Ecosystems in Transition: Managing Complementor Bottlenecks in the Disruptive Innovation of Small Satellites

Yue Song (Fowler College of Business, San Diego State University)
Yue Maggie Zhou (Ross School of Business, University of Michigan)
Xiaoping Zhao (Antai College of Economics and Management, Shanghai Jiaotong University)

This Version: November 2023

Abstract

We examine the process by which disruptive technology producers in a "transitional ecosystem" gain support from complementors of the incumbent technology. We propose that two types of rigidity—(a) technological rigidity arising from cospecialization with specific incumbent technology designs and (b) business rigidity arising from concentration in revenue from major incumbent technology customers—increase adjustment costs for the incumbent complementors to support the disruptive technology. At the same time, disruptive technology producers can adopt two ecosystem strategies—technological standardization and forward integration—to reduce the adjustment costs and incentivize the incumbent complementors to support the disruptive technology. Empirical analyses of large rocket providers' support for small satellite manufacturers before the emergence of small rockets support our propositions.

Keywords: disruptive innovation; innovation ecosystem; complementors; ecosystem strategies; space economy

1. INTRODUCTION

Disruptive innovation, the process of a disruptor "targeting overlooked customers with a novel but modest offering and gradually moving upmarket to challenge the industry leaders" (Christensen, Raynor, & McDonald, 2015), is one of the most studied subjects in business (Kumaraswamy, Garud, & Ansari, 2018), as well as science and technology (Wu, Wang, and Evans, 2019). From personal computers (Bower and Christensen, 1995) to floppy disk drives (Christensen and Bower, 1996) to CMOS sensors (Roy, Lampert, and Stoyneva, 2018) to computer numerical control machine tools (Roy and Cohen, 2017) and commercial drones (Shermon and Moeen, 2022), disruptive innovations often appear inconsequential to industry incumbents at first but eventually redefine the industry with their creative products and ideas. The factors behind their success have been examined in a large number of prior studies, which mainly focus on the delayed response from incumbent technology producers (e.g., Benner, 2009; Christensen, 1997). These producers hesitate to respond due to various constraints from their prior experiences (Furr, 2019), mindsets and framing (Raffaelli, Glynn, & Tushman, 2019; Tripsas & Gavetti, 2000), routines and structures (Henderson & Clark, 1990; Leonard-Barton, 1992), as well as pressure from the financial markets (Benner, 2007, 2010). Such hesitance to respond can be exploited by the disruptor to improve its offerings and move upmarket until the incumbents' customers widely adopt the new technology, and it is too late for the incumbents to respond.

In this paper, we expand the focus from technology producers to the innovation ecosystem, taking into account complementors providing complementary products or services that are critical to the focal technology's value proposition (Kapoor and Lee, 2013; Kapoor and Furr, 2015). We argue that because it takes time for the disruptor to secure new complementors to create a new innovation ecosystem (Adner and Kapoor, 2010; 2016; Ansari , Garud, and Kumaraswamy, 2016), the disruptor needs to first rely on complementors in the incumbent innovation ecosystem (incumbent complementors), thereby disrupting not only the incumbent technology producers but also existing relationships within the incumbent ecosystem (Christensen et al., 2018; Kumaraswamy et al., 2018). While entering the low end of a market or creating a new market segment may help the disruptor to stay off the incumbent technology producers' radar, it also discourages incumbent complementors from supporting the disruptive innovation. Hence the disruptor faces a "disruptor's dilemma": It needs to seek cooperation from incumbent complementors, the key actors in the existing ecosystem that its disruptive innovation is expected to replace (Ansari et al. 2016). How a disruptor can incentivize incumbent complementors to participate in the transition toward a new ecosystem becomes an intriguing research question.

To answer this question, we examine the process by which the disruptor can develop a "transitional ecosystem" with incumbent complementors. We highlight a "complementors' dilemma": While adapting their products and services to the disruptive technology may generate additional revenue and a growth opportunity, it entails technological and business adjustment costs. We then decompose the technological adjustment costs into three components, costs of de-cospecialize with the incumbent technology, costs of cospecialize with the disruptive technology, and costs of coordination between the two technologies. We also decompose the business adjustment costs into three components, opportunity costs in lost revenue from incumbent technology customers, search and contracting costs to secure disruptive technology customers, and costs of coordination between the two groups of customers.

Accordingly, we pin down two types of rigidity that give rise to these adjustment costs. First, incumbent complementors may face technological rigidity if they have made investments that are cospecialized with specific incumbent technology designs. While such investments increase complementarities among actors in the incumbent ecosystem, thereby tightening their joint value proposition to incumbent customers, they also result in higher adjustment costs for the complementors to de-cospecialize with the incumbent technology and coordinate between the incumbent and disruptive technologies. Second, incumbent complementors may face business rigidity if their current revenue is concentrated among a small number of incumbent technology customers. More concentrated revenue makes the incumbent complementors more reliant on a few incumbent customers for business, increasing the opportunity costs of adaptation from losing these customers. It also increases the cost of coordination between incumbent and new technology customers, as the more powerful incumbent customers are less willing to budge to accommodate the needs of new technology customers. Following these analyses, we hypothesize that incumbent complementors facing greater technological and business rigidity from the incumbent ecosystem will provide less complementary services to disruptive technology producers.

We then investigate two ecosystem strategies by which disruptive technology producers can reduce the technological and business adjustment costs for incumbent complementors, thereby increasing their incentive to support the disruptive technology. First, disruptive technology producers can design a standard interface to reduce the need for the incumbent complementors to make co-specialized investments with specific disruptive technology designs, and the coordination costs between the incumbent and disruptive technologies. Second, disruptive technology producers can forward integrate into the downstream to reduce the costs for incumbent complementors to search for and contract with potential disruptive technology customers, and the coordination costs between the incumbent and new customers. Following these analyses, we hypothesize that incumbent complementors will provide more complementary services to disruptive technology producers when more of them use a standardized technology design or forward integrate into the downstream.

We test our hypotheses by examining the complementary services provided for small satellites, a disruptive innovation in the commercial spaceflight industry that was dominated by large satellites (incumbent technology). We use quantitative data on 2,590 satellite launches from 1981 to 2017 worldwide and qualitative information collected through semi-structured interviews. We find evidence supporting our hypotheses. Incumbent launch vehicle (i.e., large rocket) providers (complementors) launched fewer small satellites when (1) they had a higher level of cospecialization with specific incumbent technology designs, or (2) they had a higher concentration of revenue from incumbent technology customers. On the other hand, incumbent launch vehicle providers' support for the small satellite technology was responsive to disruptive technology producers' ecosystem strategies. They launched a larger number of small satellites when the small satellite producers (1) used a standardized technology design or (2) forwardly integrated into the downstream.

Our study makes a few contributions. First, it broadens the focus of the disruptive innovation literature from incumbent technology producers' resistance (Bower and Christensen, 1995; Christensen and Bower, 1996; Christensen et al, 2015) to incumbent complementors' role in supporting disruptive innovations. Our findings reinforce the importance of interdependencies among key actors when studying the diffusion of disruptive innovations. In doing so, we answer the call to study disruptive innovations from a systematic perspective (Ansari et al., 2016; Kumaraswamy et al., 2018).

In addition, our study extends the innovation ecosystem literature, which has identified the lack of collaborative complementors as the most important bottleneck for ecosystem emergence

(Adner and Kapoor, 2010; Baldwin, 2015; Hannah and Eisenhardt, 2018; Jacobides and Tae, 2015), but has yet identified specific ecosystem strategies to overcome this bottleneck. We fill in this gap by identifying technological and business rigidity as two factors that contribute to ecosystem adjustment costs, as well as technological standardization and forward integration as two ecosystem strategies that disruptors can adopt to reduce the adjustment costs and entice incumbent complementors into joining the transitional ecosystem.

Finally, this study complements the literature on industry emergence under technological and market uncertainty (Benner, 2007, 2009). Disruptive innovations often create nascent industries. Our results suggest that disruptors need to navigate technological and market uncertainty not only for themselves but also for their complementors.

2. THEORETICAL BACKGROUND AND HYPOTHESIS DEVELOPMENT

Disruptive innovations have two defining characteristics (Christensen et al., 2018). First, when introduced, they are inferior to the incumbent technology in performance. They do not improve performance along the existing customer-preference trajectory but rather introduce a unique set of attributes, such as being small-sized, lightweight, and rugged (Bower and Christensen, 1995; Christensen and Bower, 1996). Second, they tend to originate in two types of markets: low-end markets overlooked by incumbents (Bower and Christensen, 1995; Christensen and Bower, 1996), and new markets where disruptive technology producers can turn non-consumers into consumers (Agarwal, Moeen, and Shah, 2017; Moeen, Agarwal, and Shah, 2020). It is their *inferior technological performance* and their *inability to attract customers from the mainstream market* that make disruptive innovations unappealing to incumbent actors surrounding the existing technology (Ansari and Krop, 2012; Bergek et al., 2013), and present the incumbent technology producers an "innovator's dilemma" (Christensen, 1997): [1] The pursuit of technological improvement and customer value enhancement within their existing business model may cause incumbents to miss the disruptive innovation until it is too late (Benner, 2007, 2009).

An ecosystem is an "alignment structure of the multilateral set of partners that need to interact in order for the focal value proposition to materialize" (Adner, 2017: 42). In particular, an innovation ecosystem is one that contains a particular innovation and the actors that need to interact for the innovation to deliver value (Adner and Kapoor, 2010, 2016). Compared with the disruptive innovation literature, the innovation ecosystem literature shifts the level of competitive analysis from between the producers of different technologies to between their respective ecosystems (Adner and Kapoor, 2016). In addition to the focal technology producers, multiple ecosystem actors contribute to the technology's success: upstream component providers, downstream customers, and complementors (Brandenburger and Nalebuff, 1996). For example, in the Airbus A380 ecosystem, engine and navigation system suppliers are the upstream component providers, airlines are the downstream customers, and airports, aircraft crew training simulator manufacturers are the complementors (Adner and Kapoor, 2010). New technology producers need a clear ecosystem strategy to align these actors to create an effective new ecosystem (Adner, 2017), especially during the early stages when new technology producers may face "ecosystem emergence challenges" (Adner and Kapoor, 2016). As other elements in the ecosystem struggle to emerge, they may become bottlenecks to constrain the performance and adoption of the focal technology.

2.1. Transitional Ecosystems

[1] It is worth noting that Christensen et al. (2015, 2018) stress the importance of studying disruption as a process, and not all disruptive innovations are successful. In our study, we adopt this perspective and focus on the initial stages of the disruptive process, before the disruptors have completely replaced the incumbents in capturing mainstream customers.

Among potential actors that the new technology producers need to secure, complementors have been identified as one of the most important potential bottlenecks (Hannah and Eisenhardt, 2018; Jacobides and Tae, 2015). When complementors provide inadequate products or services (complements), customers are unable to obtain the full benefits of the new offering, slowing down adoption (Adner and Kapoor, 2010, 2016). Before new technology producers can establish an ecosystem of their own with devoted new complementors, they need to seek cooperation from incumbent complementors, the key actors in the existing ecosystem that the disruptive innovation is expected to replace (Ansari et al. 2016). We term such an ecosystem a "transitional ecosystem". This transitional stage is characterized by the emergence of a disruptive innovation, but its dedicated complementors have yet to be developed, and incumbent technology customers have yet to switch to the disruptive technology. As illustrated in Figure 1, in a transitional ecosystem, disruptive technology producers rely on incumbent complementors to fulfill their value proposition.

[Insert Figure 1 about here]

We propose a “complementors’ dilemma”: While adapting their products and services to the disruptive technology may generate additional revenue and growth opportunity, it also entails technological and business adjustment costs. Specifically, we argue that incumbent complementors' *technological* adjustment costs can be decomposed into three components: (a) costs of de-cospecialization with the incumbent technology, (b) costs of cospecialization with the disruptive technologies, and (c) costs of coordination between the two technologies. Their *business* adjustment costs can also be decomposed into three components: (a) opportunity costs in lost revenue from incumbent technology customers, (b) search and contracting costs to secure disruptive technology customers, and (c) costs of coordination between the two groups of customers. As illustrated in Figure 1, we will hypothesize about the factors that increase (decrease) these adjustment costs and consequently decrease (increase) the incumbent complementors' incentive to participate in the transitional ecosystem.

2.2. Incumbent Complementors as Bottlenecks: Technological Rigidity

We start with rigidities that increase adjustment costs (Leonard-Barton, 1992; Gilbert, 2005). Technological rigidity arises from the complementors' cospecialized investments with specific technology design. While such cospecialization enhances compatibility, interoperability, and mutual adaptation (Baldwin, 2015; Jacobides, Cennamo, and Gawer, 2018; Teece, 1986), thereby offering a robust innovation ecosystem and greater customer value (Ceccagnoli and Jiang, 2013; Ceccagnoli et al., 2010; Santoro and McGill, 2005), it also leads to technological rigidity when facing disruptive innovations and increases technological adjustment costs. First, cospecialization with specific incumbent technology designs increases costs of de-cospecialization, which entails unraveling the intricate interdependencies in past investments. Specialized equipment may become obsolete. Specifications optimized for interoperability may need revision. Unique routines, processes, and operational standards may require alteration. For instance, adopting a disruptive imaging technology may require physicians to first unlearn the old system (Ozalp et al., 2018), discarding their years of expertise.

Second, complementors that are highly cospecialized with specific incumbent technology designs also face higher coordination costs between the incumbent and disruptive technology when providing hybrid offerings, or supporting both the incumbent and disruptive technolgies (Christensen et al., 2018; Furr and Snow, 2015). There are inherent contrasts between the two technologies: the disruptive technology is often small, rugged, and low costs, whereas the incumbent technology is often sophisticated, advanced, and more expensive. Designing a new interface for the disruptive technology that doesn't interfere with the existing one is more difficult if the existing one is specified than if it is generic. The higher costs of de-cospecialization and coordination will discourage the incumbent complementors from supporting the disruptive technology.

Hypothesis 1: A complementor will provide fewer complements for disruptive technology producers when it has a higher level of cospecialization with specific incumbent technology designs.

2.3. Incumbent Complementors as Bottlenecks: Business Rigidity

Business rigidity occurs when a company relies too heavily on a small number of major incumbent customers (Patatoukas, 2012; Zhong et al., 2021). The concentration of business among major incumbent customers increases business adjustment costs in two ways. First, it increases the opportunity costs in lost revenue from incumbent technology customers. A firm's stakeholders that provide the necessary resources also constrain its strategic change (Pfeffer and Salancik, 1978; Cho and Zhou, 2021). Complementors whose businesses are concentrated among a few incumbent customers are heavily reliant on these customers for large contracts and stable revenues (Zhong et al., 2021). Such entrenchment leads to greater opportunity costs for the complementors to serve disruptive technology customers and entice the complementors to preserve and enhance the value of the incumbent customers (Christensen and Bower, 1996).

In addition, a greater concentration of business among major incumbent customers increases the coordination costs of serving two different customer bases. Whereas incumbent technology customers often prioritize superior performance, reliability, and stability, disruptive technology customers trade those qualities for basic functionality, speed, and affordability (Christensen, 1997; Christensen and Raynor, 2003). Offering hybrid complements to serve both the incumbent and disruptive technologies may lead to conflicts between the two customer groups. When there are only a few major incumbent customers, they are more likely to have stronger bargaining power and more demanding requirements, and can exert a bigger influence on the complementors' decisions (Zhong et al., 2021). The higher opportunity costs and coordination costs will discourage the incumbent complementors from supporting the disruptive technology.

Hypothesis 2: A complementor will provide fewer complements for disruptive technology producers when it has a greater concentration of business among major incumbent customers.

2.4. Reducing technological adjustment costs through technological standardization

As we argued in Section 2.1, incumbent complementors' technological adjustment costs can be decomposed into three components: (a) costs of de-cospecialization with the incumbent technology, (b) costs of cospecialization with the disruptive technology, and (c) costs of coordination between the incumbent and disruptive technology. While disruptive technology producers may not be able to decrease (a), they can reduce (b) and (c) through technological standardization, or the joint development of a common set of standard specifications that are compatible across different technology designs (Leiponen, 2008; Tassey, 2000).

Technological standardization reduces the costs of cospecializing with any particular disruptive technology design. By providing a unified technological specification, standardization reduces the need to cospecialize (Leiponen, 2008; Miller and Toh, 2022; Ranganathan and Rosenkopf, 2014). It reduces the R&D, training, and interoperability costs for the complementors by removing the need to navigate through the intricacies of any particular disruptive technology design. Having a standard technology design also enhances economies of scale.

In addition, technological standardization reduces coordination costs between the incumbent and disruptive technologies when incumbent complementors provide hybrid offerings. Standardizing the disruptive technology design reduces potential interferences between the incumbent and disruptive technology. It leads to less disruption to investments in the incumbent technology (Venkatraman, 1989). The reduction in cospecialization costs and coordination costs will incentivize incumbent complementors to support the disruptive technology.

Hypothesis 3: A complementor will provide more complements for disruptive technology producers when more of them use a standardized technology design.

2.5. Reducing business adjustment costs through forward integration

As we also argued in Section 2.1, incumbent complementors' business adjustment costs can be decomposed into three components: (a) opportunity costs in lost revenue from incumbent technology customers, (b) search and contracting costs to secure disruptive technology customers, and (c) costs of coordination between the incumbent and disruptive technology customers. While disruptive technology producers may not be able to decrease (a), they can reduce (b) and (c) through forward integration into the downstream and becoming a customer of the disruptive technology (Harrigan, 1984).

In their early stages, disruptive technologies often face uncertain market demand (Christensen and Bower, 1996; Christensen, 1997), and complementors need to search for and contract with mostly new customers. Disruptive technology producers' forward integration into the downstream shifts demand uncertainty onto themselves and reduces the complementors' search and contracting costs.

Forward integration also reduces the coordination costs between the incumbent and disruptive technology customers when incumbent complementors provide hybrid offerings. The complexity arising from multiple bilateral relationships along the value chain causes coordination costs (Zhou, 2011; Zhou and Wan 2017). The complex relationships between the disruptive technology producer, the incumbent complementor, as well as incumbent and new customers exacerbate coordination efforts. Through forward integration, a disruptive technology producer replaces the disruptive technology customers with itself, reducing the number of independent relationships the complementor needs to manage and the potential sources of conflicts. Such streamlined interactions reduce the complementor's coordination costs. The reduction in search/contract costs and coordination costs will incentivize incumbent complementors to support the disruptive technology.

Hypothesis 4: A complementor will provide more complements for disruptive technology producers when more of them have forward integrated downstream to become their own customers.

3. EMPIRICAL CONTEXT: SMALL SATELLITE AND ITS INNOVATION ECOSYSTEM

3.1. The Disruptive Innovation of Small Satellites

The launch of the world's first artificial satellite, Sputnik 1, by the Soviet Union in 1957 marked the beginning of the satellite industry. For the next two and half decades, government agencies around the world competed in developing and launching large satellites, primarily driven by the space race between the United States and the Soviet Union during the Cold War. The established trajectory of performance improvement for satellites was closely tied to size, as large satellites were able to carry more equipment and perform more sophisticated missions (Helvajian & Jason, 2009). Large satellite manufacturers focused on the technical needs of existing customers – large satellite operators serving government space agencies, military and defense organizations, and large corporations. These end users emphasized high reliability and precision that can only be satisfied with large, sophisticated, and high-priced satellites (dos Santos Paulino and Le hir, 2016). This left an opening in the less technically advanced and less profitable segments.

In 1981, the first modern small satellite, UoSat-1, was developed by Sir Martin Sweeting and his team at the University of Surrey in the United Kingdom. Frustrated with the high costs and complexities that came with building and launching large satellites, the research team experimented with commercial off-the-shelf components and demonstrated that small satellites could be built rapidly to perform basic missions. New small satellite manufacturers followed with production.

Initially, small satellites had inferior performance compared to large satellites. Table A1 in the Appendix compares the key features of large and small satellites. Whereas large satellites had a wet mass of more than 500kg, small satellites weighed on average ten times lighter. The smaller size and reduced weight limited the functionality of small satellites. Take earth observation satellites as an example, while large ones like Geo Eye-1 offered resolutions of 41cm per pixel, small satellites like KITSAT-A offered a mere 400 m per pixel. Such poor performance drove away the most profitable and demanding customers and forced small satellites into the lower end of the existing market (e.g. government agencies in developing countries) and new market segments (e.g. research institutions and universities, NGOs, small and medium sized enterprises including startups). To these lower end and new users, small satellites are attractive as their small size and light weight allow them to be built and launched at much lower costs (e.g., $1M versus $400M for building, and $400,000 versus $400M for launching, a small versus a large satellite). They also require significantly shorter development time (e.g., as short as a day in the case of the OneWeb satellites versus up to a decade for a large satellite). These features allow new users to access space at a lower cost than previously thought possible.

Over the next 40 years, small satellites followed the path of a disruptive innovation: they greatly improved their technological capabilities (Sweeting, 2018), and their demand grew exponentially. While only 35 small satellites were launched in 1981, 1,104 were launched in 2020. However, small satellites had not won over the majority of the incumbent customers by 2020, when orders from incumbent customers contributed to less than 5% of the total small satellite sales. Accordingly, incumbent launch vehicle (LV), or rocket manufacturers continued to develope LVs for large satellites. The disruptive process continued to unfold after 2020 and started to show early signs of success. For instance, since the escalation of the Russo-Ukrainian war in 2022, small satellites have been playing an instrumental role in collecting earth imageries for the US government for intelligence (Borowitz, 2022). Recent industry reports also highlight that the proliferation of small satellites "is highly disruptive to how the government procures satellites" (Erwin, 2023).

3.2. Key Actors in the Innovation Ecosystem of Small Satellites

Figure 2 shows that a satellite is mainly made of two parts, a satellite bus and a payload (Jakhu and Pelton, 2013). The satellite bus is the platform that provides mission-specific support for the satellite; it contains several subsystems, such as those for propulsion, thermal control, and altitude control. The payload contains the main hardware to carry out the mission (e.g., imaging cameras for earth observation), as well as antennas, receivers and transmitters for communication. The satellite manufacturers procure and integrate various components into the bus and payload and assemble the satellite.

[Insert Figure 2 about here]

In addition to satellite manufacturers as the focal technology producers, the satellite innovation ecosystem consists of component manufacturers (for the satellite bus and payload), the LV and ground equipment providers as complementors, and satellite operators as customers. A satellite operator purchases a satellite from the satellite manufacturer, acquires ground equipment for data uplink and downlink to and from the satellite, and pays for a load capacity on the LV to transport the satellite into orbit.

Given their critical roles and relevance to our research question, we focus on a few key actors in the transitional ecosystem: the small satellite manufacturers as disruptors or disruptive technology producers, large satellite manufacturers as incumbent technology producers, large satellite operators as incumbent customers, and large LV providers as incumbent complementors.

3.3. Incumbent Complementors as Bottlenecks in The Transitional Ecosystem

Figure 3 shows that the evolution of the satellite innovation ecosystems can be divided into three stages. Stage 1 started in 1957 with the launch of Sputnik 1 and saw the establishment of the incumbent ecosystem for large satellites. Stage 2 started in 1981 with the successful launch of UoSat-1, the first modern small satellite. However, until the late 2010s, small satellite manufacturers relied on incumbent LV providers to launch their satellites. We label this period the transitional ecosystem stage. Stage 3 started in 2018, when Rocket Lab launched Electron, the first LV dedicated to small satellites and marked the emergence of a new ecosystem for small satellites. We focus on the transitional ecosystem stage (Stage 2) from 1981 to 2017.

[Insert Figure 3 about here]

The lack of support from large LV providers for small satellites has been repeatedly identified by industry experts as the most important bottleneck to the adoption of small satellites during this transitional stage. In our interviews, small satellite manufacturers emphasized that, "*If you build a satellite, but you can't launch it, it is pretty pointless". "The problem until recently has always been there were more ideas for the small satellites than they could ever find a launch for… the problem was* ***no one could find a launch*** *[for small satellites]. There were very few."* Industry studies have also observed that oftentimes, large LV providers required small satellites to share a ride with large satellites: "*Smaller satellites…have long been treated like second-class launch citizens, having to squeeze in on a resupply mission to the space station or* ***share a ride*** *with a larger satellite, if there's room."* (Thompson, 2018). *"The Primary Spacecraft Provider (a.k.a., "The Prime") dictates all of the mission parameters…The Secondary Spacecraft Provider (a.k.a., "Secondary Payloads", a.k.a., "Auxiliary Payloads (APLs)", a.k.a., "Piggy-Back*

Spacecraft", a.k.a., "Hitch Hikers") must adhere to the Prime's requirements and launch timelines. Otherwise, they will be left by the side of the road, sic, the launch pad." (Lim and Armstrong, 2014).

Figure 4 supports these claims. It shows that, although most of the small satellites were manufactured and operated by new entrants, the launch services were primarily provided by incumbent (large) LV providers during the transitional stage. It was not until 2018 that de novo entrants like Rocket Lab, Firefly Aerospace, Relativity Space, and ABL Space Systems started to develop LVs that provided exclusive services to small satellites.

[Insert Figure 4 about here]

3.4. CubeSat as the Standardized Small Satellite Technology Design

The CubeSat design was invented by two American professors in 1999 and first launched in 2003. It quickly became a commonly used bus design for modern small satellites. A basic CubeSat unit had multiples of 10*10*10cm cubic units and a maximum mass of 1.33 kilograms. The CubeSats design minimized the cospecialized investments required of LV providers and satellite manufacturers by standardizing and modularizing the interfaces between satellites and the LV, as well as the interfaces across multiple satellites.

In summary, the context is suitable for our study for several reasons. First, the innovation of the small satellite technology was disruptive to the incumbent large satellite technology. Started as an inferior technology only attractive to low-end and new customers with a tiny fraction (16%) of the market in 1981, small satellites had grasped 74% of the entire satellite market and served a wide range of customers by 2017. Second, the satellite industry entails an ecosystem of focal technology producers, customers, component providers, and complementors. The small satellite technology would disrupt most of these incumbent relationships. Third, the new ecosystem for the small satellite technology took a long time to develop, with dedicated key complements (e.g., small

LVs or rockets) not available until 2018, which necessitated a transitional ecosystem with the support of incumbent complementors. Fourth, incumbent LV providers as key complementors faced both technological and business rigidity when presented with the opportunity to support the small satellite technology. They had to build new relationships with numerous small satellite manufacturers and operators, which was very different from the incumbent model where LV providers only needed to coordinate with a small number of large satellite manufacturers and customers. [2] Finally, small satellite producers leveraged innovations in technological standardization (e.g., CubeSat design) and organizational form (e.g., forward integration) to address the transitional difficulties, providing an opportunity for us to study their effectiveness in garnering support from incumbent complementors.

4. EMPIRICAL DESIGN

4.1. Data and sample

We collect quantitative data from several reputable industry sources. Specifically, we obtain all satellite launch information from Gunter's Space Page Chronology, for a total of 5,581 satellites from 3,251 launches between 1981 and 2017. For launched satellites with missing data (e.g., on mass and manufacturer), we search NASA.gov, Encyclopedia Astronautica, and Spacecraft Encyclopedia to collect additional information. We match each LV to Jonathan’s Space Report to obtain information about its provider and provider type (business entity, civil, or military/defense), as well as other characteristics such as length, diameter, minimum and maximum number of stages, and apogee (highest point traveled). We exclude launches by 13 LV providers who are military or

[2] For example, incumbent LV providers need to accommodate many small satellites of different sizes and shapes, as each satellite only took up a small proportion of the total launch capacity in any given launch. Each of the small satellite customers could pay as little as $40,000 for the launch of a small satellite, less than 0.1% of what the large satellite customers were paying for each launch–between $100 to $400 million.

defense entities, as these entities might have different incentives than business firms to serve large versus small satellites; a robustness check adding them back generates similar results. Our final dataset includes a total of 4,369 satellites from 2,590 launches on 178 LVs by 22 LV providers. We perform our analyses at the launch level. Robustness checks at the LV-launch year and LV provider-launch year level generate similar results.

To supplement our quantitative data, we collect qualitative information through semi-structured interviews with industry participants at three major satellite conferences. These interviews are discussed in detail in Section 5.4.

4.2. Variables

Number of Small Satellites Launched$_{lvit}$, our dependent variable, is the number of small satellites included in launch l on LV v by LV provider i in year t. As robustness checks, we also use two alternative variables: (1) the percentage of all satellites on launch l that are small satellites, and (2) a dummy that takes the value of 1 if there is at least one small satellite on board, 0 otherwise; results are similar.

We include a few independent variables in accordance with our hypotheses. $Co-specializaiton\ with\ specific\ incumbent\ tech\ designs\ _{vl}$ gauges the level of cospecialization between LV v and the specific incumbent technology design for the large satellite on board. Each launch requires the LV provider and the satellite manufacturer to cospecialize, adapt, and adjust their respective designs to ensure that the satellite's vibration, spin balances, and thermal vacuums can survive the intense launch process (Skyrora team, 2021). The most important design for the integration process is the satellite's bus design. The more times a specific bus design has been integrated onto a focal LV, the more likely that the LV provider and the satellite manufacturer would have cospecialized their equipment, testing procedures, and launching processes.

We thus measure cospecialization between LV v and the specific incumbent technology design on the focal launch l using the number of times that the large satellite bus design on board had been integrated onto LV v in the past (before the focal launch), standardized by the total number of integrations across all large bus designs on LV v in the past. In our sample, the majority (>80%) of the launches carry only one large satellite bus. For launches with multiple large satellite bus designs, we calculate the average (standardized) number of integrations of each large satellite bus design.

$Incumbent\ tech\ customer\ concentration_{i,[t-3,t-1]}$ is measured using the share of business for LV provider i from its largest satellite customer in the three-year period from *t-3* to *t-1*. Because LV providers charge their customers by satellite mass, we use mass to proxy for sales revenue.[3]

$Standardized\ technology\ design_{\ l}$ is measured using the percentage of small satellites that use the CubeSat bus design on launch l. For launches where there is no small satellite on board, we assign a value of zero. A potential problem with this measure is that it could be endogenous to the dependent variable. First, when both variables are zero, the decision to not launch any small satellite may cause no use of the CubeSat design, rather than the other way around. To deal with this reverse causality issue, as a robustness check (discussed in Section 5.2), we rerun our econometric analysis on the subsample of launches that have at least one small satellite on board. Second, if every small satellite launched must use a CubeSat design, then this independent variable and our dependent variable might be jointly determined by a third variable and hence endogenous to each other. Upon closer inspection, we find that only 34% of the small satellites launched have

[3] Different customers can share the same bus design, and the same customer can use different bus designs for different satellites. Our summary statistics show that the ratio between the number of large satellite customers and the number of large satellite bus designs ranges from 0.33 to 3.

a CubeSat design during our sample period. Even after 2003, when the CubeSat design became widely available, only 59% of the small satellites launched in our sample have a CubeSat design. This is because other exogenous factors could constrain the use of CubeSat design. For example, certain missions demand that the satellite not be constrained by the dimensions of a Cube. These exogenous constraints alleviate our concern about endogeneity.

$Forward\ intergration_{l}$ is measured using the percentage of small satellites on launch l that are manufactured and operated by the same organization. To launches with no small satellite on board, we assign a value of zero. Similar to $Standardized\ technology\ design_{l}$, this measure could be endogenous to the dependent variable. Upon closer inspection, we find that only 44% of the small satellites launched have the same manufacturer and operator. This is because integration is constrained by other exogenous factors, such as the small satellite manufacturer's lack of necessary infrastructure, regulatory approvals, or financial resources to operate the satellite. These exogenous constraints alleviate our concern about endogeneity. Nevertheless, we perform another robustness test (discussed in Section 5.2) on the subsample of launches with at least one small satellite.

For control variables, we include the focal LV's specifications that might influence its ability to launch small satellites, including its *length, diameter*, *minimum and maximum number of stages,* and *apogee*. We also include *year dummies* to account for unobservable macro demand, supply, and technological factors that could influence the launch of small satellites. In addition, we include *LV provider dummies* to account for unobservable heterogeneity across firms.

Table 1 reports summary statistics and correlation coefficients. An average launch carries 0.60 small satellite (increasing from an average of 0.36 in 1981 to an average of 3.46 in 2017). On average, the large bus design on a focal launch has been used in about 30% of the focal LV's past launches, and a focal LV provider's largest large satellite customer in the past three years accounts for 47% of its revenue for the same period. Two percent of satellites on an average launch use the CubeSat design (increasing from an average of 1% in 2013 to an average of 15% in 2017); five percent are manufactured and operated by the same organization. Consistent with our hypothesized relationships, Cospecialization with specific incumbent technology design and incumbent technology customer concentration are negatively correlated with, whereas standardized technology design and forward integration are positively correlated with, the number of small satellites launched.

[Insert Table 1 about here]

4.3. Specifications

Because our dependent variable is a count variable, we adopt a negative binomial model to account for over-dispersion.

$$
\begin{aligned}
&ln\ (Number\ of\ Small\ Satellites\ Launched_{lvit}) \\
&\qquad = \beta_1 Cospecializaiton\ with\ specific\ incumbent\ tech\ designs_{\,v,[t-3,t-1]} \\
&\qquad + \beta_2\ Incumbent\ tech\ customer\ concentration_{\,i,[t-3,t-1]} \\
&\qquad + \beta_3\ Standardized\ technology\ design_{\,l} + \beta_4\ Forward\ intergration_{\,l} \\
&\qquad + \beta_5 X_{\,v} + \delta_i + \gamma_t,
\end{aligned}
$$

where the dependent and independent variables are as defined earlier, $and\ X_{\,v}$ is a vector of LV-level control variables as explained before. δ_i and γ_t are LV provider and year dummies, respectively.

5. RESULTS

5.1. Main analyses

Table 2 reports our main results. Model 1 includes only the control variables. Models 2-5 introduce the independent variables one at a time. Looking across models, coefficients to the control variables are consistent with our expectations. Longer and wider LVs, as well as those that had more stages and higher apogee, all designed to accommodate larger satellites, carried fewer small satellites.

[Insert Table 2 about here]

In terms of the independent variables, launches by LVs more cospecialized with a specific incumbent technology design carried fewer small satellites (p-value ≤ 0.006 in all models but Model 3), supporting H1. Calculation based on the full model (Model 5) and Table 2 indicates that, holding all other variables constant at their mean values, a one-standard-deviation increase in an LV's cospecialization with a specific large satellite bus design was associated with a 24% reduction (=exp(-0.837*0.33)-1) in the number of small satellites carried on board.

In addition, launches by LV providers with more concentrated business from large satellite customers carried fewer small satellites ($p<0.001$), supporting H2. Calculation based on Model 5 and Table 2 suggests that holding all other variables constant at their mean values, a one-standard-deviation increase in a focal launch's LV provider's share of incumbent business from its largest customer was associated with a 73% reduction (=exp(-4.246*0.31)-1) in the number of small satellites carried on board.

Furthermore, launches with a higher percentage of small satellites using the standardized CubeSat design carried more small satellites ($p<0.001$). Calculation based on Model 5 and Table 2 suggests that, holding all other variables constant at their mean values, a one-standard-deviation increase in the adoption of the CubeSat design on a focal launch was associated with a 39% increase (=(exp(2.415*0.12))-1) in the number of small satellites on board.

Finally, launches with a higher percentage of small satellites manufactured and operated by the same organization carried more small satellites ($p<0.001$). Calculation based on Model 5 and Table 2 suggests that, holding all other variables constant at their mean values, a one-standard-deviation increase in the percentage of small satellites on a focal launch that had the same manufacturer and operator was associated with a 66% increase (=(exp(2.529*0.20))-1=66%) in the number of small satellites on board.

5.2. Robustness checks and alternative explanations

We conduct a host of additional checks to ensure our results are robust to different sample selections, measurements, and levels of analysis. First, a significant portion of the incumbent customers are government entities, who may prefer to launch their satellites with military and defense LV providers, and these LV providers may be less affected by technological and business concerns. For our main analyses, we exclude non-business LV providers from our sample. As a robustness check, we add the non-business LV providers back to our sample and rerun our analysis. Results (reported in the Appendix, Table A2, Model 1) are consistent with our main analyses.

Second, SpaceX could be a potential outlier in our sample in that it is vertically integrated into three major areas of the ecosystem—manufacturing, launching, and operation. Upon closer inspection, we find that even though SpaceX launched over 1,000 small satellites to form the Starlink constellation after 2017, it launched only 87 small satellites during our sample period (1981- 2017), making it unlikely to influence our results. Nevertheless, as a robustness check, we exclude the 49 SpaceX launches during our sample period. Results (Appendix, Table A2, Model 2) show no significant difference from our main analysis.

Third, we employ two alternative measures of the dependent variable (i.e., the percentage of small satellites on board the focal launch and a dummy variable indicating whether any small satellite is on board). We also use two alternative specifications at the LV-launch year and LV provider-launch year level, respectively, using fixed-effect negative binomial models. Results (Appendix, Table A2, Models 3-6) are consistent with our main analysis.

Fourth, as discussed in Section 4.2, an alternative explanation of our finding for H3 could be that, our measure of $Standardized\ technology\ design_{\,l}$ and $Customer\ intergration_{\,l}$ are potentially endogenous to the dependent variable. To address this issue, as a robustness check, we first rerun our econometric analysis on the subsample of launches that have at least one small satellite on board. Results (Appendix, Table A2, Models 7-8) confirm that our main results are robust on this smaller sample. We run another analysis comparing the number of small satellites per launch before and after 2003 (the year when the first CubeSat design became available), and 0 otherwise. Results (Appendix, Table A2, Model 9) show that the number of small satellites per launch significantly increases after the CubeSat standard becomes available, lending additional support to H3.

Lastly, an alternative explanation of our finding for H3 and H4 is that large LV providers (as incumbent complementors) become more supportive of small satellites not because of the small satellite manufacturers' adoption of the CubeSat design or forward integration but because of shifts in the preference of incumbent customers toward small satellites. After all, the definition of disruptive innovation implies that the disruptor will keep improving its products and services to win over mainstream customers eventually, and our arguments for H2 suggest that incumbent complementors are likely to stick with their incumbent customers. To address this concern, we focus on the transitional period when incumbent customers do not seem to have shifted their preferences. Figure 4 shows that, during this period, most small satellite launches remain associated with new customers (operators) rather than incumbent customers. This suggests that the increased launch of small satellites cannot be attributed to shifts in demand from incumbent customers.

5.3. Mechanism exploration

We also conduct a few analyses to explore the potential mechanisms behind our findings. First, one of the mechanisms that we have argued, through which cospecialization with specific incumbent technology designs can reduce the incumbent complementors' incentive to support the disruptive technology (H1), is higher coordination costs between the incumbent and disruptive technology. If this mechanism were true, complementors that are highly co-specialized with a specific incumbent technology design on a launch would accept fewer small satellite bus designs and satellites from fewer small satellite manufacturers on the same launch. To test this mechanism, we use the number of small satellite bus designs and the number of small satellite manufacturers involved in a focal launch as an alternative dependent variable. Results (Appendix, Table A3, Model 1-2) support these mechanisms.

Second, we have argued that incumbent technology customer concentration reduces the incumbent complementors' incentive to support the disruptive technology (H2) partly because increased coordination costs of serving different customer types. To test this mechanism, we use the number of small satellite operators (i.e., new customers) in each launch as an alternative dependent variable. Results (Appendix, Table A3, Model 3) support this mechanism.

Third, we have argued that a standardized technology design, such as a CubeSat design, reduces the cost of cospecializing with the disruptive technology (H3) by reusing interface designs across small satellites from different manufacturers. If so, we should expect a launch that has a higher proportion of small satellites with the CubeSat design to carry small satellites from a larger number of small satellite manufacturers. Rerunning our analysis on the subsample of launches with at least one small satellite on board (Appendix, Table A3, Model 4), we confirm that the use of CubeSat design is correlated with more small satellite manufacturers sharing the same ride.

Finally, we have argued that forward integration reduces search and contracting costs for finding new customers (H4). If so, we should expect a launch that has a higher proportion of small satellites with integrated manufacturer and operator to carry small satellites from a larger number of small satellite operators. Rerunning our analysis on the subsample of launches with at least one small satellite on board (Appendix, Table A3, Model 5), we confirm that forward integration is correlated with more small satellite operators sharing the same ride.

5.4. Interviews and qualitative evidence

To develop a deeper understanding of the context and mechanisms, we attend the 2019 Satellite Innovation Conference, as well as the 2021 and 2022 Small Satellite Symposia. At these conferences, we attend most panel discussions on the challenges and opportunities in the small satellite ecosystem. In addition, we conduct 14 interviews with 11 practitioners, including founders or top executives of small satellite manufacturers, LV providers, satellite operators, and industry consultants. During these interviews, we first ask the participants to identify the key bottlenecks in the small satellite ecosystem. The lack of launch services is repeatedly identified as the key bottleneck. We then ask follow-up questions to understand the specific dynamics and coordination required among various actors. We lastly ask the participants to discuss any strategies that their companies have implemented to address the bottlenecks. The interviews are semi-structured and last one hour on average.

Our interview quotes in the Appendix (Table A4) confirm that the small satellite technology fits the definition of a disruptive innovation, and the lack of complementor service is the bottleneck for its diffusion. The quotes also provide support for the mechanisms underlying our hypotheses. For example, some interviewees emphasize that cospecialization with specific incumbent technology designs increases technological adjustment costs for complementors:

> *"Getting a satellite onto a launch vehicle requires specific interfaces"; "Once you have the same interface, it's easier to build that again as long as you do it frequently. But if you only do it once on a rocket, and then you are going to do something else for another customer, it's not very cost-effective. It's like every time a new customer wants to fly on an airplane, we have to figure out a new seat."*

The interviewees also highlight the coordination costs for hybrid offerings (launching large and small satellites together):

> *"If you were a small satellite and you say to the launch vehicle: 'you need to change your launch vehicle to meet this aggregate (flying large and small satellites together) so that everyone can fly everyone. Let's all be one big happy family.' In most cases, these vehicles will say no because they'll have to do a bunch of changes they don't want to make."*

Other interviewees confirm that dependence on a few large incumbent customers increases business adjustment costs to carry small satellites:

> *"Their (the large launch vehicle providers) livelihoods are based on these big GEO-birds (big satellites) from the US government… they don't care to put a couple hundred-kilogram spacecrafts (i.e. small satellites) on there. If anything, they say, 'we don't want you on there'. Because, you risk problems with the other customers. There is power in their hands."*

Yet other interviewees repeatedly highlight that CubeSats design reduces technological adjustment costs for incumbent complementors:

> *"These standards make it so CubeSats can easily be swapped for one another on a launch vehicle, instead of having to create a new deployer system or redesign reliability requirements for each new satellite. This makes CubeSats interoperable with government and industry launches—reducing launch costs and increasing launch opportunities"*

Finally, many interviewees confirm that forward integration reduces complementors' demand risks and coordination costs:

> *"If an operator is also building its own satellites, that makes a really big difference, because it reduces their (launch vehicle providers') risk, and it helps them to have more knowledge about the satellite that's been communicated to them."*

6. DISCUSSIONS AND CONTRIBUTIONS

In this study, we examine how disruptive technology producers can develop a "transitional ecosystem" with incumbent complementors in support of the disruptive technology. We first argue that technology rigidity and business rigidity increase adjustment costs and discourage incumbent complementors from providing products or services for the disruptive technology. We then propose two ecosystem strategies, technological standardization and forward integration, by which disruptive technology producers can help incumbent complementors reduce adjustment costs and gain their support. Our empirical tests using launches of small satellites by incumbent large satellite LV providers from 1981 to 2017 support our hypotheses.

Our study first contributes to the literature on disruptive innovation, industry evolution and the emergence of new markets (Benner, 2007, 2009; Christensen, 1997; Gort & Klepper, 1982; Moeen, 2017; Moeen and Mitchell, 2020). It answers the call to study disruptive innovation from a systematic perspective (Ansari et al., 2016; Kumaraswamy et al., 2018). It switches scholarly attention from technology producers and customers to incumbent complementors. Complementary assets and resources are crucial for the adoption of new technology in both old and nascent industries (Kapoor and Furr, 2015; Moeen, 2017), and recent studies have started to underscore how resistance from complementors prolongs the disruptive process (e.g. Adner and Lieberman, 2021; Ozalp et al, 2018). We enrich these discussions in two ways. We extend the systematic perspective by tracing complementors' resistances to rigidities that originate in two sets of ecosystem relationships, and we extend the disruptive process perspective by proposing and elaborating on the construct of a "transitional ecosystem".

Our second contribution is to the innovation ecosystem literature, which has identified the absence of collaborative complementors to be one of the most important challenges for an innovation ecosystem to emerge and expand (Adner and Kapoor, 2010, 2016; Dattee, Alexy, and Autio, 2018; Hannah and Eisenhardt, 2017). We offer some solutions to these challenges, including leveraging a transitional ecosystem, as well as technological standardization and forward integration.

Integrating the ecosystem and process perspectives of disruptive innovation generates additional theoretical insights. For example, the literature suggests that incumbent technology producers' possession of complementary assets provides them unique advantages when facing disruptive innovation (Cattani, 2006; Danneels, 2004; Roy and Cohen, 2017; Roy et al., 2018; Tripsas, 1997; Mitchell, 1989). However, in an ecosystem, it is common for key players to lack ownership of and control over complementor assets (Chung, Zhou, & Ethiraj, 2023; Chung, Zhou, & Choi, 2023). For example, there can be complementors in the ecosystem but outside the firm boundary of technology producers. This unique feature of ecosystems provides opportunities for disruptive technology producers to convert incumbent complementors to support the disruptive technology. In addition, while the literature has proposed that complementors making investments specific to a focal technology will increase the joint value of the ecosystem, thus the likelihood of its commercial success (Adner and Kapoor, 2010; Jacobides et al., 2018), our analyses suggest that the value of cospecialization may depend on the evolution stage of the ecosystem. When introducing their innovations, disruptors may need to provide opportunities for incumbent complementors to make more standardized investments to lower their adjustment costs, thereby incentivizing them to participate in the transitional ecosystem.

This paper has a few limitations that offer opportunities for future research. Most importantly, we do not have a perfect counterfactual. For example, ideally, we should examine two otherwise identical small satellites—one with the CubeSat design and one without—and compare their likelihood of being carried on the same launch. Unfortunately, we do not have data on small satellite launches that were proposed but declined by the LV providers. We try to mitigate the endogeneity concern in multiple ways, including corroborating our proposed mechanism through qualitative interviews with industry practitioners, running robustness checks, and refraining from making strong causal statements. Future research could further explore these causal effects when data on both accepted and declined launch proposals becomes available.

Second, we study the transitional ecosystem stage, but not the final stage, when the new innovation ecosystem is established. We expect two opposing effects to influence the incumbent complementors in the "new ecosystem" stage. On the one hand, as the disruptive innovation matures and establishes itself in the mainstream market, more incumbent technology customers will switch to the new technology, and the incumbent complementors will follow. On the other hand, as more new complementors dedicated to the disruptive technology enter, incumbent complementors may be crowded out. Future research can study the balance of these two competitive forces.

In sum, through both qualitative and quantitative analyses using unique data, this study provides a more nuanced study of ecosystems in transition. Despite its shortcomings, it incorporates technology and business adjustment costs to shed light on an ecosystem perspective on disruptive innovations.

References

Adner, R. (2017). *The wide lens: A new strategy for innovation*. Penguin.

Adner, R., & Kapoor, K. (2010). Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management Journal, 31*(3), 306-333.

Adner, R., & Kapoor, R. (2016). Innovation ecosystems and the pace of substitution: Re-examining technology S-curves. *Strategic Management Journal*, *37*(4), 625-648.

Adner, R., & Lieberman, M. (2021). Disruption through complements. *Strategy Science, 6*(1), 91-109.

Agarwal, R., Moeen, M., & Shah, S. K. (2017). Athena's birth: Triggers, actors, and actions preceding industry inception. *Strategic Entrepreneurship Journal*, *11*(3), 287-305.

Ansari, S., Garud, R., & Kumaraswamy, A. (2016). The disruptor's dilemma: TiVo and the US television ecosystem. *Strategic Management Journal*, *37*(9), 1829-1853.

Ansari, S. S., & Krop, P. (2012). Incumbent performance in the face of a radical innovation: Towards a framework for incumbent challenger dynamics. *Research Policy*, *41*(8), 1357-1374.

Baldwin, C. Y. (2015). Bottlenecks, modules and dynamic architectural capabilities. *Harvard Business School Finance Working Paper*, (15-028).

Benner, M. J. (2007). The incumbent discount: Stock market categories and response to radical technological change. *Academy of Management Review, 32*(3), 703-720.

Benner, M. J. (2009). Dynamic or static capabilities? Process management practices and response to technological change. *Journal of Product Innovation Management*, 26(5), 473-486.

Benner, M. J. (2010). Securities analysts and incumbent response to radical technological change: Evidence from digital photography and internet telephony. *Organization Science, 21*(1), 42-62.

Bergek, A., Berggren, C., Magnusson, T., & Hobday, M. (2013). Technological discontinuities and the challenge for incumbent firms: Destruction, disruption or creative accumulation?. *Research Policy*, *42*(6-7), 1210-1224.

Bower, J. L., & Christensen, C. M. (1995). Disruptive technologies: Catching the wave. *Harvard Business Review, 73*(1), 43-53.

Borowitz, M. (2022, Aug 16). War in Ukraine highlights importance of private satellite companies. Retrieved from https://www.astronomy.com/science/war-in-ukraine-highlights-importance-of-private-satellite-companies/

Brandenburger, A. M., & Nalebuff, B. J. (1996). *Co-opetition*. Currency/Doubleday: New York.

Cattani, G. (2006). Technological pre-adaptation, speciation, and emergence of new technologies: how Corning invented and developed fiber optics. *Industrial and Corporate Change*, *15*(2), 285-318.

Ceccagnoli, M., Graham, S. J., Higgins, M. J., & Lee, J. (2010). Productivity and the role of complementary assets in firms' demand for technology innovations. *Industrial and Corporate Change*, *19*(3), 839-869.

Ceccagnoli, M., & Jiang, L. I. N. (2013). The cost of integrating external technologies: Supply and demand drivers of value creation in the markets for technology. *Strategic Management Journal*, *34*(4), 404-425.

Cho, N., & Zhou, Y. M. (2021). Profits, Reputation and The Risk of Medical Malpractice Liability. *Strategy Science*, 6(3): 191-264.

Christensen, C. M. (1997). Marketing strategy: learning by doing. *Harvard Business Review*, *75*(6), 141-151.

Christensen, C. M., & Bower, J. L. (1996). Customer power, strategic investment, and the failure of leading firms. *Strategic Management Journal, 17*(S1), 15-30.

Christensen, C. M., & Raynor, M. E. (2003). Why hard-nosed executives should care about management theory. *Harvard Business Review*, *81*(9), 66-75.

Christensen, C. M., Raynor, M. E., & McDonald, R. (2015). What is disruptive innovation?. *Harvard Business Review, 93*(12), 44-53.

Christensen, C. M., McDonald, R., Altman, E. J., & Palmer, J. E. (2018). Disruptive innovation: An intellectual history and directions for future research. *Journal of Management Studies*, *55*(7), 1043-1078.

Chung, H.D., Zhou, Y. M., & Choi, C. (2023). When Uber Eats Its Own Business, and Its Competitors' Too: Resource Exclusivity, Oscillation, and Cannibalization following Platform Diversification. *Working paper*.

Chung, H. D., Zhou, Y. M., & Ethiraj, S. (2023). Platform Governance in the Presence of Within-Complementor Interdependencies: Evidence from the Rideshare Industry. *Management Science, forthcoming*.

Danneels, E. (2004). Disruptive technology reconsidered: A critique and research agenda. *Journal of Product Innovation Management*, *21*(4), 246-258.

Dattée, B., Alexy, O., & Autio, E. (2018). Maneuvering in poor visibility: How firms play the ecosystem game when uncertainty is high. *Academy of Management Journal, 61*(2), 466-498.

Erwin, S. (2023, August 11). Space Development Agency shaking up how the military buys satellites. *SpaceNews*. Retrieved from https://spacenews.com/space-development-agency-shaking-up-how-the-military-buys-satellites/

Furr, N. R. (2019). Product adaptation during new industry emergence: The role of start-up team preentry experience. *Organization Science, 30*(5), 1076-1096.

Furr, N. R., & Snow, D. C. (2015). Intergenerational hybrids: Spillbacks, spillforwards, and adapting to technology discontinuities. *Organization Science*, *26*(2), 475-493.

Gilbert, C. G. (2005). Unbundling the structure of inertia: Resource versus routine rigidity. *Academy of Management Journal, 48*(5), 741-763.

Gort, M., & Klepper, S. (1982). Time paths in the diffusion of product innovations. *The Economic Journal*, *92*(367), 630-653.

Hannah, D. P., & Eisenhardt, K. M. (2018). How firms navigate cooperation and competition in nascent ecosystems. *Strategic Management Journal*, *39*(12), 3163-3192.

Harrigan, K. R. (1984). Formulating vertical integration strategies. *Academy of Management Review, 9*(4), 638-652.

Helvajian, H., & Jason, S. (2009). The generation after next: satellites as an assembly of mass-producible functionalized modules. In *Small satellites: past, present, and future*. Aerospace Press.

Henderson, R. M., & Clark, K. B. (1990). Architectural Innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly, 35*(1): 9–30.

Jacobides, M. G., Cennamo, C., & Gawer, A. (2018). Towards a theory of ecosystems. *Strategic Management Journal*, *39*(8), 2255-2276.

Jacobides, M. G., & Tae, C. J. (2015). Kingpins, bottlenecks, and value dynamics along a sector. *Organization Science*, *26*(3), 889-907.

Jakhu, R. S., & Pelton, J. N. (2014). *Small satellites and their regulation* (pp. 53-54). New York: Springer.

Kapoor, R. (2018). Ecosystems: Broadening the locus of value creation. *Journal of Organization Design*, *7*(1), 1-16.

Kapoor, R., & Furr, N. R. (2015). Complementarities and competition: Unpacking the drivers of entrants' technology choices in the solar photovoltaic industry. *Strategic Management Journal*, *36*(3), 416-436.

Kapoor, R., & Lee, J. M. (2013). Coordinating and competing in ecosystems: How organizational forms shape new technology investments. *Strategic Management Journal*, *34*(3), 274-296.
Kumaraswamy, A., Garud, R., & Ansari, S. (2018). Perspectives on disruptive innovations. *Journal of Management Studies*, *55*(7), 1025-1042.
Leiponen, A. E. (2008). Competing through cooperation: The organization of standard setting in wireless telecommunications. *Management Science*, *54*(11), 1904-1919.
Leonard-Barton, D. (1992). Core capabilities and core rigidities: A paradox in managing new product development. *Strategic Management Journal, 13*(S1), 111–125.
Lim, D., & Armstrong, J. (2014). The Hitchhikers Guide to Orbit. In *Proceedings of the 28th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, USA, August 2014, SSC14-P3-10 (Utah State University: AIAA)
Miller, C. D., & Toh, P. K. (2022). Complementary components and returns from coordination within ecosystems via standard setting. *Strategic Management Journal*, *43*(3), 627-662.
Mitchell, W. (1989). Whether and when? Probability and timing of incumbents' entry into emerging industrial subfields. *Administrative Science Quarterly, 34*(2), 208-230.
Moeen, M. (2017). Entry into nascent industries: Disentangling a firm's capability portfolio at the time of investment versus market entry. *Strategic Management Journal*, *38*(10), 1986-2004.
Moeen, M., Agarwal, R., & Shah, S. K. (2020). Building industries by building knowledge: Uncertainty reduction over industry milestones. *Strategy Science*, *5*(3), 218-244.
Moeen, M., & Mitchell, W. (2020). How do pre-entrants to the industry incubation stage choose between alliances and acquisitions for technical capabilities and specialized complementary assets?. *Strategic Management Journal*, *41*(8), 1450-1489.
Ozalp, H., Cennamo, C., & Gawer, A. (2018). Disruption in platform-based ecosystems. *Journal of Management Studies, 55*(7), 1203-1241.
NASA. (2023). Integration, launch, and deployment. Small Satellite Institute. Retrieved from https://www.nasa.gov/smallsat-institute/sst-soa/integration-launch-and-deployment#_Toc121319489
Patatoukas, P. N. (2012). Customer-base concentration: Implications for firm performance and capital markets: 2011 American accounting association competitive manuscript award winner. *The Accounting Review*, *87*(2), 363-392.
Pfeffer, J., & Salancik, G. R. (1978). *The external control of organizations*. New York, NY: Harper & Row.
Raffaelli, R., Glynn, M. A., & Tushman, M. (2019). Frame flexibility: The role of cognitive and emotional framing in innovation adoption by incumbent firms. *Strategic Management Journal, 40*(7), 1013-1039.
Ranganathan, R., & Rosenkopf, L. (2014). Do ties really bind? The effect of knowledge and commercialization networks on opposition to standards. *Academy of Management Journal*, *57*(2), 515-540.
Roy, R., & Cohen, S. K. (2017). Stock of downstream complementary assets as a catalyst for product innovation during technological change in the US machine tool industry. *Strategic Management Journal*, *38*(6), 1253-1267.
Roy, R., Lampert, C. M., & Stoyneva, I. (2018). When dinosaurs fly: The role of firm capabilities in the 'avianization'of incumbents during disruptive technological change. *Strategic Entrepreneurship Journal*, *12*(2), 261-284.
Santoro, M. D., & McGill, J. P. (2005). The effect of uncertainty and asset co-specialization on governance in biotechnology alliances. *Strategic Management Journal*, *26*(13), 1261-1269.

Shermon, A., & Moeen, M. (2022). Zooming in or zooming out: Entrants' product portfolios in the nascent drone industry. *Strategic Management Journal*, *43*(11), 2217-2252.

Skyrora team. (2021, Nov 23). Launch vehicle payload integration. Retrieved from https://www.relativityspace.com/terran-r

Sweeting, M. N. (2018). Modern small satellites-changing the economics of space. *Proceedings of the IEEE*, *106*(3), 343-361.

Tassey, G. (2000). Standardization in technology-based markets. *Research policy*, *29*(4-5), 587-602.

Thompson A (2018) Watch SpaceX attempt its wickedly complex satellite launch. Accessed Dec 26, 2019, https://www.wired.com/story/watch-spacex-attempt-its-wickedly-complex-satellite-launch/

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, *15*(6), 285-305.

Tripsas, M. (1997). Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry. *Strategic Management Journal*, *18*(S1), 119-142.

Tripsas, M., & Gavetti, G. (2000). Capabilities, cognition, and inertia: Evidence from digital imaging. *Strategic Management Journal, 21*(10/11), 1147–1161.

Venkatraman, N. (1989). The concept of fit in strategy research: Toward verbal and statistical correspondence. *Academy of Management Review, 14*(3), 423-444.

Wu, L., Wang, D., & Evans, J. A. (2019). Large teams develop and small teams disrupt science and technology. *Nature*, *566*(7744), 378-382.

Zhong, W., Ma, Z., Tong, T. W., Zhang, Y., & Xie, L. (2021). Customer concentration, executive attention, and firm search behavior. *Academy of Management Journal*, *64*(5), 1625-1647.

FIGURE 1 Conceptual overview and summary of hypotheses

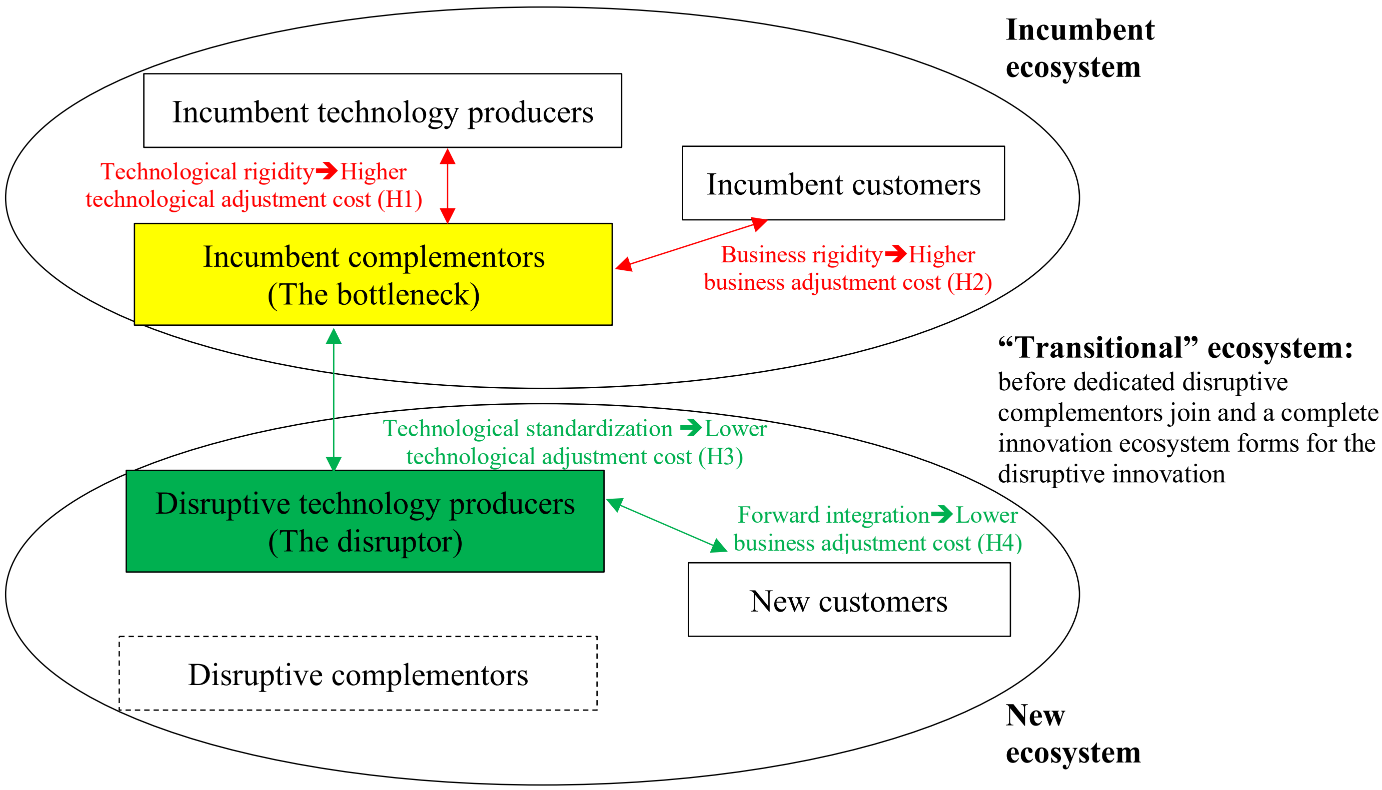
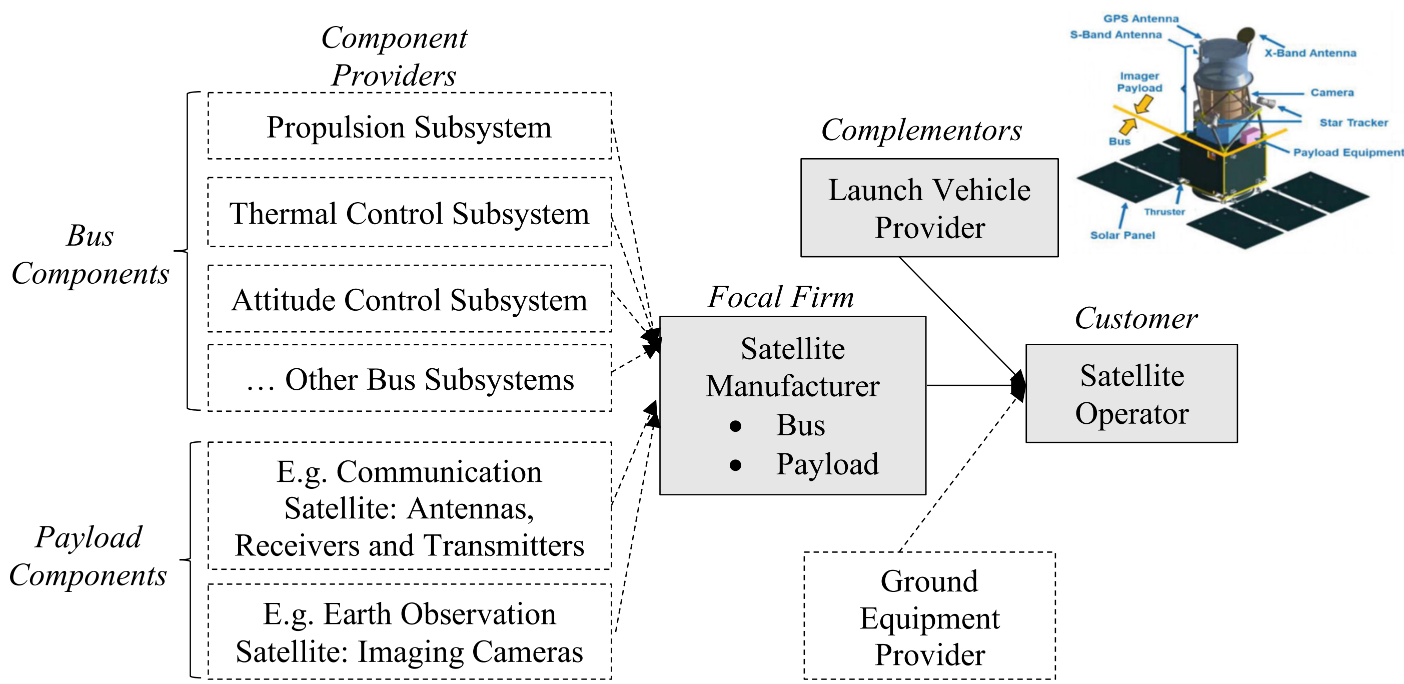
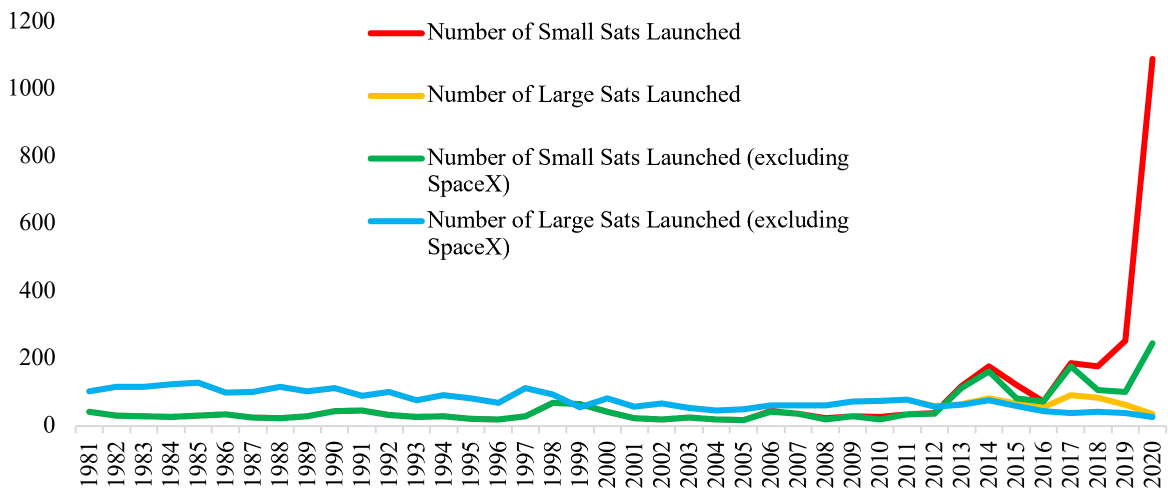


FIGURE 2 The innovation ecosystem of satellites



Picture source: https://www.intechopen.com/chapters/72725

FIGURE 3 Number of large and small satellites launched by year



Incumbent ecosystem (1957- 1981):

- 1957 - Sputnik 1 was launched

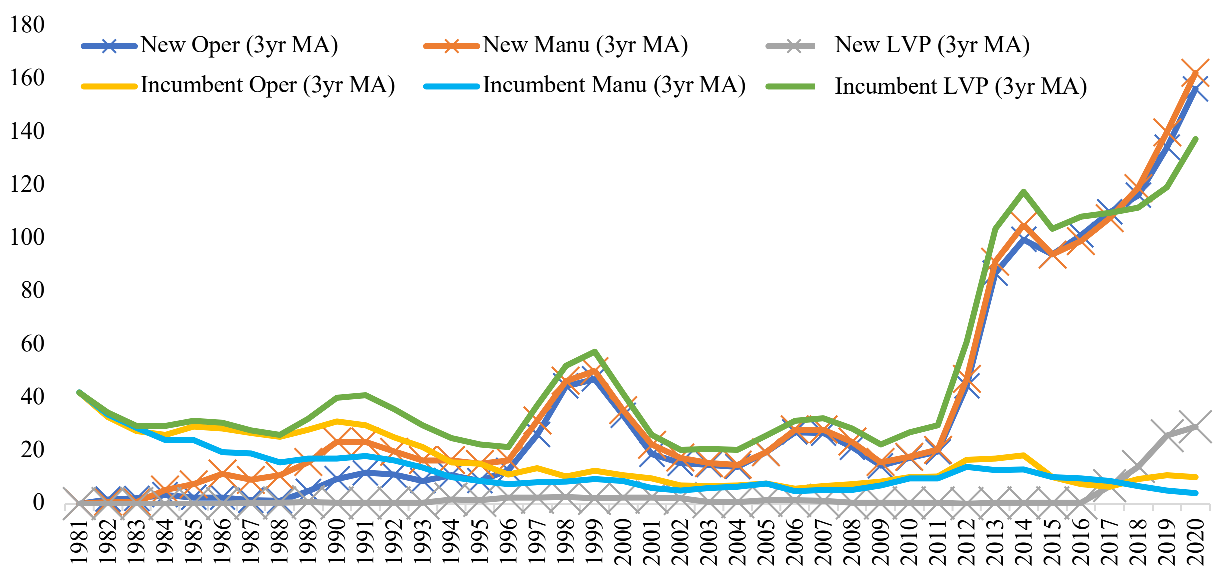
Transitional ecosystem (1981-2017): Disruptive focal tech producers emerged but had to rely on the incumbent ecosystem, especially launch services

- 1981 – UoSat -1 was launched
- 1999 – CubeSat design was introduced
- 2003 – First small sat with a CubeSat design was launched
- Early 2010s – The number of small satellites launched surpassed the number of large satellites launched.

New ecosystem (2018-now)

- 2018 – The dedicated small satellite launcher (small rockets) was successfully developed and launched

FIGURE 4 Number of small satellites launched by new versus incumbent actors



Note: Numbers are reported using three-year moving averages (3yr MA), as the number of satellites launched per year tended to fluctuate with exogenous factors such as weather, regulation, prior launch failures etc. Following Henderson and Clark (1990), we refer to the group of firms that had previously adopted the incumbent technology, i.e., firms that had manufactured (Manu), operated (Oper), or launched (LVP) large satellites before as Incumbent. New entrants (New) were firms whose initial product or service offering upon entry into the ecosystem employed the new technology, i.e., small satellite.

TABLE 1 Descriptive statistics and correlation matrix

Variables	Mean	Std. Dev.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Number of small satellites launched	.60	2.80	1.00									
(2) Cospecialization with specific incumbent technology designs	.30	.33	-0.09	1.00								
(3) Incumbent technology customer concentration	.47	.31	-0.20	0.20	1.00							
(4) Standardized technology design	.02	.12	0.61	0.01	-0.05	1.00						
(5) Customer integration	.05	.20	0.43	-0.03	-0.07	0.56	1.00					
(6) LV length(m)	46.6	10.85	-0.14	0.08	-0.05	-0.01	-0.13	1.00				
(7) LV diameter(m)	3.90	1.89	-0.09	0.11	0.16	-0.05	-0.09	0.36	1.00			
(8) LV min stage	.79	.41	0.05	-0.11	0.38	0.06	0.06	-0.00	0.13	1.00		
(9) LV max stage	3.18	1.14	-0.07	0.11	0.01	-0.06	-0.07	0.18	0.43	0.30	1.00	
(10) LV Apogee	27.64	10.25	-0.14	0.09	0.04	-0.07	-0.15	0.36	0.34	-0.01	0.26	1.00

Note: N=2,590; Year dummies and LV provider dummies are also included in the analysis but not reported in the table due to length

TABLE 2 Negative binomial estimation of the number of small satellites on board the launch

	(1)	(2)	(3)	(4)	(5)
H1: Cospecialization with specific incumbent technology designs		-1.328	-0.266	-0.601	-0.837
		[0.239]	[0.227]	[0.219]	[0.231]
		(0.000)	(0.240)	(0.006)	(0.000)
H2: Incumbent technology customer concentration			-3.855	-4.109	-4.246
			[0.258]	[0.243]	[0.247]
			(0.000)	(0.000)	(0.000)
H3: Standardized technology design				4.658	2.415
				[0.298]	[0.347]
				(0.000)	(0.000)
H4: Foward integration					2.529
					[0.239]
					(0.000)
LV length(m)	-0.068	-0.059	-0.036	-0.023	-0.016
	[0.016]	[0.016]	[0.014]	[0.011]	[0.012]
	(0.000)	(0.000)	(0.010)	(0.038)	(0.183)
LV diameter(m)	-0.581	-0.618	-0.425	-0.397	-0.390
	[0.163]	[0.162]	[0.138]	[0.121]	[0.122]
	(0.000)	(0.000)	(0.002)	(0.001)	(0.001)
LV min stage	1.621	1.639	1.748	0.607	0.315
	[0.315]	[0.315]	[0.265]	[0.237]	[0.244]
	(0.000)	(0.000)	(0.000)	(0.010)	(0.196)
LV max stage	-0.140	0.002	-0.176	-0.127	-0.070
	[0.146]	[0.147]	[0.138]	[0.121]	[0.126]
	(0.338)	(0.991)	(0.202)	(0.291)	(0.578)
LV Apogee	-0.018	-0.027	-0.030	-0.035	-0.036
	[0.009]	[0.009]	[0.008]	[0.006]	[0.007]
	(0.037)	(0.002)	(0.000)	(0.000)	(0.000)
Year dummies	Included	Included	Included	Included	Included
LV provider dummies	Included	Included	Included	Included	Included
Constant	2.741	2.726	2.576	2.508	2.084
	[0.837]	[0.834]	[0.744]	[0.604]	[0.625]
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
N	2590	2590	2590	2590	2590
Pseudo R-Square	0.153	0.160	0.224	0.299	0.331
BIC	3851.037	3828.202	3585.631	3296.086	3174.196
Log-likelihood	-1677.947	-1662.600	-1537.384	-1388.682	-1323.808

Note: Robust standard errors are reported in brackets; *p*-values are reported in parentheses