al., 2016), may come with an additional loss of control as well as changes in innovation trajectories and socioemotional priorities. Therefore,

firms with high family involvement in the TMT and a high level of (unrelated) technological diversification favor IoT exploitation over exploration. Our findings thus provide important contributions to the underdeveloped literature on the effects of relatedness in technological diversification (Kim et al., 2009, 2016), as well as to the specific literature on diversification decisions of family firms (Gomez-Mejia et al., 2010; Jones et al., 2008). Broadly speaking, we unveil that the variety of technological competencies underlying technologically diversified firms are not always beneficial in following the Industry 4.0 paradigm, despite the conventional wisdom hints the contrary because digital transformation is characterized by the complementarity of multiple technological domains and solutions. This seemingly surprising finding has its roots in the fact that managerial aspects related to technological diversification have been considered only to a limited extent in the digital transformation literature. The ability to manage multiple, rapid-changing technological competencies, that is, digital ones, especially if leading to dramatic changes in existing R&D trajectories, should not be taken for granted. Indeed, TMTs are not all similar, and some TMT characteristics (e.g., family-induced diversity) do not necessarily match with increasing technological diversification for exploratory digital innovation activities.

From a practical standpoint, it is suggested that the involvement of family members in the TMT constrains the development of exploratory IoT innovation. Therefore, TMT composition in firms that intend to be at the forefront of the digital transformation should be accurately designed by avoiding a high proportion of family members in the TMT. Considering that the benefits of family management should not be underestimated, firms may instead develop control or incentive mechanisms that mitigate the influence/emergence of family members' traits (e.g., family-centered noneconomic goals, long tenure, emotional ties to existing assets, and rigid mental models) that go against exploratory innovation attitudes. The literature on digital transformation often argues that the appointment of a CDO (Chief Digital Officer) is an important step to undertake a digital transformation (e.g., Sia et al., 2016; Weill and Woerner, 2018). As it has been argued in this paper, several characteristics of family members in the TMT (focus on family-centered noneconomic goals, long tenure, emotional ties to existing assets, and rigid mental models) lead

firms to avoid innovations that are distant from the firm's current technology base. The appointment of a nonfamily CDO might be an important measure to overcome some of these barriers. Understanding how such organizational changes can be implemented to better sense changes, seize opportunities, and transform the organization has the potential to offer an important contribution to digital transformation research (Vial, 2019).

In addition, diversification decisions of firms with family management, besides product, and international diversification, should include technological diversification. Family-managed firms should be aware that the potential benefits of technological diversification for exploratory innovation, with particular reference to the IoT domain, may turn into disadvantages when family management is predominant due to perceived excessive diversification risks, even if such risks may not be related to economic/innovation performance but to a family's socioemotional wealth priorities. Specifically, managers are advised that the negative contingent effect of technological diversification on the relationship between family management and exploratory IoT innovation is especially due to unrelated technological diversification. In other words, a technology base which is more diversified across unrelated (instead of related) domains reinforces the reluctance of family-managed firms toward exploratory IoT innovation opportunities.

In essence, the transition toward digital transformation is not straightforward (Correani, De Massis, Frattini, Messeni Petruzzelli, and Natalicchio, forthcoming), and technologically diversified family-managed firms are likely to face more difficulties in this sense, especially when such transition involves the development of digital innovations distant from current innovative trajectories. We have underlined the importance of top management antecedents for understanding business digitalization moves, highlighting that such factors can explain differences in the propensity of firms to develop IoT innovations, and that acknowledging existing resources and the socioemotional priorities of family-managed firms is a valuable basis to further explain such differences.

As with most studies, this paper presents some limitations that may open new lines of inquiry for the future. First, there may be generalizability issues due to the specific national context where historical, economic, and cultural conditions may affect the nature

of family managers and the type of firms considered. Our study is limited by its reliance on a specific sample of publicly traded German companies, which leaves out nonlisted privately held firms, such as many SMEs. Future research could, therefore, consider different national contexts and privately held firms including SMEs. Likewise, certain sectors have (correctly) been excluded for methodological reasons (i.e., patent data availability), hence, calling for research aimed at corroborating our results in different industry contexts and sectors. Second, additional variables, such as the generation of family control and management may influence our hypothesized relationships. Unfortunately, such data were unavailable for our study, and we invite future scholars to investigate generational effects in the digital transformation of family-managed firms. Third, this study refers to technological diversification as an additional source of diversification, besides exploratory innovation efforts, consistent with the strong technology-based nature of the IoT context. Nevertheless, additional moderators from diversification research may be employed in future studies (e.g., R&D internationalization), also considering that IoT might disrupt a firm's business across sectors globally. Finally, this paper relies on patent data, which provides an imperfect proxy of innovation and technological diversification activities and brings some drawbacks. Not all inventions are patentable since they may not meet patentability criteria (Choi, Kim, and Park, 2007; Dernis, Guellec, and Van Pottelsberghe, 2001) and firms may also prefer other mechanisms to protect their technologies (OECD, 2009). In addition, our IoT exploration index does not reveal if the specific, patented IoT related knowledge was used for new product development or to engage in process related innovation efforts. Previous research has revealed a difference in patenting propensity for product and process innovations. While product innovations are more often protected by patenting, process innovations are more likely subject to secrecy (Goto and Nagata, 1997; Hall and Harhoff, 2012; Nagaoka, Motohashi, and Goto, 2010). Future research may, therefore, apply additional non-patent-based measures such as survey-based measures to capture exploratory or exploitative IoT innovation related to either product or process innovation.

Nevertheless, we hope that our longitudinal study will encourage other scholars to tackle some of these promising future research avenues, paving the way for studies at the intersection of emerging digital technologies and family involvement.

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