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How New Business Models Shape Innovation Spillovers: Insights from the New Space Economy

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Abstract

Those seeking to drum up public support for the space industry frequently cite its potential to generate valuable spillovers to other industries. However, existing research on spillover effects overlooks differences in business models among commercial actors and focuses only on individual projects or specific space agencies. We analyze how evolving business models influence spillovers by comparing the dynamic capabilities of traditional aerospace conglomerates to those of new space firms, using a unique dataset of 35,696 space-related patent applications. We find that, in addition to industries directly related to space, such as aeronautics, sectors like manufacturing and communication technology in particular benefit from space activities. At the firm level, we observe that new space business models present greater spillover potential and generate more spillovers than traditional aerospace conglomerates. However, traditional conglomerates such as Airbus or Boeing induce spillovers into digital systems and clean tech, while new space firms cannot translate their digital business models into digital spillovers and occupy more peripheral positions in the innovation network of space. Additionally, based on two different innovation metrics and more than 1.6 million additional patent applications, we find no evidence that the business models of the space industry have generally led to more spillovers than other high-tech industries.

Keywords: New Space Business Models, New Space Economy, Innovation, Dynamic Capabilities, Spillover, Patent Data

JEL Classification: D62, H57, L20, L21

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1. Introduction

Against a backdrop of such pressing issues as healthcare funding, education, and climate change, private and public investments in space are a contentious matter, even in major space nations (Launius 2003). A frequently used argument to justify allocation of taxpayer money for investments in space are the space industry's potential technological spillovers (Inmarsat 2022; NASA 2023b). Today, however, innovation and the resulting spillovers in the space industry are increasingly driven by new space firms rather than by national space agencies or traditional aerospace conglomerates (Denis et al. 2020). New space firms are privately owned companies developing space technologies and services that are often more affordable than those offered by traditional government-led programs. Although the space industry is inherently prone to spillovers due to such factors as its complexity (Ayres 1988), cross-sector connections (Manotti et al. 2021), and long-term project workflows (Sadlier et al. 2019), new space business models may amplify these effects through more dynamic capabilities (Teece 2007).

Dynamic capabilities are those whereby an organization may purposefully integrate, build and reconfigure internal and external resources to adapt to rapidly changing environments. In the context of new space firms, these capabilities encompass a focus on downstream applications (Mazzucato and Robinson 2016), involvement in an innovation ecosystem (Manotti et al. 2021), policy-enabled appetite for risk (Golkar and Salado 2021), iterative development (Denis et al. 2020), implementing off-the-shelf components (Song et al. 2024), new manufacturing schemes (Robinson and Mazzucato 2019), and an organizational culture driven by venture capital (VC) (Denis et al. 2020). This study examines and compares the spillover potential and realized spillovers of new space firms with those of traditional aerospace conglomerates, as well as their relative position in the space innovation network. We also identify differing directions of technological spillovers, depending on whether an innovation stems from a new space firm or an aerospace conglomerate.

There is much anecdotal evidence for spillovers from space research (see NASA's yearly *Spinoff* report for examples). An example of such positive externalities is the filter membranes developed for the International Space Station. These filters are now being used in water bottles designed by the British startup nkd LIFE[1] and for cleaning contaminated water on Earth (NASA 2022). This

[1] See https://nkdlife.com/about/.

example illustrates the traditional spillover pathway in the space industry, beginning with an innovation by a space agency or an aerospace conglomerate acting as a contractor for a space agency. Innovation scholars have highlighted the space industry's business model as particularly conducive to spillovers, given its complexity (Cohendet 1997), cross-industry links (Robinson and Mazzucato 2019; Manotti et al. 2021), long-term collaboration of skilled workers (Sadlier et al. 2019), rigorous performance standards and narrow to non-existent error margins (Cohendet 1997).

The dynamics of innovations and spillovers are shifting, with a growing number of new space firms introducing new innovative technologies that could spill over across and beyond the space industry. Although no universally accepted definition exists, we identify seven key elements distinguishing new space firms from traditional aerospace conglomerates, leading to their enhanced dynamic capabilities. They include a focus on downstream applications (Mazzucato and Robinson 2016), integration into a broader new-space ecosystem (Manotti et al. 2021; Billing et al. 2024), higher risk appetite and iterative development approaches enabled by policy changes (Madsen and Desai 2010), reliance on off-the-shelf components (Song et al. 2024), alternative manufacturing methods (Robinson and Mazzucato 2019; Carter and Pezeshkan 2023), and an overall agile development culture (Song et al. 2024).

In line with Teece's (2007) dynamic capabilities framework, these seven distinctive elements of new space firms' business models help them to sense, seize and constantly reconfigure efficiently. More precisely, these elements let firms work in a favorable appropriability regime (Zhao 2017), generate positive agglomeration externalities (Rausser et al. 2023), produce radical instead of incremental innovation (Schnitzer and Watzinger 2022), enable organizational and ecosystem-wide learning through failure (Teece and Pisano 2003), eliminate or at least substantially reduce the need for downgrading complex space innovations (Cohendet 1997), and help new space firms to quickly aggregate knowledge and skills (Arrow 1962). All of these factors contribute positively to spillovers. New space firms possessing these dynamic capabilities are transforming their markets, such as SpaceX and Rocket Lab revolutionizing space launch systems through the development of reusable rockets, and Planet Labs delivering daily high-resolution satellite imagery globally via its CubeSat network. These new space firms operate in areas previously reserved for traditional aerospace conglomerates such as Airbus, Boeing, and Lockheed Martin.

Current quantitative studies on space spillovers do not account for this shift in innovation dynamics in the space industry from traditional aerospace conglomerates to new space firms. These studies

are also mostly limited to individual countries (Vidmar et al. 2020), projects (Petroni and Venturini 2023) or space agencies (Bach et al. 2002; Sadlier et al. 2019). Moreover, they depend strongly on the specific project analyzed and may not consider the broader industry or the increasingly important new space firms. Hence, despite frequent claims of space spillover exceptionalism (Robinson and Mazzucato 2019; NASA 2022; NASA 2023b), systematic quantitative evidence across high-tech industries is lacking. We therefore collect 1,623,364 additional patent applications from the semiconductors, optics, and aeronautics industries to compare them to our data set of 35,696 space-related patents.

In particular, we examine three dynamics of knowledge spillovers in the space industry. First, we investigate whether the space industry's unique business models generate more spillovers than other high-tech industries. Second, based on the theoretical framework of dynamic capabilities (Teece 2007), we analyze how different business models in the space industry (new space vs. traditional aerospace conglomerates) affect spillover potential and realized spillovers. We assess how the position of a new space firm in the space innovation network differs from that of traditional aerospace conglomerates. Third, we analyze whether various industries benefit from space spillovers, depending on whether the innovation is put forward by an aerospace conglomerate or a firm with a new space business model.

The evidence shows a significant difference between traditional aerospace conglomerates and new space firms with regard to spillover potential and the number of realized spillovers. Firms with a new space business model exhibit not only significantly higher spillover potential but also generate more spillovers than traditional aerospace conglomerates, and do so despite occupying a more peripheral position within the space innovation network. However, we find no support for the claim that the space industry and its business models have led to more spillovers than other high-tech industries.

According to our analysis, the spillover dynamics of traditional aerospace conglomerates and new space firms are not directly comparable with each other, as the direction of the spillovers differs. All space firms contribute to spillovers in aeronautics, communications, and manufacturing, but traditional aerospace conglomerates are especially prominent in driving spillovers in digital communication and green technologies. In contrast, new space firms, despite their more digital innovations, do not generate more digital spillovers, but do contribute more to manufacturing spillovers than traditional aerospace conglomerates.

Our findings support managers from both traditional aerospace conglomerates and new space firms in developing strategies and dynamic capabilities to capture value from cross-industry spillovers and fostering collaboration with other industries. Our results also help managers of new space companies understand their firm's role in promoting innovations within the broader new space ecosystem. Understanding the distinctive directions of spillovers from traditional aerospace conglomerates and new space firms can offer guidance for managing knowledge exchange between such diverse organizations. Our findings show that space technologies also aid clean tech innovation on Earth, offering aerospace conglomerate executives a narrative to garner public approval and potentially even appeal to environmentally conscious investors. Based on our findings, policymakers can guide research and procurement efforts toward spillovers with wider societal benefits. If policymakers justify public space investments based on their potential for future spillovers, allocating a greater share of public contracts to new space firms could be warranted.

The structure of this manuscript is as follows: In section 2, we develop our research questions and situate them in the current literature. We describe our data and method in section 3 and present our results in section 4. In section 5, we discuss potential limitations and implications of our findings. We conclude with a summary in section 6.

2. Theoretical Foundation

2.1. Space Spillovers

Spillovers are effects that extend beyond the immediate benefits of an innovation. They often impact unrelated actors and involve costs or gains that are difficult to quantify in monetary terms (Nelson 1959; Robinson and Mazzucato 2019; Sadlier et al. 2019). In some cases, the original innovators may struggle to appropriate a sufficient return from innovation spillovers, which makes them detrimental to their business. However, the literature often focuses on the positive impact of spillovers on ecosystems and the role of policy in enhancing spillovers (Robinson and Mazzucato 2019; Carter and Pezeshkan 2023). While high-tech industries are generally prone to spillovers, several studies argue that the space sector uniquely combines factors that amplify such effects (e.g., Cohendet 1997; Robinson and Mazzucato 2019), supporting claims of exceptional spillover potential. For example, Mazzucato (2018) states that the space economy and especially its spillovers can be a valuable template for solving the greatest challenges of our time, such as climate

change. Other studies across national and international space programs estimate a high ripple effect of space R&D, with multiplier factors ranging between 3 and 7.49. This suggests that each unit invested in space R&D can generate up to 7.49 units of value for the broader economy (Bach et al. 2002; Aerospace Technology Institute 2019; Sadlier et al. 2019; Bryan et al. 2025). Institutes close to the aerospace industry have also calculated considerable private returns, estimating that space companies achieve approximately 15% ROI annually from their investments in space R&D (Aerospace Technology Institute 2019). From the reviewed literature, five elements and associated mechanisms can be identified that underlie the space industry's distinction in this regard.

First, the space industry is one of the most complex, even among high-tech industries (Cohendet 1997). For example, a space shuttle is estimated to have about 2.5 million moving parts and 10 million individual parts in total (Ayres 1988; NASA 2023a). As a result of this complexity, competition among traditional aerospace conglomerates has centered on innovation rather than on price (Mazzucato 2018), fostering the occurrence of radical innovation and subsequent spillovers (Ziemnowicz 2013). Complex products such as multi-million-dollar satellites have also often involved close collaboration between customer and contractor, fostering inter-firm knowledge spillovers through joint development (Manotti et al. 2021).

Second, this form of collaboration reflects a broader pattern in the space industry, which maintains numerous ties to other industries that may also facilitate spillovers. Supply chains in space involve non-space actors, who may later integrate products developed for space applications into their regular business operations (Denis et al. 2020). Likewise, mature space technologies like the Global Navigation Satellite System (GNSS) are deeply embedded in the business models of many non-space firms, such as software companies offering services from ride-hailing to logistics tracking. The complex interconnections between the space industry and its extensive network of suppliers and beneficiaries may create conditions where spillover effects are particularly pronounced. For example, Bondarev and Krysiak (2021) show that complex inter-industry interactions, rather than simple supplier–demander relationships, are prone to spillovers. Xu et al. (2022) highlight that interconnections in Chinese knowledge clusters also foster spillovers.

Third, the space industry is also geographically interconnected. Space firms pursue global markets because limited home market size can hinder economic sustainability, particularly for non-U.S.

firms (Manotti et al. 2021). Policy frameworks such as the geographical return[2] principle in Europe further encourage the geographic spread of large aerospace firms, which establish subsidiaries throughout Europe to secure shares of national contract allocations. Through their international subsidiaries, these conglomerates can diffuse innovation across multiple local ecosystems, thereby engaging a growing number of partners that may benefit from spillover effects (Chapman 2015; Robinson and Mazzucato 2019; Lamine et al. 2021). Local space ecosystems also play a key role in bringing together innovations from academic space research and industry (Lucena-Piquero and Vicente 2019; Janzwood 2021), which can foster further research and spillovers (Hünermund et al. 2022).

Fourth, to be able to manage all of their teams across diverse locations, departments, and suppliers, traditional aerospace conglomerates were early adopters of digital tools and virtual work environments, giving rise to further innovations (Malhotra et al. 2001). The teams themselves often consist of multidisciplinary, highly-skilled workers who collaborate for extended periods, given that complex space projects can require years to complete. Sadlier et al. (2019, p. 2) summarize these arguments, characterizing the space industry's workflows as occurring across "*large network[s] of multi-disciplinary teams with significant resources over very long periods of time.*" However, Beaudry and Schiffauerova (2009) highlight that, even though aerospace teams may work together for a long time, it is typically on a project-by-project basis, and that they are eventually dissolved or reassembled. This reconfiguration of teams and their embedded knowledge is a key mechanism for knowledge spillovers, allowing for transfer and recombination of tacit knowledge (Almeida and Kogut 1999; Terjesen and Patel 2017; Audretsch et al. 2024; Kantor 2025). This intra-firm project mobility is particularly relevant for spillovers in high-tech industries such as the space industry, given that high-skilled workers are less prone to inter-firm mobility than low-skilled workers, potentially moderating this important spillover channel (Jinyoung and Marschke 2005). Notably, the mobility of high-skilled workers has increased in recent years, especially in high-tech clusters such as Silicon Valley (Jinyoung and Marschke 2005; Agarwal et al. 2009).

[2] In the European space context, geographical return is the principle that each member state's financial contribution to a shared space program—such as those of the European Space Agency (ESA)—be proportionally returned to its domestic industry through contracts and investments.

Fifth, a highly qualified workforce is needed in the space industry because space applications are known for their high standards and almost non-existent error tolerance (Cohendet 1997). This is both a curse and a blessing. High standards force engineers and other employees to think of solutions that have never been tried before. The space industry therefore often serves as an integrator of innovations into other ecosystems, linking technologies that had not been connected before, promoting innovation and potential spillovers (Sadlier et al. 2019). Nevertheless, strict requirements often lead not only to a bureaucratic development process that can be time-consuming, but also to overengineered products or processes that cannot be directly transferred to other industries. Inventions from the space industry, therefore, must often be simplified in some way or another to offer a benefit for industries on Earth (Cohendet 1997). Hence, while the space industry's R&D intensity is higher than that of most industries, it does not necessarily result in a greater spillover effect (Collette et al. 2018; Zwart 2020; OECD 2021). A minimum of R&D spending is necessary to absorb spillovers by developing capabilities that integrate external knowledge into the firm's business model (Cohen and Levinthal 1990; Rothaermel and Hess 2007; Noteboom et al. 2017). Audretsch et al. (2024) argue that spillovers can partly substitute for internal capabilities that require R&D funding, rendering R&D investment an incomplete measure of spillover potential.

Scholars have recently questioned the broader claim of exceptionalism associated with the space industry and its high ROI (Hertzfeld 2013; Sadlier et al. 2019). This skepticism is largely based on long time lags in realizing spillovers and the technological downgrading often required for civilian or terrestrial use (Cohendet 1997; Sadlier et al. 2019). In addition, other high-tech industries might operate under business models that produce spillover dynamics akin to those observed in the space sector (OECD 2021). Space advocates nevertheless persist in framing the industry's alleged spillover capacity as a rationale for public support, which leads us to ask:

RQ1. Does the space industry's business model make spillover effects particularly pronounced compared to other high-tech industries?

Additionally, current studies often fail to attribute spillover effects to specific actors, typically restricting analysis to comparisons between firms and academic institutions (EPO 2022; Baber and Ojala 2024). However, the mixture of firms in the space industry is becoming increasingly heterogeneous with the emergence of the new space economy. Due to their distinct business

models, new space firms may generate spillovers that differ significantly in scale and direction from those of traditional aerospace conglomerates.

2.2. New Space Business Models and Dynamic Capabilities

Most of the new space firms that emerged over the past two decades have business models that differ significantly from those of traditional aerospace conglomerates (Golkar and Salado 2021). Although there is no universally accepted definition of what a business model is, particularly when compared to closely related strategy concepts (Zott et al. 2011), we adopt the definition put forth by Teece (2010), that a business model explains how value is delivered to customers and converted into revenue. Especially in tech-focused industries such as new space, the business model is a key determinant of success, as it connects the technological input and economic output (Zott and Amit 2020).

To explore how the two fundamentally different business models of traditional aerospace conglomerates and new space firms impact spillovers, we rely on Teece's (2007) dynamic capabilities framework. The framework explains the large intra-industry performance differences among firms in technological sectors by identifying capabilities that facilitate value capture in changing environments (Teece 2007). According to Teece (2007, p. 1319) "*dynamic capabilities can be disaggregated into the capacity to (1) sense and shape opportunities and threats, (2) seize opportunities, and (3) maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets*." Sensing is an aptitude for managing internal and external knowledge flows from emerging technological innovations to market needs in a way that allows a firm to discover and value potential opportunities (Teece 2007). Seizing concerns the "*enterprise structures, procedures, designs and incentives*" (Teece 2007, p. 1334) required to act upon an identified opportunity effectively and in a way that is economically sustainable. The third and final dynamic capability, reconfiguring, concerns a firm's ability to preserve successfully seized opportunities through effective knowledge management and cospecialization, while at the same time maintaining firm structures that enable continued sensing and seizing of new opportunities.

Several scholars describe the combined working of these three dynamic capabilities as the change rate at which ordinary or functional capabilities, such as advertising or routine plant operations,

improve relative to competitors' capabilities (Collis 1994; Winter 2003). In contrast to other well-known strategic frameworks (Porter 1980; Teece 2007), dynamic capabilities allow firms to see the market competition not as an exogenous variable but rather as another variable that can be influenced and shaped. Consequently, Teece (2007) argue that their framework is particularly well suited in explaining the Schumpeterian rents derived from innovation. Although Di Stefano et al. (2010) caution researchers to examine carefully how dynamic capabilities are operationalized, given that their features vary considerably by definition, empirical evidence confirms that firms possessing such capabilities are able to behave in an intensely entrepreneurial manner by repeatedly sensing, seizing, and reconfiguring opportunities (e.g., Rothaermel and Hess, 2007; Bingham and Eisenhardt, 2011).

Recent studies have highlighted the role of dynamic capabilities in enabling technology transfer and stimulating spillovers, especially in the context of university technology transfer. For example, Belitski and Sikorski (2024) demonstrate how dynamic capabilities foster technology transfer at the University of Reading. Ma et al. (2023) show that dynamic capabilities are essential for Dutch universities to promote knowledge spillovers. Drawing on panel data from more than 1,000 Chinese universities, Li and Tang (2021) demonstrate that the success of technology transfer across several indicators is heavily shaped by the dynamic capabilities of individual academic institutions. Using data from 90 German universities, Guerrero and Menter (2024) confirm these findings for dynamic research and teaching capabilities, but stress that trying to develop dynamic capabilities across multiple dimensions at once can create tensions when resources are limited.

Recognizing the central role of dynamic capabilities in promoting innovation and spillovers, we apply Teece's (2007) dynamic capabilities framework to compare the business models of traditional aerospace conglomerates with those of new space firms, illustrating how dynamic capabilities enable new space firms to enhance both innovation and knowledge transfer. We identify seven elements in new space business models that differentiate them from traditional aerospace conglomerates, enabling them to sense, seize on and reconfigure opportunities, and to potentially generate unique spillover dynamics. Figure 1 presents an overview of the business model elements and resulting spillover dynamics distinguishing new space firms from traditional aerospace conglomerates. Table 1 then maps these elements onto the theoretical framework of dynamic capabilities proposed by Teece (2007).

Note that most of the dynamics driving spillover in traditional aerospace conglomerates, and the historical space industry more broadly, remain relevant for new space firms, as well. On the other hand, the combination of the seven spillover-driving dynamics that are particularly relevant for new space business models is largely unique to new space firms. For example, although some conglomerates have adopted certain new space manufacturing methods, they have not embraced corresponding changes in organizational culture or iterative development.

[Figure 1 and Table 1 around here]

Our first unique factor supporting new space spillovers is the focus of new space firms on downstream applications instead of upstream manufacturing (Mazzucato and Robinson 2016; Billing et al. 2024). Downstream applications are those where in-space assets are used to deliver data and communication to customers on Earth. Meanwhile, upstream efforts are primarily those to get space assets into space in the first place, i.e., through launch providers and satellite manufacturers (Euroconsult 2022). To enable direct application on Earth, downstream space services are simplified and offered in user-friendly, prepackaged formats, facilitating spillover more easily than complex upstream processes such as advanced materials science.

New space firms are also often able to complement their offerings with "cospecialized assets," such as consulting for satellite-based Earth observation, extending beyond the traditional space industry and enhancing spillover potential (Teece 2010). Cospecialized assets form a subset of complementary assets, characterized by a bidirectional dependence between the asset and the innovation (Teece 1986). For example, clients of new space Earth observation firms often lack the technical expertise to analyze synthetic-aperture radar data, making them reliant on the firms' analytical software to extract value. Without the software solution, the innovation of high-temporal-resolution radar imaging satellites would have little value; without the imagery, the software itself would be of no use. As Teece (2007) notes, such valuable complementary assets are typically located downstream, close to the customer interface. Shifting from lengthy upstream hardware development cycles to offering complementary software solutions allows firms to respond more quickly to changing market demands and customer feedback, thereby strengthening their sensing capabilities (Teece 2007). Faster and more easily customizable products also enable more precise price differentiation, allowing firms to better respond to customers' willingness to pay. At the same time, the appropriability regime, the legal framework that enables protection and value capture from innovations, is more favorable for downstream, Earth-based assets than for

upstream ones, where enforcing territorial IP rights such as patents is more difficult due to limited regulation in space (Zhao 2017). As a result, the appropriability regime could also increase the monetary value of spillovers originating from downstream activities, helping firms to seize on valuable opportunities even in non-space areas (Teece 2007).

Compared to conglomerates, new space firms are embedded in even broader, often cross-border ecosystems, so much that the whole industry is often viewed as a single ecosystem (Manotti et al. 2021; Billing et al. 2024). Similar to digital ecosystems, value in the space industry is created not only in the firms themselves but also together with other firms in the new space ecosystem (Zott et al. 2011). New space firms must therefore constantly refine their business models to manage positive and negative shocks introduced by other ecosystem participants. For example, if a firm introduces an innovation that significantly lowers launch costs, such as reusable rockets, many other space firms whose business models may depend on launching space assets will also benefit. At the same time, firms continue to compete in the ecosystem. This competition, over seizing bottlenecks (e.g., launch capacities) or ecosystem-wide standards (e.g., CubeSat bus designs), is vital for sustaining innovation within the ecosystem (Saxenian 1994). As proposed by Teece (2010) and in contrast to traditional strategy frameworks such as the one proposed by Porter (1980), new space firms view the business environment as a variable they can actively shape. As a result, the new space ecosystem relies on dynamic relationships, where firms frequently switch roles between suppliers and customers, generating value that exceeds the sum of individual contributions (Jaffe et al. 1998; Robinson and Mazzucato 2019). These frequent and deep interactions can lead to "Jacobs-type externalities" (Rausser et al. 2023, p. 7), where knowledge is exchanged and interdisciplinary spillovers can emerge (Saxenian 1994; Terjesen and Patel 2017). Audretsch et al. (2024) argues that the knowledge spillovers arising from well-functioning ecosystems can, up to a certain degree, substitute for internal R&D funding when pursuing innovation.

Importantly, it is not only the passing along of private sector knowledge that has driven innovation in the new space ecosystem. Many new space firms now use miniaturization of space assets to achieve lower costs for their business models, a trend that was spurred by academics who could not afford large satellite systems for their research (Golkar and Salado 2021; Song et al. 2024). Similarly, many technical innovations in the new space industry have resulted from purposely deviating from the conventional design and manufacturing practices of traditional space firms (Golkar and Salado 2021).

New space ecosystems have also attracted new actors who were not previously interested in space applications. For example, financial market actors use satellite data for market intelligence (Robinson and Mazzucato 2019), once again presenting new avenues for potential spillovers. In line with Teece (1986), the growing maturity of the new space ecosystem has been accompanied by a trend toward vertical integration, marked by numerous mergers and acquisitions of successful new space firms. Although vertical integration can reduce inter-firm knowledge flows and spillovers, access to critical know-how remains limited. The space industry's high specialization and political restrictions, such as the International Traffic in Arms Regulations (ITAR), still prevent firms from acquiring key manufacturing processes through simple firm or talent acquisitions (Teece 2007; Teece and Pisano 2003).

Because of public space programs envisioning new procurement measures that transferred more development risks to private firms, new space firms are also more risk-taking than traditional aerospace conglomerates. One example of a policy shift is in public procurement, where cost-plus contracts, known for weak cost controls, have been replaced with fixed-price contracts that encourage efficiency (NASA 2019). These contracts also foster innovation by granting private firms greater technological freedom in exchange for taking more risk. This is different from earlier approaches where public agencies predefined solutions. The incentives of fixed-price contract types are specifically favorable for new entrants to the space market because incumbents with established assets tend to be more risk-averse as their assets and routines become entrenched (Teece 2007).

By embracing these higher risks, new space firms have also been able to introduce novel development approaches, fostering rapid innovation. One of the most prevalent new development approaches is rapid prototyping, where the risk of failure is accepted and even embraced (Madsen and Desai 2010). As Teece and Pisano (2003) note, activities such as rapid prototyping can lead to important organizational knowledge such as heuristics (Bingham and Eisenhardt 2011) and increase a firm's survival probability, particularly when prototyping costs are low (Teece 1986). Fittingly, Schnitzer and Watzinger (2022) find that innovations from VC-financed firms, which develop products in a fast, iterative, and risky manner similar to new space companies, generate greater spillovers than firms pursuing incremental innovations, consistent with the innovation behavior of aerospace incumbents (Teece 2007). A potential explanation for this finding is that

radical innovations are less easily appropriable than incremental ones, allowing for greater spillovers (Schnitzer and Watzinger 2022).

An important difference between traditional aerospace conglomerates and new space firms is also reflected in their approach to failure, a natural consequence of fast, iterative development. Driven by a new leadership approach, new space executives now openly acknowledge failures and frame them as part of the improvement process, in contrast to the risk-averse communication style of traditional aerospace conglomerates.[3] It is important to note that traditional aerospace conglomerates often operate on a larger financial scale, making the cost of an individual failure far more substantial. Boeing, for example, is involved in the production of the Starliner, a multi-million-dollar human-rated spaceship. A possible failure of a spacecraft could not only result in the loss of valuable infrastructure, but also in a significant loss of trust in other Boeing products not designed for space. Additionally, failure in itself does not guarantee learning; the knowledge gained from failure must first be integrated into existing processes and routines (Teece and Pisano 2003).

The decrease in costs for new space prototypes can also partially be attributed to the increased willingness of new space firms to make use of commercial off-the-shelf components, which are substantially cheaper than "space-grade" components (Denis et al. 2020; Song et al. 2024). This behavior increases spillover potential because space innovations become less complex and costly, making them easier to implement in terrestrial applications. In the past, the technical complexity of innovations in traditional aerospace conglomerates has frequently been cited as a constraint to space-related knowledge spillovers (Cohendet 1997; Sadlier et al. 2019). Complementing the use of commercial components, long-standing, successful production techniques from other industries are entering the space domain. Economies of scale, achieved through standardized production, serve as a prominent example. While the space industry was traditionally known for low production volumes due to its complexity (see Section 2.1), firms such as Amazon[4] and SpaceX now manufacture dozens of launchers and thousands of identical satellites, scaling up production capabilities (Robinson and Mazzucato 2019; Carter and Pezeshkan 2023). Repetition fosters learning effects that can be transferred to future projects and across domains, thereby generating

[3] See for example the statement of the CEO and Co-Founder of Isar Aerospace Daniel Metzler, after his firm's first rocket test flight resulted in an explosion seconds after takeoff:
https://www.linkedin.com/posts/isaraerospace_what-a-success-at-1230-pm-cest-isar-aerospaces-activity-7312077012813201408-599t

[4] See https://www.aboutamazon.com/news/innovation-at-amazon/inside-project-kuiper-satellite-facility-kirkland.

spillovers (Arrow 1962; Bingham and Eisenhardt 2011). Arrow (1962, p. 159) highlights that the "*learning effect is not compensated in the market*," pointing to its role as a positive externality.

The growing influence of Silicon Valley's rapid prototyping and scaling mindset in the space industry is no accident. Many new space startups are funded by VC, which forces space firms to achieve success quickly over the predefined life cycle of a fund. Venture capitalists also often take a board seat and obtain significant influence, which brings fresh perspectives to leadership teams traditionally dominated by space veterans (Finkelstein and Sanford 2000; Cornet et al. 2023). Overall, a more diverse set of stakeholders is now interested in these new space firms, which can help in detecting spillover potential for underused space innovations. Prominent business angels with roots in the IT industry have also launched or invested in space firms, transferring their "go fast and break things" mentality into the new domain (Denis et al. 2020). These business angels also act as intellectual architects, inspiring employees to value radical innovation over cautious, incremental progress (Carton 2018). As a result, new space players are assumed to be more agile in product and production processes than traditional aerospace conglomerates (Vidmar 2020).

The influence of the Silicon Valley mindset extends even further. Teece (2010) highlights that the ability to dynamically adjust business models represents a competitive advantage equal to capabilities such as production expertise. This adaptability is evident in the European new space sector, where many startups have shifted their focus toward defense amid rising geopolitical tensions. Paired with the fact that new space startups are typically young, lean organizations with minimal hierarchies, their distinct and agile culture may foster greater innovation and subsequent spillovers than traditional aerospace conglomerates, where information often decays as it moves through hierarchical layers (Teece 2007; Manotti et al. 2021; Billing et al. 2024).

Although many of the various spillover dynamics between new space startups and traditional aerospace conglomerates are driven from within the firms and by entrepreneurs, public agencies have also significantly shaped the industry's spillover potential. While earlier studies, especially in Europe, pointed to innovation-inhibiting regulation by space agencies (Lamine et al. 2021), recent research highlights their role in enabling commercialization, especially in the U.S., which is conducive to spillover effects (Mazzucato and Robinson 2016). On a broader level, Mazzucato and Robinson (2016) argue that space agencies have shifted from market-fixing to actively creating markets, increasingly acting as orchestrators of commercial space markets (Teubal and Steinmueller 1982; Cloitre et al. 2023).

As new space firms gain influence and increase their share of governmental contracts (Silicon Valley Defense Group 2024; Somerville 2025) it is important to assess whether the shift in innovation dynamics from traditional aerospace conglomerates to new space firms leads to different spillover dynamics, which often justify space investments. It is also not yet well understood which industries can benefit from space spillovers, besides a few commonly known examples, such as the medical industry (Venturini and Verbano 2014). Identifying additional spillover directions for their space technologies would be valuable information for aerospace managers. At the same time, non-space actors operating within and in proximity to new space ecosystems could benefit from directions for potential collaboration that might benefit their business model. We therefore investigate the following two research questions:

RQ2. How do traditional aerospace conglomerates and new space firms differ in spillover potential and realized spillovers?

RQ3. Do traditional aerospace conglomerates and new space firms produce spillovers in different domains?

Existing spillover research not only rarely distinguishes between firm types; it also tends to limit its focus to individual nations (Venturini and Verbano 2014; Vidmar et al. 2020), projects (Petroni and Venturini 2023), or space agencies (Bach et al. 2002; Sadlier et al. 2019). Due to the historically high capital intensity of space R&D (Collette et al. 2018; OECD 2021), only a few countries were able to afford large-scale programs to promote meaningful space-related R&D before the advent of the new space economy. As a result, literature on space-related spillovers is focused on the U.S., the nation that spends by far the most on its space industry (Cohendet 1997; Euroconsult 2022). But even though space budgets of other countries do not come close to the space budget of the U.S., countries like China, France, and Japan are still spending multiple billions of dollars per year on space-related research, producing relevant innovations and spillovers (Euroconsult 2022). Given this trend toward globalization, we analyze the impact of space business models on spillovers from an international perspective.

3. Data and Method

Answering our research questions requires a measure that is as uniform as possible on a worldwide scale and which enables quantitative analysis of knowledge flows. A measure that meets these

requirements is patent data. Analyzing patent data is a well-established method in economics and innovation research for investigating and comparing knowledge flows across firms, industries and countries (e.g., Rassenfosse et al. 2013; Denter 2021). Patents indicate not simply technological innovations, but marketable innovations that are worthy of the lengthy process of protection (Hünermund et al. 2022).

To measure spillover effects, academics often focus on patent citations (Nelson 2009; Acosta et al. 2022). Patents cite other patents to present the current state of the art and how an innovation differs from established solutions. If a patent cites another patent, it is reasonable to assume that the citing patent builds on the knowledge included in the earlier patent, and hence a knowledge spillover has taken place from the existing invention to the innovation seeking protection (Jaffe et al. 2000). The number of citations a patent receives can also be used as a quality indicator; a higher number of citations is often associated with a greater economic impact (Carpenter et al. 1981; Trajtenberg 1990; Acosta et al. 2022).

3.1. Data

We extracted the patent data from the European Patent Office's Worldwide Patent Statistical Database, called *Patstat.* Patstat is one of the most frequently used tools for extracting patent data because it offers access to over 100 patent offices around the world (Rassenfosse et al. 2014). To extract all patents of certain industry branches or fields of technology from Patstat, researchers use the classification of patents under the International Patent Classification System (IPC) (Collette et al. 2018). Under this system, one or more codes are assigned to each patent, representing a specific industry or field of technology—in our case, space-related patent applications.

Using Patstat, we extracted 18,727 patent applications in the field of "Cosmonautics; Vehicles or Equipment Therefor" (IPC Code B64G) in autumn 2022, constituting our *Baseline* dataset. Although other authors have used additional IPC codes alongside B64G (Collette et al. 2018), we focus explicitly on the area of cosmonautics because it is the core area of space research. The 18,727 patent applications in our *Baseline* dataset were cited 20,243 times by 16,969 patent applications, which constitute our *Citation* dataset. Some patents in our *Baseline* dataset were cited multiple times by patents in the *Citation* dataset. Figure 2 provides a temporal overview of these two datasets. We selected the period 2012 to 2022 to capture technological innovations during a

phase of significant investment growth in the new space industry, particularly driven by the influx of VC (for a chronological overview of VC funding in the space industry, see Bryce Tech 2022). For each patent application, we extract all IPC codes, the title, the assignee, the inventor, the filing date, and whether the patent was granted or filed through the Patent Cooperation Treaty (PCT).

[Figure 2 around here]

3.2. Method

To compare the spillovers of space business models with those of other high-tech industries, we extracted 1,623,364 patent applications and patent citations from the semiconductors, optics, and aeronautics industries. We chose these three industries for comparison because they receive extraordinary amounts of R&D funding (OECD 2021), portending an abundance of spillovers. Additionally, the space and aeronautics industries are heavily intertwined, as can be observed in the numerous traditional aerospace conglomerates around the world such as Airbus, Boeing and Lockheed Martin. As a result, the business models for aeronautics and space are often similar, potentially leading to similar spillover dynamics.

We constructed two metrics to analyze the impact of different business models on spillover potential and realized spillovers. First, we examine the number of different IPC codes on the respective patent applications, a measure often referred to as patent breadth or patent/classification scope (Lerner 1994; Sakakibara and Branstetter 2001; Dechezleprêtre et al. 2017; Hu et al. 2023). As Hu et al. (2023, p. 4) state, "*an increase in IPC categories means that patented inventions span a single technical field and have diversified technical features*." We use this patent scope to estimate how many different industries could benefit from innovation-induced spillovers through connections to the respective industry.

Second, we measure realized spillovers as the average number of citations per patent, which is a common metric in the patent literature (Jaffe et al. 1993; Jaffe and Rassenfosse 2017; Rassenfosse et al. 2014). Singh (2005), for example, uses patent citations to contrast intra- versus inter-region/firm knowledge diffusion. Mowery et al. (1996) and Almeida and Kogut (1999) additionally argue that, although patent citations capture only codified knowledge flows, they tend to mirror patterns of tacit knowledge diffusion.

To investigate our second research question, which concerns the differences in spillover potential and quantity between traditional conglomerates and new space firms, we assigned the patent applications in our *Baseline* and *Citation* datasets, respectively. Overall, we assigned 3,287 patent applications to traditional aerospace conglomerates and 1,262 patents to new space firms using fuzzy name matching and manually verifying each match. We then determined how many citations a particular patent application had received. For each patent application, we counted all citations within three years of its earliest publication date. This prevented overestimation of the spillover potential of older patent applications, which had been public for a longer period and therefore could be cited more often. Hence, we considered only patent applications published before 2020 and thus had three years to be cited. We also assigned an additional 7,460 patent applications to state-affiliated entities such as universities, space agencies, militaries or state-owned firms. Finally, we assigned 1,504 patent applications to individuals and 1,422 patent applications to firms whose primary activities were not in the aerospace industry, such as LG or Mitsubishi.

To distinguish traditional conglomerates from new space firms, we classified each firm's business model and product development approach using its website and other publicly available sources such as LinkedIn. We relied on the differentiation criteria defined in section 2.2 and summarized in Figure 1. If the business model or development processes could not be determined, we looked at the ownership and funding structure using Crunchbase to determine factors indicative of new space firms, such as VC funding. We also checked whether firms were included in new space investment funds or listed on new space lists of major VC funds.

To compare spillover potential and realized spillovers across industries, traditional aerospace conglomerates and new space firms, we apply two well-established non-parametric tests (e.g., Helm et al. 2018; Hillebrand et al. 2023) after confirming the data's non-normal distribution. Specifically, we apply the Kruskal–Wallis test to account for non-normality and Dunn's pairwise test using Bonferroni correction for multiple comparisons.

We used network analysis and firms' assigned classification to situate each firm in our space innovation network. We constructed yearly network graphs mapping patent assignees as nodes and their citation relationships as edges to measure firm-year eigenvector and betweenness centrality. We then regress firm-year eigenvector and betweenness centrality on a dummy distinguishing traditional aerospace conglomerates from new space firms, following the established approach of

using multiple centrality metrics to analyze firm ecosystems (Lo and Hung 2017; Horn and Kudic 2024; Buratti and Menter 2025).

To address our third and final research question, concerning which industries benefit from space-induced spillovers, we again rely on network analysis. Using the *Citation* dataset, we created a network matrix representing the IPC codes often appearing together in the same patent application. If, for example, a patent application is grouped into the three categories B64G ("Cosmonautics"), H01 ("Antennas"), and B64C ("Aeroplanes and Helicopters"), we marked the connections in our citation dataset. We count subcategories (e.g., B64G) rather than counting each subclass (e.g., B64G "*1/00*") because treating subclasses as separate industries would overestimate inter-industry spillovers and underestimate intra-industry spillovers. Figure 3 provides a visual explanation of the procedure. We also visualize the knowledge flows from conglomerates and new space firms using Sankey diagrams.

[Figure 3 around here]

4. Empirical Results

Figure 4 and Table 2 address our first research question, detailing the spillover dynamics of the space industry business model compared to other high-tech industries. The analysis of spillover potential, measured by the diversity of IPC codes on patent applications, reveals significant variation among industries. Patent applications citing semiconductor and aeronautics patents exhibit a broader range of IPC codes than those citing cosmonautics patents, suggesting greater spillover potential. These differences are statistically significant at the 1% level (see Table 2). For our measure of realized spillovers, we find the aircraft industry to be the sector with the most citations per patent, with an average of 1.39 citations per patent in our observation period. The difference between the number of citations in the different industries is statistically significant at the 1% level, except for the difference between the optics and semiconductor industries (see Table 2). Overall, we find no evidence that the business model of the space industry leads to greater spillover potential or a higher number of realized spillovers compared to other high-tech industries.

[Figure 4 and Table 2 around here]

Regarding our second research question, we find spillover potential and the number of realized spillovers to be significantly higher when patents stem from new space firms rather than traditional aerospace conglomerates. Figure 5 reports the average number of IPC codes (spillover potential) and the citations per patent application (realized spillover) for traditional aerospace conglomerates and new space firms. While patent applications from new space firms include, on average, 4.05 IPC codes, traditional aerospace conglomerates only list 3.73 IPC codes on their patent applications, which is 8% less. On average, patent applications introduced by new space firms have been cited 1.92 times three years after the earliest publication date. If an aerospace conglomerate brings forward a patent application, the patent application is on average cited only 1.23 times over a three-year observation timeframe, which is 36% less. Table 2 shows that the difference in spillover potential and realized spillovers is statistically significant at the 5% and 1% levels, respectively.

[Figure 5 and Table 3 around here]

Table 4 reports the strongest links in the innovation network of space-related spillovers, depending on whether a patent builds on a conglomerate or new space patent. The strongest link we found starting from cosmonautics is to the aerospace industry. We also find strong spillovers into communications, 3D printing (additive manufacturing and forming of plastics) and photovoltaics. We further analyze spillover direction based on whether knowledge originates from traditional aerospace conglomerates or new space firms; conglomerates mainly contribute to layered products and manufacturing of plastic. Like traditional aerospace conglomerates, new space firms drive spillovers primarily into the structural elements industry.

[Table 4 around here]

Figure 6 adds to this finding by mapping knowledge flows from conglomerates and new space firms. Although new space firms' patents are strongly linked to digital applications such as data transmission, data processing, antennas, and wireless networks, they do not lead to a significant share of spillovers into digital industries. Table 4 only reports a strong link from waveguides and resonators to dynamo-electric machines. Figure 6 also shows that traditional aerospace conglomerates generate a particularly large proportion of spillovers into the domains of photovoltaics, rocket engines/motors, semiconductors, and other microelectronics.

[Figure 6 around here]

Finally, we analyzed how the roles of traditional aerospace conglomerates and new space firms diverge within the ecosystem of space patents. Figure 7 shows an example network diagram for the year 2019. Table 5 provides the result of regressing firm-year eigenvector and betweenness centrality on a new space firm dummy. We find that new space firms have significantly lower eigenvector centrality, indicating they are less embedded in the core of the space network than traditional aerospace conglomerates. They also exhibit significantly lower betweenness centrality, suggesting a weaker role as intermediaries within the network. In contrast, traditional aerospace conglomerates, though less central than expected, are more often situated within the network's core. Our findings on network centrality remain robust when controlling for year fixed effects or random effects.

[Figure 7 and Table 5 around here]

5. Discussion

5.1. Positioning our Results Within the Literature

When comparing the space industry to other industries with business models that are also R&D intensive, we do not find the space industry to be more innovative than other industries. Overall, our analysis does not offer a clear picture of which business model of the studied high-tech industries is most prone to spillovers, as some industries lead in spillover potential, while other industries lead in realized spillovers. Thus, our findings indicate that complex business models and extensive supplier networks—such as those found in the space industry—do not necessarily lead to higher levels of spillovers, contrary to earlier findings (Ayres 1988; Venturini and Verbano 2014). For example, our results contradict Guillard et al. (2023), who state that the absolute value of spillovers induced by space-related innovations is substantially higher than for spillovers from other industries, even though the total number of innovations is comparatively low.

Much more compelling are our results concerning the impact of new space business models on spillover dynamics. Given that new space firms show greater spillover potential and a higher number of realized spillovers in our analysis, we further tested this result by restricting the sample to patents that received at least one citation, using citations as a common proxy for quality (Nelson 2009; Denter 2021; Acosta et al. 2022). Even under this stricter criterion, firms with new space business models continue to outperform conglomerates in spillover potential, with the difference

remaining statistically significant from zero at the 5% level (see Table 5). Our findings highlight the technological relevance of new space firms and strengthen the case for re-evaluating how public contracts are allocated in the industry. Although VC-funded firms have proliferated in defense contracting, a sector closely linked to space, they still receive a minimal share of total public contracts compared to traditional aerospace conglomerates (Somerville 2025). This ongoing concentration of contracts among conglomerates may reflect a gap between rhetorical justifications of space investments through spillovers and actual allocation practices.

[Table 5 around here]

Our findings also indicate that space-related innovations contribute to advances in photovoltaic and energy storage, industries central to the transition toward low-carbon energy systems. While the environmental costs of space activities such as rocket launches are often criticized, our analysis highlights the enabling role of the space industry in fostering technologies essential for a sustainable energy future. Our study shows that traditional aerospace conglomerates lead new space in clean tech spillovers, primarily due to their strong concentration in photovoltaic technologies. Combined with the pattern that new space firms often produce digital advances that have yet to yield spillovers, this difference in spillovers suggests unmet potential for new space firms. In essence, our findings support policymakers in understanding which non-space industries benefit from space research funding, facilitating better targeting of programs promoting technology transfer in the space industry.

Surprisingly, new space firms with downstream digital business models produce spillovers that predominantly benefit non-digital industries. This finding adds an unexpected dimension to the discussion on how digital capabilities and spillovers interact. Ferreira et al. (2024) argue that digital capabilities alone do not enhance performance but require external knowledge flows to realize their impact. At least within the new space industry, we find a notable lack of these dynamics, potentially limiting the performance of businesses dependent on digital capabilities. This result could stem from multiple factors, notably the fact that digital innovations embed significant tacit knowledge not captured in patent-based measures (Castellani et al. 2021). However, Figure 6 reveals digital data processing to be one of the originating knowledge streams, suggesting that potential knowledge flows indeed would have been observable. Another explanation could be that non-space firms seeking to benefit from space ecosystems lack sufficient absorptive capacity in digital innovation. This may be explained by differences in dynamic capabilities between the originating

actors (new space firms) and the receiving actors, which are often traditional aerospace conglomerates or non-space firms building on space-based digital innovations (Bouncken and Kraus 2022). In any case, this divergence among new space business models and the resulting spillovers offers a promising direction for future research.

In other respects, our results align with predictions from the existing literature. Specifically, the direction of knowledge flows appears to depend on the presence or absence of dynamic capabilities, as illustrated by the contrasting spillover patterns of traditional aerospace conglomerates and new space firms (Teece 2007). However, our results only partially align with the assumption that spillovers occur "close in" with previous activities (Teece 1988). While we do find a large flux of knowledge from space to aerospace, we also find numerous innovations especially in manufacturing that are not directly related to space. Our results also contribute to the literature that empirically examines the characteristics of firms with dynamic capabilities despite persistent ambiguities in operationalizing the theoretical concept (Di Stefano et al. 2010). Consistent with earlier studies linking dynamic capabilities to enhanced knowledge spillovers (e.g. Ma et al. 2023; Belitski and Sikorski 2024; Guerrero and Menter 2024) our results show that aerospace firms possessing such capabilities achieve higher spillover capacity and realization. Despite their peripheral positions in the innovation network, new space firms exhibit unexpectedly strong spillovers, suggesting that business model diversity—not centrality—shapes spillover intensity in the aerospace sector.

5.2. Limitations

While patent data is commonly used in the innovation literature, some critics warn against overinterpreting it (Harhoff et al. 2003; Jaffe and Rassenfosse 2017). A frequently discussed concern is the risk of missing important patents during patent data searches. This risk may stem from biases relating to such factors as the geographic location and historical presence of patenting firms within a given field (Nelson 2009). We have sought to counteract this issue by explicitly targeting the field of cosmonautics, which is also the focus of government funding programs. Although we acknowledge that not every relevant patent may have been captured, our data offers a minimally representative cross-section of the overall patent landscape in the space industry.

The validity of our approach is supported by the strong and consistent association with the aviation industry across the entire dataset. Given the dominance of major traditional aerospace conglomerates, these expected patterns reinforce the robustness of our results. The strong link between the communications industry and the space industry is also intuitive. After all, satellite communication and navigation are the fields that earn the most revenue in space (Euroconsult 2022). Hence, these areas of the space industry provide stronger incentives for firms to protect their marketable innovations through patents, which further validates our approach.

Our findings on new space firms and traditional aerospace conglomerates depend on the accurate classification of patent assignees into their respective categories. Despite the use of clear-cut classification criteria and the depiction of business model differences (Figure 1), firm classification unavoidably entails a degree of subjectivity. While our classification criteria are grounded in prior research, the weighting of specific elements may diverge from the approaches outlined by Golkar and Salado (2021) and Moranta and Donati (2020). To validate our classification, two experts representing academic space research and a public space agency independently classified a subsample of firms from our sample using only the information provided in this paper. We subsequently calculated the interrater reliability for their classification of traditional aerospace conglomerates and new space firms and found strong agreement among the two raters and our classification (Fleiss's kappa = 0.83, $p < 0.01$) (Fleiss 1971).

An additional source of noise arises from the phenomenon that, for an average patent, about two-thirds of the citations are added by the respective patent examiners (Alcácer and Gittelman 2006). These examiners review the patent application and decide whether it is granted. In total, 40% of all patents include citations added by examiners. Nevertheless, the literature suggests that citations added by inventors or examiners are similar to each other (Alcácer and Gittelman 2006). It has been further observed that examiner-added citations do not introduce a pronounced local bias, which would otherwise suggest, for example, a tendency among U.S. examiners to favor citations of U.S. patents (Lukach and Plasmans 2002).

Our analysis excludes innovations that firms choose to protect as trade secrets. Collette et al. (2018) argue that innovations in space are less often patented and more often handled as trade secrets. According to the authors, this is because many innovations in the space industry are difficult to reverse engineer, and thus firms have weaker incentive to patent. Nevertheless, with 18,727 patents in our *Baseline* dataset alone, and an average of 1,873 patent applications per year, we still analyze

an enormous number of innovations. Ultimately, there should be no difference between traditional aerospace conglomerates and new space firms regarding whether innovations are protected through patents or as trade secrets.

5.3. Managerial Implications

Managers in the space industry, both in traditional aerospace conglomerates and new space firms, can use our findings as a basis for internal assessments of potential and realized spillovers. The common spillover areas we observed across firm types and the broader industry—especially in manufacturing practices such as 3D printing—provide a useful starting point for focused internal analyses. Identifying a company's potential spillover channels can improve the appropriability of economic benefits. Targeting spillovers in areas like green technology can also support eligibility for programs like the EU Green Deal and attract environmentally conscious investors. Even less obvious features, such as weight reduction through layered products that conserve fossil fuels, can be presented as contributions to an economic transition. New space managers should also critically assess why their often environmentally beneficial business models, like reusable rockets and large-scale ecosystem monitoring, show few measurable and monetizable spillovers into green technology. Traditional aerospace conglomerates might contend that their spillovers currently follow different trajectories and create unique forms of value, even if new space firms generate more spillovers overall.

While appropriating the direct and indirect effects of innovation is important, managers of new space firms must also recognize the critical role of ecosystem partnerships in enabling value creation. To uphold the idea that ecosystems create value beyond individual contributions, firms must accept that some returns of their innovations benefit other firms and may not appear on their own balance sheet. Accordingly, the Sankey diagrams from our study can help in identifying promising collaboration partners across and beyond the space industry, supporting the development of both new and existing ecosystems. Firms can use our insights to form alliances in target industries such as energy storage, communications, or specialized manufacturing, where spillovers have historically been more likely. Especially firms building on new space innovations and the overall new space ecosystem should investigate why digital business models do not result in digital spillover. Additionally, managers of firms seeking digital spillovers from partnerships with new-

space firms should lower expectations regarding measurable positive knowledge flows in digital sectors.

Managers of traditional aerospace conglomerates should also assess how incorporating certain differentiating elements of new space firms could foster the dynamic capabilities needed in the rapidly changing space industry. Among these drivers, traditional aerospace conglomerates should recognize the value of off-the-shelf components, which create additional opportunities for economies of scale. Conversely, rapid and iterative development driven by policy-induced risk appetite is unlikely to be adopted by conglomerates that depend on cost-plus contracts. Similarly, we consider a significant shift in traditional aerospace conglomerates' business models toward downstream activities unlikely. Traditional aerospace conglomerates have significant opportunities to strengthen their sensing capabilities by engaging more deeply and transparently with their existing ecosystems of suppliers and subsidiaries. This holds true even if the ecosystem approach that works for new space firms is not directly applicable to conglomerates. Established space firms will nevertheless need to engage with these emerging structures. Managers should thus proactively decide which technologies to internalize and which to pursue through partnerships with new space actors. Such an activity would benefit from our identification of sectors most likely to absorb spillovers, potentially reducing the need for internal R&D funding.

6. Conclusion

This article investigates the impact of the diverging business models of new space firms and traditional aerospace conglomerates using a unique dataset of 35,696 space-related patent applications over the past decade. We find that firms with new space business models and stronger dynamic capabilities exhibit greater spillover potential and generate more spillovers than traditional aerospace conglomerates. While traditional aerospace conglomerates generate spillovers in digital communication infrastructure and photovoltaics, new space firms mainly influence manufacturing and dynamo-electric machines. Interestingly, digitally driven new space business models do not generate more spillovers in digital industries. Moreover, new space firms still occupy more peripheral positions in the space innovation network compared to traditional aerospace conglomerates. Finally, we find no evidence that the overall space industry's business model, whether from new space ventures or traditional aerospace conglomerates, produces more spillovers than those of other high-tech industries.

Our findings contribute to the literature on space-related spillovers and the mechanisms that drive them. We further refine the classification of new versus traditional space firms, using dynamic capabilities as an explanatory lens to account for differences in spillover potential and realization. Unlike previous studies on space spillovers, we assess not only realized spillovers but also the underlying spillover potential in the space industry. We question the view that network centrality drives spillover magnitude and demonstrate that business model differences better explain the observed spillover effects. We also challenge claims of space spillover exceptionalism found in prior studies and provide evidence that the space industry is generally no more spillover-intensive than other high-tech sectors.

Future research should identify additional factors, beyond the characteristics of the space industry, that indicate whether a high-tech sector generates more or fewer spillovers. The preemption of trade secrets in the space industry also warrants investigation. In this context, the extent to which patent behavior and innovation protection in the space industry differ from other high-tech sectors should be examined. Patent applications also ought to be evaluated using not only citation counts but also additional measures of value. This approach would allow patents with higher expected economic value, based on alternative criteria, to be weighted differently, which would allow for a stronger analytical framework and potentially more meaningful conclusions. Innovation researchers could further examine how the peripheral placement of new space firms coincides with their strong spillover performance. Finally, while our study underscores the differences between the business models of traditional aerospace conglomerates and new space firms and the effect of these differences on spillover dynamics, it remains uncertain whether elements of dynamic capabilities such as VC financing or iterative testing have equal impact, highlighting the need for further research.

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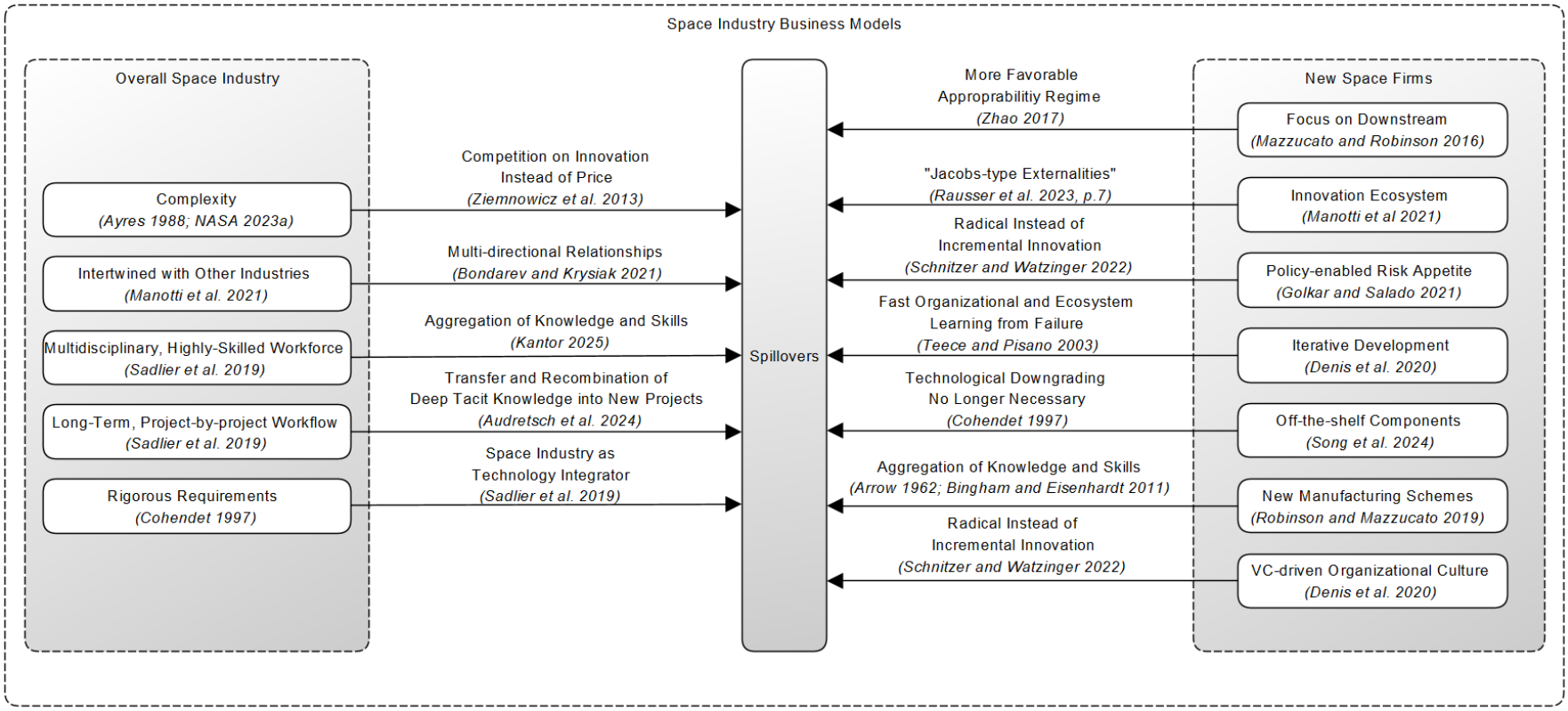
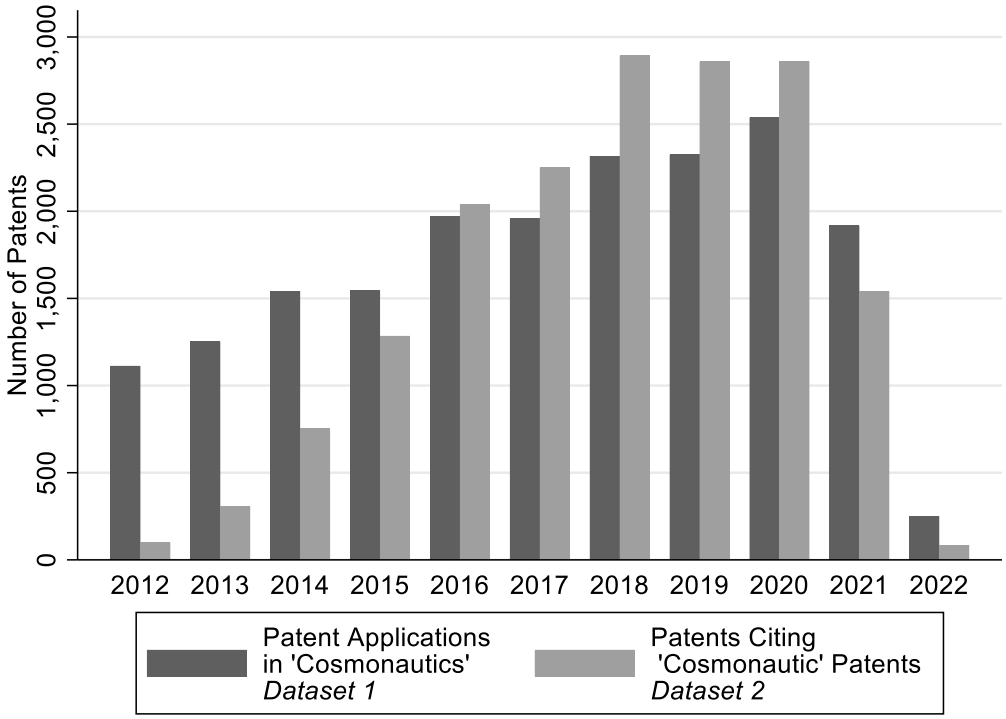
Figure 1. Differences between Traditional Aerospace Conglomerates' and New Space Firms' Business Models and Their Impact on Spillovers



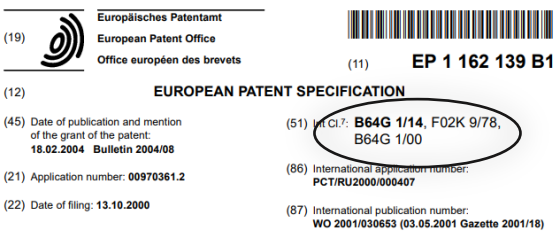
Graph displays the elements differentiating the business models of the aerospace industry and the new space industry, and how they influence spillover dynamics.

Figure 2. Dataset Overview



The figure displays the number of extracted space-related patent applications and citing patent applications per year.

Figure 3. Explanation Network Analysis



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(11) EP 1 162 139 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent: **18.02.2004 Bulletin 2004/08**

(51) Int Cl.[7]: **B64G 1/14**, F02K 9/78, B64G 1/00

(21) Application number: **00970361.2**

(86) International application number: **PCT/RU2000/000407**

(22) Date of filing: **13.10.2000**

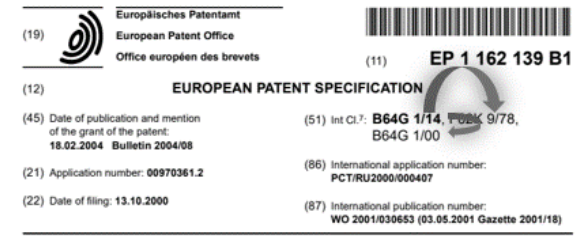
(87) International publication number: **WO 2001/030653 (03.05.2001 Gazette 2001/18)**

(54) **REUSABLE BOOSTER FOR THE FIRST STAGE OF A LAUNCHER**
WIEDERVERWENDBARE ZUSATZRAKETE FÜR DIE ERSTE STUFE EINER TRÄGERRAKETE
ACCELERATEUR A USAGE MULTIPLE POUR PREMIER ETAGE DE LANCEUR

Network Matrix

	B64G	F02K
B64G	0	0
F02K	-	0

Step 1: IPC Codes of a single patent application are extracted and the Network Matrix is created. Note that we only count each sub**category** separately and that we summarize the sub**classes** 1/14 and 1/00 both to be affiliated with the subcategory B64G.



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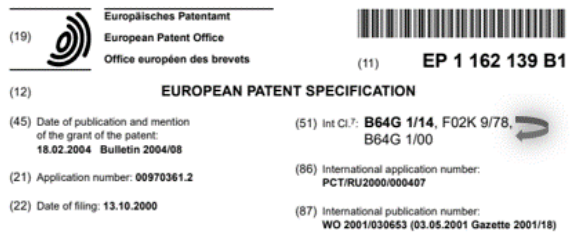
Network Matrix

	B64G	F02K
B64G	+1	+1
F02K	-	0

Step 2: All connections for the first IPC Code are inserted in the undirected Network Matrix.



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(11) EP 1 162 139 B1

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ACCELERATEUR A USAGE MULTIPLE POUR PREMIER ETAGE DE LANCEUR

Network Matrix

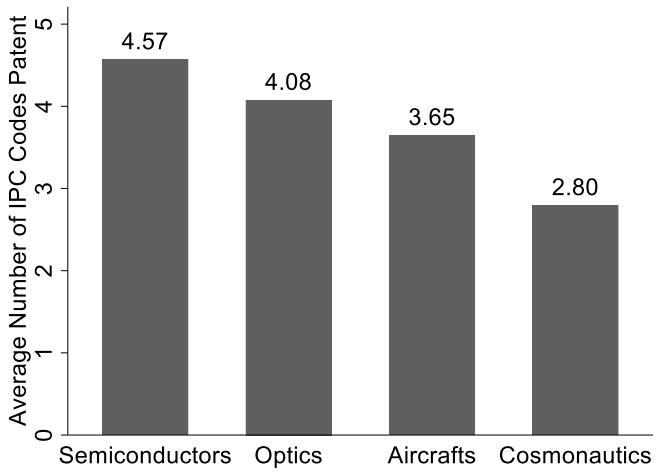
	B64G	F02K
B64G	+1	+2
F02K	-	0

Step 3: In the last step, the remaining connection between F02K (9/78) and B64G (1/00) is accounted for in the Network Matrix. We repeat this process for all patent applications in our *Citation* dataset.

Figure 4. Comparison of the Spillover Potential and Realized Spillovers for Selected High-Tech Industries

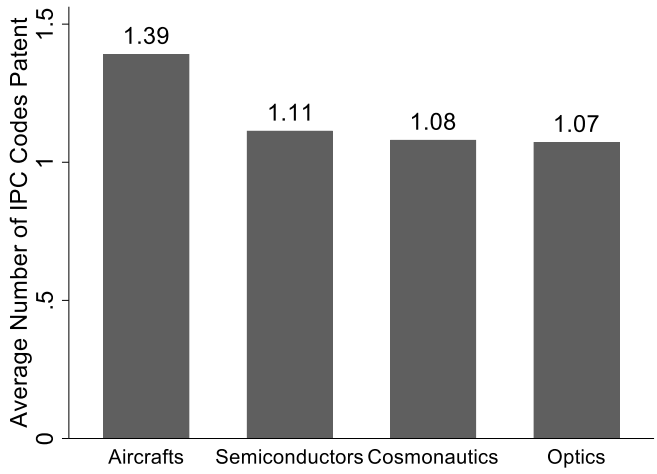
Spillover Potential

Number of different IPC Codes per Patent Application



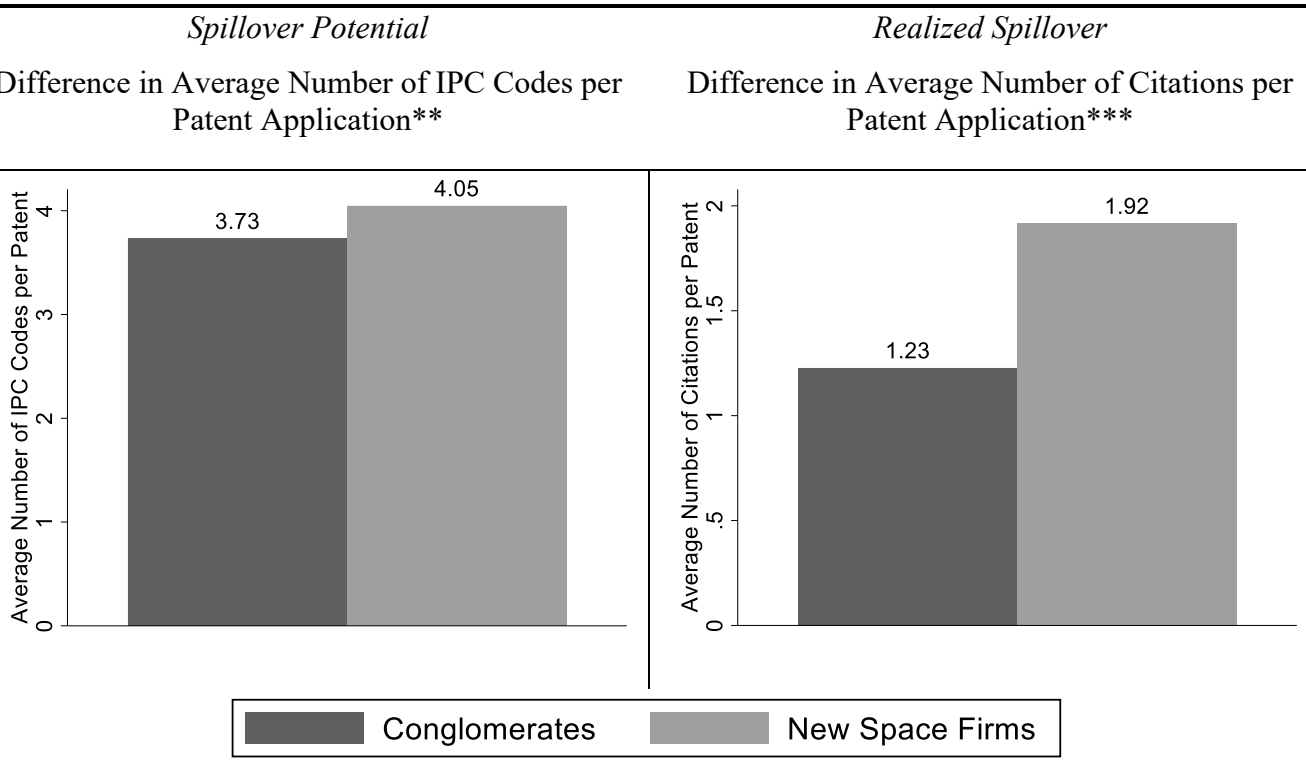
Realized Spillover

Average Number of Citations per Patent Application



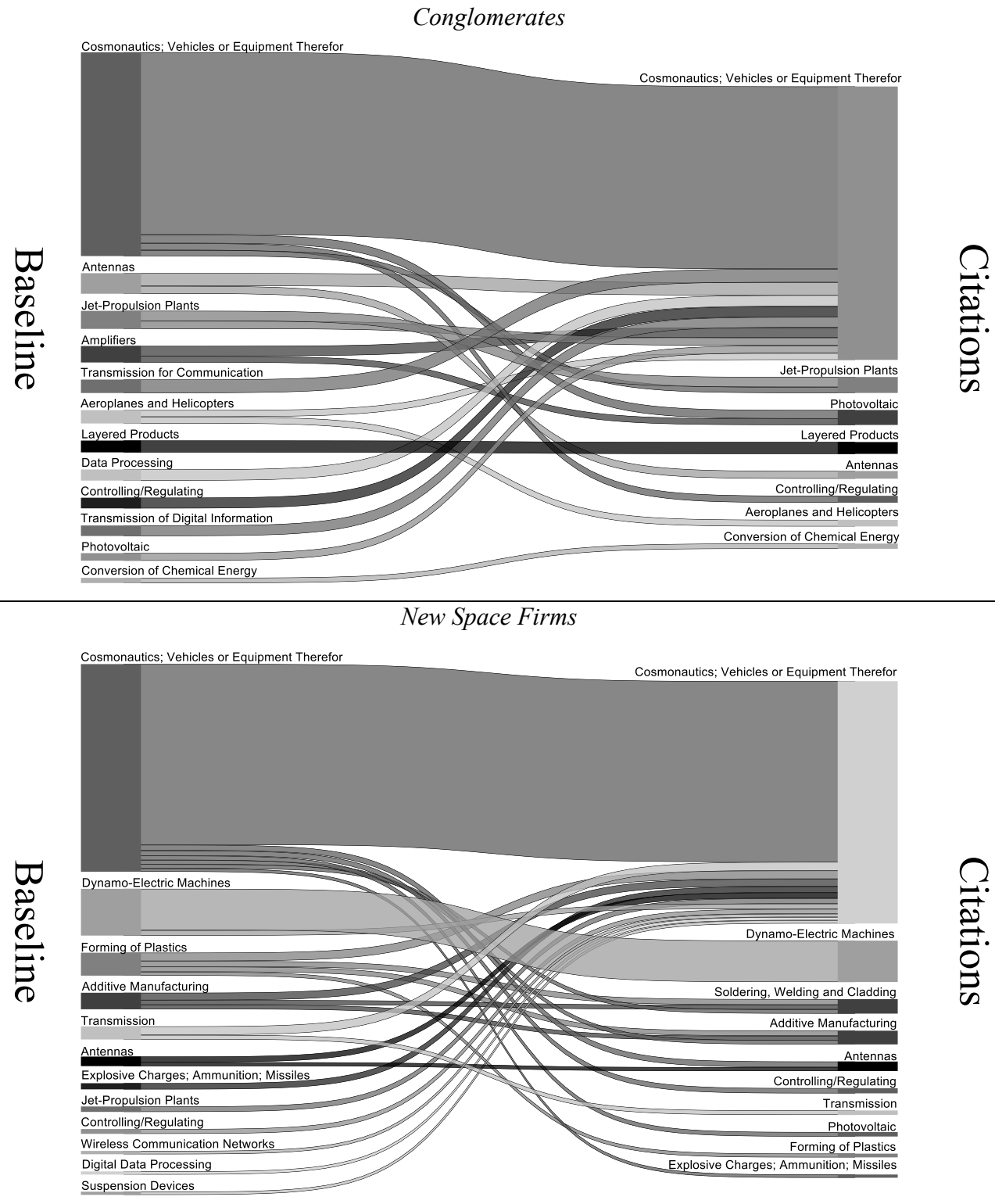
The figure displays the average number of IPC codes and citations per patent application, by industry.

Figure 5. Comparison of the Spillover Potential and Realized Spillovers of Traditional Aerospace Conglomerates and New Space Firms



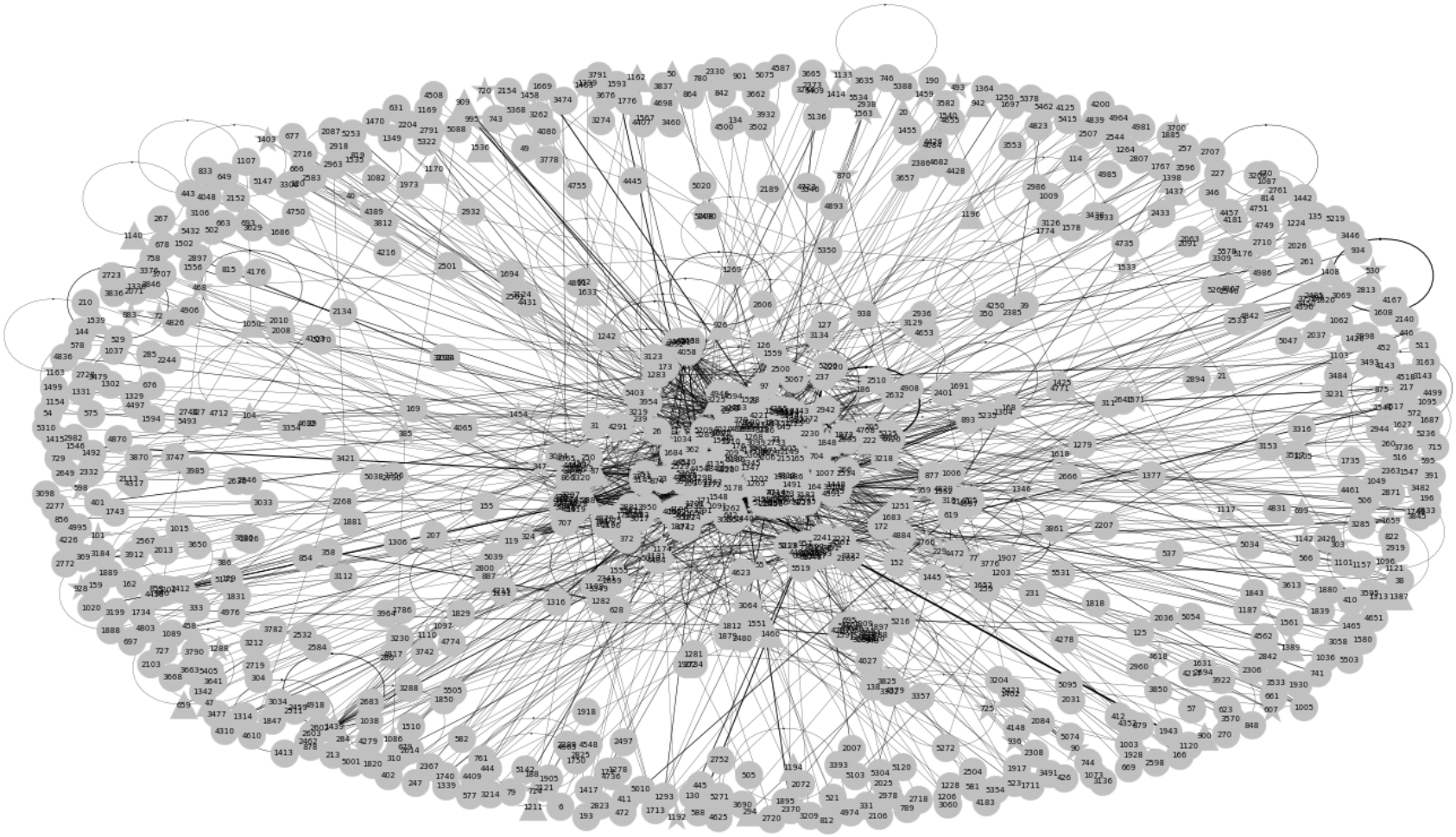
The figure displays the average number of IPC codes and citations per patent application, depending on whether the patent was assigned to a new space firm or aerospace conglomerate. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level, based on a Kruskal–Wallis test under the null hypothesis of equal distributions.

Figure 6. Spillover Dynamics for Conglomerates and New Space Firms



Graph displays the knowledge flows from space-related patents to cited patents, depending on the type of space firm. Both graphs were created using the Stata "Sankey package," developed by Naqvi (2024).

Figure 7. Exemplary Network of Space Patent Assignees for the Year 2019



Nodes represent individual patent assignees. Edges represent patent citations between patent assignees. Triangles denote traditional aerospace conglomerates, stars denote new space firms and circles denote all other patent assignees (e.g., militaries, non-space firms, universities).

Table 1. New Space Business Models and Dynamic Capabilities

Element	Sensing	Seizing	Reconfiguring
Focus on Downstream	Shorter and continuous feedback loops compared to upstream	- New revenue models (e.g., SaaS); - Better appropriability regime compared to upstream	Fosters cospecialization via value-added services (e.g., software for analyzing satellite imagery)
Innovation Ecosystem	Leverage supplier, complementor and competitor innovations	Compete over bottlenecks or standards (e.g., launch capacities, CubeSat buses)	Business model adoption to ecosystem-wide changes (e.g., lower launch costs)
Policy-enabled Increased Risk Appetite	Fixed-price regimes enhance market sensing and error monitoring compared to firms working under cost-plus	Greater autonomy in sourcing internal and external knowledge (e.g., make–buy decisions)	Fixed-price regime necessitates constant incentive alignment
Iterative Development	Enables rapid testing and evaluation of sensed opportunities		Organization routinely manages failures and incorporates new knowledge
Off-the-shelf Components	Access to supplier innovations from non-space sectors	Expands the make–buy–ally decision space	Builds a reusable knowledge base for off-the-shelf components
New Manufacturing Schemes	-	Reassess boundaries via vertical integration to internalize bottlenecks	-
VC-driven Organizational Culture	Additional channels to identify exogenous science and technology	Diversified management may better recognize infliction or patterns observed in other industries (e.g., VC board member with scale-up experience)	VCs implement strict mechanisms to align incentives, such as option pools and board participation

The table shows the seven elements setting new space business models apart from those of traditional aerospace conglomerates, highlighting how they help new space firms to sense, seize on and reconfigure opportunities (Teece 2007).

Table 2. Result of Dunn's Pairwise Comparison for Two Different Innovation Metrics, Including Bonferroni Correction

Spillover Potential Number of different IPC Codes per Patent Application				*Realized Spillover* Average Number of Citations per Patent Application			
	Cosmonautics (n = 16,969)	Aircraft (n = 96,864)	Optics (n = 438,023)		Cosmonautics (n = 18,727)	Aircraft (n = 122,496)	Optics (n = 568,420)
Aircraft (n = 96,864)	-52.87***			Aircraft (n = 122,496)	5.57***		
Optics (n = 438,023)	-81.03***	-50.94***		Optics (n = 568,420)	14.34***	19.95***	
Semiconductors (n = 184,492)	-101.20***	-89.37***	-64.56***	Semiconductors (n = 213,069)	14.24***	18.10***	0.81

The table shows the result of Dunn's pairwise comparison, including Bonferroni correction, under the null hypothesis of equal distributions. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 3. Kruskal-Wallis Test Results for the Comparison of Traditional Aerospace Conglomerates and New Space Firms

Spillover Potential	*Realized Spillover*
Number of Different IPC Codes per Patent Application	Average Number of Citations per Patent Application
-2.19**	49.52***

The table displays the test results of a Kruskal–Wallis test under the null hypothesis of equal distributions, depending on space firm type. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 4. Strongest Connections to Non-Space Industries in the Citation Dataset

Ranking	Overall Space Industry	Conglomerates	New Space Firms
1.	Airplanes and Helicopters - Equipment for Aircraft (n = 1,526)	Working of Plastics - Layered Products (n = 413)	Structural Elements - Building Construction (n = 88)
2.	Transmission - Wireless Communication (n = 1,491)	Transmission of Digital Information - Wireless Communication Networks (n = 186)	Control of Electric Motors - Adaptations of Dynamo-Electric Machines (n = 85)
3.	Transmission - Antennas (n = 1,107)	Cosmonautics; Vehicles or Equipment Therefor - Layered Products (n = 175)	Cosmonautics; Vehicles or Equipment Therefor - Explosive Charges (n = 81)
4.	Additive Manufacturing - Forming of Plastics (n = 1,014)	Additive Manufacturing - Forming of Plastics (n = 165)	Transmission - Wireless Communication Networks (n = 78)
5.	Cosmonautics; Vehicles or Equipment Therefor - Photovoltaics (n = 859)	Molding Materials - Forming of Plastics (n = 146)	Frames of Engines or Other Machines - Manipulators (n = 77)

Table displays the top five connections between citing patent applications for the overall space industry, for conglomerates and for new space firms.

Table 5. Regression Analysis on Firm Network Position

	Eigenvector		*Betweenness*	
	Model 1	*Model 2*	*Model 3*	*Model 4*
New Space Dummy	-0.26** (0.10)	-0.25** (0.09)	-0.17** (0.08)	-0.16** (0.08)
Constant	0.35*** (0.10)	0.06** (0.03)	0.20** (0.08)	0.05* (0.03)
Year Fixed Effects		Yes		Yes
R^2	0.0264	0.0501	0.0344	0.0468
F-statistic	6.91**	2.60**	5.10**	1.93*
N	651	651	651	651

Variables Eigenvector and Betweenness are scaled by 100 for readability. Pooled OLS regression, standard errors clustered at firm level. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Table 6. Kruskal–Wallis Test Results for High-Quality Patents (Citations ≥ 1): Comparison Between Traditional Aerospace Conglomerates and New Space Firms

Spillover Potential
Number of different IPC Codes per Patent Application for the Respective Citation Dataset
1.94**

The table displays the test results of a Kruskal–Wallis test under the null hypothesis of equal distributions, depending on space firm type. * denotes significance at the 10% level, ** at the 5% level, and *** at the 1% level.