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Abstract: By integrating the evolutionary perspective and the behavioural theory of the firm, this study draws on the generational technological change (GTC) and organisational search (OS) literatures and explores how problemistic and slack search, local and non-local search, search timing, and cumulative search experience of incumbent firms and new entrants lead to firm product innovation performance in new generational markets. Several distinctive features of GTC are discussed, including incremental and non-drastic innovation, co-existence of generations, and necessity for significant managerial attention and financial investment. With an in-depth investigation on the mobile phone manufacturing industry, particularly focusing on the Chinese mobile phone manufacturing industry, this study sheds light on irreversible evolutionary dynamics and GTC for incumbent firms and new entrants, OS for new generational technological knowledge, and their effects on product innovation performance in the new generation.

Keywords: generational technological change; GTC; organisational search; mobile phone manufacturing industry; MPMI; product innovation; evolutionary perspective; the behavioural theory of the firm.

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1 Introduction

Generational technological change (GTC) refers to significant progress in a technological regime, and is an irreversible evolutionary force for firms in high-technology industries (Lawless and Anderson, 1996). Given that present technological generations can mature in ever changing and innovation-intensive markets, firms are often compelled to search for new generational technological knowledge (GTK). New GTK is created by individuals, organisations, and organisational networks and their interactions (Anderson and Tushman, 1990) to meet customer needs and preferences regarding the improvement of current generation products (Panwar et al., 2020; Tabrizi and Walleigh, 1997). Diverse actors who create GTK across a society include customers, R&D managers, researchers, components producers, software developers, finished product producers, governmental organisation, and international standardisation organisation (Berkhout et al., 2007). These actors generate new GTK that includes but is not limited to production techniques, technical requirements, standards, and dominant features of upcoming generational products.

New GTK is not always recognised as such in its emergent stages but cumulatively helps advance the technological features embodied in next-generation products. For firms, managing GTC by searching for new GTK is critical during the transition period when the current technology generation fades and a new one is emerging. Thus, firms must decide why (Cyert and March, 1963), where (March, 1991), and when (Lawless and Anderson, 1996; Katila and Chen, 2008) to search for new GTK and utilise their

cumulative search experiences to guide their innovation. Such search behaviours are essential in high-technology industries to realise product innovation performance targets in the coming generation (Greve, 2003). Innovation in the GTC context refers to a firm's introduction of new generational products (Turner et al., 2010; Wang et al., 2017a).

Despite being a promising phenomenon for research, GTC has received limited attention in the literature (Brown and Eisenhardt, 1997; Lawless and Anderson, 1996; Qian and Wang, 2020; Turner et al., 2010, 2013). Previous studies mainly focus on the relationship between external or internal factors of firms and their product innovation and market performance in the new generation (Brown and Eisenhardt, 1997; Lawless and Anderson, 1996; Qian and Wang, 2020; Turner et al., 2010, 2013). The search behaviours for new GTC and the effects of these search behaviours on product innovation of firms in new generational markets remain largely underexplored (Wang et al., 2017a). Particularly, the current GTC literature largely fails to differentiate between incumbent firms (hereafter: incumbents) and new entrants that are mainly start-ups or small businesses, despite the significant commonalities and differences in their search behaviours and impact of search on product innovation. Incumbents and new entrants that fail in the search process may find it difficult to achieve their product innovation objectives. An integrative theoretical framework has yet to be proposed which explains the role of searching for new GTC during the transition period in an innovation-intensive market and its effect on product innovation performance for incumbents and new entrants. These knowledge gaps suggest the following question as the focus of our theorising: how do organisational search (OS) activities of incumbents and new entrants during the generational technology transition period affect their product innovation performance in new generational markets?

To address this research question, we systematically summarise the specific characteristics of GTC, explore various dimensions of OS, and apply the evolutionary perspective and the behavioural theory of the firm to develop propositions regarding GTC, OS, and firm product innovation with reference to the Chinese mobile phone manufacturing industry (MPMI). In doing so, we introduce an integrative and evolutionary framework that examines the influence of a firm's OS behaviours on its product innovation performance in the new generation. This study makes several significant contributions to the literature on GTC. First, drawing upon evolutionary and behavioural theories, we discuss the fundamental evolutionary nature of GTC and discuss how new GTC acquired through a firm's OS plays an essential role in modifying its routines tailored to the current technology generation, allowing for its adaptation to GTC. Second, to systematically discuss the OS activities of incumbents and new entrants for new GTC, we categorise OS into relevant dimensions by considering the matters of 'why', 'where' and 'when' as well as cumulative search experience. This classification enables us to propose the effects of problemistic and slack search, local and non-local search, search timing, and cumulative search experience during the generational transition period on firm product innovation performance in new generational markets. Particularly, we differentiate how various search dimensions can affect product innovation for incumbents and new entrants in the GTC context. Finally, we employ the MPMI as a reference for understanding the evolutionary process of GTC, allowing us to explore the GTC phenomenon and a firm's efforts in adaptation. In particular, the Chinese MPMI significantly reinforces our theoretical framework, enabling us to

establish propositions regarding the relationships between OS and product innovation in new generations for incumbents and new entrants.

2 Conceptual background and theory

2.1 Generational technological change

A new technology regime or paradigm begins with a breakthrough innovation, thereby creating discontinuity (Taylor and Taylor, 2012). Distinctly different scientific principles to those of current technologies drive the emergence of new technology regimes (Sood and Tellis, 2005), within which an individual generation that shares the same underlying scientific principle evolves (Taylor and Taylor, 2012). Hence, a generation can be understood as “a particular form or variation of technological solution” [Taylor and Taylor, (2012), p.548] within a technology regime. Such technological solutions can be generated by GTC, representing “a significant advance in technical performance” [Lawless and Anderson, (1996), p.1187]. In particular, the transition period between technological generations is crowded with incumbents and new entrants seeking to achieve high market shares and profits. For new entrants that are mainly entrepreneurial and small firms, innovation is essential to survive and secure competitive advantage in an uncertain technological environment (Palmer et al., 2001; Niu and Wang, 2023). In this context, incumbents and new entrants need to continually invest in technological advancements to avoid the risk of falling behind competitors in successfully commercialising their own innovations.

Compared with other conventional concepts of technology and innovation, GTC has unique attributes (Abernathy and Utterback, 1978) which are worthy of attention (Taylor and Taylor, 2012). In the technology life cycle, the introductory stage of a new technological generation (Anderson and Tushman, 1990; Taylor and Taylor, 2012) has multiple dominant features (Suárez and Utterback, 1995) affecting product innovation (Utterback and Abernathy, 1975). When dominant features and standards (Suárez and Utterback, 1995) are ultimately selected among several alternatives, product innovation is then typically eclipsed by process innovation that focuses on the efficient production of large product quantities (Utterback and Abernathy, 1975). This stage leads to incremental innovation (Dewar and Dutton, 1986) reflected in the evolutionary refinement of products. At first, generational technology slowly improves mainly due to its uncertainties, then gradually accelerates with investments and developmental efforts, then unavoidably declines because of new generational technology emergence and overtaking, thereby forming an S-curve (Foster, 1986). However, the emergence of new generation technology does not always necessarily and rapidly overtake or replace the current generation technology. Rather, a transition period may exist and lead to overlapping S-curves in an industry. Figure 1 graphically articulates this discussion about GTC and our research context.

Research suggests that successful product innovation and performance outcomes are often associated with firms that

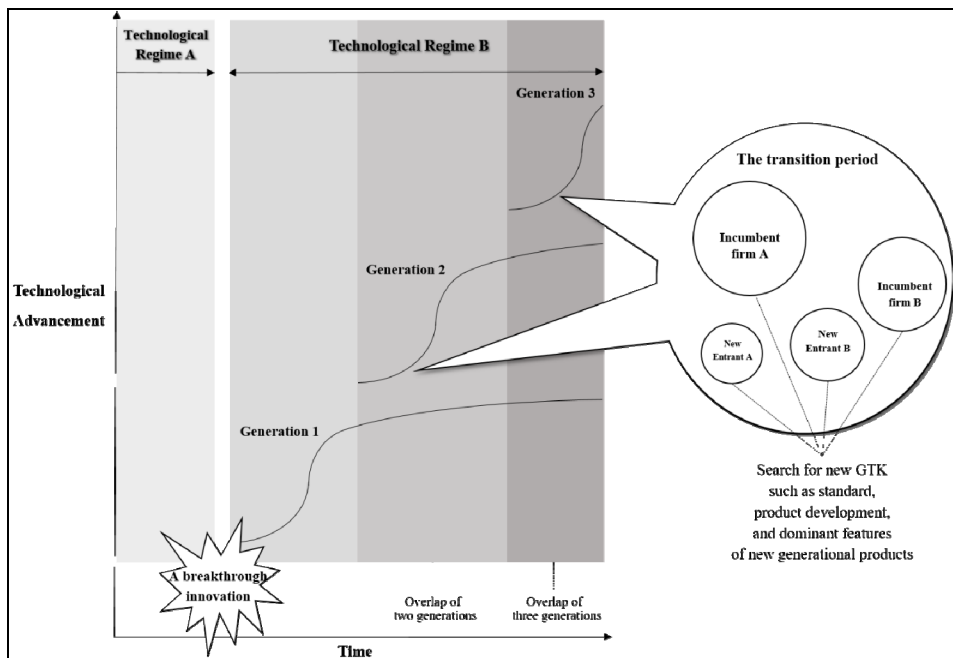
- 1 differentiate themselves in selected niche markets and adopt emerging generational technology early, leaving local rivals in prior generational markets (Lawless and Anderson, 1996)

- 2 respond in a timely fashion to competitor introductions of generational innovation (Turner et al., 2010)
- 3 introduce a product with market-leading position and with less compatibility with its foundational technological roots (Chen et al., 2022).

Research also indicates that firms often achieve high product innovation and market performance levels when they

- 1 embrace continuous multiple-product innovation and experimentation, repeatedly execute transitions between generations and incorporate new technical knowledge into new generational products (Brown and Eisenhardt, 1997)
- 2 develop competencies and routinise generational innovation from repeated experience (Turner et al., 2013)
- 3 sustain and extend operations in an industry, have low levels of technological complexity, and compete in multiple product markets (Qian and Wang, 2020).

Figure 1 Graphic description of GTC and the present research context



Previous findings have thus expanded our knowledge of GTC, but our understandings are still limited (Brown and Eisenhardt, 1997; Lawless and Anderson, 1996; Qian and Wang, 2020; Turner et al., 2010, 2013), particularly of the link between the OS behaviours of firms and the emergence of new GTK. Considering that OS offers insights into how firms seek and acquire knowledge to adapt to environmental change (Argote and Greve, 2007; Levitt and March, 1988) and develop innovation (Greve, 2003), it becomes essential to explore the role of OS in GTC context. On this matter, Wang et al. (2017a) bridged behavioural theory and GTC, and explored how problemistic search leads to technology

advancement. However, to better understand how incumbents and new entrants search for new GTK during the generational technology transition period, it is necessary to fully examine the diverse dimensions of OS and their effects on firm product innovation performance. Moreover, it is imperative to differentiate the search behaviours that are closely associated with the distinctive characteristics of incumbents and new entrants. Considering GTC as an evolutionary force, we draw on the behavioural theory of the firm (Cyert and March, 1963) and evolutionary theory (Nelson and Winter, 1982) to explore the impact of firms' OS behaviours on their product innovation performance in new generation markets.

2.2 Features of GTC

The GTC literature is complex with various well-defined concepts and features (Turner et al., 2010). Here, we review previous studies and identify the prominent GTC features that may affect a firm's OS behaviours.

First, as a definitional matter, GTC is a non-drastic, evolutionary, or incremental innovation (Lawless and Anderson, 1996; Qian and Wang, 2020; Turner et al., 2010) that involves the significant refinement and expansion of current-generation products within a given technological regime (Suárez and Utterback, 1995). New paradigms emerge and create discontinuity upon the recognition of new scientific principles (Gao et al., 2019). However, GTC is inherently evolutionary and incremental because these innovations are variations of technological solutions based on the same underlying scientific principles (Taylor and Taylor, 2012), providing better features for the current generation products. Each GTC can differ in terms of the degree of technological advancement. In the near term, GTC might create distractions to customers because new generational products can require customers to learn new features of the product and adjust their behaviours (Chen et al., 2022). However, GTCs are generally understood as incremental rather than disruptive or radical innovations if their advances are not based on different technological principles (Sood and Tellis, 2005).

Second, new generational technology does not immediately and completely replace that of the old generation (Lawless and Anderson, 1996; Panwar et al., 2020; Qian and Wang, 2020). Each technology generation typically involves socio-political and economic interactions among multiple participants. A significant body of literature on innovation has underscored the significance of distinguishing between incumbents and new entrants as well (Guo et al., 2022; Tripsas, 1997). For incumbents, the formation and rebuilding of relationships as well as the achievement of economies of scale in production may take time. Incumbents may also reduce the prices of their older products (Panwar et al., 2020). During this generational technology transition period, new entrants endeavour to capitalise on the opportunities arising from the emergence of the new generational market (Taylor and Taylor, 2012), in which case uncertainty increases as they compete with incumbents for leadership (Kapoor and Furr, 2015). Incumbents and new entrants often exhibit different levels of existing complementary capabilities and resources, which drive their participation in technology leadership competition in the new generation (Henderson and Clark, 1990; Kapoor and Furr, 2015). More specifically, incumbents have already established organisational structures, processes, and routines that are closely designed for the current technological regime (Tripsas, 1997). Nevertheless, if new entrants can effectively leverage specialised complementary assets linked to the new generation, even if initially inferior, new entrants can take the lead in

the new generation (Tripsas, 1997). Uncertainty further rises due to unspecified standards or evolving product features of the new generation (Taylor and Taylor, 2012). Third, GTC characteristically requires a substantial amount of financial investment in R&D (Swift, 2016) and considerable attention from top management teams (TMTs) (Tabrizi and Walleigh, 1997). In many cases, developing a new generational product requires a commitment of diverse resources. For instance, firms may need to upgrade their production facilities (Lee et al., 2011) and technological reconfigurations (Qian and Wang, 2020) to establish routines for the new technological generation. However, TMTs and R&D managers are largely preoccupied with their current production routines and advancement of previous and current generational products. Thus, building their commitment to achieve GTC may be difficult.

2.3 Integrating evolutionary and behavioural theories of OS

GTC is fundamentally evolutionary (Lawless and Anderson, 1996). Thus, an evolutionary perspective (Nelson and Winter, 1982) provides a theoretical lens for exploring the link between a firm's OS behaviours and its product innovation performance outcomes in new generational markets (Katila and Chen, 2008). The behavioural theory of the firm (Cyert and March, 1936) contributes foundational concepts and substantial portion of the philosophy of evolutionary perspective (Dosi and Marengo, 2007). The core argument of the behavioural theory posits that due to bounded rationality (Simon, 1947), actors have ambiguous goals and lack the ability to thoroughly evaluate alternatives in order to achieve goals, undergoing search processes that entail satisfaction and sacrifice. Evolutionary perspective also adopts the assumption on bounded rationality (Greve and Argote, 2015). As one of the key concepts of evolutionary theory (Nelson and Winter, 1982), OS, that is rooted in behavioural theory, can be defined as the "the process of seeking solutions to existing or anticipated problems" (Argote et al., 2021). OS is necessary to modify routines aimed at adaptation to environmental changes, such as GTC (Argote and Greve, 2007; Levitt and March, 1988). Here, knowledge assumes a central role in the mutation of organisations. In the evolutionary perspective, an organisation is an adaptive learning entity that creates and stores knowledge. Routines process information, retain knowledge from previous decision making, and guide current patterns of organisational behaviours (Cyert and March, 1963; March and Simon, 1958; Nelson and Winter, 1982). However, when a new cycle of GTC emerges, the environment may no longer be favourable to existing routines. In this case, firms may commence OS to explore new GTC and accordingly modify current routines to guide future actions (Nelson and Winter, 1982).

Industry players may acknowledge that GTC either provides them opportunities to earn higher profits or poses a risk of antiquating their business. However, as GTC is not a radical but, rather, an incremental transformation, and technological standard and dominant feature preferences may be ambiguous during the generational transition period, organisations may not always be sensitive to the importance of searching for new GTC as a basis for revising current routines. Without such search and modifications, the timely introduction of new generational products becomes uncertain. Simultaneously, TMTs and R&D managers need to turn their focus from performance in the current technological generation to product innovation in the next generation. GTC gained from OS must be applied and current routines must be modified. Ultimately, the searches

undertaken by firms may lead to new routines and technological choices in new generations. In the subsequent section, we delve into the diverse dimensions of OS that is critical for firms to adapt to GTC.

2.4 Dimensions of OS

OS assumes a critical role in accessing, developing, and creating knowledge to facilitate innovation and new product development, thereby occupying a central position in technology change (Weiss and Heide, 1993) and innovation theories (Laursen, 2012). OS that is widely examined in the technology and innovation literature (Katila and Ahuja, 2002; Katila and Chen, 2008) has several dimensions (Argote et al., 2021). A synthesis of the OS and technology and innovation literature leads us to suggest the importance of understanding ‘why to search’ (Cyert and March, 1963), ‘where to search’ (March, 1991), and ‘when to search’ (Lawless and Anderson, 1996; Katila and Chen, 2008). In addition, cumulative search experience of a firm is another important factor that affects innovation processes and outcomes (Levinthal and March, 1993).

Regarding ‘why to search’, the factors that may motivate OS have been extensively investigated (Argote et al., 2021). Specifically, problemistic and slack searches (Cyert and March, 1963) explain organisational motivation. In problemistic search, market performance that is lower than the target of comparable organisations can prompt the search for solutions (Posen et al., 2018; Wang et al., 2023b). When the evaluated performance has not surpassed the aspirational level, organisations may embark on OS for strategies to address problems (Audia and Greve, 2006). Slack can be defined as “the pool of resources in an organisation that is in excess of the minimum necessary to produce a given level of organisational output” [Nohria and Gulati, (1996), p.1246]. Such resources may include unused administrative factors, redundant R&D facilities and staffs, and spare finances (Greve, 2007; Nohria and Gulati, 1996). Slack resources can also motivate organisations to assume risk and seek further opportunities (Cyert and March, 1963; Levinthal and March, 1981; Greve, 2007; Wang et al., 2017b), indicating ‘slack search’.

Regarding ‘where to search’, we consider both local and non-local search. The former means that firms seek internal and embedded knowledge generated through their experiences and routines (Laursen, 2012; March, 1991; Nelson and Winter, 1982). To deal with technological change, most firms are unable to search entire industry knowledge stocks, but instead reference their own knowledge bases (Pavitt, 1988). Searching for knowledge “that is in the neighborhood of the organisation’s current knowledge base” [Laursen, (2012), p.1184] is understood as a local search. Local search is highly associated with exploitation, defined as “learning gained via local search, experiential refinement, and selection and reuse of existing routines” [Baum et al., (2000), p.768].

A non-local search refers to OS that explores novel and salient knowledge beyond a firm’s established knowledge base (Levinthal and March, 1981; March, 1991; Katila and Ahuja, 2002). This search is closely related to the exploration of new and unfamiliar knowledge (March, 1991; Piezunka and Dahlander, 2015). Exploration refers to “learning gained through processes of concerted variation, planned experimentation, and play” [Baum et al., (2000), p.768].

‘When to search’ is related to search timing, which innovation theorists (e.g., Lawless and Anderson, 1996; Mitchell, 1989; Katila and Chen, 2008) consider an important

determinant of innovation performance (Ehls et al., 2020). For instance, the early adoption of emerging generational technology might create first- or early-mover advantages, leading to sustainable competitive superiority (Lawless and Anderson, 1996).

Lastly, in addition to the aforementioned three OS considerations, we propose that search experience is highly relevant to innovation outcomes. In the search literature, the routinisation of OS itself is rarely considered (Tzeng, 2009). Nonetheless, while accumulating experiences, organisations often develop routines to address environmental changes (Tzeng, 2009), with their ability to learn being critical to competitiveness (Levinthal and March, 1993; Wang et al., 2023a). Similarly, processes for new knowledge search can be embedded in organisational routines (Argote and Miron-Spektor, 2011; Wang et al., 2022).

2.5 Firms' innovation performance in GTC

A firm's OS behaviours can lead to its product innovation performance in the new generation. Building on characteristics of GTC, scholars have provided specific meanings and measurements of firm product innovation performance. Regarding product innovation, Lawless and Anderson (1996) argued that a firm must choose to be a generalist that spans several generations or a specialist that focuses on one generation. Generalists need to carry out multiple product innovations in several generations (Brown and Eisenhardt, 1997). Hence, managers need the ability to routinely develop new generation products through experiments and rhythmically transfer products of current generations to the next ones (Brown and Eisenhardt, 1997). An indicator of product innovation can be significant innovation advancement at the product line level (Turner et al., 2010, 2013) and the degree of generational technological advancement (Wang et al., 2017a) that is distinctively defined by the specific features of examined industries.

3 Generational technology change of the MPMI

Given the abstract nature of GTC, we draw on the Chinese MPMI as a reference point. For several reasons, the MPMI provides an ideal setting for exploring evolutionary GTC and firms' OS behaviours leading to new GTC acquisition. First, the generation of mobile phones is classified based on the technology used to connect to networks, thereby facilitating accurate identification. Second, mobile phone manufacturers are highly motivated to search extensively for the next GTC that can guide their innovations for upcoming generations. Third, several market generations overlap. For mobile phone manufacturers, managing the generational technology transition period is critical to appropriating value from prior generation products. At the same time, mobile phone manufacturers must develop new generational products equipped with new standards and dominant features. Therefore, OS for newly emerging GTC has become important for manufacturers to survive through multiple technological and product generations.

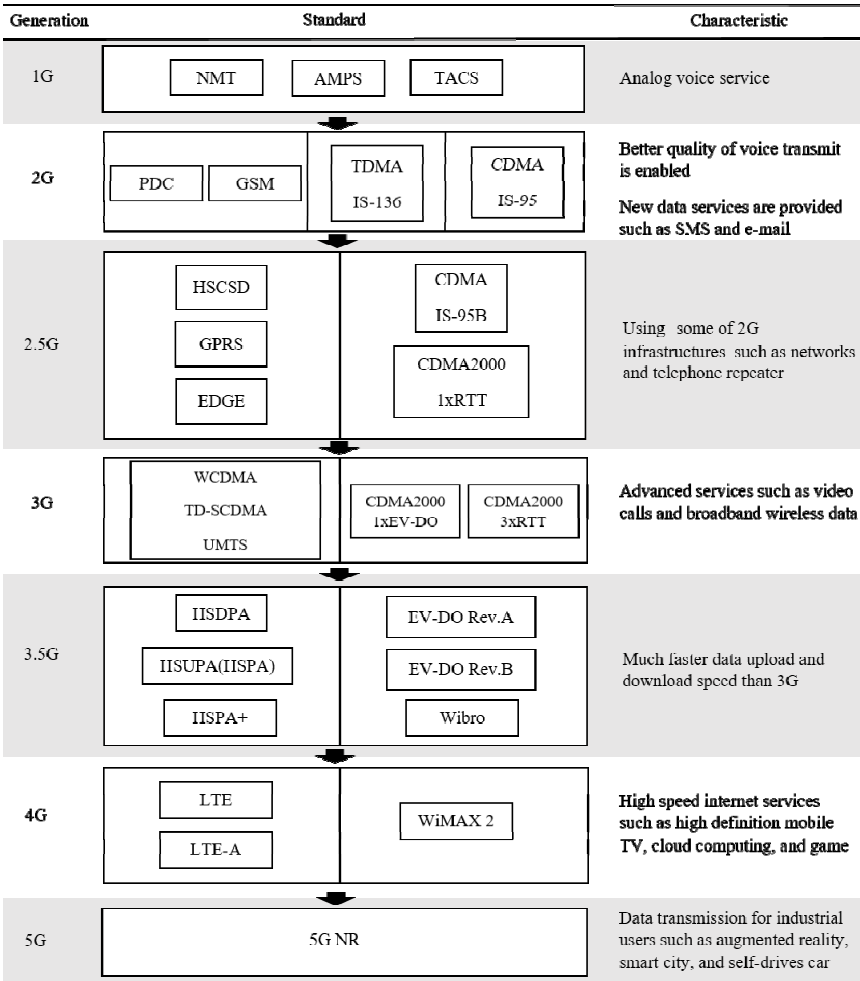
In the following sections, we elaborate the evolution of the MPMI and discuss how new features and standards of their generational products have historically advanced. First, we delve into the origins of cellular network technology and trace the development of each generation of mobile phones, starting from the first generation (1G) and progressing to 5G. Second, we explore the process of standardising mobile handset

generational technology and provide an overview of the technological progress trajectories of cellular network technology, along with the corresponding characteristics of each generation. Finally, we specifically focus on the Chinese MPMI to provide a more detailed elaboration on our theoretical framework.

3.1 History of cellular network technology and GTC of the MPMI

The history of cellular network technology extends back to the 1890s when Marconi transmitted wireless signals over a distance of more than a mile, marking the beginning of wireless telegraphy era (Agar, 2013; Steinbock, 2005). The initial mobile phone was large and heavy, and thereby difficult to popularise. However, technological advancements on the components, telecommunication infrastructure development, and political coordination and global endeavours for the commercialisation of the mobile phone enabled its popularisation (Agar, 2013).

Figure 2 Technological progress trajectories of cellular network technology and generational characteristics



Since the advancements from 1G to 2G, the evolution of mobile phone technology has been mainly based on the data processing capability of chips. Moreover, type of chip largely determines the services that these devices provide to consumers. In 1983, 1G was developed as part of a military pursuit. This technology, characterised by analogue voice transmission, was later transformed into 2G that enabled digital or data exchange services (Gupta and Jain, 2016). This change in signal transmission mode was critical in the evolution of cellular network technology (Gupta and Jain, 2016). Digital voice encoding enables new services, such as SMS and e-mail, and provides better sound quality, allowing advancements from business to consumer mass markets (Steinbock, 2005). Yet, unlike the innovation from 1G to 2G, movement from 2G to 2.5G was a stepping stone to advance to 3G technology. 2.5G can use 2G infrastructures such as networks and telephone repeaters, which require huge investments. The value chain changes were also not as large as expected, allowing consumers to adapt to new services smoothly and incrementally. In summary, although coexistence of several generational technologies is possible, GTC shows variations of innovation levels.

In 2001, 3G technology emerged, supporting higher data transmission rates and capacity than 2G (Agrawal et al., 2015), thereby enabling multimedia services (Gupta and Jain, 2016). A later development to 3.5G increased the data transmission speed. In 2009, Sweden and Norway became the first countries to offer commercial 4G services (Bhandari et al., 2017). 4G's download speeds were ten times faster than 3G, facilitating high-speed internet services like cloud computing, video conferencing, gaming, and high-definition mobile TV (Bhandari et al., 2017).

South Korea introduced the first 5G service in 2019 (Shin et al., 2020). Intended to have much higher capability than the current 4G, 5G was designed to fit growing demands for data transmission from industrial users such as companies using cloud computing and the internet of things (IoT) (Salih et al., 2020). Typical augmented reality and virtual reality services, smart city, building and services with IoT, self-driving car, and applications in education and autonomous vehicles were enabled. However, 5G remains in the early stages of its adoption (Bhandari et al., 2017).

3.2 Standardisation of generational technology

Mobile handset manufacturing involves diverse actors across socio-political and economic arenas, including chip producers, hardware components makers, contents providers, service providers, original equipment manufacturers (OEM) and original development manufacturers (ODM), research institutes, application developers, and governmental organisations (Berkhout et al., 2007). In the MPMI, a major concern is the standardisation of generational technologies set in advance by international organisations (Ghosh et al., 2019). Among these entities, several cooperate or compete with one another in pursuing a global or regional standard for their generational technologies, given that such certification guarantees their future success. Moreover, international organisations such as Institute of Electrical and Electronics Engineers, 3rd Generation Partnership Project, and the International Telecommunication Union set the industry standards. In such cases when a standard is selected among several alternatives, GTC becomes irreversible for all participants. This change may pose an enormous threat or opportunity worldwide for large and small mobile handset manufacturers with uncertain positions in future generations.

Table 1 Standards of each technology generation and abbreviations

<i>Generation</i>	<i>Standard</i>	<i>Abbreviation</i>
1G	Nordic mobile telephone	NMT
	Advanced mobile phone system	AMPS
	Total access communication system	TACS
2G	Programme delivery control	PDC
	Global system for mobile communication	GSM
	Code-division multiple access	CDMA
	Time division multiple access	TDMA
2.5G	High speed circuit switched data	HSCSD
	General packet radio service	GPRS
	Enhanced data rate for GSM evolution	EDGE
	CDMA Interim Standard 95B	CDMA IS-95B
	CDMA2000 1× round trip time	CDMA2000 1× RTT
3G	Wideband code division multiple access	WCDMA
	Time-division synchronous CDMA	TD-SCDMA
	Universal mobile telecommunications system	UMTS
	CDMA2000-evolution-data optimised	CDMA2000 1× EV-DO
	CDMA2000 3× round trip time	CDMA2000 3× RTT
3.5G	High speed downlink packet access	HSDPA
	High speed uplink packet access	HSUPA
	Evolved high speed packet access	HSPA+
	EV-DO revision A	EV-DO Rev. A
	EV-DO revision B	EV-DO Rev. B
	Wireless broadband	Wibro
4G	Long-term evolution	LTE
	LTE advanced	LTE-A
	Worldwide interoperability for microwave access	WiMAX
5G	5G new radio	5G NR

Figure 2 summarises the MPMI technological progress trajectories (Christensen and Rosenbloom, 1995) and the standards and characteristics of each technological generation. Table 1 provides detailed explanation on the communication standard terms.

3.3 Chinese MPMI

To further elaborate on our theoretical logic, we provide more detailed applications. Firms in the Chinese MPMI have experienced several generations of communication standards and have transformed from being followers in 2G period to dominant players in 3G and 4G to advance leaders in the 5G global market. In this transformation, the search behaviours of firms played important roles.

3.3.1 *Evolution of the Chinese MPMI*

The evolution of the Chinese MPMI illustrates how some firms have managed OS during GTC. In China, 1G development lasted from 1990 to 1997. By then, most of the Chinese mobile phone manufacturers had adopted OEM mode (Fan, 2010; Jin and Von Zdetwitz, 2008). The development of 2G mobile phones started in the mid-1990s. Huawei and ZTE started to build their domestic brands, focusing on developing GSM and CDMA, respectively. Although Huawei did not outperform ZTE during the 2G period, they accumulated considerable experience in the development of GSM. Lenovo is another Chinese manufacturer that leveraged its advantage in the PC domain and entered the MPMI.

In early 2000, China began to transition from 2G to 3G (Fan, 2010; Jin and Von Zdetwitz, 2008). By then, the Chinese indigenous industry standard, TD-SCDMA, was competing with two global standards, CDMA-2000 and WCDMA (Chen and Wen, 2016). Several local brands such as the three mentioned above have invested large resources in developing TD-SCDMA and dominated the market (Chen and Wen, 2016). During the transition from 3G to 4G, Huawei and ZTE continued its success but new local manufactures such as Vivo and OPPO began to emerge mainly due to their earlier commitment to 4G technology. Meanwhile, firms such as Lenovo that had unsuccessful OS for new GTC began to fall behind (Han, 2018). During the transition from 4G to 5G, Huawei, Xiaomi, Vivo, and OPPO have become the top four domestic players.

In the next section, we develop propositions to illustrate the relationship between OS behaviours and firm innovation in new generational markets during the technological transition period. We provide context-based illustration referencing Chinese manufactures to demonstrate the relationship between firms' OS behaviours and their innovation outcomes.

4 **Propositions related to GTC, OS, and product innovation performance**

4.1 *Problemistic search for new generational technological knowledge*

According to the behavioural theory of the firm, decision makers with bounded rationality search for solutions to their current problems when performance is below target 'aspirational' levels (Cyert and March, 1963; Greve, 2007). This observation can be applied to the GTC context. In Proposition 1, we specifically focus on the incumbents' problemistic search, as new entrants are not currently operating in the generational market. Managers of incumbents tend to be largely occupied with established routines to produce and improve their current generation products (Tabrizi and Walleigh, 1997) and less likely to take risks to modify their routines during the exploratory phase of the new technological generation. When the current generation products show higher performance than their aspiration level, managers are less likely to recognise that the new environment set by GTC may no longer be favourable to their current routines. Moreover, such managers can be less sensitive to the need for change because GTC is incremental rather than disruptive. However, when the current generation products perform lower than their aspiration level, managers may realise that the new environment is unfavourable to their routines, and low performance can continue in the new technological generation (Feldman and Pentland, 2003). Such a scenario can invoke OS for new GTC, thereby

modifying existing routines in accommodation of the new environmental context, enhancing product innovation performance (Posen et al., 2018).

Greve (2003) provided empirical evidence that a firm performing below its target incurs high R&D expenditures and shows motivation to explore risky solutions. Antonelli (1989) argued that firms may invest in R&D when their profitability declines below an acceptable level. Wang et al. (2017a) investigated the effect of problemistic search on firm innovation and performance in the new generation. Consistent with our current arguments, flat-panel manufacturers were found more willing to take risks and motivated to participate in problemistic search when their performance outcomes did not meet their aspiration levels (Wang et al., 2017a).

During the GTC of the Chinese MPMI, the problemistic search of Vivo and OPPO advanced their product innovation performance in new technological generations. During the transition from 2G to 3G, these companies were unwilling to simultaneously invest R&D in developing co-existing standards, including CDMA-2000, WCDMA, and TD-SCDMA, and rather focused on mature standards such as those in the global market. However, in 2012, China Mobile experienced substantial growth relying on TD-SCDMA chips invented by MediaTek, a Taiwanese chip design firm. In 2013, sales of mobile phones with TD-SCDMA reached 0.155 billion CNY, which equalled the sum of sales of CDMA-2000 and WCDMA-equipped phones. OPPO and Vivo were late to support TD-SCDMA and suffered considerable difficulties due to a lack of prior commitment to 3G development. By the end of 2013, their low performance motivated both companies to stop investing in 3G R&D and to start searching for 4G GTK. Hence, OPPO and Vivo were able to launch several series of 4G new smartphones. Table 2 shows that OPPO has done relatively more search for 4G patents than Vivo.

In short, evidence from the Chinese MPMI suggests the following proposition.

Proposition 1: The problemistic search for new GTK of incumbents during the transition period is positively related to their product innovation performance in the new generation.

4.2 Slack search for new generational technological knowledge

OS theorists suggest that excess resources may prompt firms to engage in experimental search (Cyert and March, 1963; Levinthal and March, 1981). Proposition 2 focuses specifically on exploring the incumbents' slack search, taking into account the absence of new entrants' participation in the current generational market. During the generational technology transition period, incumbents face risks in searching for new GTK mainly because standard or dominant features for new generation products are uncertain. The feature improvements customers want for such products can also be unclear. Moreover, incumbents must not only search for GTK associated with the new generation markets, but they also need to keep improving their current products, thereby requiring both considerable management attention and extensive resources (Cyert and March, 1963). TMTs and R&D managers may be reluctant to search for new GTK and set new routines unless their firms have abundant resources (Nohria and Gulati, 1996). The slack resources such as underutilised R&D staff and uncommitted funds and other forms of capital (Greve, 2007) can enable firms to loosen or otherwise modify their current routines, search for new GTK, and incorporate new practices (Chen and Miller, 2007;

Greve, 2003). Again, such search behaviour can contribute to firm product innovation performance in the new technological generation.

Table 2 Shares of 4G and 5G declared patents in the global market

<i>Company</i>	<i>5G patent global share</i>	<i>5G patent global share</i>	<i>4G patent global share</i>	<i>4G vs. 5G patent share difference</i>	<i>5G 3GPP contributions global share</i>	<i>Number of 5G patent family</i>	<i>Number of 5G patent not declared to 2G, 3G, 4G</i>	<i>Number of patent with date after 2012</i>	<i>Average year of 5G patent</i>	<i>Patent value index (citation * family size)</i>
Year	2021	2020	2020	2020	2021	2020	2020	2020	2020	2020
Huawei	13.52%	14.61%	9.99%	4.62%	21.64%	3,147	2,839 (90.2%)	2,618	4.31	0.85
Lenovo	1.12%	0.45%	0.16%	0.29%	1.23%	97	82 (84.5%)	81	6.15	0.71
OPPO	4.57%	3.00%	0.39%	2.61%	1.29%	647	647 (100%)	641	2.99	0.09
Vivo	3.68%	1.11%	0.00%	1.11%	1.28	238	238 (100%)	238	1.3	0.04
Xiaomi	1.70%	NA	NA	NA	0.30%	NA	NA	NA	NA	NA

Source: IPLytics report 'who is leading the 5G race', 2020, 2021 and Pohlmann et al. (2020)

Table 3 New generational product market shares of smartphones in China domestic market (%)

<i>Company</i>	<i>5G</i>		<i>4G</i>					<i>3G</i>		
	<i>Year</i>		<i>Year</i>					<i>Year</i>		
	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
Huawei	30.7	45.5	39.72	25.85	20.43	16.3	14.45	9.60	9.66	7.56
Lenovo	<1.2	<2	<2	<2	<2	2.35	6.13	11.23	8.83	7.93
OPPO	14.6	11.0	16.37	19.98	18.1	16.8	8.10	NA	NA	NA
Vivo	16.1	15.6	18.48	19.33	15.35	14.8	8.05	NA	NA	NA
Xiaomi	10.5	8.3	10.53	12.88	12.325	8.65	14.95	11.35	2.9	2.1

Notes: Data from 2020 to 2021 are based on the Getui big data report on 5G smartphone market share; data from 2012 to 2019 are from IDC quarterly mobile phone tracker and Qianzhan Database on smartphone market share.

The effect of slack resources is widely studied. For example, Bentley and Kehoe (2020) found that slack human resources improve performance among firms that pursue strategic change, and this relationship is strengthened with high levels of financial slack resources. Greve (2003) showed that slack search is positively associated with innovation development in the Japanese shipbuilding industry. In Taiwan, electronic manufactures with more financial slack resources also had high investments in R&D (Lu and Fang, 2013).

The success of Huawei, OPPO, and Vivo did not prevent their search for new GTK. Rather, their success contributed to slack resources which, in turn, promoted their innovation competency. Huawei has accumulated abundant financial and human resources over technological generations and has become one of the leading companies promoting 5G. In early 2015, OPPO established a new team in charge of developing their 5G standard. In 2016, Vivo also established a 5G R&D centre in Beijing. These increased

R&D resources led OPPO and Vivo to launch new 5G smartphones in early 2019. In 2020, their global patent shares related to 5G are larger than those of 4G. For example, a comparison of 4G to 5G shows that OPPO declared 3% of all 5G families, which is 2.61 percentage points higher than their declarations for 4G (0.39%) (Table 2, column 8). These three companies submitted a high number of proposals to 3GPP (Table 2, column 6), and thus have successfully launched several new 5G models. In the first quarter of 2021, the new products allow OPPO and Vivo to hold 16.1% and 14.5% of the 5G smartphone global market share, respectively (Hyers, 2021). In the Chinese domestic smartphone market, Huawei, Vivo, and OPPO's new generational products shares are the top three in 5G (Table 3, columns 2–3).

In consideration of this anecdotal evidence, the following relationship is proposed.

Proposition 2: The slack search for new GTK of incumbents during the transition period is positively related to their product innovation performance in the new generation.

4.3 *Local vs. non-local search for new generational technological knowledge*

Incumbents generally operate through sequential generations, and with such experience can accumulate knowledge on GTC and generational technology. Such knowledge may have been embedded among their employees, research teams, and organisational routines, thereby creating a knowledge base (Argote and Todorova, 2007). Incumbents tend to exploit such established knowledge stocks (March, 1963; Nelson and Winter, 1982; Pavitt, 1988; Yun et al., 2022) because they are efficient and reliable compared to those generated through exploratory learning (Laursen, 2012). The exploitation of current knowledge stocks can be advantageous, particularly when new GTK has uncertainties with regard to value, efficacy, costs, etc. during the technological transition period (Eggers and Park, 2018). Martin and Mitchell (1998) supported the above arguments and found that incumbents are likely to exploit their knowledge base and introduce new products similar to their existing ones in terms of a set of core features. Helfat (1994) showed that incumbents tend to continue their current R&D to exploit and expand their knowledge base.

Meanwhile, new entrants to an emerging technological generation are mainly start-ups or businesses from other technological domains. Thus, these firms cannot generally depend on their own established knowledge base to exploit new GTK (Polidoro and Tang, 2021) during the transition period. New entrants need to explore new GTK to improve their understanding of this new market and to catch up with incumbents that are technologically advanced and experienced. Exploration for novel, salient, and vivid knowledge can provide them with new material and stimulate their innovation (Katila, 2002). Through exploration in the new technological generation, they can enhance their industry understanding and combine novel and salient GTK, chase incumbents and even take the technological lead in new generational markets.

The above argument is supported by previous literature on innovation. Brown and Eisenhardt (1997) argued that to successfully prepare for the future, managers must not depend on a single plan but rather experiment with various probes. The barrier to entrants is high in innovation-intensive industries, but those who enter the emerging technological generation with significantly advanced technology can challenge the incumbents' leading positions (Mathews, 2005). Lee et al. (2011) showed that if the incumbent of the current generation is a leader with cutting-edge generational technology, new entrants are more

inclined to invest in technological advancement efforts. Palmer et al. (2001) also argued that small businesses are often innovative as they have less inertia that prevents them from responding to a changing environment.

In the Chinese MPMI, chips have long been a bottleneck innovation for manufactures, most of whom rely on existing companies such as Qualcomm, MediaTek, and Intel. In 2006, Huawei became a new entrant in the chip domain, one of the few companies that attempted to search beyond their current arena and develop its own chips and processors. Huawei successfully invented its first chip, K3, and then established its knowledge base in the chip and processor domain. Later, as a new technological generation was introduced, Huawei engaged in knowledge exploitation as an incumbent. Kirin 910, an ARM-based chip, entered the market in 2012 and was used in 4G smartphones. Since 2020, the 5G Kirin 9000 chipset has been employed in the Mate40 Pro model. Huawei's initial non-local search and subsequent local search for technical knowledge in chip domain help them outperform competitors such as Lenovo.

In terms of patenting in 5G, Huawei and Lenovo were the early incumbents and engaged in knowledge exploitation. Certain portions of their patents were also declared for 2G, 3G, and 4G (Table 2, column 8). However, OPPO and Vivo, as new entrants and without a strong foundation in earlier generation technology, paid more attention to exploration, then declared 100% of their patents to 5G. Despite adopting different paths, Huawei, Oppo, and Vivo all realised strong new generational product performance based on their innovative 5G products (Table 3, columns 2–3).

The following propositions are indicated.

Proposition 3a: Exploitation for new GTK of incumbents during the transition period is positively related to their product innovation performance in the new generation.

Proposition 3b: Exploration for new GTK of new entrants during the transition period is positively related to their product innovation performance in the new generation.

4.4 Timing for new generational technological knowledge search

Firms need to outpace their competitors in searching for new GTK to dominate their knowledge space and obtain more opportunities for innovation (Katila and Chen, 2008). During the generational transition period, before the knowledge space becomes crowded (Katila and Chen, 2008), quickly acquiring GTK can help firms preempt and outperform competitors (Markman et al., 2005). Early searchers can become technical leaders in new technological generations and set the path for future innovations. Firms that delay the search for new GTK may find any knowledge they acquire to be redundant with that of competitors and not a basis for advantage. In this case, the late-acting firms can expect lower sales for their new generational products.

By contrast, early searchers can have sufficient time to combine new GTK with their existing knowledge stocks, modifying current routines, and creating new products as needed across technological regimes (Kaplan and Vakili, 2015). Still, both incumbents and new entrant can be expected to experience challenges as early searchers. Incumbents face the double pressures of improving their current generational products and of investing in plant, equipment, and specialised personnel for the new technological generation. New entrants can have particular difficulties searching for and recognising the value of new GTK until a consensus is reached regarding the standards and dominant features of new generation products.

In the Chinese MPMI, early search for GTK has been demonstrated to help firms achieve high innovation performance in the new generation markets. In 2001, as a major global computer producer, Lenovo decided to expand its business into the Chinese MPMI in pursuit of enhanced earnings. While most of their computer industry competitors attempted to survive in the OEM mode, Lenovo embarked on an early search for new GTK in 2G. To obtain GTK related to GSM and CDMA, Lenovo formed an alliance with the Xiahua Group. Consequently, Lenovo successfully developed 2G smartphones with music, colour screens, and cameras with high resolution.

Success in its early search for 2G GTK established a solid, knowledge-based foundation for Lenovo's subsequent success in the 3G battle. In terms of standard choice, Lenovo was one of the few companies that invested in TD-SCDMA development, which was considered risky at that time. Lenovo launched their first TD-based mobile phone early in the 3G era, and their subsequent models effectively incorporated many advanced 3G-based features, such as video call and high-speed data transmission. In the 3G market, Lenovo outperformed other competitors such as Huawei from June 2012 to December 2014 (Table 3, columns 9–11). In late 2013, 4G smartphones started to appear in the market. However, Lenovo's search in 4G and 5G has lagged behind (Table 2), due to the company's greater focus on sales instead of R&D. Thus, Lenovo's competitiveness and technological advancement was stymied by its strong emphasis on appropriating value from prior technological generations. Despite the longer average years of 5G patent families, Lenovo did not launch successful new products comparing with the other companies in this technological generation (Table 3, columns 2–3).

By contrast, during the 4G to 5G transition, Huawei engaged in more intensive early search, gaining much longer average years of 5G patent families principal rivals OPPO and Vivo (Table 2, column 10). Huawei also engaged in substantial early search after 2012 when 5G inventions started to emerge (Table 2, column 9), and thus achieved the best new generational product performance among its rivals (Table 3).

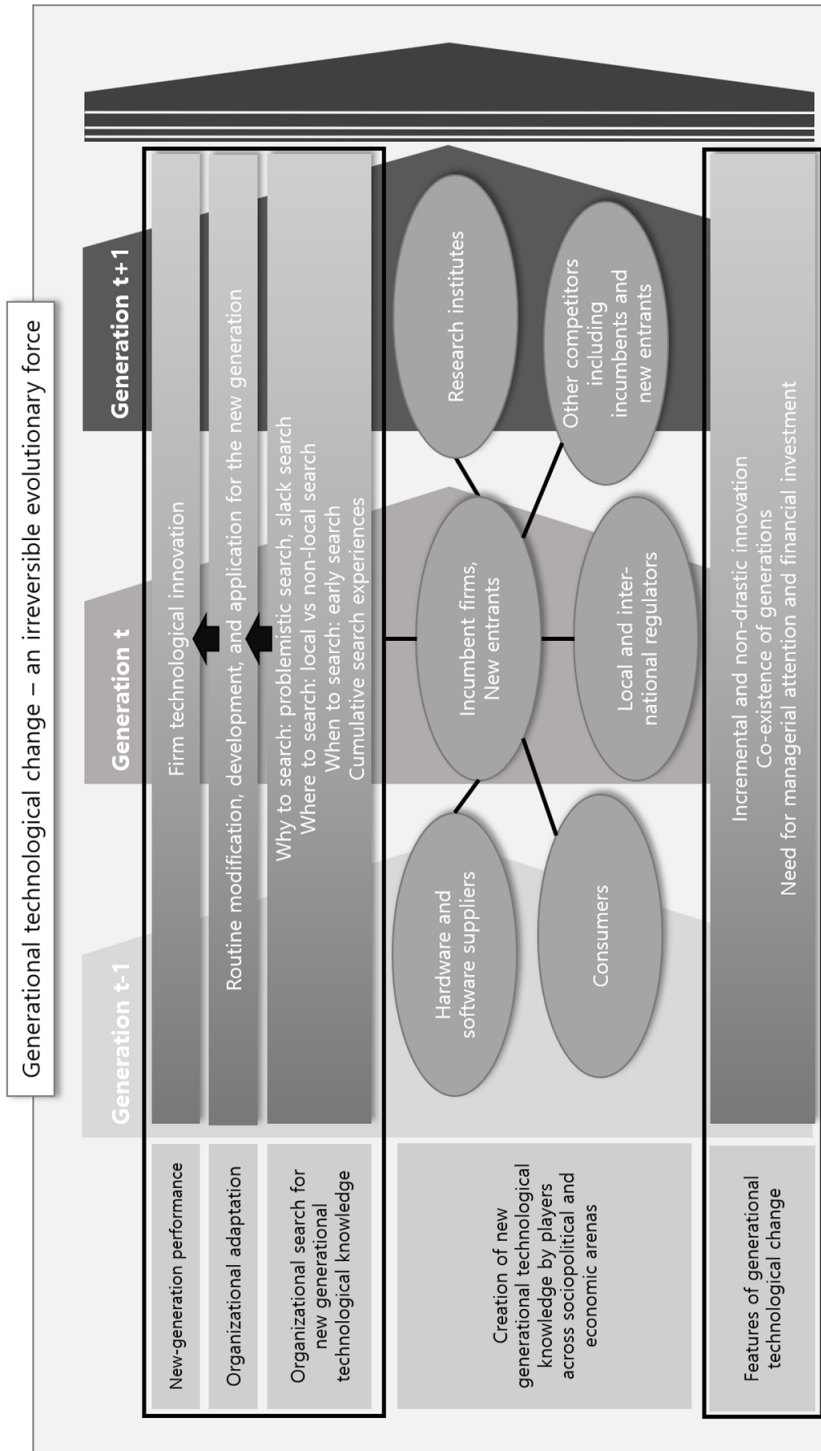
In summary, the Chinese MPMI experience supports the following proposition.

Proposition 4: Incumbents' and new entrants' early search for new generational technological knowledge during the transition period is positively related to their product innovation performance in the new generation.

4.5 Cumulative search experience

While accumulating search experience in sequential technological generations, incumbents develop their own routines for handling GTC (Tzeng, 2009). Their successes and failures may be used to direct and focus future searches and reduce their associated costs. Learning from cumulative experience helps firms transition in an evolutionary fashion between generations of technology rooted in common scientific principles (Hannan and Freeman, 1977). These experiences can contribute to their successful search for and recognition of new, relevant GTK and to their successful introduction of new-generation products. New entrants cannot immediately use accumulated search experience to address GTC, but eventually draw on it as they continue operating in sequential technological generations. As Hoang and Ener (2015) observed, firms benefit from their sequential exploration experiences by linking their current technological knowledge with the latest available know-how in a new product market.

Figure 3 GTC, OS, and firm innovation performance



In the Chinese MPMI, OPPO's cumulative search experience in the antenna domain established its dominant position in the 5G market. During the transition from 4G to 5G, signal strength has become more important for data transmission. The new 5G smartphones need compatibility with 1G–4G networks to receive signals. With their success in the antenna domain for approximately 10 years, OPPO has accumulated several unique patents and could utilise such experience in antenna design in their Find X2 model in 2020. According to OPPO, the Find X2 device can simultaneously receive multiple channels of 5G and 4G signals to establish the fastest and most stable connection. Meanwhile, Huawei's cumulative search in several complementary technological domains allowed them to establish a strong R&D team and deliver high-quality 5G patent families that receive higher forward citations than those of Lenovo, OPPO, and Vivo (Table 2, column 11). These patents helped Huawei to launch successful new 5G products and maintain their dominant market position.

To conclude, we propose the following.

Proposition 5: The cumulative search experience of incumbents and new entrants for sequential generations are positively related to their product innovation performance in the new generation.

Building upon evolutionary and behavioural theories, we propose a theoretical foundation on the relationship between firms' OS behaviours and their innovation performance outcomes in new generational markets. Figure 3 presents the framework for dynamics underlying the GTC phenomenon. The figure presents our propositions regarding the relationships between various dimensions of OS and firm innovation performance, as well as the underlying core mechanism of organisational adaptation, derived from our understanding of previous literature on the GTC and GTK creation.

5 Discussion

Previous studies of GTC mainly discussed how firms' external and internal factors affect their innovation and performance outcomes in new technological generations. By contrast, this study initially builds on our present understanding of GTC and subsequently integrates the GTC and OS literatures to explain how incumbents and new entrants address evolutionary concerns during the technology transition period in an ever changing and innovation-intensive market. After integrating the relevant research streams, we build a conceptual framework for understanding relationships among GTC, OS, and firm product innovation performance in the new technological generation. This framework, rooted in evolutionary and behavioural theories, provides needed understanding of core dynamics underlying the GTC phenomenon.

More specifically, our framework takes into account the distinctive characteristics of GTC, including evolutionary and incremental innovation, the co-existence of generations, and the necessity for managerial attention and financial investment. Furthermore, we incorporate multiple dimensions of OS and account for diverse search behaviours of firms within our framework. In doing so, we propose that incumbents and new entrants must make decisions regarding why, where, and when to search for new GTK and utilise their accumulated search experiences to effectively manage GTC. Theoretically, we argue that through the application of newly acquired GTK, firms can modify routines tailored to the current generation and adapt to the new generation. This, in turn, guides

organisational behaviours that are conducive to the new generation, ultimately leading to enhanced product innovation performance in new generational markets.

5.1 Contributions

Theoretically, this study adds to the emerging literature that discusses how GTC features are distinctive from those of other types of innovations. First, drawing on evolutionary theory, we recognise that discrete technological generations require that organisations be adaptive learning entities, and that adaptation occurs through separate search processes when considering within-regime adaption. To support this argument, we link behavioural theory to evolutionary perspective and discuss how GTK is acquired through the diverse OS behaviours of incumbents and new entrants and can induce the modification of routines designed around current technological generations. Through this approach, we present an integrative theoretical framework that sheds light on the dynamics underlying the phenomenon of GTC.

Second, we expand GTC literature by explaining how three potential foci of OS – including why, where, and when to search – and cumulative search experience help firms acquire new GTK, affecting innovation outcomes during the generational transition period. In this evolutionary period, new entrants that are mainly start-ups and small businesses often enter into new generational markets to seize emerging opportunities, thereby competing with incumbents. Thus, we distinguish the OS behaviours of incumbents and new entrants. ‘Why to search’ is manifested in both problemistic search (driven by incumbents’ poor performance in the current generation) and slack search (driven by incumbents’ excess resources). ‘Where to search’ is manifested as the incumbents’ local search and new entrants’ non-local search for new GTK, while ‘when to search’ is represented by the timing of search among both incumbents and new entrants for new GTK. Together with the search experience of incumbents and new entrants, the diverse OS decisions of firms can affect the modification of their existing routines and allow them to adapt to or create technological change.

Third, we use MPMI as a reference point to explore the abstract evolutionary nature of GTC and a firm’s search behaviours. We highlight that MPMI exemplifies an evolutionary process of GTC effectively, as the generations of mobile phones are clearly identified, and mobile phone manufacturers are highly motivated to adapt to new generations and have to manage the generational technology transition period. Specifically, we focus on the Chinese MPMI where mobile phone manufacturers actively endeavour to address the emergence of new technological generations. The Chinese MPMI offers strong support for our theoretical logics, allowing us to build our propositions regarding the effect of a firm’s diverse OS behaviours on its product innovation performance in the new generation markets.

5.2 Practical implications

This study also provides insights for practitioners tasked with managing GTC during the generational technology transition period. The practical implications differ somewhat for the managers of incumbent firms versus new entrants. During generational transition periods, the new technological domain is prone to become crowded by incumbents seeking sequential growth opportunities and new entrants seeking initial market share. In

the early transition stage, technology standards may not be solidified and dominant designs may not be established (Teece, 1986). In this context, managers of incumbents need to be careful to not directly compare technology investment attractiveness on customary financial bases. This is because predictable returns from current technological generations will commonly seem more favourable than speculative returns from new generations (Christensen and Bower, 1996), despite the long-term promise of the latter.

For the managers of new entrants, there will be sparse, incomplete, or marginally relevant knowledge stocks to leverage. Knowledge accumulation may be slower and less predictable, a situation that typically calls for incremental bets and, if possible, strategic flexibility (Hagel et al., 2008). New entrants are advised to follow the principles associated with introducing ‘minimum viable products’ (see Moogk, 2012), establishing, for example, milestones, performance reviews, and go-no go decision points as bases for recognising and choosing preferable technology development paths.

5.3 Limitations and future studies

Our proposed theory has several limitations, two of which may be most relevant. First, our theory only accounts for manufacturers’ actions and outcomes and does not consider the important role of diverse players in an industry, including component suppliers, consumers, and international standard organisations. Second, the insights offered herein were developed in the context of a particular high-tech industry – the mobile phone industry. The dynamics discussed may or may not be relevant to other technology-based industries, such as those where technological changes have often been more dramatic in character (e.g., quantum computing, artificial intelligence). These observations point to promising domains for future theorising and research. Finally, future research may also benefit from exploring search process choices and their effects when firms diversify into minimally related or unrelated technological domains, as is often the case among firms leveraging ‘last gasp’ technologies.

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