ABSTRACT

In the era of big data-driven digital economies, technology commercialization capability has become the lifeblood of high-tech enterprises to shape competitive advantage and achieve multiplier growth, while the related research is still limited. Drawing on the dynamic capability theory, this study asserts that external user engagement provides an imperative way to enhance technology commercialization capability. Although the highly complicated external environment may weaken this link, high-tech enterprises’ own big data analytics capability contributes to effectively coping with the unpredictable changing environment, thereby amplifying the brighter side of user engagement. The moderated moderation model and hypotheses were supported by the unique surveys of 216 high-tech enterprises. Further, the findings broaden the vision of related research fields and provide meaningful practical guidance for strategic decision-making and dynamic capability constructing of high-tech enterprises in the new era.

KEYWORDS

Big Data Analysis, Data-Driven Digital Economies, Dynamic Capability, Environmental Uncertainty, High-Tech Enterprise, Information Management, Technology Commercialization, User Engagement

INTRODUCTION

The world has entered an era of big data-driven digital economies, where high-value big data have given rise to the development of many new industries and business models and led to a more turbulent external environment. Unpredictable market demand and rapid iterating on disruptive technologies have put forward higher requirements for high-tech enterprises’ technology commercialization capability (TCC). TCC is an enterprise’s ability to transform technologies or ideas into products or services that match market demand (Kirchberger & Pohl, 2016; Shan et al., 2021; Zahra & Nielsen, 2002), which has become the lifeblood of high-tech enterprises to shape their competitive advantage and achieve multiplier growth (Chen et al., 2011). However, not all novel technologies can be successfully developed and achieved. The ability of high-tech enterprises to commercialize technologies is generally insufficient due to unfavorable factors such as resources shortages and lack of market information (Chen, 2009; Zahra & Nielsen, 2002). Accordingly, it has become an important issue of practice and
academic concern for high-tech enterprises to improve their TCC through the purposeful integration and reconfiguration of internal and external resources and capabilities in order to adapt to the highly complex external environment (Helfat & Peteraf, 2003; Teece, 2007).

The rapid development of emerging technologies such as big data and cloud computing make internal and external knowledge sharing between high-tech enterprises more convenient and efficient; dynamic actors with different goals and resources could co-innovate and greatly improve the innovation efficiency of high-tech enterprises (Briel et al., 2018; Nambisan et al., 2017). As that is the terminal goal of technology commercialization, users’ data, information, and creativity have become scarce valuable resources of high-tech enterprises (Kuang et al., 2019; Vargo & Lusch, 2010), which provide a new way to improve TCC.

User engagement is the behavior in which users share and contribute information in various forms, actively provide creative ideas, test new products and services, and finally influence the commercialization level of enterprises (Fang et al., 2008; Nambisan & Baron, 2010). User engagement broadens the information source channels of high-tech enterprises and provides more choices for these enterprises to obtain high-quality product ideas, screen and evaluate ideas, and form preliminary new product concepts (Dong & Sivakumar, 2017). Thus, improving the ability of high-tech enterprises to adjust the application groups and market categories of products and services becomes timely. Therefore, user engagement helps high-tech enterprises to acquire heterogeneous resources and knowledge; meanwhile, it helps enterprises to grasp market preferences, thus becoming a means for more high-tech enterprises to improve their TCC. For instance, Facebook started rewarding apps that engage users more (Claussen et al., 2014), and Xiaomi, the well-known Chinese high-tech enterprise, established “Xiaomi Community.” However, scholars have not conducted extensive research on the important role of user engagement in improving high-tech enterprises’ TCC, especially in the digital context, which lacks theoretical insights.

While the digital economy brings growth opportunities for high-tech enterprises, the external environment that enterprises face has become increasingly complex (Nambisan, 2017; Zhu et al., 2022). Although user engagement helps to reduce the risks in the process of technology commercialization, the uncertainty of the external environment still brings great challenges to the effect of technology commercialization (Nacu & Avasilcai, 2014). On the one hand, market uncertainty leads to unpredictable users’ preference and demand (Bao et al., 2020; Kohli & Jaworski, 1990), which makes it more difficult for enterprises to scan the environment and identify information (Richard et al., 2019). On the other hand, technical uncertainty means shorter product development cycles and faster technology obsolescence (Jiao et al., 2019), which puts forward higher requirements for enterprises to increase the speed and efficiency of technology commercialization. Therefore, the uncertainty of the external environment makes it more difficult for high-tech enterprises to effectively use the resources provided by users, and this key factor cannot be ignored when discussing the role of user engagement. Therefore, this study attempts to reveal the role of user engagement in improving high-tech enterprises’ TCC in the context of environmental uncertainty.

As discussed previously, the influence of user engagement on TCC is restricted by environmental uncertainty. How high-tech enterprises solve this adverse influence to enhance technology commercialization, thereby maximizing the effect of user engagement, has become a key issue. Big data analytics capability (BDAC) is an important dynamic capability for enterprises to match the acquired data with their development needs (Chen et al., 2015; Gupta & George, 2016). BDAC will inspire the insight of high-tech enterprises and enable them to make better predictions on the future market situation, so as to make more accurate and stable resources allocations (Wang & Wei, 2007) to effectively cope with the fast and unpredictable changing environment (Chen et al., 2015). With BDAC, enterprises will give full play to the value of big data in the process of technology commercialization, and enhance the efficiency of users engaged in technology commercialization. Therefore, this study attempts to explore the deep moderation mechanism of BDAC, so as to reveal how high-tech enterprises effectively utilize user engagement to improve TCC in an uncertain environment.
Drawing on the dynamic capability theory, the resources and capabilities of enterprises should change with the external environment (Teece, 2007). This means that enterprises can acquire valuable resources by enhancing their interactions with external users and improve their ability to analyze big data. By doing this, high-tech enterprises are better able to cope with the negative impact of uncertain external environmental factors and improve TCC. Therefore, based on the dynamic capability theory, this study takes high-tech enterprises as the research object and constructs a research model among user engagement, TCC, environmental uncertainty, and big data analytics capability. This study contributes to theory and the literature in three major ways. First, this study reveals the influence mechanism of external user engagement on high-tech enterprises’ TCC, and the contextual role of environmental uncertainty in this process. Second, this study explores the moderation role of big data analytics capability in dealing with an uncertain environment. Third, this study expands the research field of dynamic capability theory by exploring the mechanism of BDAC in the digital economies. Generally speaking, this study aims to expand and refine the relevant theoretical fields and provide practical guidance for high-tech enterprises to make strategic decisions to cope with an uncertain environment.

LITERATURE REVIEW

Technology Commercialization Capability

TCC is the ability of enterprises to timely transform technology or ideas into products or services that match the users’ needs (Shan et al., 2021; Zahra & Nielsen, 2002). Technology commercialization plays a very important role for enterprises, especially for high-tech enterprises, which have high innovation and high growth (Dai et al., 2018). Technology commercialization has become the key to influencing and restricting the survival of high-tech enterprises (Lin et al., 2015). Zahra and Nielsen (2002) pointed out that from the perspective of capability, technology commercialization represents the capability of enterprises in developing products and services to the market, which can be reflected by the speed of commercialization. Furthermore, Chen (2009) defined three dimensions of TCC: commercialization speed, market scope, and technology breadth. Among these, commercialization speed refers to the speed of launching products, market scope indicates the range of demographic and geographic markets that apply the products, and technology breadth refers to the breadth of technologies used in the new products launched. This study adopts the three-dimensional viewpoint of TCC.

The influencing factors of TCC are the issues that scholars pay more attention to, including internal and external factors. Internal factors highlight the internal organizational resources and capabilities (Zahra & Nielsen, 2002). In terms of external factors, market factors have attracted more attention of scholars. For many new technologies and services, users’ demands and opinions are the basic driving forces for technology adoption and diffusion (Balachandra et al., 2010). Enterprises should not only meet the requirements of performance, but also meet the user’s needs (Chen et al., 2011), since the ability to generate profits through technological innovation depends on whether users can discover the value of innovation (Ranjan & Read, 2016).

Generally speaking, TCC, as an important ability of high-tech enterprises to maintain competitiveness, has reached a consensus among researchers (Chen et al., 2011). Meanwhile, the enterprises’ internal resources and knowledge level and external market factors are also cited as critical factors affecting TCC. Practice shows that user engagement helps enterprises to acquire heterogeneous resources and knowledge, and to better grasp market preferences, which has become an imperative means for more enterprises to improve their TCC. However, it does not yield insights into how user engagement can improve the TCC of high-tech enterprises, which needs more theoretical support.
User Engagement

Currently, the effectiveness of user engagement in enterprise development has been proven by more and more enterprises. These enterprises have gained a great deal of valuable information and knowledge by encouraging users to engage in technology research and development (R&D) or product construction. User engagement is the user’s behavior of interacting with enterprises; actively providing data, creative ideas, and knowledge to enterprises in various links such as R&D, design, product testing, and so forth; and influencing the commercialization level of the enterprises (Fang et al., 2008; Nambisan & Baron, 2010). To date, many scholars have discussed how users engage in the process of new product and services development (Cui & Wu, 2016; Xiao et al., 2022). First, users can serve as information sources and provide key data resources, such as user demand and user experience, to promote enterprises to identify potentially valuable ideas and demands (Carbonell et al., 2009). Second, users can interact with enterprises as co-developers, which enable enterprises to more accurately grasp and utilize users’ knowledge to promote the effective generation of new solutions or new knowledge (Boger & Horst, 2014; Sawhney et al., 2005). Third, some users can also participate in R&D as innovators, which would give users more rights and allow them to play a leading role in product design, which is then adopted and commercialized by enterprises (Nambisan, 2002).

Furthermore, the literature highlights the importance of user engagement for enterprises in achieving growth. For instance, Brem and Bilgram (2015) opined that users’ engagement could provide internal employees with knowledge and experience that they lack. Carlson et al. (2018) found that the products developed by users’ engagement are more user-oriented, thereby making the products more competitive. Consequently, user engagement plays a pivotal role in the whole commercialization process, from new technologies’ R&D to launch.

It is surprising that the published research on user engagement is limited, since the user has already become the critical actor for enterprises (Lusch & Nambisan, 2015). First, it is difficult to ignore the user’s role in helping high-tech enterprises to gain timely insight into market demand, and to quickly adjust the application groups and market range of new technologies, thereby enhancing TCC (Elsharnouby & Mahrous, 2015; Fang et al., 2008). However, research on this path is still insufficient. Second, the existing studies mostly focus on the ways users are engaged and effects of user engagement, while few studies considered contextual mechanisms of user engagement in enterprise development (Xie & Wang, 2019). With the optimization of production operation and management methods by digital technology, new technologies are constantly iterative, and market factors are increasingly abundant. All of this is forcing the interactions between users and enterprises to face uncertainty that is more complicated. Therefore, it is of great significance for extending the field of user engagement research into the context of environmental uncertainty. To address this gap, this study discusses how user engagement impacts TCC under the moderation mechanism of environmental uncertainty.

Environmental Uncertainty

Environmental uncertainty refers to the degree of rapid change and unpredictability of the external environment (Duncan, 1972), which mainly includes technical uncertainty and market uncertainty (Bstieler & Gross, 2003). The level of uncertainty is being further amplified by the digital economy (Soluk et al., 2021; Zhao & Zhou, 2022; Zhu et al., 2022). With the rapid development of digital technologies, many breakthrough and disruptive technologies emerge one after another. The increasing market demand and fiercely competitive market environment have a profound impact on high-tech enterprises, forcing them to develop dynamic capabilities to keep up with rapidly changing environments (Soluk et al., 2021; Teece et al., 1997).

Typically, environmental uncertainty is taken as a contextual variable for exploring how enterprises can develop long term under the quick-changing technology and turbulent market (Miller, 2010; Vedadi & Greer, 2021). Several scholars have recognized that user engagement helps to reduce the risks in enterprise’s operation (Carbonell et al., 2009). In a highly uncertain environment,
enterprises find it hard to cope with the quick changes of the environment simply through their own knowledge and technologies (Yu et al., 2020). As a result, it may be more beneficial for enterprises to widely acquire external knowledge and resources for opening up new potential market segments (Bhawe & Zahra, 2019).

Still, there are some viewpoints that show that the effect of user engagement will be affected in an uncertain environment. For example, in a highly uncertain environment, the users’ demands are often huge in quantity and variety, which may result in a large number of new ideas, making data processing more complicated for enterprises, and even leading to confusion caused by excessive knowledge load within the enterprises (Hoyer et al., 2010). Some enterprises may also determine the new technologies’ characteristics based on the judgment of users’ preferences in a certain category or region, but lack comprehensive cognition of different markets, which eventually leads to the commercialization of technologies that can only serve a single niche market (Gassmann et al., 2010). Although a few prior studies have already argued whether the link between user engagement and high-tech enterprises’ TCC will be affected in a highly uncertain environment, the subject has not been widely discussed.

**Big Data Analytics Capability**

Big data, as the critical production factor, has become the lifeblood of enterprise development. Although the exponential growth of big data may bring more value, some studies have pointed out that big data on its own is unlikely to be a source of competitive advantage, since all enterprises of equal scale may collect a mass of data from various sources (Carr, 2003; Gupta & George, 2016). In the highly complex and rapidly changing external environment, how to transform original massive data into usable information and achieve appropriate utilization and configuration is the essential issue for enterprises (Salman et al., 2022; Teece, 2014; Wixom et al., 2013).

BDAC is the dynamic capability of enterprises to match the acquired data with their development needs (Gupta & George, 2016). BDAC empowers high-tech enterprises to screen, integrate, and reconfigure the internal/external disparate data, giving full play to the value of data in technology commercialization, thereby improving the effectiveness and efficiency of user engagement in technology commercialization. BDAC is well-established in the literature; Akter et al. (2016) conceptualized BDAC in three main aspects: 1). BDA management capability, which is an enterprise that specializes in managing data properly, thereby turning data into opinions or decisions about the development of products/services; 2). BDA technology capability, which refers to an enterprise’s ability to create a flexible utilization of data for rapid development and deployment, thus solving the problems of an enterprise’s business; 3). BDA talent capability, which means the enterprise’s managers or employees have professional analytics skills to perform assigned tasks about data.

BDAC is widely acknowledged to play a critical role in high-tech enterprises development. The literature highlights the BDACs effects on enterprises’ decision-making quality and performance (Saleem et al., 2020). More Broadly, BDAC is helpful for high-tech enterprises to be able to make more accurate resources allocations and strategic decisions, so as to restrain the negative impact of a complex external environment. For instance, Chen et al. (2015) suggested that BDAC could help reduce uncertainty by stimulating insight and knowledge creation and improving effective strategic decision-making ability. Further, the insights gained through BDAC may reduce the uncertainty of demand and supply. In contrast, the lack of BDAC may cause expensive asset-intensive buffers, such as cash, inventory, and so on (Chen et al., 2015). Some studies have shown that BDAC is conducive to enhancing the effectiveness of user engagement. In other words, although users could provide information that enterprises need, if enterprises could not judge the information clearly, they then may not be able to properly match user needs with their technology development, resulting in blurred product concepts (Thomke & Hipple, 2002). High-tech enterprises with high BDAC will perform better in combining the subjective judgment of user preferences with the objective evaluation of market information, resulting in more accurate business decisions (Brynjolfsson & McAfee, 2012; Gillon et al., 2014).
Overall, given that higher requirements are put forward for the TCC of high-tech enterprises in the digital economies era, the engagement of external users may have positive facilitation on the improvement of this ability, while the negative effect of environmental uncertainty requires a higher level of BDAC to be moderated. Dynamic capability theory provides a theoretical basis to explain this phenomenon. As dynamic capability theory argued, enterprises should dynamically allocate, integrate, and reorganize their resources and capabilities, thereby keeping their core competitiveness dynamically in line with the external environmental changes (Teece, 2007; Shi et al., 2020). This means that by enhancing the interaction with external users, enterprises can integrate valuable resources needed in different stages of development, meanwhile improving their own massive data resources management ability, which is helpful to cope with the negative impact of an uncertain external environment, in addition to improving their TCC. Therefore, this study attempts to explore the mechanism of user engagement on the TCC of high-tech enterprises, reveals the moderating role of environmental uncertainty and big data analytics capability in this connection, and then builds a moderated-moderation model (see Figure 1). In next section, the study will put forward the hypotheses through careful logical deduction.

Figure 1. The theoretical model

**HYPOTHESES**

**The Influence of User Engagement on Technology Commercialization**

In the era of the digital economy, high-tech enterprises can rapidly promote technology in different industries, while they are exposed to more complex market competition. Furthermore, it is essential for high-tech enterprises to strengthen TCC, so as to seize the opportunity window (Shan et al., 2021). The core of technology commercialization is how an enterprise can quickly and accurately transform their technology into products or services that match market demand (Chen, 2009; Zahra & Nielsen, 2002), which implies that user engagement cannot be ignored in improving TCC. User engagement is an interactive process between enterprises and existing and potential users at different development stages. During this period, users not only provide innovation-related data resources for high-tech enterprises, but also participate in activities, such as jointly designing and testing new services (Cui & Wu, 2016; Ranjan & Read, 2016). In the process of innovation, close relationships with users enable high-tech enterprises to obtain the diversified resources needed in development and manufacturing, and provide important supports for high-tech enterprises to improve their TCC (Athaide et al., 2010).
Specifically, this study examines the impact of user engagement on high-tech enterprises’ TCC in three aspects. To begin with, user engagement could speed up commercialization. Users and high-tech enterprises share and communicate based on previously accumulated information and ideas (Boselli et al., 2008; Ordanini & Pasini, 2008), providing more choices for high-tech enterprises to obtain high-quality product ideas, screen, and evaluate ideas, and form preliminary new product concepts (Dong & Sivakumar, 2017). Using this approach, high-tech enterprises can greatly improve innovation efficiency, shorten the development cycle, and accelerate the speed of bringing innovative technologies to the market. More importantly, high-tech enterprises could more intuitively understand the current and future needs of users, thus quickly starting technology commercialization according to those needs (Zhang & Chen, 2008).

Secondly, user engagement is beneficial to expand the market scope of technology application. In detail, user engagement helps to bridge the spatial gap in transactions (Archpru & Chandler, 2011; Chan et al., 2010; Ramani & Kumar, 2008), which assists high-tech enterprises in better understanding the personalized needs of users in different regions, so as to determine different development plans and improve market acceptance of new products and services. Additionally, increasing the depth and scale of user engagement will gradually form network externality, attracting more potential users and then expanding the market scope of technology commercialization (Amit & Zott, 2001; Sussan & Acs, 2017).

Finally, user engagement actively broadens the technical breadth of products. Given the high complexity of many innovative products, high-tech enterprises are usually unable to own all of the technologies for design and testing. User engagement provides additional technical references for high-tech enterprises, enables enterprises to integrate new technologies that are suitable for product innovation (Athaide et al., 2010), and leads to high integration and value realization of new technologies in products (Fisher & Smith, 2011; Vargo & Lusch, 2010). Therefore, by enhancing the interaction with external users, enterprises could acquire valuable resources, such as information, ideas, and technologies, thereby improving the speed, breadth, and quality of technology commercialization. In light of the above reasoning, this study puts forward the following hypothesis:

**Hypothesis One**: User engagement is positively related to TCC improvement of high-tech enterprises.

The Moderating Role of Environmental Uncertainty

With the advent of the digital economy era, market demand is changing more rapidly, and technology changes are becoming more frequent, leading to greater environmental uncertainty for high-tech enterprises. These unpredictable environmental factors profoundly affect the business activities of high-tech enterprises and put forward higher requirements for high-tech enterprises to accurately predict the dynamics of user preferences, as well as reasonably adopt users’ data in technology commercialization (Jiao et al., 2019). This makes it more challenging to attain efficiency and effectiveness in interactions between enterprises and users (Bao et al., 2020).

Concretely, high-tech enterprises may be up against market uncertainty and technical uncertainty (Bstieler & Gross, 2003; Kohli & Jaworski, 1990). As for market uncertainty, the higher level of market uncertainty is causing increased rapid changes in user preferences and user groups’ composition, making it more difficult to predict user demand (Zhou et al., 2005). The technology commercialization of high-tech enterprises requires a great deal of human and material capital. Unfortunately, some products have not yet started market penetration, thus the information and technology provided by users may already be outdated (Hanvanich et al., 2006). If high-tech enterprises commercialize based on past user preferences, they will bear higher risks, thus slowing down the speed of technology commercialization and reducing the market scope of commercialization. In addition, the turbulent market environment results in more complicated external competition, which means that it is more difficult for enterprises to collect valid data about users (Bstieler & Gross, 2003; Hoskisson &
Busenitz, 2017). High-tech enterprises need to invest substantial costs in environmental scanning and data discrimination, which in turn increases the cost of product innovation (Richard et al., 2019).

Meanwhile, in an environment with a high level of technical uncertainty, the breakthrough of new technologies leads to shorter product development cycles and faster technology obsolescence (Jiao et al., 2019). This phenomenon is more obvious in the high-tech industry, which sets higher demands on the TCC of high-tech enterprises (Dai & Ma, 2007). High-tech enterprises must frequently rebuild and expand their existing knowledge base and professional skills in order to meet users’ new demands in time (Song & Montoya-Weiss, 2001). Additionally, the low accuracy of data, caused by technical uncertainty, may make managers’ decision-making very difficult, and they may even be forced to change an enterprise’s strategic positioning in a short period of time (Jiao et al., 2019). Obviously, higher environmental uncertainty inhibits the effect of user engagement in improving TCC of high-tech enterprises. These observations underpin the following hypothesis.

**Hypothesis Two:** The positive relationship between user engagement and technology commercialization is weakened when high-tech enterprises face high environmental uncertainty.

The Moderated Moderating Role of Big Data Analytics Capability

The ability of high-tech enterprises to integrate, construct, and allocate internal/external resources and capabilities in the turbulent environment (Teece et al., 1997; Yu et al., 2020), thereby quickly and timely transforming technology into products/services that match the market demand, has become the key to maintaining the survival and growth of high-tech enterprises (Chen, 2009). Drawing on dynamic capability theory, BDCA is a vital dynamic capability of high-tech enterprises (Chen et al., 2015; Gupta & George, 2016), which has a significant effect on coping with the dynamic changes of environment, promoting high-tech enterprises to make more accurate, steady, and effective utilization of the resources provided by user engagement, thus improving the efficiency of technology commercialization. Accordingly, this study proposes that BDAC would weaken the negative effect of environmental uncertainty on the link between user engagement and TCC.

Specifically, the stronger the BDA management capability, the better high-tech enterprises will be able to reveal users’ behavior dynamics (Zotoo et al., 2020), predict future users’ needs, and determine potential new markets more accurately, and the better they will be able to reduce the risks and uncertainties caused by the rapid change of user’s preferences (Wang & Hajli, 2016). When an enterprise has stronger BDA management capability, its ability to identify valuable user data and filter invalid data is stronger, leading to the promising direction of R&D (Srinivasan & Arunasalam, 2013). This approach could be beneficial for high-tech enterprises to identify problems in advance and preset solutions to help enterprises make quick decisions in times of crisis (Wang & Hajli, 2016).

The stronger BDA technical capability enables enterprises to flexibly use all kinds of data and quickly develop and deploy data to solve business problems. The sharp changes in user preferences bring more challenges to enterprises’ resources allocation. BDA technical capability provides opportunities for high-tech enterprises to reconfigure their resources in a way that is more in line with the trends of supply and demand markets. For example, by being able to make faster and more accurate predictions, high-tech enterprises could be able to identify in advance which products need to expand or reduce the scale of assets (Wang & Wei, 2007). This would bring better asset utilization and avoid expensive asset-intensive buffers, thus weakening the adverse effects caused by temporary changes in product design (Chen et al., 2015). Therefore, when high-tech enterprises have stronger BDA technical capabilities, they can perform better in controlling the risks of over-judgment of users’ information, and then expand the adoption of users’ personalized needs. It not only helps to improve the efficiency of users’ engagement, but also further enhances users’ satisfaction, resulting in a benign iterative effect of users’ engagement.

Finally, stronger BDA talent capability emphasizes the related skills learned and possessed by managers and employees in high-tech enterprises. A turbulent external environment forces high-tech enterprises to make more accurate and timely strategic decisions in development. Stronger BDA talent capability allows managers to combine their subjective judgment of user data with the objective
evaluation of complex market conditions (Brynjolfsson & McAfee, 2012; Gillon et al., 2014). In this way, high-tech enterprises could better predict the changes of the external environment, utilize the heterogeneous resources and knowledge provided by users more reasonably and accurately, and improve the TCC. In conclusion, this study suggests that BDAC plays a vital role in reducing environmental uncertainty and promoting the link between user engagement and TCC. Following this line of logic, this study proposes the following hypothesis:

**Hypothesis Three:** The stronger the big data analytics capability of high-tech enterprises, the weaker the moderating effect of environmental uncertainty on the user engagement-TCC link.

**METHODODOLOGY**

**Sampling and Data Collection**

This study employed a questionnaire approach to collecting data for testing the validity of the model and research hypotheses. In China, the scale of digital economy is steadily expanding with a good development prospect, while data-driven development and changeability of the environment in China made this country an ideal context for the research. Considering that, this study selected the Guangdong Province, Jilin Province, and other regions with different innovation vitality indexes in China in which to distribute and collect study questionnaires. To ensure the validity and reliability of the questionnaires and data, the questionnaire design followed three steps:

1. According to the model, the questionnaire items were determined based on the relevant maturity scales. To ensure the accuracy of measures, the authors had all items translated by different professionals.
2. The authors invited three entrepreneurs from high-tech enterprises to discuss the items and asked them to put forward their opinions on possible problems based on the enterprise practice. The questionnaire items were then revised according to the feedback, thereby creating the initial questionnaire.
3. Pre-research was conducted with 20 enterprises selected in the Jilin Province as the pre-research objects, which further improved the initial questionnaire according to the trial filling situation, to create a formal questionnaire. The formal questionnaire of this study mainly included two parts. The first was basic information. This section introduced the relevant background information of this survey, including the purpose and description, and collected basic information such as the age, industry, scale, and address of the surveyed enterprises. The second is the measurement of core variables. This part primarily involved the related measurement of the core variables of this study, including user engagement, TCC, environmental uncertainty, and big data analytics capability.

The research team members began the distribution of questionnaires in January 2021. Due to the potential impact of COVID-19, this survey was mainly conducted online through the questionnaire survey platform to design access links that cover all of the contents of the questionnaire, making full use of emerging technologies, such as mobile Internet and social media, to widely push questionnaire links to high-tech enterprises in targeted areas. Eventually, team members distributed and collected more than 600 questionnaires. Subsequently, team members screened the relevant data, excluding the samples of non-high-tech enterprises, which were not involved in a variety of high-tech industries, including new energy, electronics, biopharmaceuticals, medical equipment, telecommunications, computer software, environmental technologies, and advanced materials (Dai et al., 2018). Meanwhile, team members also excluded the samples of which completion rate was less than 75%, and the samples,
which missed key information (e.g., high-tech enterprise age). Finally, the remaining 216 valid and complete questionnaires were analyzed using the quantitative analysis method.

**Variable Settings**

All variables employed in this study required seven-point Likert-style responses, ranging from “strongly disagree” to “strongly agree,” for multiple items. The related items of each variable are detailed in the following paragraphs.

**Technology Commercialization Capability (TCC).** To capture TCC comprehensively, this study followed Chen (2009) in taking an 11-item scale to indicate technology commercialization speed, market scope, and technology breadth. The 11 items included whether the high-tech enterprise had the ability to: Create product concepts in time (TCC1); Develop products in time (TCC2); Launch products into the market in time (TCC3); Improve existing products to adapt to different population markets (TCC4); Improve existing products to adapt to different regional markets (TCC5); Create new products for different population markets (TCC6); Create new products for different regional markets (TCC7); Acquire technology to improve existing products (TCC8); Acquire technology and create new products (TCC9); Integrate technologies to improve existing products (TCC10); and Integrate technologies to create new products (TCC11).

**User Engagement (UE).** This study mainly refers to the 4-item scale adopted by Cui and Wu (2016), which included whether high-tech enterprises: Organized meetings with users to improve product innovation (UE1); Consulted with users to improve product innovation (UE2); Invited users as members of product innovation R&D (UE3); and Used relevant tools to promote user engagement (UE4).

**Environmental Uncertainty (EU).** Environmental uncertainty construct was a 4-item scale reporting the marker and technology uncertainty as perceived by the respondents. Building on Su et al. (2013), the four items included the predictability degree of: User demand in the industry (EU1); Industry-related policies (EU2); Competitors’ actions (EU3); and Technology trends in the industry (EU4).

**Big Data Analytics Capability (BDAC).** This study mainly refers to the relevant 4-item scales adopted by Akter et al. (2016), which included whether the high-tech enterprise had the ability to: Form opinions and decisions on developing products/services through data analysis (BDAC1); Form opinions and decisions on improving products/services through data analysis (BDAC2); Use data analysis tools (BDAC3); and Solve business problems by using relevant data analysis (BDAC4).

**Control Variables.** This study included two control variables in the analysis. First, the scale characteristics of high-tech enterprise (ES), that is, the variable “high-tech enterprise scale” was set according to the number of employees owned by the high-tech enterprise, including 1). 1–20; 2). 21–50; 3). 51–200; 4). 201–500; and 5). more than 500. Second, the age characteristics of high-tech enterprises (EA), that is, the control variable “high-tech enterprise age” was set according to the time when the enterprises were officially registered.

**Reliability and Validity**

This study used reliability and validity analysis methods, which are commonly used to verify the validity of questionnaires. First, the reliability analysis showed that Cronbach’s alpha of core variables were higher than 0.8 (see Table 1). That is, the questionnaire had good reliability. Second, the study conducted a confirmatory factor analysis to verify the validity of the questionnaire, and the results showed that the factor loading of the items of variable were all higher than 0.7 (see Table 1). Meanwhile, the Composite Reliability (CR) of each core variable was higher than 0.8, and the Average Variance Extracted (AVE) was higher than 0.6, which showed that the convergence validity of the core variable was ideal. Further testing the discriminant validity of the core variables (see
Table 2), the correlation coefficients among the core variables were less than the square root of AVE, which indicated that there was a correlation among the core variables, while there was also discrimination between them, which indicated that the core variables had good discriminant validity. Due to the collection of all variables from the same source, this study used the Harman one-factor test to examine the potential problem of common method variance. The data test results showed that the first factor accounted for 32.934% of the variance, which did not exceed 40%. Hence, common method bias was unlikely to be a serious problem. In total, the relevant data results showed that this survey questionnaire had high reliability.

Table 1. Reliability and validity

<table>
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<tr>
<td></td>
<td>TCC2</td>
<td>0.847</td>
<td></td>
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<tr>
<td></td>
<td>TCC3</td>
<td>0.796</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>TCC4</td>
<td>0.815</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>TCC5</td>
<td>0.832</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>TCC6</td>
<td>0.827</td>
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<tr>
<td></td>
<td>TCC7</td>
<td>0.759</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>TCC8</td>
<td>0.801</td>
<td></td>
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<tr>
<td></td>
<td>TCC9</td>
<td>0.807</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>TCC10</td>
<td>0.803</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>TCC11</td>
<td>0.816</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EU</td>
<td>EU1</td>
<td>0.798</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EU2</td>
<td>0.855</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EU3</td>
<td>0.820</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>EU4</td>
<td>0.822</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BDAC</td>
<td>BDAC1</td>
<td>0.871</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BDAC2</td>
<td>0.919</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>BDAC3</td>
<td>0.815</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BDAC4</td>
<td>0.733</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BDAC2</td>
<td>0.919</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BDAC3</td>
<td>0.815</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BDAC4</td>
<td>0.733</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RESULT

The regression analysis is used to verify the relevant hypotheses. The descriptive statistics and correlation analysis showed that there was a correlation among the core variables, and the correlation coefficient was no more than 0.8 (see Table 2).

Table 2. Descriptive statistics and correlation analysis

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>UE</th>
<th>TCC</th>
<th>EU</th>
<th>BDAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE</td>
<td>5.338</td>
<td>1.199</td>
<td>0.819</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCC</td>
<td>5.424</td>
<td>1.105</td>
<td>.704**</td>
<td>0.812</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EU</td>
<td>2.655</td>
<td>1.130</td>
<td>-.616**</td>
<td>-.579**</td>
<td>0.824</td>
<td></td>
</tr>
<tr>
<td>BDAC</td>
<td>5.247</td>
<td>1.390</td>
<td>.706**</td>
<td>.602**</td>
<td>-.544**</td>
<td>0.837</td>
</tr>
</tbody>
</table>

Note: * * p < 0.01

A hierarchical regression analysis was conducted to test the hypotheses (see Table 3). The control variables were analyzed. The results indicated that the effects of the high-tech enterprise’s scale on TCC were significant, while the effects of the high-tech enterprise’s age was not significant. This may be due to the high-tech enterprises of selected samples were relatively young, so the effect of age was not significant. Then, to investigate the nature of the moderated moderation effects, slope difference tests for the three-way interactions of user engagement, environmental uncertainty, and big data analytics capability in TCC were conducted (Dawson & Richter, 2006). A slope difference analysis was used to test the joint effect of the moderation by environmental uncertainty and big data analytics capability in the effect of the independent variable user engagement on the dependent variable TCC. This was done to determine whether the gradients representing the different levels of environmental uncertainty and big data analytics capability differed significantly in their effects on the dependent variable (as depicted in Figure 2). This helped to refine the insights into the moderated moderation.

As shown in Table 3, according to Model 2, user engagement has a significant positive impact on TCC (β = 0.688, p<0.001), thus Hypothesis One is supported. Combining Figure 2 with Model 3 in Table 3, environmental uncertainty has a significant negative moderating effect on the positive relationship between user engagement and TCC (β = -0.101, p<0.01), thus Hypothesis Two is supported. Combining Figure 2 with Model 4 in Table 3, big data analytics capability weakens the negative moderating effect of environmental uncertainty in the link of users engagement and technology commercialization (β = -0.085, p < 0.01), therefore Hypothesis Three is also supported.
**DISCUSSION AND IMPLICATIONS**

**Discussion**

Drawing on the dynamic capability theory, this study uses high-tech enterprises as the research object and constructs a theoretical model among user engagement, TCC, environmental uncertainty, and big data analytics capability. Through the empirical testing of 216 valid samples, the hypotheses are well supported. Empirical results show that external user engagement plays a positive role in promoting the TCC of high-tech enterprises, and this effect will be weakened in the highly uncertain environment.

Table 3. Hierarchical regression results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Technology Commercialization Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
</tr>
<tr>
<td>User engagement</td>
<td>0.688***</td>
</tr>
<tr>
<td>Environmental uncertainty</td>
<td>-0.268***</td>
</tr>
<tr>
<td>Big data analytics capability</td>
<td></td>
</tr>
<tr>
<td>User engagement × Environmental uncertainty</td>
<td>-0.101**</td>
</tr>
<tr>
<td>User engagement × Environmental uncertainty ×</td>
<td></td>
</tr>
<tr>
<td>Big data analytics capability</td>
<td></td>
</tr>
<tr>
<td>Scale</td>
<td>0.190***</td>
</tr>
<tr>
<td>Age</td>
<td>0.047</td>
</tr>
<tr>
<td>F</td>
<td>10.049***</td>
</tr>
<tr>
<td>R2</td>
<td>0.46</td>
</tr>
<tr>
<td>Adj- R2</td>
<td>0.041</td>
</tr>
<tr>
<td>ΔR2</td>
<td>0.046</td>
</tr>
</tbody>
</table>

Note: ***p<0.001, **p<0.01, *p<0.05, +p<0.1

Figure 2. Visualization of the moderated moderation effects
environment. The strengthening of enterprises’ big data analytics capability will restrain the negative role of environmental uncertainty in the link of user engagement and TCC.

**Theoretical Implications**

Based on the environmental uncertainty, this study explores the internal mechanism among user engagement, TCC, and big data analytics capability. The following findings have important implications for related theoretical development.

Drawing on the dynamic capability theory, this study reveals the key path for high-tech enterprises to improve their TCC, and it further expands the research field of dynamic capability theory. In detail, the existing research mainly gets insights in how the single factors (either internal factors of enterprises or external environmental elements) influence high-tech enterprises TCC. From the perspective of dynamic capability theory, this study shows empirically that high-tech enterprises should reconfigure their internal/external resources and capabilities for enhancing their TCC, thereby realizing the dynamic fit between their development strategies and the highly uncertainty environment (Helfat & Peteraf, 2003; Teece, 2007). For one thing, high-tech enterprises should actively invite external users to participate in business activities in various forms so that they can acquire diversified valuable resources, and thus timely and accurately integrate users’ creativity, real needs, and feedback. In addition, high-tech enterprises need to improve their own big data analytics capabilities, fully inspire their insight, and enable themselves to make better predictions about the future environment. This would enable them to avoid the possible adverse effects of the external environment as much as possible, because they could allocate resources more accurately and take maximum advantage of valuable data resources found through high-tech enterprise technology commercialization. Accordingly, the major findings address the gap in the existing research and contribute to theory and future researches in improving high-tech enterprises’ TCC.

Furthermore, this study expands the research field of dynamic capability theory by exploring the mechanism of big data analytics capability in the digital economy era. This leads to responses to the call for developing dynamic capability theory to embrace the changes brought on by the digital economy (Karimi & Walter, 2015). Simply put, big data has become a vital engine for high-tech enterprises to establish sustainable competitive advantages and explore potential opportunities in the digital economy era. How to explore and release the efficiency of big data, and fully transform the value behind big data into the high-tech enterprises’ TCC, is a great challenge. The related findings of this study assert that by developing big data analytics capability as a high-level dynamic capability, high-tech enterprises could actively allocate internal/external resources and capabilities accurately and better understand the business environment and user needs faced by different development stages (Cappa et al., 2021), thus improving the efficiency of dealing with big data (Chen et al., 2015). Besides, the digital economy context provides more possibilities for the links of diversified actors. The co-creation with users or other actors is conducive to promoting the transformation of knowledge and information and enhancing the dynamic capability development of high-tech enterprises. Therefore, this study provides beneficial supplements for the development of dynamic capability theory in the digital context.

This study also deepens the theoretical research of user engagement by exploring the contextual role of environmental uncertainty. Despite the importance of user engagement, the literature is still limited. The core of technology commercialization is how an enterprise can quickly and timely transform technologies into products/services that match market demand, which highlights the critical role of user engagement, but few scholars have paid attention to this issue. The center of attention of prior studies on user engagement is on the ways and by which mechanisms users engage, while few studies are concerned with the contextual mechanism when user engagement happens (Xie & Wang, 2019). However, the more complicated issue of uncertainty of the environment is unlikely to be ignored when users interact with high-tech enterprises. Accordingly, this study contributes more insights into
the literature of user engagement by examining the relationship between user engagement and high-tech enterprises’ TCC, and moreover, discussing the contextual role of environmental uncertainty.

**Practical Implications**

This study yields some interesting insights for practice. First, high-tech enterprises should encourage users to participate in business activities in various ways to improve their TCC. As the rapid advancement of digitization and the impact of digitalization increases, high-tech enterprises must accurately grasp market preferences and timely commercialize technologies into products/services that match market expectations. Meanwhile, digitalization induced disintermediation opens new opportunities for value-creating interactions with end users, which expands the depth and breadth of user engagement (Autio et al., 2018; Sussan & Acs, 2017). Therefore, this study calls on high-tech enterprises to strengthen the connection with users to comprehensively improve the speed, market scope, and technology breadth of technology commercialization. Specifically, users can engage with business activities in various forms, and in turn, high-tech enterprises will recognize users’ needs more comprehensively, optimize products/services in time through deep interaction with users. Simply put, through the in-depth interaction with users, high-tech enterprises could explore more niche markets and create values that cannot be created by acting alone. Consequently, this study has practical implications for guiding the sustainable growth of high-tech enterprises.

Additionally, this study asserts that high-tech enterprises should strengthen the building of big data analytics capabilities to identify, integrate, and configure internal/external data resources more accurately and robustly. The era of the data-driven digital economy has already become a reality. High-tech enterprises should build a big data analytics capability that competitors cannot match, thereby gaining insightful opinions from data resources and formulating reasonable business strategies. More importantly, high-tech enterprises should adopt diversified means to attract professional talent in big data analyzing, gathering diversified actors, to further improve the dynamic integration and configuration of big data. The stronger the big data analytics capability, the more that high-tech enterprises can improve their objective understanding of the macro market, thus avoiding wrong decisions caused by the excessively subjective judgment of user data.

**LIMITATIONS AND FUTURE RESEARCH DIRECTIONS**

As with any other research, this study is not without limitations, which need to be further explored in the future. Firstly, it may be a dynamic process for high-tech enterprises to improve their technological commercialization capability, hence, there may be differences in the degree to which user engagement can improve TCC at different development stages. An interesting avenue for future research would be to focus on different development stages of high-tech enterprises to reveal the dynamic relationship between user engagement and TCC of high-tech enterprises.

Second, this study focuses on the role of user engagement in improving the high-tech enterprises’ TCC, without deeply arguing the reverse empowerment on how TCC affects user engagement. With the long-term, in-depth interaction between users and high-tech enterprises, high-tech enterprises will gradually rely on the heterogeneous resource provided by users, while users create products/services dependencies by degrees. By then, the close interactive relationship between users and high-tech enterprises will no longer be a simple buying and selling relationship, but a symbiotic relationship based on mutual trust and common vision (Lu et al., 2021). Users will deeply engage with the production and operation of high-tech enterprises, co-create, and share value with high-tech enterprises. It would also be interesting to reveal this mechanism through case studies in the future.

Finally, this study only focused on high-tech enterprises based in China. Since the impact of data-driven technology is a global phenomenon, related studies could be expanded to including a broader sample of high-tech enterprises outside China. It would be interesting to see if the country-
level differences (e.g., different markets and institutional conditions) affect the relationship between user engagement and TCC.

CONCLUSION
This study asserts that the increasingly blurred boundaries of high-tech enterprises empower external users with more rights in the era of data-driven digital economy. User engagement, as the vital path for high-tech enterprises to clarify market trends and obtain valuable data, has played a positive role in promoting TCC. The environmental uncertainty has weakened the positive influence of external user engagement on TCC. Hence, high-tech enterprises need to develop their own big data analytics capability for making more accurate and stable resources allocations and strategic decision-making, so as to restrain the negative impact of the external environment, and then enhance the positive link between user engagement and TCC. Moreover, this study expands the research field of dynamic capability theory by exploring the mechanism of big data analytics capability in the digital economies. Overall, the study leads to an instructive development path for high-tech enterprises in the era of digital economies and is likely to open new avenues of research into academic and enterprises’ policy and practices.

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PMID:34489813


Li Cai is a professor and doctoral supervisor of the School of Business and Management, and the dean of Innovation and Entrepreneurship Research Institute at Jilin University. She is also the vice-chairman of Chinese Association for Science of Science and S&T Policy, and the Membership of Advisory Committee of National Natural Science Foundation. She is a winner of National Outstanding Youth Fund and a National candidate for New Century Million Talents Project (first batch). She has won more than 10 Scientific and Technological Progress Awards and Outstanding Achievement Awards in Scientific Research. Her major research interests are innovative and entrepreneurial management. She has been in charge of over 10 projects of National Natural Science Foundation of China (NSFC) and has published more than 100 papers, 6 monographs and 1 translation.

Shan Lu is a Ph.D. student at School of Business and Management, Jilin University. She got her master’s degree and bachelor’s degree from Jilin University. Her major research interests are innovative and entrepreneurial management, digital economy, application of big data analytics.

Biao Chen received his Phd degree from Jilin University in 2016. Currently, he is an assistant professor in School of Business at Zhengzhou University in Zhengzhou, China. His study involves in entrepreneurial learning and entrepreneurial strategy.