The Innovation Waltz: Unpacking Developers’ Response to Market Feedback and Its Effects on App Performance

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Abstracts

To remain competitive in the intensely competitive mobile app market, developers often rely on user feedback to fuel the innovation process. Past studies, however, have rarely examined the impact of developers' incremental innovation strategies by treating app innovation as a continuous process. This knowledge gap prompted us to advance a framework of developers' incremental innovation strategies comprising four coping strategies: sailing, optimizing, supplementing, and patching. Employing a multi-state Markov model to capture the probability of a developer employing an incremental innovation strategy in response to distinct types of market feedback during the app innovation process, we analyze data sourced from the Android app store that consists of 4,583 apps, 29,307 updates, and 231,817 reviews. We discovered that market feedback affects the adoption of the four incremental innovation strategies differently. Additionally, we found that sailing, supplementing, and optimizing strategies boost app downloads, while supplementing, optimizing, and patching strategies improve app ratings.

Keywords: Digital Innovation, Application Updates; Incremental Innovation Strategies, Application Performance

Introduction

Over the last decade, the digital landscape has changed dramatically, with mobile applications (apps, thereafter) becoming an integral part of people's daily lives (Wu et al. 2022). Apps have grown rapidly in popularity, culminating in an intensely competitive app market (Wang 2021). The ubiquity of apps is evidenced by the substantial volume of apps available on two of the most popular platforms, namely the Apple App Store and the Google Play Store. As of the third quarter of 2022, the Apple App Store boasted a repository of approximately 1.6 million apps while the Google Play Store has a collection of over 3.55 million apps (Statista 2023). Although these statistics paint a picture of a thriving market for app developers to capitalize on, they also reveal a paradox that is characteristic of the app industry. The presence of a massive number of apps, in particular, accentuates the importance of delivering new and superior-quality apps that stand out in a highly competitive marketplace. In turn, developers are compelled to frequently update their apps to remain competitive. But at the same time, this versioning strategy poses a paradox in that developers face the dilemma of balancing the need to update their apps regularly with the demand for significant innovation, which may not be always achievable with each iteration.

To better cater to the demands of a competitive market, a growing trend in facilitating the innovation process involves soliciting feedback from users as the primary source (Ghose and Han 2011). Solicited through diverse means such as online forums or social media wherein users may share their product expectations and/or usage experiences with developers and/or peers, user feedback yield critical insights into market demand that could guide the versioning process: developers can update their apps according to user feedback (Ho-Dac 2020). In so doing, developers harness external knowledge from users to drive the product innovation process (Dahlander and Gann 2010). Unlike physical products which must innovate through the launch of new products, digital products like apps allow for incremental innovation through a evolutionary process (Nambisan et al. 2017), translating into massive opportunities for innovating based on market feedback. Additionally, the ease with which apps can be upgraded renders the product innovation process to be a prominent strategic consideration. Because versioning act as the primary means for apps to bolster product functionality, eliminate bugs, and bring consumers up to speed with new technology (Doğan et al. 2011), market feedback plays an indispensable role in the innovation process of apps.

Developers can change innovation tactics based on external knowledge received from users. The addition of new functions and services to the app may expand its innovation boundary while enhancements to existing functions and services may increase its innovation depth (Tian et al. 2020). Tik Tok, for example, has implemented both strategies by incorporating a store window feature into its app that allows creators to place products in the store window and embed them in their videos. Meanwhile, developers are constantly optimizing their video recommendation algorithm to deliver a superior user experience. Research on digital innovation has traditionally focused on how a developer's innovation strategy affects its success (Li et al. 2022; Tian et al. 2020; Wen et al. 2022). These studies demonstrate that app innovations can substantially boost customer experience (Tian et al. 2020), increase productivity and improve market positioning (Saffarizadeh et al. 2018), culminating in better market performance (Comino et al. 2019; Tiwana 2015). Yet, despite the fact that these studies generate invaluable insights, further knowledge of the impact of app innovation remains limited because most of these studies investigate app innovation separately, ignoring the continuity of the innovation process. From the standpoint of innovation trajectories, we uncover the incremental innovation tactics employed by developers. Specifically, we identify each innovation as a state, and identify the relationship between two innovations as a state transition. In this sense, incremental innovation strategies employed by developers can be conceived as a series of states and transitions. Moreover, given the ever-changing nature of users' needs as they interact with the app, leveraging users' external knowledge to facilitate app innovation is inherently unpredictable. Thus, it is critical to create a systematic typology of incremental innovation approaches in mobile apps to better understand how developers can tackle the uncertainties associated with external environment related to users and reap its associated advantages. Against this backdrop, the present study aims to bridge the gaps in the existing literature by addressing the following research questions:

RQ1. How does market feedback impact developers' incremental innovation strategies?

RQ2. How do developers' incremental innovation strategies affect apps' performance, including downloads and ratings?

To explore how developers respond to user feedback in uncertain market environments, we turn to coping strategies as a valuable source of insight. Coping strategies are defined as "constantly changing cognitive and behavioral efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the person's resources" (Lazarus and Folkman 1984, p.141). These strategies are essential for policy makers operating within strategic and innovative environments that are constantly subjected to environmental unpredictability and variability (Smart and Vertinsky 1984). While coping mechanisms have been studied in the context of uncertainty management in the innovation process at the firm level (Schneckenberg et al. 2017; Zhang and Doll 2001), there is a need to further investigate their role in handling uncertainty associated with market feedback of mobile apps. In an app development environment, there are various aspects that may tax or exceed the resources at the disposal of developers. First, the rapid pace of technological advancements and market trends in the mobile app industry creates uncertainty. To remain competitive and meet user expectations, developers must continuously learn and adapt to the latest technological tools, frameworks, and platforms, straining their cognitive capabilities and time resources. Second, mobile apps are subjected to continuous user feedback and reviews, which can vary from positive to outright dismissive. Addressing user concerns and responding promptly necessitates significant time and effort investment, especially when confronted with negative feedback that require extensive debugging and improvement. Even though developers may rely on specific incremental innovation strategies to cope with the external environment, there is a lack of understanding of the innovation trajectory mechanisms behind these strategies and the potential effects of their implementation. Our research aims to bridge this gap by developing a theoretical framework that elucidates coping mechanisms for managing uncertainty in app innovation from the app level. Our framework identifies four distinct incremental innovation strategies and empirically demonstrates their role in influencing app performance.

Theoretical Foundation and Hypotheses Development

Incremental Innovation Strategy in App Development

The literature on technological innovation has extensively studied the issue of distinguishing between various types of innovation and their competitive implications (Gatignon et al. 2002). Scholars have put forth several typologies, including radical vs incremental (Dewar and Dutton 1986), core vs peripheral (Ma et al. 2015), architectural vs modular (Henderson and Clark 1990), and disruptive vs routine (Christensen et al. 2013; Pisano 2015). App innovation, which consists of adding new features or enhancing existing apps, does not necessarily align with radical, core, or architectural innovation. Rather, it is a continuous incremental innovation that encompasses the implementation of novel features or functionalities, or improvements to an existing app, in an effort to increase its usage (Foerderer et al. 2018). Notably, prior literature has explored the concept of core versus support app innovation, where core innovation is defined as the addition of new business functionality that provides a new product or service category to an existing app, while support innovation is defined as the addition of new support service functionality related to an existing product or service offering (Tian et al., 2020). However, the categorization discusses digital product innovation only from the perspective of feature addition.

A unique characteristic of digital innovation is the modular reusability of its products. This is because digital products are not standalone units with fixed meanings and relations; they have a layered modular architecture that can be readily edited, reprogrammed, and recombined to realize the potential of being part of multiple value paths simultaneously (Henfridsson et al. 2018; Kallinikos et al. 2013; Yoo et al. 2010). In mobile app development, developers can use various combinations of functional and experiential components to incrementally innovate products. This results in the separation of the two distinct components of app development. For instance, an app may be upgraded with a new interaction interface than its prior version but still performing the same functionality. Ghemawat (1991) noted that in product innovation, marketing focuses on the customer base, while R&D focuses on the know-how, and these two resources are linked strategically. Thus, owing to the relatively exclusive and coupled characteristics of functionality and experience, app innovation should be considered in terms of duality. Consequently, two types of app innovation can be observed: functional innovation, which focuses on adding new features or content to an existing app, and experiential innovation, which aims to improve the app's performance and address any existing issues. This duality-based approach can provide a more nuanced view of app innovation and allows for a better understanding of the innovation process and its impact in the digital product space. It is worth noting that a developer can integrate numerous dimensions of innovation at the same time during a version update. Furthermore, the emphasis placed on different types of innovation may vary from one update to another. Consequently, the realm of app innovation can be segregated into four distinct states based on contingent upon the prominence accorded to functional and experiential innovation: (1) low-level functionality-low-level experience update; (2) low-level functionality-high-level experience update; (3) high-level functionality-low-level experience update; and (4) high-level functionality-high-level experience update (as shown in Figure 1). Specially, according to our classification, state (1) exhibits the lowest level of innovation, and thus, it is designated as the base state. In comparison to the base state, the remaining three states are considered as ascending states.

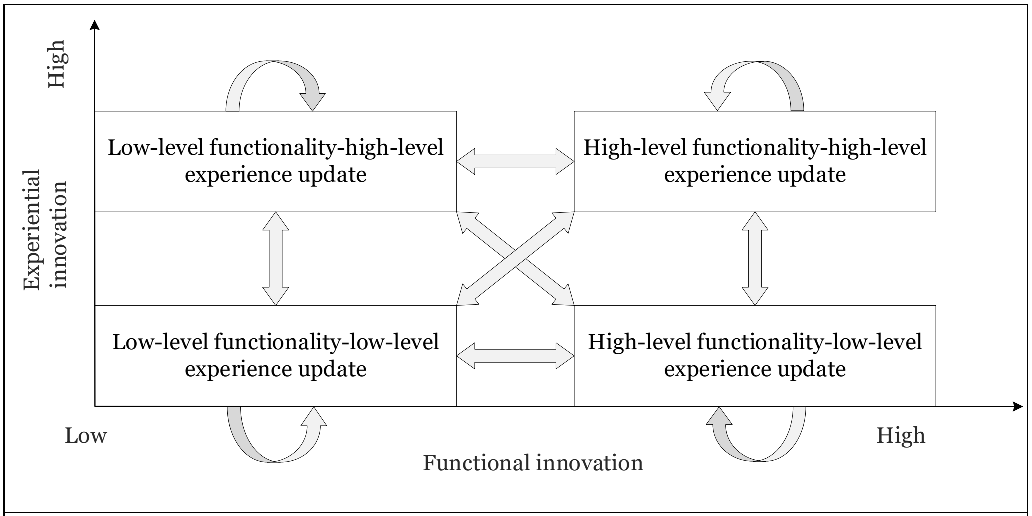

Figure 1. App Innovation State Classification and Incremental Innovation Strategies

By drawing upon the aforementioned state classification, it is feasible to discern as many as 16 discrete incremental innovation strategies within a portfolio consisting of two updates to an app (as shown in Figure 1, double arrows represent two trajectories). Nonetheless, it is not unusual to observe the manifestation of analogous incremental innovation strategies across these update portfolios. First, the state transition of an app from a base state of low-level features and experiences to a higher-level state that involves an update to one or both of these dimensions is a basic incremental innovation (Ettlie et al. 1984), which involves a single improvement of an existing app to enhance its features or experiences after a period of inactivity. We name this class of incremental innovation strategy as "sailing". According to the resource-based view theory (Barney 2001), companies must leverage their unique resources and capabilities to achieve a competitive advantage in the market. In the case of sailing, developers can leverage their existing functional and experiential components to create higher-level features and experiences. By doing so, they can differentiate themselves from competitors and attract more customers. An example of this is a messaging app that initially enabled only text messaging but has since added the ability to make video calls, resulting in higher-level features and experiences.

Second, the state transition in which the app remains in the same ascending state for two consecutive updates, with no significant changes to the level of innovation of its features or experiences can be explained by the concept of continuous improvement (Zangwill and Kantor 1998), which involves making incremental changes to an existing app to improve its performance or usability. This incremental innovation strategy is named "optimizing". The continuous improvement theory states that organizations must continually improve their processes, products, and services to achieve long-term success (Zangwill and Kantor 1998). In the case of optimizing, developers can focus on improving the use experience of their existing features without introducing any new ones. By doing so, they can maintain their current level of innovation and ensure customer satisfaction. For example, a photo editing app may not introduce any new features but optimize the use experience of existing features in two consecutive updates, thus maintaining its current level of innovation in terms of functionality.

Third, state transitions between different ascending states of an app, where two consecutive updates involve changes in the level of functionality and experience innovation can be explained by the concept of complementary innovation (Foerderer 2020), which involves complementing new features or experiences to an existing app to enhance its value proposition. This incremental innovation strategy is named "supplementing". The complementary assets theory suggests that companies must acquire and integrate complementary assets to achieve innovation success (Teece 1986). In the case of supplementing, developers can add new features or functionalities to their existing apps to complement their existing functional and experiential components. By doing so, they can create a more comprehensive and valuable app for customers. An example of this is a navigation app that adds a new feature to help users find a parking spot and improves the user interface in a subsequent update.

Finally, a state transition of an app from an ascending state to a basic state, characterized by a reduction in the innovation level of functionality or experience in two consecutive updates can be explained by the concept of downsizing innovation (Dougherty and Bowman 1995), which involves reducing the complexity or scope of an existing product to improve its efficiency or cost-effectiveness. We name this class of incremental innovation strategy as "patching". The downsizing theory suggests that companies must downsize their products or services to improve their efficiency and profitability (McKinley et al. 1995; McKinley et al. 2000). In the case of patching, developers may remove some of the features or functionalities added in the last major update or make minor fixes to the product to simplify the product and reduce costs. By doing so, they can improve their profitability and ensure the sustainability of the product. For example, a video editing app may remove some of the features that were added in the last major update, resulting in a lower-level state.

Market Feedback and Knowledge Contribution

Being geographically unrestricted, mobile app stores or third-party platforms offer a platform for gathering market feedback from a large pool of users as potential contributors with diverse anecdotal knowledge and motivations. These users input qualitative and quantitative data about usage experiences, bug reports, and app ratings. To fully utilize these common resources, app developers can browse user evaluations and obtain any information they require. When developers discover useful information, they can compile it and incorporate it into the next version of the app. Scholars have conducted various studies on user feedback and found that users are keen to express their experience in feedback (Sridhar and Srinivasan 2012). Likewise, users are willing to post their feelings in online forums after purchasing and using mobile apps (Palomba et al. 2015). In addition to this, users also provide app developers with information to improve apps, such as product defects (Khalid et al. 2015), new requirements for the product, or new ideas to improve the product (Zhang et al. 2021). For instance, Villarroel et al. (2016) classified user reviews into clusters of bug reports and feature requests by text mining methods to aid app developers to accelerate the release time of a new version of the app. Therefore, previous research identified three types of knowledge contributed by users in mobile app markets: experiential comments, bug reports, and feature requests.

Online forums enable users to spontaneously participate in all stages of innovation of products, including idea generation, design, engineering, testing, and launch (Wong et al. 2016). During these stages, consumers play different roles in app innovation based on their level of autonomy and influence in the innovation process according to the purpose of the collaboration, including insight providers (e.g., Van Dijk 2011), ideators (e.g., Brabham 2008), and co-creators (e.g., Prahalad and Ramaswamy 2004). Furthermore, in the context of mobile apps, users may also play the role of information seekers in the process of app innovation, that is, participate in the creation of product innovation for information seeking (Van Dijk 2011). For instance, users post requests for information on product usage, such as walkthroughs in game apps, in online forums, sparking discussions. Developers can learn to improve the product by following discussions and reading reviews. Therefore, information requests may also be a type of knowledge that users contribute to innovation in mobile app development. Based on the above discussion, this study considers information requests as the fourth type of knowledge contributed by users involved in innovation in in mobile app development and proposes a typology of knowledge contribution in mobile app markets (as shown in Table 1).

Knowledge Contribution Types	**Brief Description**	**Concepts in Extant Literature**	**References**
Experiential comments	Users share their usage experience	Usage experience	Pagano and Maalej (2013), He et al. (2020), Zhang et al. (2021)
Bug reports	User-reported bugs about the app	Bug reports	Khalid et al. (2015), Pagano and Maalej (2013), Noei et al. (2019)
Feature requests	Users' requests to add one or more features	Feature requests	Iacob and Harrison (2013), Noei et al. (2019)
Information requests	Users request app-related information, such as game walkthroughs	N. A	(This study develops: Feedback from users seeking information in the marketplace)

Table 1. A Typology of Knowledge Contribution in Mobile App Markets

In mobile app innovation creation, uncertainty is a common occurrence due to the diversity and complexity of user knowledge contributions. Users bring their unique perspectives, experiences, and expectations to the table, which makes it challenging to determine which knowledge is most relevant and useful for creating a successful product. Moreover, as users' needs and requirements for the app vary greatly at different stages of development and use, coping with this uncertainty and making decisions accordingly becomes even more challenging. Related studies emphasize that uncertainty is a crucial phenomenon that influences the design or configuration of business model innovation (Massa and Tucci 2013; Schneckenberg et al. 2017). Scholars commonly utilize coping strategies to investigate how participants interpret and deal with uncertainty in the decision-making environment. These coping strategies include processing more information, using strategy tools, and employing real options logic (Dong 2021; Jarzabkowski and Kaplan 2015; Klingebiel and Adner 2015). Thus, focusing on the mechanisms of coping with uncertainty provides a useful perspective for understanding how developers in app development make decisions in the face of a complex and diverse set of user knowledge contributions. This understanding can help developers design better apps and create more effective decision processes that consider the diversity of user knowledge contributions and the challenges of coping with uncertainty in decision-making.

In today's fiercely competitive market, innovation has become a prerequisite that can set mobile app providers apart from their rivals (Li et al. 2022). However, the app innovation process inherently involves complexity and uncertainty (Baird and Maruping 2021), making it challenging to achieve successful incremental innovation. Thus, it becomes critical for developers to effectively manage these challenges to create robust and effective app solutions that cater to the evolving needs of users. To overcome these challenges, developers utilize various coping strategies and mechanisms (e.g., Fjeldstad et al. 2012; Vidgen and Wang 2009), one of which involves adopting different incremental innovation strategies based on market feedback. This targeted approach enables developers to adeptly manage the complexity and uncertainty inherent in the app innovation process, yielding effective solutions.

Building on the importance of targeted coping strategies for successful incremental innovation, it is essential to understand how developers take incremental innovation strategy decisions to respond to different types of market feedback. We posit that when feature requests make up the majority of the market feedback, developers are inclined towards "sailing" incremental innovation strategy. This is because feature requests provide developers with clear and specific goals to strive for (Palomba et al. 2015). This clarity can help them navigate the inherent uncertainty that comes with innovation, enabling them to concentrate on enhancing existing features and user experiences, particularly when apps have been dormant for some time. Additionally, because feature requests are typically made by end-users who have a clear understanding of what they want (Iacob and Harrison 2013), developers may be able to more easily incorporate their suggestions into the product, leading to a smoother and more efficient incremental innovation process. With these factors in mind, it is reasonable to anticipate that developers are more likely to adopt a "sailing" incremental innovation strategy when feature requests dominate the market feedback. Thus, we propose the following hypothesis based on the above discussion:

Hypothesis 1: *The distribution of knowledge contribution exerts diverse impacts on the incremental innovation strategy implemented by developers, such that when feature requests dominate the market feedback, developers are more inclined to adopt the "sailing" incremental innovation strategy.*

In instances where experiential comments hold more prominence, the distribution of knowledge contribution may also impact the incremental innovation strategies employed by developers. Such instances may prompt developers to adopt a "supplementing" approach. Experiential comments are typically based on real-world usage of a product (Al-Shamaileh and Sutcliffe 2023), and can supplement existing knowledge to enhance the product's overall performance. By incorporating experiential feedback into their development process, developers can better respond to uncertainty and evolving customer demands and achieve a balance between innovation in functional and experiential aspects. The "supplementing" incremental innovation strategy involves adding new features to complement existing ones or optimize performance significantly, depending on the previous app updates. Through this strategy, developers can holistically improve the product's quality by integrating user-contributed feedback from experiential comments. This leads to the following hypothesis:

Hypothesis 2: *The distribution of knowledge contribution exerts diverse impacts on the incremental innovation strategy implemented by developers, such that when experiential comments dominate the market feedback, developers are more inclined to adopt the "supplementing" incremental innovation strategy.*

When information requests dominate the distribution of knowledge contributions, developers may opt for an "optimizing" incremental innovation strategy. This is because information requests are often related to specific issues or challenges that need to be addressed (Borgatti and Cross 2003), and responding to these requests requires a focused approach to problem-solving. To optimize the product, developers may need to refine or restructure certain features or processes to align with users' needs (Porter and Heppelmann 2014). This process can involve significant trial and error, as developers experiment with different solutions to identify the most effective approach. Therefore, an information request-dominated distribution of knowledge contributions may foster a more iterative and focused innovation approach, resulting in the creation of more robust and effective solutions over time. As a result, we propose the following hypothesis:

Hypothesis 3: *The distribution of knowledge contribution exerts diverse impacts on the incremental innovation strategy implemented by developers, such that when information requests dominate the market feedback, developers are more inclined to adopt the "optimizing" incremental innovation strategy.*

Finally, when bug reports dominate the market feedback, developers are more likely to employ a "patching" incremental innovation strategy. Bug reports are a type of contribution that highlights flaws or errors in the product (Daniel et al. 2013). These issues can range from minor inconveniences to serious defects that render the product unusable. A "patching" incremental innovation strategy involves fixing these bugs as quickly as possible to minimize the impact on users. This strategy is essential for maintaining the quality and reliability of the product, as it ensures that users can continue to use it without interruption. Moreover, by fixing bugs quickly, developers can prevent the accumulation of technical debt that can hinder future development efforts. Therefore, a "patching" incremental innovation strategy is an effective coping mechanism for dealing with the uncertainty that arises from bugs and technical issues in app innovation. Based on the above discussion, we propose the following hypothesis:

Hypothesis 4: *The distribution of knowledge contribution exerts diverse impacts on the incremental innovation strategy implemented by developers, such that when bug reports dominate the market feedback, developers are more inclined to adopt the "patching" incremental innovation strategy.*

Mobile app stores such as Google Play use the star rating mechanism to collect user feedback and ratings. Through the star rating mechanism, users can provide ratings for an app after downloading. Consumers usually rely on ratings to choose new apps to purchase (Khalid et al. 2015), ratings and downloads are therefore of unavoidable importance to the profitability and success of apps (Palomba et al. 2015). Therefore, this study further explores the impact of developers' incremental innovation strategy decisions on their product downloads and ratings. A "sailing" incremental innovation strategy means that the app moves from a basic update to a high level of functional and/or experiential innovation and is expected to drive downloads by making the app more attractive and appealing to users. Research has established that the addition of attributes to a product increases consumers' perception of its capabilities, thereby enhancing product evaluation prior to ownership (Mukherjee and Hoyer 2001). As a result, the "sailing" incremental innovation strategy is likely to attract new users and drive downloads. However, the impact of the "sailing" incremental innovation strategy on existing users is not well understood. From an economic perspective, existing users may incur the cost of switching from a familiar to an unfamiliar product due to the magnitude of innovation (Klemperer 1987; Shapiro et al. 1999). This cost mainly stems from the learning cost (Shapiro et al. 1999), which refers to the effort required by users to achieve the same level of comfort or familiarity with the new version of the app as with the old one (Chen and Hitt 2002). As a result, conservative users[1] who are already familiar with the existing version may react negatively to the "sailing" incremental innovation strategy due to the additional cost, resulting in a decrease in their ratings. However, exploratory users may not be deterred by the learning cost and may instead react positively to the innovative features

[1] Conservative users engage in passive innovation resistance because they hold a conservative viewpoint, as opposed to users who hold a liberal viewpoint and whose exploratory behavior tendencies are categorized as curiosity-driven, variety-seeking, and risk-taking (Raju 1980).

introduced through the "sailing" incremental innovation strategy. Given these considerations, we propose the following hypothesis:

Hypothesis 5: *Sailing has a positive effect on app downloads (H5a) but may have no effect on app ratings (H5b).*

An "optimizing" incremental innovation strategy refers to an app that maintains a consistently high level of functional and/or experiential innovation over two consecutive updates. This means that users are more likely to notice and appreciate the app's ongoing improvements, which can result in positive word-of-mouth recommendations, increased downloads, and improved ratings. The positive experience of users is more likely when the app is updated in an "optimizing" form, as it becomes more useful, engaging, and easy to use, leading to increased satisfaction and a greater likelihood of recommending the app to others (Xu et al. 2015). In turn, this can lead to increased app downloads, as more people become aware of the app and its positive reputation (Liu and Sun 2013). Therefore, by adopting an "optimizing" incremental innovation strategy, app developers can ensure a consistently positive user experience with their apps, encourage positive ratings and reviews, and ultimately drive the growth and success for their apps. Based on the above discussion, we propose:

Hypothesis 6: *Optimizing has a positive effect on both app downloads (H6a) and app ratings (H6b).*

A "supplementing" incremental innovation strategy is an approach that involves adjusting an app's high-level functional and experiential innovation in a balanced and consistent manner across two consecutive updates. This strategy ensures that the app provides a complete and well-rounded set of services to its users, as both the functional and experiential components are continuously improved. The result is an improved user experience, which leads to positive reviews from existing users and increased downloads from new users (Dhar and Bose 2022; Harris et al. 2016). Therefore, when developers adopt a "supplementing" incremental innovation strategy, apps are more likely to receive higher ratings and more downloads. Based on the above discussion, we propose the following hypothesis.

Hypothesis 7: *Supplementing has a positive effect on app downloads (H7a) and app ratings (H7b).*

A "patching" incremental innovation strategy refers to the process of transitioning an app from a high level of feature and/or experience innovation to a basic update. It may not be immediately clear whether patching has a positive or negative impact on app ratings and downloads based on the definition of "patching". However, it's important to consider the context of "patching". If a product has been on the rise for some time, it may have accumulated a large number of features that can make it complex and difficult to use (Thompson et al. 2005). In this case, patching can be a way to simplify the product and make it more accessible to a broader audience, which can result in improved ratings. Furthermore, "patching" addresses bugs and other issues that may have occurred in previous updates, leading to an improved overall user experience and more positive ratings. However, the impact of patches on app downloads may depend on their specifics and acceptance by new users. It's unclear whether patches will affect app downloads, as users may prioritize the app's core functionality over specific features included in it (Keertipati et al. 2016). Thus, the effect of patches on app downloads may be influenced by factors such as the acceptance of patches by new users. Based on the discussions above, we propose the following hypothesis.

Hypothesis 8: *Patching has a positive effect on app rating (H8a) but may have no effect on app downloads (H8b).*

Research Context

In this study, we focus on a primarily user-facing Android app store that provides a platform for users to download and use mobile apps. The platform offers users an opportunity to share information about their usage experiences, product defects, and other requirements. The critical benefits therefore include the provision of a more comprehensive look at market feedback.

Data Description

The Android app store is an all-encompassing platform that furnishes users with comprehensive information about every app available for download. From download statistics to ratings, software size, latest updates, version information, and internet connectivity requirements, the platform offers a wide array of valuable insights that help users make informed decisions. It provides record forms for developers to post details about their apps, including historical versions, update timestamps, and corresponding details. These records enable us to effortlessly track an app's update history and gain a better understanding of the progress made by developers through consecutive update condition records. To operationalize the variable for apps' update state in our model, we discretize the unstructured text data provided in the update log. Typically, it can be overwhelming for developers to fill out such a detailed update report for each update. As a result, the lack of effort from developer leads to missing information such that only 84.31% of apps' update condition points can be observed.

Multi-State Markov Model

Markov simulation offers a dynamic prediction method that simulates cohorts' progression from one state to another at finite intervals, based on state transition probabilities (Norris 1998). This approach enables us to overcome the limitations of static methods. To address this challenge, we propose a multi-state Markov-based model that uses Markov simulation to fit the dynamic update process of the app. A multi-state Markov model is a model for a continuous-time stochastic process where individuals move through a finite number of states. In this study, we adopt a similar approach and identify an app's update state as a deterministic state, whenever it is observable, to determine whether market feedback from users changes this state. Such transitions may be triggered by interactions between developers and users, knowledge-sharing, or other activities in the mobile app store. The time-variant update activity defines the sequence of observed results of the app, and Markov transitions explain the dependence on subsequent activities.

State Transition Matrix

Assuming there are n states that discretize all possible update states of the app into update state 1 through n. Due to the random nature of state changes, the update states of the app can be drastically varied each time. We define the state transition probability as $P = \{p_{it}(m, k)\}$, where $p_{it}(m,k) = P(S_{it+1} = k | S_{it} = m), 1 \leq m, k \leq n$ and S_{it} denotes the state of app i at time t. In other words, the transition outcomes of a given time t depend only on the preceding time *t-1*. Moreover, the transitional probability matrix P including the transitional probability for every pair of states has the following properties: (1) $p_{it} \geq 0$ (2) $\sum_t p_{it} = 1$. As previously stated, the update state of a mobile app on a development platform varies with knowledge contribution as reflected in the market feedback. To capture this trend, a probabilistic transfer matrix must be developed that models a continuous measure of the level of knowledge contribution. Essentially, if the contribution of a certain type of knowledge from the platform exceeds a specified threshold, developers may decide to make the app to undergo a particular update. As shown in Figure 2, an app in the base state has the option to either remain idle or transition to any of the n-1 higher innovation states (ascending states). On the other hand, an app in an ascending state can remain unchanged, transition to another ascending state, or descend back to the base state.

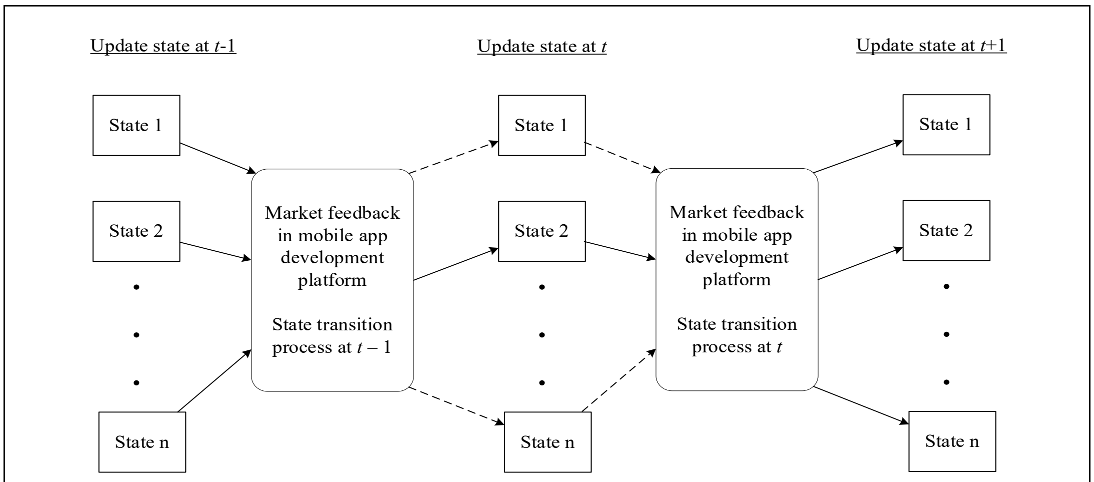

Figure 2. Multi-state Markov Model Diagram

As outlined in §2, our model includes four app update states: state 1 (low-level functionality-low-level experience update), state 2 (low-level functionality-high-level experience update), state 3 (high-level functionality-low-level experience update), and state 4 (high-level functionality-high-level experience update). In a multi-state Markov model, there are two types of states: transient states that can transition to another state and absorbing states that have no path to transition to other states. In our study, all four states are transient because they can transition to each other. An app can remain in its current update state or transition to any of the other update states, including state 1→state 1, state 1→state 2, state 1→state 3, state 1→state 4, state 2→state 1, state 2→state 2, state 2→state 3, state 2→state 4, state 3→state 1, state 3→state 2, state 3→state 3, state 3→state 4, state 4→state 1, state 4→state 2, state 4→state 3, and state 4→state 4. Next, we fit a multi-state Markov model to describe how an app transitions between its update states and how users' knowledge contributions affect these transitions. We assume that an app's movement in the discrete states 1-4 is governed by transition intensities Q_{rs}: r, s = 1, 2, 3, 4. The transition probability matrix Q is given as

$$Q = \begin{bmatrix} -(q_{12}+q_{13}+q_{14}) \ \ q_{12} \ \ q_{13} \ \ q_{14} \\ q_{21} \ \ -(q_{21}+q_{23}+q_{24}) \ \ q_{23} \ \ q_{24} \\ q_{31} \ \ q_{32} \ \ -(q_{31}+q_{32}+q_{33}) \ \ q_{34} \\ q_{41} \ \ q_{42} \ \ q_{43} \ \ -(q_{41}+q_{42}+q_{43}) \end{bmatrix}$$

where $Q_{rs}(t_o, t)$ indicates the transition probability that an app in state r at time t_o will transit to state s at time t. For example, $Q_{14}(t$=0.01) denotes the probability of an app progressing from state 1 to state 4 with 0.01 years.

Variable Set and Description

Our dataset encompasses the period between 2013 and 2019 and is comprised of three main components. The first part is app-level data, which includes the app name, app ID, app icon image, average consumer rating, reviews, download counts, category ID, whether the app has advertisements, whether it requires a network connection, and app description. The second component is app-version-level data, which includes the app ID, details of each update, and corresponding time stamps. Lastly, the third component includes all comment data collected during each app version update, which includes the comment ID, app ID, app version ID, comment content, and time stamp for each comment. Following the exclusion of non-Chinese apps, apps with only one version, or apps with blank updates (i.e., apps that have not provided any update information for a given version), our sample comprises 4,583 apps, 29,307 updates, and 231,817 reviews.

Operationalization of Knowledge Contributions

As discussed in §2, there are four forms of knowledge contributions: experiential comments, bug reports, and feature requests, and information requests. These knowledge contribution measures are derived from user feedback on mobile apps in the marketplace. Similar to user reviews on online shopping sites, user feedback in mobile app stores provides a wealth of insights into the experiences and needs of individual users. We perform semantic analysis of user reviews using the Latent Dirichlet Allocation (LDA) model, a popular topic modeling approach. For each feedback, the analysis returns a number indicating the probability that the feedback belonged to a particular category. However, since users often provide multiple pieces of information in each feedback, it is inappropriate to categorize feedback into just one category. Therefore, we assign four probabilities (which add up to one) to each feedback based on the topics addressed. Using this classification scheme, we interpret the probabilities as the number of different types of knowledge contributions provided by users. As expected, experiential comments are found to be the most common type of knowledge contribution in mobile app stores, followed by bug reports, and finally, feature requests. Statistical details are presented in Table 2.

Variable	**Type**	**Mean**	**Sd. dev.**	**Min**	**Max**
Experiential comments	In-period	0.325	0.233	0	0.995
Bug reports	In-period	0.243	0.190	0	0.997
Feature requests	In-period	0.209	0.181	0	0.997

Information requests	In-period	0.223	0.185	0	0.997

Table 2. Knowledge Contribution Statistics

Operationalization of App Innovation State

Again, we use LDA to extract the main topics covered in each update detail and generate a list indicating the probability that each update belongs to each category. The results of our LDA model show that there are five types of app updates: adding features, adding content, improving performance, fixing bugs, and regular update. A list is then generated for each update indicating the likelihood of belonging to each update category. Based on our definitions of functional and experiential innovation, we combine the probabilities of adding features and adding content to determine the likelihood of belonging to functional innovation, and the probabilities of improving performance and fixing bugs to determine the likelihood of belonging to experiential innovation. The probabilities for functional and experiential innovation are standardized into two levels (high and low) using the mean value as the threshold, resulting in four app innovation states: (1) low-level functionality-low-level experience update; (2) low-level functionality-high-level experience update; (3) high-level functionality-low-level experience update; and (4) high-level functionality-high-level experience update. We employ these four update states to create a multi-state Markov model and assess the effects of knowledge contribution on developers' incremental innovation strategy decisions.

A total of 29,307 updates were recorded for 4,583 apps from 2013 to 2019. The frequency of transitions from one state to the next one is shown in Table 3. Among 24,723 transitions, 62% stayed in the identical state after one transition. 1.46% showed an update from low-level functionality-low-level experience update state to high-level functionality-high-level experience update state, and 1.26% showed an update from high-level functionality-high-level experience update state to low-level functionality-low-level experience update state.

From\To	**State 1**	**State 2**	**State 3**	**State 4**
State 1	4028(16.29%)	1026(4.15%)	1199(4.85%)	312(1.26%)
State 2	1003(4.06%)	4102(16.59%)	962(3.89%)	443(1.79%)
State 3	1182(4.78%)	983(3.98%)	5949(24.06%)	766(3.1%)
State 4	362(1.46%)	444(1.8%)	730(2.95%)	1232(4.98%)

Table 3. Observed Number of App Update State Transitions from One Visit to the Next Visit

Analytical Findings

Multi-state Markov Model Results

To examine the impact of user knowledge contributions on the incremental innovation strategies adopted by developers, we use the distribution of the four knowledge contributions as covariates in the present study. These covariates are then integrated into a multi-state Markov model over time, allowing us to estimate the effect of the covariates on transition probabilities. We summarize the results of the effect of the covariates on the four incremental innovation strategies in Table 4. The values in the Table 4 reflect the effect of different types of knowledge contributions on the likelihood of developers to adopt incremental innovation strategies, which is assessed by calculating the average value of the corresponding state transition probability set based on the impact of different types of knowledge contributions.

According to Table 4, each of the four types of knowledge contributions can affect the likelihood of developers adopting different incremental innovation strategies for their apps. Specifically, the feature request and experiential comment types of knowledge contributions are found to increase the probability of developers adopting "sailing" incremental innovation strategies. In these two types of contributions, users provide explicit requests for new features and share their experiences with the app. This information is especially useful when the app is in a low-innovation state, as it prompts developers to update the app's features and improve the user experience accordingly.

On the other hand, bug reports are another type of knowledge contribution that can affect the developers' coping strategies. When the app is experiencing a high level of innovation, developers may choose to stay in the current update state and focus on optimizing the app instead of moving to another state. In this case, bug reports can be helpful in identifying and addressing any problems that may arise during the optimization process.

Feature requests, information requests, and experiential comments are three types of knowledge contributions that increase the probability of developers adopting the "supplementing" incremental innovation strategy. Compared to bug reports, these three types of knowledge contributions are relatively less targeted but more informative to developers, so when developers receive a lot of such feedback after a highly innovative update to the app, they selectively receive user knowledge for the "supplementing" incremental innovation strategy to achieve balance the purpose of improving the app functionality and experience.

Interestingly, the impacts of all four types of knowledge contributions on the probability of developers adopting a "patching" incremental innovation strategy are extremely low, less than 2%. This suggests that the decision to adopt this strategy may be an intrinsic one, rather than one that is influenced by market feedback. Overall, these findings shed light on the different types of knowledge contributions that can affect developers' decision-making when it comes to adopting incremental innovation strategies for their apps.

Covariates	Sailing	Optimizing	Supplementing	Patching
Feature requests	0.038	-0.164	0.071	-0.012
Information requests	-0.045	-0.043	0.044	0.000
Experiential comment	0.072	-0.149	0.036	0.004
Bug reports	-0.078	0.165	-0.046	0.004

Table 4. Effects of Covariates on Incremental Innovation Strategies

CB-SEM Results

To measure the four incremental innovation strategies, sailing, optimizing, supplementing, and patching, it is necessary to use a statistical analysis method that can capture the multiple interrelated variables involved. This is where covariance-based structural equation modeling (CB-SEM) come in (Fornell and Bookstein 1982). In this case, the latent variables are the four incremental innovation strategies, and the observed variables are the various states and transitions that make up each strategy. Moreover, CB-SEM allows for the testing of complex hypotheses and models, which is essential when dealing with a complex and multifaceted construct such as incremental innovation strategies. To conduct CB-SEM data analysis, we use the various state transitions for each strategy as formative indicators and employ Mplus (Muthén and Muthén 2007).

The results indicate that H5a (sailing →downloads, β=0.144, p<0.001) and H5b (sailing →ratings, β=0.019, p>0.05) are supported, demonstrating that the "sailing" incremental innovation strategy significantly increases the number of app downloads but does not affect app ratings. H6a (optimizing →downloads, β=0.366, p<0.001) and H6b (optimizing →ratings, β=0.082, p<0.001) are also supported, showing that the "optimizing" incremental innovation strategy significantly increases both the number of downloads and ratings of the app. Furthermore, H7a (supplementing → downloads, β=0.260, p<0.001) and H7b (supplementing → ratings, β=0.074, p<0.001) are supported, indicating that the "supplementing" incremental innovation strategy significantly increases both the number of downloads and ratings of the app. Finally, H8a (patching →ratings, β=0.220, p<0.001) and H8b (patching →downloads, β=0.107, p>0.05) are supported, revealing that the "patching" incremental innovation strategy significantly increases app ratings but has no impact on downloads.

Discussion

Implications for Theory

This study presents several notable theoretical contributions. First, innovation has long been recognized as a critical driver of economic growth and business development (Hausman and Johnston 2014). While innovation is often associated with breakthrough discoveries and radical inventions, incremental innovation also plays a vital role in driving progress (Ettlie et al. 1984; Miric and Jeppesen 2020). However, previous research has tended to view incremental innovation as a static state (e.g., Almeida Costa and Zemsky 2021; Miric and Jeppesen 2020), rather than a dynamic trajectory. Researchers have overlooked the nuances and complexities of the different strategies that developers adopt to drive incremental innovation by treating incremental innovation as a totality. Our contribution to the field is to open up the concept of incremental innovation and view it from a trajectory perspective. We propose that incremental innovation should be seen as a dynamic process, with different stages and strategies that developers can adopt to drive progress. By taking a trajectory view of incremental innovation, we can better comprehend the different strategies that developers use to drive progress, and how these strategies evolve over time as market demands change. We argue that understanding the trajectory of incremental innovation is critical to driving organizational success and strategic advancement. By recognizing the different strategies that developers use to drive incremental innovation, we can better facilitate and promote innovation across a wide range of industries and sectors. Our contribution challenges the traditional static view of incremental innovation and offers a typology of incremental innovation strategy.

Second, innovation is a complicated, iterative process that is influenced by numerous internal and external factors (Autio 1997). In the context of incremental innovation, market feedback is a critical mechanism for driving progress. However, previous studies have overlooked the impact of antecedents on incremental innovation strategy, especially in the context of mobile apps. Our second contribution to the field is to examine how antecedents affect incremental innovation strategy, with a particular focus on the role of market feedback. Specifically, we propose a framework for understanding the different types of knowledge contribution that market feedback can provide, and how these contributions can shape the trajectory of incremental innovation. We identify four types of knowledge contribution: feature requests, information requests, bug reports, and experiential comments. In particular, we argue that information requests represent a novel type of knowledge contribution that has been largely overlooked in prior research. Information requests occur when users express a need or desire for additional information about a product feature, but do not necessarily request a change to the feature itself. This type of feedback is valuable because it can reveal gaps in users' understanding of a product. As such, our framework for understanding the different types of knowledge contribution from market feedback represents a significant theoretical contribution to the field of knowledge contribution, particularly in the context of mobile apps. By highlighting the importance of information requests as a distinct type of feedback, we expand the range of knowledge sources driving incremental innovation strategies.

Third, our study also makes a significant contribution to the field of innovation strategy by introducing a novel methodological approach. Specifically, we adopt a multi-state Markov model approach to trace the innovation trajectories of app developers as they engage in app innovation. This approach allows us to capture the intricate and dynamic nature of innovation processes, which are characterized by multiple states and transitions. By offering a comprehensive view of the innovation process, our study goes beyond previous research that focused solely on the outcome of innovation activities, instead of exploring the underlying processes that drive these outcomes. Moreover, we use these trajectories as formative indicators to shed light on the incremental innovation strategies employed by app developers. This represents a significant methodological advancement as it fills a gap in existing research, which has failed to measure incremental innovation strategies though dynamics indicators. By using this approach, our study provides a more profound understanding of the factors that drive innovation and the conditions under which these different strategies prove most effective. Furthermore, our utilization of state transition trajectories within a multi-state Markov model opens new opportunities for future research concerning innovation dynamics. Our findings suggest that this approach can facilitate in-depth investigations into the complexities of the innovation process and lead to the identification of additional strategies that have not been considered in previous research. Overall, our study marks a significant contribution to the field of innovation strategy, offering a new perspective and methodology to explore the processes that drive innovation.

Implications for Practice

Our research has important practical implications for all stakeholders involved in the mobile app industry. From the platform side, our study sheds light on the importance of designing user feedback mechanisms that capture different types of knowledge contributions. For instance, platform owners can design a dynamic feedback system that can improve user engagement and guide developers in adopting incremental innovation strategies. By observing user feedback in the market, platform owners can provide timely advice to developers on product updates and enhancements, based on the needs and preferences of the user base. This approach not only allows platform owners to stay in tune with market trends and user preferences, but it also encourages users to actively participate in shaping the development of the platform. By giving users a voice and an opportunity to provide specific feedback on aspects of the product that they would like to see improved, platform owners can foster a sense of community and enhance user satisfaction. Furthermore, this approach promotes a culture of continuous improvement and innovation, as platform owners and developers are encouraged to adopt a more iterative approach to app innovation. Rather than relying on large, infrequent updates, this approach allows for smaller, more frequent updates that can be tailored to specific user needs and preferences.

From the developer side, given the uncertainty and dynamic nature of the mobile app market, developers must adopt a flexible and adaptive approach to innovation. They should balance different types of knowledge contributions to achieve optimal outcomes, considering the level of innovation in their app, user needs and preferences, and market trends. Developers should also be prepared to pivot their innovation strategies when faced with unexpected changes in the market or user needs. For instance, developers can employ different incremental innovation strategies at various stages of app development to achieve desired goals. During the early stages when the app has limited features, lackluster experience, and a small user base, a "sailing" strategy may be employed to increase user downloads. However, as the app gains more users, a strategy that improves both ratings and downloads may be necessary to maintain and expand the user base. In such cases, the "optimizing" and "supplementing" strategies are more appropriate. Moreover, when the app is stable and has become popular, a "patching" strategy can be used to improve specific areas and enhance viewership. By strategically implementing various incremental innovation strategies at different stages of development, developers can maximize the app's impact on downloads and ratings, leading to greater success and market share in the competitive app market.

Limitations and Future Directions

The study is limited by the fact that it only focuses on a single mobile app store in China, which may not be representative of the broader mobile app market. Therefore, the findings of this study may not be generalizable to other regions or platforms. The study's findings may also be limited by the fact that it relies solely on data collected from user comments and app updates, which may not accurately reflect the actual user experience or the development process. Other data sources, such as user surveys or interviews with developers, could provide more in-depth insights into the impact of market feedback and incremental innovation strategies on app performance. While the study examines the relationship between market feedback, incremental innovation strategies, and app performance, it does not establish causality between these variables. Other factors, such as market competition or the formation of niche markets, could also impact app performance, making it difficult to attribute any observed effects solely to market feedback or incremental innovation strategies. Furthermore, it is essential to acknowledge that our criteria for classifying app innovation might not be universally applicable to all app updates. For example, app updates could entail modifications to the app's pricing or business model restructuring, which may not distinctly align with functional or experiential innovation.

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