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Market Valuation of Aerospace Firms Developing Frontier Technologies: The Role of Venture Capital and Intangible Assets

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To my family
And to those who believe in innovation

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Introduction

1.1 Innovation as an Engine of Economic and Social Progress

Innovation has long occupied a central position in economic and managerial thought. Since the pioneering work of Joseph Schumpeter (1934), it has been understood as the driving force of creative destruction, that process by which new products, technologies, and organizational models progressively replace obsolete ones, transforming the structure of markets and redefining competitive dynamics. In this perspective, innovation is not limited to incremental improvements of existing performance, but represents a qualitative leap capable of reshaping entire industrial sectors.

In the following decades, the evolution of economic theory provided a more systematic framework for understanding the role of innovation in growth. With the theory of endogenous growth and in particular with the contributions of Romer (1990) and Aghion and Howitt (1992), innovation was formalized as a genuine factor of production. Knowledge became an autonomous asset, distinct from physical capital, capable of generating positive externalities and technological spillovers that sustain long-term growth. In these models, investment in research and development (R&D), human capital, and intangible assets not only increases firm productivity but also enhances the overall innovative capacity of an economic system, thus creating a virtuous cycle of progress.

A crucial aspect of this perspective concerns the distinction between private and social returns to innovation. Since the benefits of new knowledge extend beyond the boundaries of the firm that created them, collective returns are generally higher than private ones. This justifies the role of the State and public institutions in promoting and supporting innovation through tax incentives, funding programs, and investments in research infrastructures. Empirical evidence confirms that government intervention plays a catalytic role in sustaining innovative ecosystems, particularly in high-technology industries where the risks and costs associated with R&D are substantial[1]. Public investment often acts as a complement rather than a substitute for private effort, reinforcing collaborative dynamics among universities, research centers, and firms.

During the past two decades, attention has progressively shifted from tangible to intangible capital. Empirical studies conducted in advanced economies have shown that investments in immaterial assets such as software, patents, trademarks, corporate reputation, and organizational know-how have now surpassed value investments in physical capital. This transformation marks a profound structural change: the competitiveness of firms depends less and less on the availability of machinery and equipment, and increasingly on the ability to generate, protect, and exploit knowledge.

According to Corrado, Hulten and Sichel (2005), the "knowledge economy" is characterized by the predominance of intangible assets as key drivers of productivity and firm valuation[2]. Their subsequent work (2009) further formalized this perspective, emphasizing how intangible investments contribute to long-term economic growth beyond traditional measures of capital accumulation[3]. These findings have been corroborated by OECD and World Bank analyses, which highlight the growing weight of intangibles in

[1] **mazucato2013**; David C. Mowery and Nathan Rosenberg. *Technology and the Pursuit of Economic Growth*. Cambridge University Press, 2010; Richard R. Nelson. *National Innovation Systems: A Comparative Analysis*. Oxford University Press, 1993.

[2] Carol A. Corrado, Charles R. Hulten, and Daniel E. Sichel. *Measuring Capital and Technology: An Expanded Framework*. University of Chicago Press, 2005.

[3] Carol Corrado, Charles Hulten, and Daniel Sichel. «Intangible Capital and U.S. Economic Growth». In: *Review of Income and Wealth* 55.3 (2009), pp. 661–685.

national wealth accounting and policy frameworks[4].

The growing relevance of these assets also implies new challenges for measurement, policy design, and accounting standards, given their limited visibility on traditional balance sheets[5]. As Brynjolfsson and McAfee (2020) observe, the increasing dematerialization of production and value creation requires a rethinking of how innovation and knowledge capital are captured within economic statistics[6].

1.2 Aerospace Industry Overview

The aerospace industry is a high-technology strategic sector that encompasses the design, production, and maintenance of spacecraft, aircraft, and related systems. It is divided into three main segments: civil aviation, defense, and space, each with distinct characteristics and dynamics.

In 2024, the global aerospace market was valued at approximately USD 373.61 billion, with a projected growth of around USD 791.78 billion by 2034, representing a compound annual growth rate (CAGR) of 7.8%[7]. However, growth is not uniform across segments. For example, the commercial segment has experienced significant growth, with passenger revenues expected to increase by 15.2% in 2024, reaching USD 744 billion[8]. The rise in air travel demand and the expansion of public and private space programs further drive technological innovation in the sector.

The aerospace market structure is highly concentrated, with a few large multinational corporations dominating various operational areas. Market

[4]World Bank. *The Changing Wealth of Nations 2020: Building a Sustainable Future*. World Bank, 2020.

[5]Jonathan Haskel and Stian Westlake. *Capitalism Without Capital: The Rise of the Intangible Economy*. Princeton University Press, 2018.

[6]Erik Brynjolfsson, Andrew McAfee, and Daniel Rock. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. W. W. Norton Company, 2020.

[7]Precedence Research. *Aerospace Market Size, Share, and Trends 2024 to 2034*. Accessed: 2025-09-09. 2024.

[8]Deloitte. *Aerospace and Defense Industry Outlook*. Accessed: 2025-09-09. 2024.

concentration allows economies of scale and high R&D investment capacity, but also increases dependency on major firms and government programs.

A distinctive feature of the sector is the dual-use nature of aerospace technologies that can be used for both civilian and military purposes. Technologies originally developed for military applications, such as advanced satellite navigation systems or sensors, have been adapted for civilian use, encouraging innovation in logistics, telecommunications, meteorology and commercial satellites[9]. The dual-use nature presents regulatory and strategic challenges, but also increases the sector's innovative and commercial potential. In fact, the diffusion of dual-use technologies has historically acted as a bridge between defense-driven innovation and civilian technological advancement, significantly contributing to productivity spillovers and industrial diversification[10]. Recent analyses by the European Commission and OECD highlight that dual-use R&D programs not only foster cross-sectoral learning but also strengthen supply chain resilience and technological sovereignty[11].

The aerospace industry is also characterized by long development cycles, high capital intensity, and technological complexity. Developing new aircraft can take more than ten years and billions of dollars in investment, making the collaboration between firms, governments, and financial institutions crucial[12]. Digitalization and the adoption of Industry 4.0 technologies, such as artificial intelligence, big data, and virtual simulations, are accelerating certain design and maintenance processes, reducing costs, and increasing

[9] NATO Parliamentary Assembly. *Critical Dual-Use Technologies*. Accessed: 2025-09-09. 2024.

[10] Barry Bozeman and Albert N. Link. «Public Support for Private R&D: The Case of the Small Business Innovation Research Program». In: *The Journal of Technology Transfer* 25.1 (2000), pp. 63–69; Albert N. Link and John T. Scott. *Public R&D and Knowledge Transfer: Implications of the Bayh-Dole Act*. Routledge, 2016; Vernon W. Ruttan. *Is War Necessary for Economic Growth? Military Procurement and Technology Development*. Oxford University Press, 2006.

[11] European Commission. *EU Strategy for Dual-Use Technologies 2022*. European Commission, 2022; OECD. *Dual-Use Innovation and Industrial Policy: Balancing Security and Growth*. OECD, 2023.

[12] ATI. *Funding Growth in Aerospace*. Accessed: 2025-09-09. 2022.

system safety.

Finally, intangible assets play an increasingly important role. Patents, trademarks, and technological know-how are key tools for sustaining competitive advantages, ensuring reputation, and attracting investment. In a sector characterized by continuous innovation and high technological complexity, the ability to transform knowledge into concrete applications is crucial not only for economic growth but also for strategic and geopolitical leadership[13].

1.3 Thesis Overview

The present thesis is structured to progressively guide the reader from a broad conceptual discussion of innovation and intangible assets to a focused empirical analysis of their role in the aerospace industry. The purpose of this section is to provide a roadmap of the research journey, to outline the logic behind the organization of chapters, and to clarify how each part contributes to answering the central research question. By doing so, the thesis not only ensures coherence, but also positions its contributions within the broader academic and practical discourse on the valuation of frontier technologies.

The opening chapter introduces the motivation for the research and sets the context. It highlights the strategic importance of aerospace as a driver of both civilian and military technological advancement, while highlighting the growing attention to intangible assets such as research capacity, intellectual property, and organizational know-how. The chapter situates the aerospace industry within the framework of global innovation systems and explains why traditional valuation approaches, which often rely heavily on tangible capital and easily quantifiable indicators, are insufficient for capturing the full spectrum of value creation in this sector. This initial discussion also defines the research question and clarifies the scope of the investigation.

Chapter 2 presents a review of the relevant literature, bringing together theoretical perspectives from economics, innovation studies, and financial valuation. Drawing on Schumpeter's theory of creative destruction, Romer's

[13] Accenture. *Commercial Aerospace Insight Report*. Accessed: 2025-09-09. 2024.

model of endogenous technological change, and later developments in the economics of innovation, the chapter synthesizes the main findings of previous research on the role of intangible assets in firm performance. It also identifies the gaps that remain unresolved, particularly with regard to the aerospace and defense sector, where secrecy, state involvement, and long innovation cycles limit the explanatory power of conventional proxies such as patents and citations. The literature review therefore provides both the intellectual foundation and the justification for the empirical analysis that follows.

Chapter 3 is devoted to the methodological framework. It introduces the econometric models employed to estimate the relationship between intangible assets and firm valuation, with particular attention to the adaptation of Griliches–Hall–Sandner type approaches to the aerospace context. The chapter describes the construction of variables, the sources of data and the strategies used to address potential limitations. Special emphasis is placed on the challenges of measuring knowledge capital in industries where disclosure is selective and incentives to patent are weak. The methodology chapter thus establishes the analytical tools needed to test the hypotheses derived from the literature.

Chapter 4 presents the empirical analysis. Using a dataset of publicly listed aerospace and defense firms, it applies econometric models to assess the impact of R&D, patents, and citations on market valuation. The results confirm the importance of R&D expenditures, but also reveal the limited explanatory power of patent-based measures. The chapter not only reports statistical results, but also interprets them in light of the structural specificities of the aerospace sector. The paper discusses the implications of these findings, comparing them with results from other industries such as pharmaceuticals and information technology, where intangible indicators tend to perform more robustly. This analysis underscores the unique challenges of evaluating innovation in aerospace.

Finally, Chapter 5 provides the conclusion, synthesizing the main insights of the research and reflecting on their broader implications. It discusses what the findings mean for managers, policy makers and investors, while also acknowledging the limitations of the study. The chapter outlines promising directions for future research, including the development of alternative indicators of innovation, the integration of private firms into empirical samples, and the extension of analysis to emerging markets. In doing so, it reaffirms the contribution of this thesis to understanding intangible assets and firm valuation in the frontier technology sectors.

Chapter 2

Review of the Literature

2.1 Innovation and Growth: Theoretical Foundations

The contribution of Joseph Schumpeter goes beyond the well-known concept of "creative destruction": His analysis distinguishes between different types of innovation and emphasizes the entrepreneur as a key agent of economic transformation. Schumpeter identifies five categories of innovation: new products, new production methods, new sources of supply, new market organizations, and new industrial combinations. He highlights that radical innovation generates spillover effects that reshape industrial structures and provide temporary competitive advantages for pioneering firms[1].

Paul Romer (1990) formalizes innovation as a driver of endogenous growth. In his models, knowledge is treated as a non-rival, partially non-excludable good with diminishing returns at the individual level but increasing returns at the aggregate level due to technological spillovers. Romer introduces production functions that combine physical capital K, labor L, and human capital H with a stock of knowledge A, resulting in sustained growth without decreasing aggregate returns:

[1] Joseph Schumpeter. *The Theory of Economic Development*. Harvard University Press, 1934.

$$Y = A \cdot F(K, L, H), \quad \dot{A} = \delta \cdot H \cdot A$$

where δ represents the efficiency with which human capital transforms knowledge into innovation. In this framework, R&D investments generate positive externalities that enhance the productivity of the entire economic system[2].

Aghion and Howitt (1992) developed a formal model of growth through "creative destruction," that integrates both sequential innovations and technological leaps. Their framework considers a set of sectors in which innovation periodically replaces existing technology, driving continuous growth. The model differentiates between incremental and radical innovations and represents the probability of innovative success as a function of the intensity of research and the available human capital. The core dynamic can be summarized as follows.

$$\dot{K}_t = \lambda(I_t) K_t$$

where K_t is the technological stock and $\lambda(I_t)$ is the probability of technological advancement as a function of R&D investment I_t. This approach explains endogenous growth in sectors characterized by continuous innovation, such as aerospace, and emphasizes the importance of institutional incentives and intellectual property in fostering creativity[3].

In summary, these models provide a conceptual framework for interpreting innovation not merely as incremental improvement but as a fundamental driver of long-term economic growth. They justify the quantitative analysis of R&D, patents, and intangible assets as instruments to measure and understand the impact of innovation on economic performance[4].

[2]Paul Romer. «Endogenous Technological Change». In: *Journal of Political Economy* 98 (1990), S71–S102.

[3]Philippe Aghion and Peter Howitt. «A Model of Growth Through Creative Destruction». In: *Econometrica* 60 (1992), pp. 323–351.

[4]Bronwyn H. Hall. «The Financing of Research and Development». In: *Oxford Review of Economic Policy* 26 (2010), pp. 44–55; David C. Mowery. «The Aerospace Industry and Innovation». In: *Research Policy* 49 (2020), pp. 103–118.

2.2 Innovation in the Aerospace Industry: Complexity, Interdependence, and Technological Leadership

The aerospace industry represents a technologically advanced and strategically relevant global ecosystem. Innovation in this sector is not limited to research and development, but is a continuous and systemic process that involves public and private actors, complex technologies, global supply chains, and regulatory frameworks aimed at competitiveness and security.

A defining feature of the industry is the high technical and systemic complexity of aerospace products. Civil aircraft, satellites, propulsion systems, and space infrastructure combine multiple technological domains: structural mechanics, aerodynamics, propulsion, avionics, advanced materials, embedded software, predictive algorithms, and artificial intelligence. This integration requires a distributed and multi-level innovation process where subsystem coherence is as crucial as the performance of each component. This complexity is reflected in extended development cycles: new aircraft or launch systems often take 10–15 years to reach industrial maturity, posing high financial and technological risks[5].

Innovation intensity is confirmed by significant R&D investment. According to the OECD, aerospace manufacturers allocate 10–15% of annual revenue to R&D, among the highest in all global industries[6]. These investments are essential to maintain technological leadership and comply with stringent international safety and reliability standards set by EASA, FAA, and NASA.

Another hallmark of aerospace innovation is the strong interdependence between actors and supply chains. Global multi-tier value chains are coordinated by a few major system integrators such as Boeing, Airbus, Lockheed Martin, or Leonardo, who rely on networks of highly specialized suppliers

[5] Mowery, see n. 4.

[6] OECD. *Space Economy Investment Trends 2024*. OECD Science, Technology and Innovation Policy Papers, Accessed: 2025-09-09. 2024.

for individual modules or components. The industry's functioning depends on the ability of each actor to share knowledge, adopt common standards, and co-innovate in a synchronized manner. Collaboration among firms, public institutions, research centers, and space agencies is therefore central, as technical knowledge is often tacit, context-specific, and co-created[7].

A distinctive aspect of aerospace innovation is the dual-use nature of technologies. The boundary between civilian and military applications is often blurred, with many technologies originating in defense programs later being adapted for civilian markets and vice versa. The OECD identifies aerospace as a key dual-use sector, highlighting that cooperation between military and civilian domains improves technology transfer, resource optimization, and industrial robustness. Strategic public programs such as NASA Artemis, ESA Horizon Europe, and DARPA, combined with public-private partnerships, support the most advanced technological trajectories[8].

In recent years, new private actors and the *new space economy* have emerged. Companies such as SpaceX, Blue Origin, Rocket Lab, and Virgin Orbit have introduced radically different innovation models, redefining the industry landscape. SpaceX, in particular, has revolutionized orbital launch strategies with reusable rockets and accelerated development cycles through vertical integration of production and supply chain control. These firms leverage enabling technologies such as additive manufacturing, digital simulation, algorithmic design, and agile organizational structures, promoting calculated risk taking and flexibility[9].

Although aerospace generates fewer patents than the ICT or pharmaceutical sectors, its patents have higher citation rates, indicating greater technical impact and originality. Much of the knowledge is protected through

[7]European Commission. *Strategic Dependencies and Capacities in the Aerospace Sector*. European Commission Report, Accessed: 2025-09-09. 2021.

[8]OECD. *Science, Technology and Innovation Outlook*. OECD Publishing, Accessed: 2025-09-09. 2021.

[9]The Economist. *SpaceX and the New Space Economy*. Special Report on Space Innovation, Accessed: 2025-09-09. 2024.

trade secrets, proprietary standards, and non-disclosure agreements, meaning that granted patents often represent high-value, hard-to-replicate inventions. Patent citation analysis thus provides a reliable proxy for estimating the market value of aerospace innovation[10].

Finally, the aerospace industry is a powerful source of technological spillovers across other domains, including automotive, energy, robotics, civil engineering, security, and healthcare. Technologies developed for aerospace, such as lightweight composite materials, advanced navigation systems, precision sensors, and additive manufacturing techniques, are increasingly adapted and integrated into these sectors, improving efficiency, safety, and innovation capacity in the wider economy[11].

2.3 Innovation and Public Policy

At the industrial level, innovation is widely recognized as the main determinant of competitive advantage. Companies that innovate systematically achieve higher performance, higher profit margins, and a higher capacity to attract investment. In a global and uncertain competitive environment, the ability of an organization to learn, adapt and generate new solutions is a critical survival factor.

From a macroeconomic perspective, innovation significantly contributes to total factor productivity (TFP) and long-term growth. Endogenous growth models explicitly incorporate technological innovation as a fundamental input in the production function (Romer, 1990; Aghion & Howitt, 1992)[12]. Public policies promoting R&D, intellectual property protection, and knowledge diffusion have proven effective in sustaining growth[13]. National and supranational policies, such as the European Union's Horizon

[10]Bronwyn H. Hall, Adam B. Jaffe, and Manuel Trajtenberg. «Market Value and Patent Citations: A First Look». In: *NBER Working Paper Series* 11283 (2005).

[11]Hall, Jaffe, and Trajtenberg, see n. 10.

[12]Romer, see n. 2; Aghion and Howitt, see n. 3.

[13]OECD, *Science, Technology and Innovation Outlook*, see n. 8.

Europe program, foster aerospace innovation by providing funding for frontier research, facilitating collaboration between industry and academia, and mitigating the financial risks of large-scale projects.

Innovation is inherently uncertain and cumulative. Many R&D investments do not produce immediate results and the benefits often manifest in the long term[14]. This justifies the central role of public policy in reducing systemic risk, fostering ecosystems conducive to knowledge sharing, and supporting the development of specialized human capital. For example, government-sponsored programs in the United States and Europe have accelerated the development of new materials, propulsion technologies, and autonomous systems that later diffuse across the private sector.

2.4 Intangible Capital and Firm Valuation

Econometric models for estimating firm value have progressively emphasized intangible assets, in particular knowledge capital and intellectual property, as central determinants of market performance. Traditional valuation approaches focused primarily on tangible assets and cash flow fundamentals. However, since the 1980s, an extensive empirical literature has shown that intangible drivers such as research and development expenditures, patent stocks, and measures of patent quality explain a large and growing share of firm market value. These econometric models aim to disentangle the contribution of technological knowledge from that of physical capital and to provide investors and policy makers with operational tools to assess innovation-driven growth.

A compact way to introduce the literature is to start from the conceptual decomposition used by Griliches (1981). Let V_{it} denote the market value of firm i at time t, A_{it} the value of tangible assets and K_{it} the stock of knowledge. The multiplicative valuation framework can be written as

$$V_{it} = q_{it}\big(A_{it} + K_{it}\big),$$

[14] Mowery, see n. 4.

where q_{it} is a time- and firm-specific valuation coefficient that captures market expectations and rents. Since K_{it} is not directly observable, empirical work proxies it with observables such as lagged R&D expenditures or patent counts. A standard estimable log-linear panel specification (Griliches, 1981) is

$$\log V_{it} = \alpha + \sum_{j=0}^{J} b_j \, \mathrm{R\&D}_{i,t-j} + \sum_{k=0}^{K} c_k \, \mathrm{PAT}_{i,t-k} + \mu_i + \lambda_t + \varepsilon_{it},$$

where μ_i are fixed effects for firm, λ_t time fixed effects, and ε_{it} the idiosyncratic error. Coefficients b_j and c_k can be interpreted as semi-elasticities (or elasticities, depending on scaling) that capture the short- and medium-run responsiveness of firm value to innovation inputs and outputs.

A methodological innovation introduced by Griliches (1981) is the decomposition of innovation inputs and outputs into an expected component and a surprise component. For example, model R&D dynamics as an autoregression.

$$\mathrm{R\&D}_{it} = \sum_{\ell=1}^{p} \phi_\ell \, \mathrm{R\&D}_{i,t-\ell} + u_{it},$$

so that the residual u_{it} represents the unexpected, or surprise, component of R&D. Analogously, patent counts or citations can be decomposed into predictable and unpredictable parts. Including expected and unexpected components in the valuation regression generally shows that surprise components have markedly stronger explanatory power, consistent with the interpretation that markets respond primarily to novel and unanticipated information on technological prospects[15].

Hall, Jaffe and Trajtenberg (2005) enrich the Griliches (1981) framework by explicitly incorporating patent quality through citation measures. Their preferred empirical specification normalizes by tangible assets and reads:

[15] Zvi Griliches. «Market Value, R&D, and Patents». In: *Economics Letters* 7.2 (1981), pp. 183–187.

$$\log\left(\frac{V_{it}}{A_{it}}\right) = \gamma+\beta_1 \log\left(\frac{\text{R\&D}_{it}}{A_{it}}\right)+\beta_2 \log\left(\frac{\text{PAT}_{it}}{\text{R\&D}_{it}}\right)+\beta_3 \log\left(\frac{\text{CIT}_{it}}{\text{PAT}_{it}}\right)+\mu_i+\lambda_t+\varepsilon_{it}.$$

In this form, CIT_{it} denotes aggregate forward citations to firm i's patents in period t. Hall et al. (2005) decompose citations into an expected component, based on observable patent characteristics (technology class, number of claims, family size, grant year, etc.) and a residual (unexpected) component. The residual component, the citation surprise, carries strong predictive power for market valuation because it signals recognition from the scientific / technological community beyond what can be predicted from patent traits. Hall et al. (2005) also demonstrate nonlinearities: a small number of highly cited patents (blockbusters) can generate outsized valuation effects relative to many low-impact patents[16].

Empirically, Hall et al. (2005) rely on a large dataset of several thousand U.S. firms combining Compustat financials with NBER patent and citation data over the period 1965–1995. Their results show that R&D expenditures remain a robust positive determinant of Tobin's q, patent counts alone lose significance once citation-based measures are included, and citation-weighted patents drive most of the explanatory power. Importantly, they highlight that the market does not value patents equally: only those with unexpected and high citation impact contribute significantly to firm valuation. This evidence is particularly strong in science-based industries such as pharmaceuticals and electronics, whereas the valuation impact of patents is weaker in traditional sectors.

Sandner and Block (2011) broaden the inventory of intangibles by including trademark- and marketing-related assets as independent contributors to firm value. Their multiplicative framework can be expressed as

$$V_{it} = A_{it}^{\alpha}\, \text{R\&D}_{it}^{\beta_1}\, \text{PAT}_{it}^{\beta_2}\, \text{CIT}_{it}^{\beta_3}\, \text{TM}_{it}^{\beta_4}\, \text{MA}_{it}^{\beta_5}\, W_{j,it}^{\beta_6}\, \varepsilon_{it},$$

which, once logged, yields a standard linear regression where trademark

[16] Hall, Jaffe, and Trajtenberg, see n. 10.

stock TM_{it}, marketing assets MA_{it} and qualitative indicators $W_{j,it}$ (oppositions, seniority, class coverage) enter alongside technological variables. Their large-sample evidence indicates that trademarks add independent explanatory power for valuation, especially in industries where brand and reputation are central to competitive advantage[17]. Their study exploits a broad European sample of more than 8000 listed firms across multiple industries, showing that the market consistently capitalizes not only R&D and patents but also trademarks and marketing assets. They find particularly strong effects in consumer-oriented industries such as food, beverages, fashion and retail, while in the capital-intensive and B2B sectors the impact of trademarks is more modest.

Other extensions have also incorporated human capital (measured through inventor mobility or top scientist recruitment), design rights, and collaborative R&D networks, all of which suggest that the portfolio of intangibles relevant for valuation is wider than technological knowledge alone.

From an econometric point of view, there are several recurring identification and measurement issues that practitioners must address.

First, endogeneity. R&D (and in some cases patenting) are potentially endogenous with respect to expected future profits. Strategies to mitigate endogeneity include firm fixed effects to absorb time-invariant heterogeneity, instrumental variables exploiting exogenous variation in R&D incentives (for example policy changes, tax credit intensity by region, or patent law shifts), and dynamic panel estimators (Arellano–Bond or system GMM) when short panels and persistent regressors create dynamic bias.

Second, measurement of patent quality. Raw forward citation counts are influenced by technology class and the citation accumulation process; therefore, one should normalize citations (e.g. by technology field and citation window), control for patent family size and claim counts, and examine robustness to excluding self-citations. Alternative quality proxies include patent renewal decisions, family breadth, claim counts, and European vs. US grant differences.

[17] Philipp G. Sandner and Jörn H. Block. «The Market Value of R&D, Patents, and Trademarks». In: *Research Policy* 40.7 (2011), pp. 969–985.

Third, timing and lag structure. In sectors like aerospace, the effect of innovation on market value can materialize with long and irregular lags; consequently, empirical models should test a range of lag structures and possibly use distributed lag specifications or perpetual inventory methods for constructing patent and R&D stocks:

$$K_{it} = (1-\delta)K_{i,t-1} + \mathrm{R\&D}_{it},$$

where δ is the depreciation rate of knowledge. Choosing δ appropriately (and testing sensitivity) is important to capture accumulation and obsolescence.

Fourth, heterogeneity across sectors. Elasticities differ by industry: high-tech, IP-intensive sectors (pharmaceuticals, aerospace) typically exhibit stronger valuation responses to patent quality measures than low-tech sectors. Therefore, interaction terms or separate estimations by sector improve interpretability. Evidence also suggests that sample design matters: cross-industry studies (Hall et al., 2005) report stronger average effects, while single-industry studies (e.g., Cockburn and Griliches, 1988, on pharmaceuticals) highlight much larger elasticities but with greater heterogeneity within firms. European studies based on EPO data generally find weaker effects than U.S. studies, likely due to structural differences in capital markets and innovation disclosure.

Finally, statistical inference. Given panel clustering, robust standard errors clustered at the firm level (or two-way clustering by firm and time) are standard. Researchers also report alternative specifications (level regressions, ratio regressions, and Tobit models when censoring occurs) and perform placebo or falsification tests to increase credibility.

The operational interpretation of coefficients is also crucial for policy. The coefficients on logarithmic regressors can be translated into dollars equivalents by computing percentage effects on market value at sample mean levels. For example, an estimated elasticity of 0.05 for the log of R&D implies that a 10 percent increase in R&D is associated, ceteris paribus, with a 0.5 percent increase in firm value. Multiplying the percentage change by the firm's market capitalization yields an implied dollar impact that policy analysts often use to weigh the social returns to R&D.

In sum, the Griliches (1981) – Hall et al. (2005) – Sandner and Block (2011) line of work provides a coherent and extensible econometric toolkit: start from a baseline log-linear valuation equation, enrich it with measures of patent quantity and quality, include reputation-related intangibles where relevant, carefully model expectations versus surprises, and address endogeneity and timing with panel methods and instrumental strategies. However, despite a large body of evidence, important gaps remain. Most studies rely on large U.S. or European samples from manufacturing and high-tech sectors, while regulated and defense-oriented industries are underrepresented. In addition, many indicators of intangible capital (classified R&D contracts, proprietary knowledge, informal know-how) are absent from standard databases, limiting external validity. A further challenge is posed by the dual-use nature of many technologies, as previously discussed in the introduction. Innovations in such contexts can serve both civilian and military applications, which complicates patenting decisions, citation dynamics, and the observable impact of R&D in standard datasets. Consequently, these characteristics exacerbate measurement challenges and highlight the need for empirical studies that tailor existing valuation models to sectors where intangible assets are strategically important but partially unobservable.

Chapter 3

Data and Methodology

3.1 Construction of the Sample

The construction of the data set used in this analysis followed a structured multistep procedure designed to ensure both representativeness of the aerospace and defense sectors and reliability of the financial and technological information used for econometric estimation. The starting point was the *PwC Global Aerospace and Defense Top 100 Companies, 2024 edition*[1], one of the most authoritative industry rankings worldwide. From this list, we extracted the top 50 companies by revenues, thus covering the global leaders in aerospace manufacturing, defense systems, and space-related technologies. This initial selection ensures that the sample captures both large established manufacturers and technologically advanced firms that are recognized as industry leaders on a global scale.

Since the objective of the study was to link market valuation with innovation signals, the sample was subsequently restricted to publicly listed companies. State-owned or government-controlled companies, which are common in this industry (e.g., Singapore Technologies or Israel Aerospace Industries), were systematically excluded. These firms often lack transparent market-based valuation metrics and, in many cases, their financial

[1] PwC. *Global Aerospace and Defense: Annual Industry Performance Review 2024*. Accessed: 2025-09-09. PricewaterhouseCoopers, 2024.

statements are not fully accessible in standardized form. Furthermore, private companies such as SpaceX or Blue Origin, while highly relevant for the industry, were not included at this stage because their valuation cannot be directly compared to listed firms. A detailed discussion of this exclusion and its implications is provided in Section 3.2.

The restriction on listed companies introduces a certain bias in terms of corporate structure, ownership, and financial transparency. Publicly traded firms are generally subject to more stringent reporting standards and greater scrutiny by investors and regulators, allowing for more reliable econometric analysis. On the other hand, several innovative private firms, particularly in emerging space technologies, are not represented in the sample. This trade-off reflects a common challenge in empirical research in the aerospace and defense sectors, where the most cutting-edge firms may operate outside conventional financial disclosure regimes.

After removing non-listed companies, data collection proceeded through the publicly accessible API of *Financial Modeling Prep*. This source provides harmonized financial data, including balance sheets, income statements, cash flow statements, and market capitalization for publicly traded firms on multiple exchanges. Yearly observations were collected for variables such as total revenues, net income, R&D expenditures (where disclosed), earnings before interest and taxes (EBIT), and market capitalization. Companies with missing or inconsistent financial data were further excluded to maintain a coherent and analyzable data set. After this double-filtering process, the final data set consists of 32 publicly listed aerospace and defense companies, representing a substantial share of global industry revenues while maintaining completeness in the variables necessary for subsequent econometric modeling.

To complement financial indicators, patent-based measures of innovation were incorporated. Patent data were retrieved from the *World Intellectual Property Organization* (WIPO)[2], restricted to categories **B1** (granted patents without previously published application) and **B2** (granted patents

[2]World Intellectual Property Organization. *WIPO Patent Database*. Accessed: 2025-09-09. 2025.

with previously published application), and matched with registrations at the *United States Patent and Trademark Office* (USPTO)[3]. This ensures that only legally enforceable patents of high technical significance are included. The raw bibliometric data was processed and cleaned using `Stata`, with harmonization of assignee names through fuzzy matching and manual quality checks to ensure accurate attribution to multinational firms.

3.1.1 Description of the Sample

The resulting data set combines financial fundamentals and technological indicators at the firm-year level for 32 companies in the aerospace and defense sector. This integrated approach allows exploration of how intangible assets, particularly those related to innovation, are reflected in firm valuation. It provides a balanced compromise between breadth, covering the largest firms worldwide, and depth, ensuring availability of both financial and patent data. In addition, the data set reflects substantial diversity in firm size, market orientation, and technological specialization.

The sample spans multiple continents, including North America, Europe, Asia, the Middle East, and South America. North American companies dominate in number and patent intensity, reflecting the concentration of aerospace and defense R&D investment in the United States. European firms, while smaller in number, contribute significantly to technological diversity, particularly in areas such as civil aviation, satellite technologies, and defense electronics. Asian firms, including Japan's Mitsubishi Heavy Industries and Israel's Elbit Systems, offer a perspective on large-scale manufacturing capabilities and integration into regional supply chains. However, given that the sample is composed exclusively of publicly listed firms, the continental breakdown provides limited additional insight as the majority of observations originate from the United States.

In terms of stock market representation, companies are listed on major exchanges such as the New York Stock Exchange (NYSE), NASDAQ, London Stock Exchange (LSE), Euronext Paris, Borsa Italiana, Tokyo Stock

[3] United States Patent and Trademark Office. *USPTO Patent Database*. Accessed: 2025-09-09. 2025.

Exchange (TSE), XETRA in Germany, and NASDAQ Stockholm. Among the 32 companies in the sample, 22 are listed on the NYSE (69%) and 2 on NASDAQ (6%), while the remaining 8 are distributed across other major international exchanges (25%). This concentration reflects both the dominance of American firms in aerospace and defense and the preference for transparent financial reporting standards.

Patent activity is highly heterogeneous. The mean number of USPTO patents per firm is approximately 4,200, while the median is 972, indicating a strongly right-skewed distribution: a few large firms account for a disproportionate share of the total patent stock. GE Aerospace (30,703 patents), Boeing (18,136) and Mitsubishi Heavy Industries (16,672) alone hold more than 50% of all patents, while smaller firms — including Heico, KBR, Parsons and TransDigm Group — have zero registered patents. High-impact patents, proxied by citation-weighted counts, follow a similar pattern: the top 10 firms account for roughly 80% of the citation-weighted patent stock. This indicates that innovation is concentrated in a limited number of firms, while smaller or niche companies focus on specialized technological areas.

The technological specialization is diverse. Leading domains include aircraft and engine design, avionics, satellite systems, defense electronics, propulsion technologies, and, increasingly, space systems and unmanned aerial vehicles. During the observed period, the distribution of the technological focus remained relatively stable, with modest upward trends in emerging areas.

Government agencies play a significant role in supporting and guiding innovation. In the United States, large firms maintain close partnerships with the Department of Defense, NASA, and other federal agencies, which provide funding, contracts, and strategic direction for research activities. This involvement of the public sector amplifies the concentration of innovation among the largest firms and affects both the scale and the direction of technological development.

Table 3.1 provides a detailed overview of the companies included in the sample, including country of incorporation, stock exchange, and total number of patents.

Company	Country	Exchange	Number of Patents
Airbus	France	Euronext Paris	8732
Amphenol	USA	NYSE	781
BAE Systems	UK	LSE	3178
Boeing	USA	NYSE	18136
Bombardier	Canada	TSX	1245
Booz Allen Hamilton	USA	NYSE	115
Eaton	USA	NYSE	2
Elbit Systems	Israel	TASE	295
Embraer	Brazil	B3	179
GE Aerospace	USA	NYSE	30703
General Dynamics	USA	NYSE	412
Heico	USA	NYSE	0
Honeywell	USA	NYSE	15132
Howmet Aerospace	USA	NYSE	117
Huntington Ingalls	USA	NYSE	31
KBR	USA	NYSE	0
L3Harris	USA	NYSE	111
Leonardo	Italy	Borsa Italiana	148
Lockheed Martin	USA	NYSE	4790
Melrose Industries	UK	LSE	901
Mitsubishi Heavy Industries	Japan	TSE	16672
MTU Aero Engines	Germany	XETRA	840
Northrop Grumman	USA	NYSE	2682
Parker Hannifin	USA	NYSE	1679
Parsons	USA	NYSE	0
Rheinmetall	Germany	XETRA	252
Rolls-Royce	UK	LSE	6003
RTX	USA	NYSE	688
Saab	Sweden	NASDAQ Stockholm	535
Safran	France	Euronext Paris	3506
SAIC	USA	NYSE	167
Serco	UK	LSE	163
Spirit AeroSystems	USA	NYSE	199
Textron	USA	NYSE	2782
Thales	France	Euronext Paris	3191
TransDigm Group	USA	NYSE	0
Viasat	USA	NASDAQ	972

Table 3.1: Overview of Sample Companies: Country, Stock Exchange, and Patent Counts

This table underscores the diversity of the sample in terms of both geographic distribution and patent activity, which is crucial to understand subsequent analyses that link innovation efforts to market valuation. The sample includes both highly patent-intensive companies and companies with low or specialized patent activity, reflecting different strategic approaches to R&D investment in the aerospace and defense industry. In the following sections, these characteristics are leveraged to examine how innovation contributes to firm value and competitive advantage in a global context.

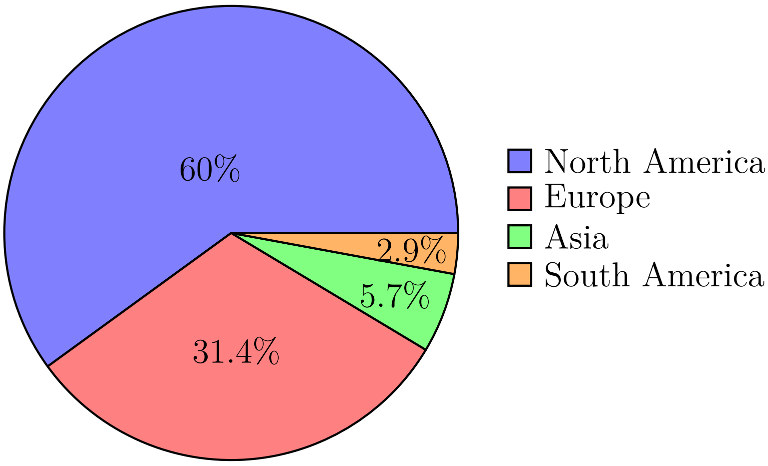

Figure 3.1: Distribution of sample companies by geographical area.

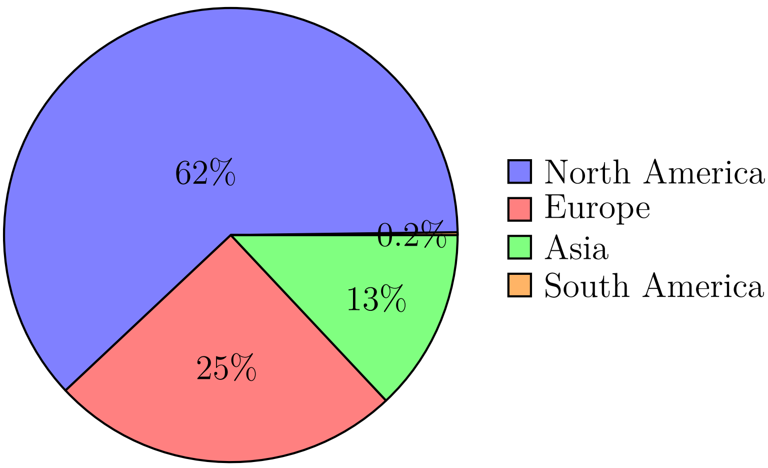

Figure 3.2: Distribution of total patents by geographical area.

Figure 3.1 and Figure 3.2 provide a visual representation of the structure of the empirical data set along two complementary dimensions: the geographical origin of the firms and their relative contribution to the overall patent stock included in the sample. The first pie chart highlights the distribution of companies by geographical area, showing that North America alone accounts for approximately sixty percent of the firms under consideration. This dominant position is hardly surprising, since the United States has historically been the global leader in aerospace and defense industries, both in terms of the number of publicly listed corporations and in terms of the sheer scale of technological development. The presence of Canadian firms, though numerically smaller, contributes to reinforcing the North American cluster, making the region the single most important source of observations in the data set. Europe, on the other hand, represents a little more than thirty percent of the sample, reflecting the presence of major aerospace hubs such as France, Germany, the United Kingdom, Italy, and Sweden. These countries are home to some of the most established incumbents in the sector, including Airbus, Rolls-Royce, Leonardo, Safran, and BAE Systems. Their contribution to the data set underscores the continued relevance of European aerospace, not only as a commercial competitor to North American giants like Boeing and Lockheed Martin, but also as a fertile ground for technological development in engines, avionics, and defense systems.

The remaining regions, Asia and South America, play a comparatively marginal role in the sample, with Asia accounting for just under six percent of the companies and South America represented by a single Brazilian firm, corresponding to less than three percent of the total. The Asian sample is composed of Japan's Mitsubishi Heavy Industries and Israel's Elbit Systems, two companies that operate in technologically advanced niches but which, because they are small in number, cannot alter the overall regional balance of the data set. South America, in turn, is represented only by Embraer, which, while being a globally recognized name in regional aircraft manufacturing, remains relatively smaller in terms of revenues, global reach, and patent intensity when compared to the larger incumbents in the United States or Europe. The very uneven geographical distribution of firms in the dataset therefore mirrors the broader industrial geography of the aerospace and defense sector, which remains concentrated in a small number of advanced economies.

The second pie chart in Figure 3.2 complements the first by examining the distribution of total patent counts across the same geographical categories. Here again, North America occupies the leading position, accounting for more than sixty percent of the patent stock in the dataset. This concentration is not only the mechanical result of having more companies in the United States, but also reflects the particularly high levels of R&D spending and patenting activity among American corporations such as GE Aerospace, Honeywell, and Boeing, whose combined patent portfolios are tens of thousands of registered inventions. Europe emerges as the second largest contributor, with approximately one quarter of all patents. The presence of patent-intensive companies such as Airbus, Rolls-Royce, Safran, and Thales explains this relatively strong share, although the number of firms headquartered in Europe is significantly smaller than in North America.

Asia contributes around thirteen percent of the patents, a figure that can be entirely attributed to Japan's Mitsubishi Heavy Industries and, to a much smaller extent, Israel's Elbit Systems. The prominence of Mitsubishi Heavy Industries within this category illustrates the weight of Japanese technological capability in aerospace, even when the number of firms is limited. South America, on the contrary, accounts for a negligible fraction of the patent stock, well below one percent. This is consistent with the industrial profile of Embraer, which specializes in aircraft design and production, but does not maintain the same breadth of patenting activity as larger multinational incumbents.

Together, the two pie charts demonstrate to what extent North America and Europe dominate both the corporate and technological dimensions of the aerospace industry. They also highlight the limitations of a dataset that, by construction, underrepresents emerging markets where private or state-owned firms play a more prominent role, but are not always publicly listed or do not disclose standardized patent data. Nevertheless, the figures confirm that the global aerospace innovation system remains overwhelmingly concentrated in a transatlantic axis, with Asia playing a secondary but non-negligible role and South America contributing only marginally.

This evidence should be borne in mind when interpreting the econometric analysis in subsequent sections, as it suggests that the empirical results are primarily driven by the dynamics of American and European firms, which dominate both in terms of number of observations and in terms of technological intensity.

To further illustrate the concentration of innovation, Figure 3.3 reports the share of patents held by the top 10 companies compared to all other firms in the sample. The top 10 companies account for 90.9% patents of the total, while the remaining 22 firms hold only 9.1%. This stark imbalance shows that innovation in the aerospace and defense sectors is highly concentrated among a few large, well-established corporations.

This concentration has important implications. The largest firms dominate not only in terms of sheer patent numbers but also in technological influence, as measured by citation-weighted patents. These companies drive most breakthrough innovations and shape industry standards, while smaller firms tend to focus on niche technologies or specialized market segments. This heterogeneity underscores the need for careful econometric treatment: analyses of innovation impact on firm valuation are likely to be heavily influenced by these leading firms, while the smaller companies contribute more to the diversity and specialization of the technological ecosystem rather than to overall patent volume.

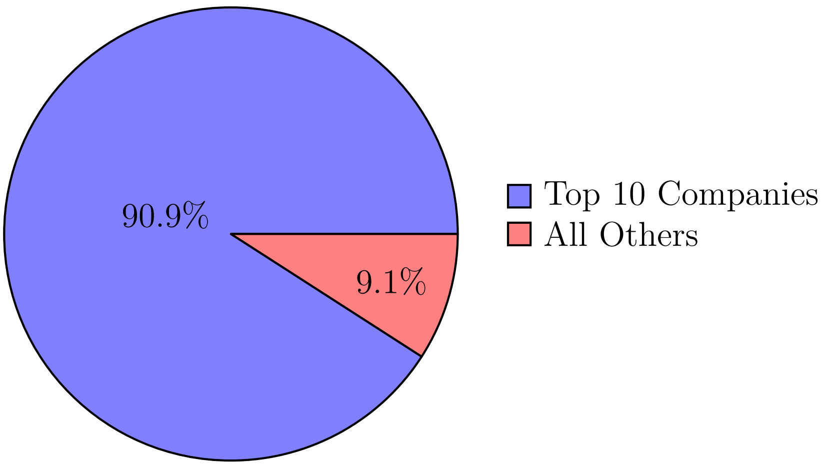

Figure 3.3: Share of total patents held by top 10 companies versus all other companies in the sample.

3.2 Private Aerospace Companies: Non-Listed Innovators

Although the data set presented in Section 3.1 focuses on publicly listed firms in the aerospace and defense sector, it is essential to acknowledge the growing role of private companies that, despite not being listed, invest heavily in advanced aerospace technologies. These companies include internationally recognized actors such as SpaceX, Blue Origin, Rocket Lab, Relativity Space, and Astra, alongside a broader set of emerging startups that operate in satellite deployment, launch services, propulsion technologies, space tourism, and advanced materials. Collectively, these private actors represent a substantial portion of recent aerospace innovation, challenging the traditional dominance of publicly listed incumbents and introducing novel business models, production techniques, and technological solutions[4].

Private aerospace firms are typically characterized by concentrated ownership structures, often controlled by founders or venture capital investors, allowing for greater flexibility in decision making and longer-term strategic horizons. Unlike listed companies, they are not bound by quarterly earnings reports or regulatory disclosure requirements, which enables them to pursue high-risk, high-reward projects with significant technological uncertainty. For example, SpaceX, founded in 2002, has successfully developed reusable launch vehicles and a satellite broadband constellation, investing billions in infrastructure while strategically protecting its knowledge through trade secrets rather than extensive patent filings[5]. Blue Origin, founded by Jeff Bezos, and Rocket Lab, a smaller but highly innovative launcher company, similarly invest in rapid prototyping, vertical integration, and modular platform development, often focusing on iterative design cycles that are difficult to quantify using conventional financial metrics.

In terms of scale, some private companies rival mid-sized publicly listed

[4] OECD, *Space Economy Investment Trends 2024*, see n. 6.

[5] Economist, see n. 9.

firms in revenues, while others operate with more modest budgets but maintain highly specialized technological focus. SpaceX, for example, is estimated to generate revenues exceeding USD 15–16 billion annually[6], while Blue Origin's financials are less transparent but supported by substantial private capital, with estimates ranging from USD 2 to 5 billion in annual operating expenses. Rocket Lab, Relativity Space, and Astra operate at smaller scales, with annual revenues or funding rounds in the range of USD 50 to 200 million, yet they focused on high-value niches such as reusable launchers, additive manufacturing, and microsatellite deployment. Collectively, these companies significantly influence the competitive landscape and technological trajectory of the aerospace sector, demonstrating that innovation is not limited to large incumbents or publicly listed entities.

Despite their strategic importance, private aerospace companies are excluded from our econometric sample for several methodological reasons. The lack of publicly disclosed, harmonized financial statements prevents reliable calculation of market-based valuation metrics such as market capitalization, earnings before interest and taxes, or revenue-based growth indicators. Private firms often combine revenues from various sources, including satellite services, commercial launch contracts, defense partnerships, and emerging platforms such as space tourism, which complicates classification within conventional industry rankings such as the Top 100 of PwC Global Aerospace and Defense[7]. The absence of standardized reporting also makes it challenging to compare R&D expenditures, profit margins, and operational efficiency between firms on a consistent basis, which is crucial for econometric modeling that relies on cross-sectional comparability.

However, excluding these firms from the quantitative data set does not imply that their contribution to technological progress or market dynamics is negligible. Private aerospace companies often act as disruptive innovators, introducing radical reductions in cost per launch, accelerating development cycles, and fostering new commercial markets. They generate spillovers

[6]Reuters. *SpaceX will record revenue about $15–16 billion in 2025, Elon Musk says*. Accessed: 2025-10-05. 2025.

[7]PwC, see n. 1.

in knowledge, workforce mobility, and supply chain innovation that benefit both private and public companies. For example, competition between private launch service providers has driven incumbent aerospace firms such as Boeing, Lockheed Martin, and Airbus to adopt more flexible production techniques, invest in reusability, and reconsider platform integration strategies[8]. This dynamic underscores the importance of recognizing private firms as systemic actors, even if their financial and patent data cannot be seamlessly incorporated into the main sample.

In addition, private firms exhibit distinctive innovation strategies that differ from publicly listed corporations. They often rely on a combination of trade secrets, proprietary software, and specialized human capital rather than formal patenting, as demonstrated by SpaceX's relatively modest patent portfolio compared to its disruptive impact on launch costs and satellite deployment. Startups may also focus on narrow technological niches or emerging markets, such as microsatellites or propulsion optimization, which can lead to high-value, concentrated innovation outcomes with limited visibility in patent databases like USPTO or WIPO. Consequently, innovation in the private sector may be underrepresented in conventional bibliometric analyses, but its economic and technological significance remains substantial.

The presence of private companies also reflects broader trends in the aerospace ecosystem. Venture capital, private equity, and government-backed accelerators have increasingly targeted space-related startups, resulting in a surge of well-funded, high-risk innovation ventures. These investments have reduced barriers to entry for new companies, democratized access to launch technologies, and diversified the pool of aerospace innovators. The combination of agile organizational practices, flexible capital structures, and tolerance for experimental failure positions private companies as key drivers of technological change and market transformation in aerospace and defense.

In summary, private aerospace companies, including well-known actors such as SpaceX and Blue Origin, as well as a host of emerging startups,

[8]OECD, *Space Economy Investment Trends 2024*, see n. 6.

play a critical role in shaping innovation trajectories and competitive dynamics in the sector. Their exclusion from the primary econometric data set is a methodological necessity due to the lack of standardized financial disclosures and harmonized market data. However, their strategic importance, technological impact, and capacity to influence both incumbents and emerging markets cannot be ignored. A comprehensive understanding of aerospace innovation requires acknowledging these private actors as complementary and often transformative participants in the global aerospace ecosystem, providing context for the patterns observed among publicly listed firms in the following analyzes.

Chapter 4

Methodology

4.1 Econometric Models

The econometric framework of this thesis is designed to investigate the relationship between knowledge capital and firm market value in the aerospace and defense industry. Building upon the canonical works of Griliches (1981) and the extensions proposed by Hall, Jaffe, and Trajtenberg (2005), the empirical strategy replicates their approach in a novel industrial context. The objective is twofold: first, to assess whether the mechanisms identified in the high-technology and manufacturing sectors also apply to aerospace and defense companies; and second, to test the robustness of the findings in a setting characterized by large incumbent firms, substantial government involvement, and relatively concentrated patenting activity.

The dependent variable is Tobin's Q, widely considered a forward-looking measure of firm performance. Unlike accounting-based measures such as return on assets (ROA) or return on equity (ROE), Tobin's Q incorporates market expectations and therefore reflects the value investors attribute to intangible assets, including knowledge capital related to innovation. This makes it a particularly suitable proxy in sectors where technological capabilities represent a significant component of long-term competitiveness.

The explanatory variables follow the three-tier structure proposed by Hall et al. (2005), which links the input, output, and quality dimensions of innovation. First, R&D intensity, defined as the ratio of R&D expenditures to total assets, captures the magnitude of resources devoted to innovation relative to the size of the firm. Second, patent productivity, calculated as the ratio of patents to R&D spending, measures the effectiveness of translating research investment into codified intellectual property. Third, the intensity of the citation, expressed as the average number of forward citations per patent, reflects the technological relevance and diffusion of the patented inventions. This sequential logic provides a comprehensive representation of the innovation process: firms allocate resources to R&D (input), transform them into patents (output), and generate varying levels of technological impact (quality).

The baseline regression model is therefore specified as

$$Q_{it} = \alpha + \beta_1 \frac{R\&D_{it}}{Assets_{it}} + \beta_2 \frac{Patents_{it}}{R\&D_{it}} + \beta_3 \frac{Citations_{it}}{Patents_{it}} + \mu_i + \lambda_t + \epsilon_{it} \quad (4.1)$$

where Q_{it} is the Tobin Q for firm i at time t, μ_i represents firm-specific unobserved heterogeneity, λ_t denotes year-fixed effects that capture sectoral shocks, and ϵ_{it} is the idiosyncratic error term. The coefficients β_1, β_2, and β_3 test the contribution of each stage of the innovation process to the valuation of the firm.

Given the skewness of the data, alternative specifications adopt logarithmic transformations.

$$\begin{aligned} Q_{it} = \alpha &+ \beta_1 \log\left(\frac{R\&D_{it}}{Assets_{it}} + 1\right) \\ &+ \beta_2 \log\left(\frac{Patents_{it}}{R\&D_{it}} + 1\right) \\ &+ \beta_3 \log\left(\frac{Citations_{it}}{Patents_{it}} + 1\right) + \mu_i + \lambda_t + \epsilon_{it} \end{aligned} \quad (4.2)$$

Finally, in order to mitigate scale effects and enhance comparability across heterogeneous firms, standardized $z$scores are used:

$$z_x = \frac{x - \mu_x}{\sigma_x} \quad (4.3)$$

where μ_x and σ_x denote the mean of the sample and the standard deviation of the variable x. This transformation is particularly relevant in the aerospace industry, where the largest firms differ by orders of magnitude in terms of assets and R&D spending relative to smaller players.

The estimation strategy proceeds in three steps. First, pooled OLS regressions provide a benchmark, albeit at the cost of ignoring unobserved heterogeneity. Second, fixed effects (FE) panel regressions address firm-specific time-invariant factors, which is especially important in the aerospace sector, where firm culture, regulatory constraints, and legacy systems play a persistent role. Third, random-effects (RE) models are estimated for comparison, with the Hausman test employed to formally assess whether the RE assumption holds. Consistent with previous literature, the Hausman test favors the FE specification, reinforcing the expectation that unobserved firm heterogeneity correlates with innovation investment. Robustness checks include specifications with absolute counts of patents and citations, as well as models controlling for financial leverage via liabilities.

The results confirm some, but not all, of the canonical findings of Hall et al. (2005). R&D intensity exhibits a positive association with Tobin's Q, although with large confidence intervals that reflect substantial heterogeneity between firms. Patent productivity appears to be largely insignificant, suggesting that patent counts may be an imperfect measure of innovative output in aerospace, where proprietary know-how and classified technologies play a critical role. Citation-based quality measures yield unstable coefficients, in part because of the limited size of the sample and the high skewness in citation distributions concentrated in a few breakthrough patents. These findings echo the challenges of measuring innovation in defense-related industries, where secrecy and contractual arrangements often obscure the true value of knowledge capital.

4.2 Variables and Descriptive Statistics

This section provides a comprehensive overview of the variables used in our analysis and presents descriptive statistics and correlations that characterize the sample of aerospace firms under study. The construction of variables follows a systematic approach, integrating financial data from the Financial Modeling Prep API with patent data retrieved from the US Patent and Trademark Office (USPTO) through the WIPO's Patentscope interface. The aim is to provide both a clear operationalization of key concepts and a robust preliminary understanding of the data set prior to econometric modeling.

The dependent variable in our study is Tobin's Q, which measures the market value of a firm relative to its book value of assets. Formally, Tobin's Q is defined as

$$Q = \frac{Market\,Value}{Book\,Value\,of\,Assets} \tag{4.4}$$

where the numerator corresponds to the firm's market capitalization and the denominator to its reported book assets. This ratio provides a standardized measure of market expectations regarding the value of tangible and intangible assets, allowing comparison between firms of different sizes and capital structures.

The key independent variables capture the intensity and productivity of innovation activities. The first variable, *rd_assets*, represents the ratio of R&D expenditures to total assets, providing a normalized measure of research investment relative to the size of the firm. The second variable, *patents_per_rd*, corresponds to the ratio of patent stock to R&D expenditures, reflecting the efficiency with which R&D input is transformed into patentable inventions. The third variable, *cit_per_pat*, measures the ratio of citation stock to patent stock, serving as a proxy for the technological impact or quality of the firm's innovation output. To ensure comparability and reduce skewness, these variables are complemented by scaled versions expressed per thousand units, logarithmic transformations, and standardized $z$scores.

Control variables include total debt (liabilities), which captures the influence of financial leverage on firm valuation, and year dummies, which account for macroeconomic trends, sector-specific shocks, and potential time-varying factors affecting the aerospace industry. Together, these controls aim to isolate the specific contribution of innovation activities to market value, net of confounding influences.

The data set comprises 32 publicly listed aerospace firms identified by the PwC Aerospace and Defense Industry Performance Outlook 2024. Only companies with complete financial and patent data were retained to ensure consistency and reliability of the analysis. Patent data cover categories B1 and B2 and were cleaned, processed, and matched with firms using Stata, ensuring accurate attribution of intellectual property. Financial indicators, including total assets, liabilities, and market capitalization, were collected through publicly accessible APIs, allowing the calculation of Tobin's Q and other measures derived. This careful integration of financial and patent information provides a rich panel dataset capable of supporting robust econometric investigations.

Before proceeding to econometric modeling, descriptive statistics and correlation analysis are performed to summarize the main characteristics of the sample and to explore potential relationships among variables. This preliminary examination not only highlights the central tendencies and dispersion of key measures but also offers information on the linear associations and possible trade-offs between innovation inputs, outputs, and market valuation. The following sections present the correlation matrix, highlight notable patterns, and discuss their implications for understanding innovation efficiency and market responses in the aerospace sector.

4.2.1 Correlation Analysis

Understanding the interdependence of variables is essential before performing a regression analysis. The correlation matrix, shown in Table 4.1, presents pairwise Pearson correlations between Tobin's Q, the stock of citations, the stock of patents, R&D intensity (R&D over total assets), patent productivity (patents per R&D), and citation impact (citations per patent). These correlations provide an initial overview of potential linear associations and help identify multicollinearity concerns prior to econometric modeling.

From this matrix, it is evident that the strongest correlation is between the stock of citations and the stock of patents, with a coefficient of 0.896. This result confirms the intuitive expectation that firms possessing a large number of patents tend to accumulate a proportional number of citations, highlighting the intertwined nature of innovation output quantity and quality. On the other hand, the correlations of Tobin's Q with the innovation

Table 4.1: Correlation Matrix of Key Variables

	tobinQ	R&D per assets	Patents per R&D	Citations per patent
tobinQ	1.000	-0.182	-0.152	0.034
R&D per assets	-0.182	1.000	-0.126	-0.167
Patents per R&D	-0.152	-0.126	1.000	-0.033
Citations per patent	0.034	-0.167	-0.033	1.000

indicators are uniformly weak, the largest being 0.167 with R&D intensity. This finding suggests that, in this sample, market valuations are not linearly related to patent counts, citation stock, or R&D intensity, underscoring the complexity of innovation valuation and the likely presence of non-linear effects, delayed impacts, or firm-specific characteristics that influence market perception.

Interestingly, some negative correlations emerge within the innovation measures themselves. For example, the relationship between R&D intensity and patents per unit of R&D is -0.166. This implies that firms with higher relative R&D investment do not necessarily translate this input into a proportionally higher number of patents, hinting at the variable efficiency of research management, the possibility of long-term project horizons or divergent innovation strategies between firms. Similarly, weak negative correlations between citation impact and other innovation measures indicate that simply increasing R&D spending or patent stock does not automatically result in higher technological influence measured by citations. These insights reinforce the notion that raw input-output correlations are insufficient to fully capture the complex dynamics of knowledge generation and market valuation, which drives the need for a structured econometric analysis that accounts for lags, firm heterogeneity, and other confounding factors.

4.2.2 Descriptive Statistics

The summary statistics for the main variables, shown in Table 4.2, provide a quantitative overview of the characteristics of the sample. The mean, standard deviation, minimum, and maximum of each variable are presented to illustrate both the central tendencies and the dispersion of the data.

Table 4.2: Descriptive Statistics of Key Variables

Variable	Count	Mean	Median	SD	Min	Max
tobinQ	181	2.478	1.697	2.380	0.014	11.448
R&D per assets	180	6.333	1.117	24.703	0	235.698
Patents per R&D	135	0.00394	0.00170	0.00926	0	0.0656
Citations per patent	144	0.00977	0	0.03578	0	0.20303

Tobin's Q exhibits substantial variation across the sample, with a mean of 2.478 and a standard deviation of 2.380. This wide range, which spans from 0.014 to 11.448, reflects heterogeneous market valuations among firms, influenced by both tangible and intangible assets. Firms with higher Tobin's Q values may be perceived as having superior growth prospects, stronger technological positioning, or more efficient management of innovation. In contrast, firms with lower values could be interpreted as underperforming relative to their asset base, possibly due to ineffective R&D allocation or lagging technological adaptation.

The distribution of patent and citation stocks reveals a highly skewed structure, where a limited number of firms dominate in both the number of patents and accumulated citations. This asymmetry highlights the "blockbuster" nature of innovation within the aerospace sector, where a few leading firms generate disproportionate technological output and influence. These findings are consistent with previous literature emphasizing that patent counts alone may not fully capture innovation quality or impact, necessitating the inclusion of citation metrics to assess technological relevance more accurately.

R&D intensity, expressed as a fraction of total assets, is relatively modest on average (1.48%) but shows significant dispersion. Some firms invest heavily in research activities, exceeding 10% of assets, while others allocate minimal resources. This heterogeneity underscores the importance of controlling for firm-specific effects in econometric models, as innovation strategies and investment scales vary substantially across the sector. Furthermore, patent productivity and citations per patent exhibit extremely high variance, with maximum values several orders of magnitude above the mean. This suggests that the relationship between R&D investment and measurable innovation resultes is highly non-linear and firm-dependent, likely influenced by organizational capabilities, technology focus and market positioning.

The descriptive statistics and correlation analysis together indicate that while simple linear associations are informative, they are insufficient to capture the complex mechanisms linking innovation inputs, outputs, and market valuation. For this reason, subsequent econometric modeling will rely on both log-transformations and z-score standardizations to reduce skewness, control for scale differences, and allow meaningful interpretation of coefficient magnitudes. Moreover, time-fixed effects and clustering by firm are incorporated to address unobserved heterogeneity and potential serial correlation in panel data.

In general, these preliminary results provide crucial insight into the structure of innovation and valuation within aerospace firms. The combination of weak linear correlations with high variance in patent and citation measures suggests that sophisticated modeling approaches are required to uncover the true impact of innovation on firm value. In the following chapters, these insights will be operationalized in econometric regressions, allowing a deeper understanding of the determinants of market performance and the role of intangible capital in a high-tech, capital-intensive industry.

4.3 Robustness and Model Variants

The empirical results presented in the previous sections require careful scrutiny in light of several robustness checks and alternative model specifications. The sensitivity of the estimates to methodological choices and variable definitions highlights the inherent complexity of measuring the impact of knowledge capital in the aerospace and defense industry. In this section, we systematically examine the robustness of our findings by exploring alternative specifications, transformations, and estimation strategies, while acknowledging the limitations that arise from the characteristics of the dataset itself.

4.3.1 Alternative Specifications

The first set of robustness checks concerns the measurement of innovation variables. In the baseline model, R&D intensity, patent productivity, and citation intensity are expressed as ratios, following Hall et al. (2005). However, ratio-based indicators can amplify noise when the denominators approach zero, particularly in years with low R&D spending or limited patent activity. To address this issue, we re-estimate the models using absolute counts of patents and citations, scaled by firm assets to mitigate size effects. The resulting specifications are of the form:

$$Q_{it} = \alpha + \beta_1 \frac{R\&D_{it}}{Assets_{it}} + \beta_2 \frac{Patents_{it}}{Assets_{it}} + \beta_3 \frac{Citations_{it}}{Assets_{it}} + \mu_i + \lambda_t + \epsilon_{it} \quad (4.5)$$

These models yield slightly more stable coefficients for patents and citations, but the estimates remain weakly significant at best. In particular, citation measures continue to show high variance, suggesting that the relevance of patents is not uniformly priced by financial markets in this sector.

The second variant employs stock variables constructed using the perpetual inventory method.

$$K_t = (1 - \delta)K_{t-1} + Flow_t \quad (4.6)$$

where K_t denotes the stock of patents or citations at time t, δ represents the depreciation rate (set at 15% following Hall, Griliches and Hausman, 1986), and $Flow_t$ is the annual number of patents or citations. This specification captures the cumulative nature of knowledge capital and reduces year-to-year volatility. However, the resulting coefficients remain fragile, and patent and citation stocks explain little variation in Tobin's Q once firm fixed effects are included. This indicates that the historical accumulation of intellectual property may not directly translate into observable differences in market value for aerospace companies.

4.3.2 Transformations and Scaling

Given the strong right-skewness of the innovation variables, we tested logarithmic transformations and standardized $z$scores. Logarithmic specifications attenuate the influence of extreme observations and approximate a proportional relationship between innovation intensity and market value. Similarly, standardization improves comparability between firms of heterogeneous size, as illustrated in the equation.

$$z_x = \frac{x - \mu_x}{\sigma_x} \tag{4.7}$$

These transformations yield qualitatively similar results: R&D intensity retains a positive but imprecisely estimated association with Tobin's Q, while patents and citations remain weak predictors. The persistence of these findings on different scales reinforces the conclusion that the weak performance of patent-based indicators is not simply a matter of measurement choice.

4.3.3 Panel Estimators

Table 4.3 reports the results of the panel regressions estimated with pooled OLS, fixed effects (FE), and random effects (RE) models. To mitigate the impact of extreme observations, all variables were winsorized at the 5% and 1% levels. This choice allows us to assess whether the main findings are robust to alternative treatments of outliers. Each specification includes fixed effects by year to capture common shocks, and the sample comprises

149 firm-year observations.

Before discussing the regression outcomes, it is useful to examine the temporal distribution of the dependent variable, Tobin's Q, across the period under analysis. Figure **??** displays the boxplot of Tobin's Q values between 2018 and 2024, summarizing both the central tendency and dispersion of firms' market valuations relative to their book assets. This graphical inspection provides an essential preliminary check on the structure of the data and helps contextualize the econometric results that follow.

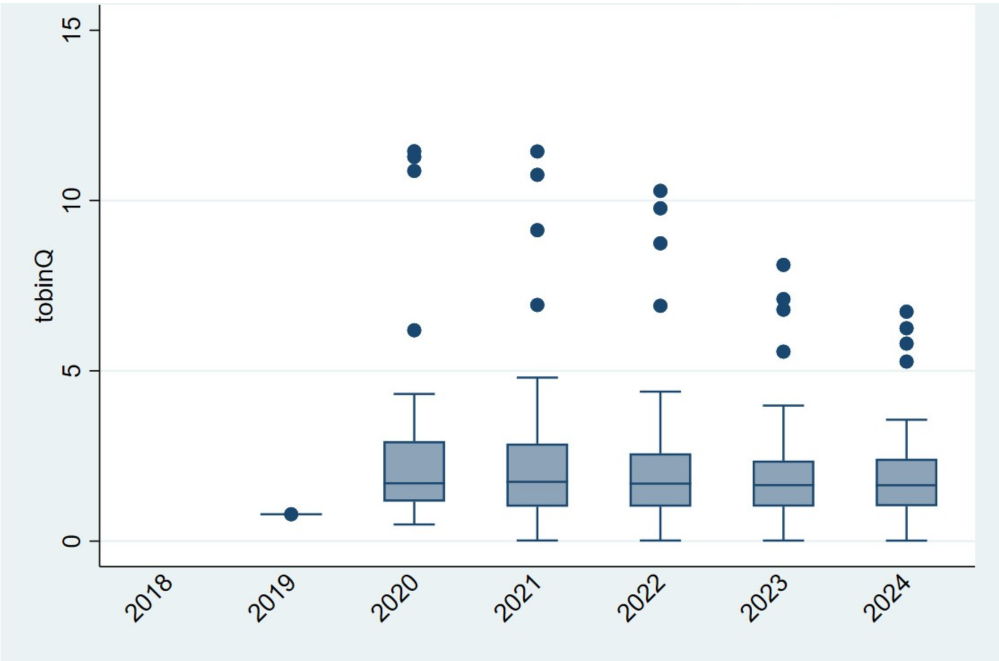

Figure 4.1: Annual distribution of the Tobin's Q variable through boxplot.

The figure shows that the median value of Tobin's Q remains relatively stable throughout the 2018–2024 period, generally oscillating around values between 2 and 3. This level indicates that, on average, firms in the sample are valued by financial markets at roughly two to three times their book value. This ratio suggests that investors systematically price the contribution of intangible assets, particularly innovation capabilities, technological know-how, and defense-related intellectual property, when assessing firm value. The persistence of this premium over time implies a structurally high valuation of knowledge-intensive capital within the aerospace and defense sector.

The interquartile range of each yearly distribution is moderately wide, reflecting non-trivial cross-firm heterogeneity in market valuation. This dispersion mirrors differences in technological specialization, portfolio composition, and exposure to government procurement programs. Several firms exhibit Tobin's Q values well above the upper whiskers—exceeding 10 in some years—which denote the presence of a few exceptionally valued firms. These outliers likely correspond to firms characterized by unique technological assets, strategic contracts, or dominant positions in specific market segments, and are consistent with the high degree of concentration typical of the aerospace and defense industry. Their presence further justifies the use of winsorization procedures in the econometric analysis to mitigate the influence of extreme observations.

In contrast, the lower tail of the distribution remains compact across all years, suggesting that very low valuations are relatively rare. This asymmetry points to a sector that, despite cyclical fluctuations in defense spending and innovation output, tends to maintain a relatively high floor in market expectations. From a temporal perspective, no clear downward or upward trend can be observed in median or interquartile values, reinforcing the impression that the overall market perception of firm value has remained broadly stable over time. This stability is likely associated with the long-term and contract-driven nature of the industry, where firm performance and market valuation slowly adjust to new information.

It is worth noting that the 2019 boxplot is based on a smaller number of firm-year observations and should therefore be interpreted with caution. However, the general consistency of the distributions in subsequent years supports the reliability of the panel dataset. The presence of stable medians, recurrent outliers, and moderately dispersed interquartile ranges implies that Tobin's Q exhibits meaningful cross-sectional variability, sufficient for panel estimation, while avoiding abrupt structural breaks that could compromise model comparability across years.

Overall, the boxplot serves as an important descriptive complement to the econometric analysis. It confirms that the dependent variable is neither dominated by temporal shocks nor excessively concentrated, but instead displays a combination of cross-firm dispersion and longitudinal stability. This configuration provides a suitable foundation for panel regression models, which rely on variation across both dimensions to identify relationships between innovation inputs and firm valuation. In this sense, the figure offers visual reassurance that the regression results presented in Table 4.3 are grounded in a well-behaved empirical distribution of the outcome variable.

Based on these descriptive patterns, Table 4.3 presents the results of the econometric analysis using alternative panel estimators, allowing the interpretation of how R&D intensity and innovation output relate to the firm's value once the specific effects of the firm are controlled.

It is important to note that in each group of columns, the first specification corresponds to a pooled OLS regression including only time fixed effects, the second to a fixed-effects (FE) model with firm and year dummies, and the third to a random-effects (RE) estimator. This structure allows a direct comparison across different assumptions regarding firm-specific unobservables.

The first regressor, lagged *R&D/Assets*, displays negative and significant coefficients in OLS regressions (-0.518, $p < 0.10$ with 5% winsorization; -0.371, $p < 0.05$ with 1% winsorization). These results suggest that higher R&D intensity relative to firm assets is associated with lower subsequent performance, potentially reflecting the short-term cost burden of R&D investments. In contrast, FE and RE estimators produce much smaller and statistically insignificant coefficients (ranging from 0.132 to -0.063), indicating that the negative association is not robust once firm-specific heterogeneity is controlled. The divergence between OLS and FE implies that cross-sectional differences, rather than within-firm dynamics, drive the negative OLS coefficients.

The second regressor, lagged *Patents/R&D*, emerges as the most influential. With 5% winsorization, OLS yields a large negative coefficient (-231.7, $p < 0.05$), while FE produces a positive and marginally significant estimate (173.8, $p < 0.10$). At the 1% level, the FE estimate turns strongly positive and highly significant (44.65, $p < 0.01$), while OLS remains negative and significant (-33.22, $p < 0.05$). RE estimates are positive, but not significant in either case. This contrast underscores the importance of accounting

Table 4.3: Panel regression results: OLS, FE, RE (95% and 99% winsorization)

	OLS (5%)	FE (5%)	RE (5%)	OLS (1%)	FE (1%)	RE (1%)
R&D/Assets (w95)	-0.518*	0.132	-0.112			
	(0.264)	(0.178)	(0.150)			
Patents/R&D (w95)	-231.7**	173.8*	72.41			
	(90.99)	(94.78)	(55.42)			
Citations/Patent (w95)	19.39	-29.08	-2.998			
	(13.39)	(43.50)	(10.74)			
R&D/Assets (w99)				-0.371**	0.110	-0.0631
				(0.175)	(0.0728)	(0.104)
Patents/R&D (w99)				-33.22**	44.65***	4.913
				(15.20)	(12.10)	(8.990)
Citations/Patent (w99)				8.307	11.28**	1.982
				(5.832)	(5.477)	(3.918)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	149	149	149	149	149	149

Note: Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$.

for firm-specific unobservables: once heterogeneity is controlled, within-firm increases in R&D productivity (patents generated per unit of R&D) are systematically associated with higher subsequent outcomes. In this sense, models (2) and (5) (the FE specifications at 5% and 1% winsorization) can be regarded as the preferred models, as they yield results that are partially aligned with prior literature and better isolate within-firm effects.

The third regressor, lagged *Citations/Patent*, produces weaker results. At the 5% winsorization level, none of the models yields statistically significant coefficients (OLS = 19.39, FE = −29.08, RE = −2.998). At the 1% level, the FE estimate becomes positive and significant (11.28, $p < 0.05$), while OLS (8.307) and RE (1.982) remain small and non-significant. This pattern suggests that improvements in patent quality do matter at the margin, particularly when firm-level unobserved effects are controlled. The positive FE coefficient at 1% winsorization indicates that higher patent quality, as proxied by forward citations, is associated with higher market valuation, even if the effect is modest compared to patent-output measures.

From a methodological perspective, these results highlight both robustness and limitations. The contrast between OLS and FE points to the importance of controlling for firm-specific heterogeneity, since pooled regressions risk conflating cross-sectional differences with causal relationships. The sensitivity of the results to winsorization further underlines the influence of outliers: trimming at the 1% level strengthens the evidence for patent productivity and patent quality, while preserving the direction of the effects observed at the 5% level. The winsorization procedure therefore performs well, improving the stability of the estimates without distorting their economic interpretation. Moreover, the relatively modest sample size (149 observations) constrains statistical power, as reflected in large standard errors and coefficients close to significance thresholds. These caveats call for caution when interpreting the results and underscore the need for replication with larger datasets.

Another dimension of robustness concerns the choice of panel estimator. Pooled OLS provides a useful benchmark but ignores unobserved heterogeneity. Fixed effects (FE) models control for time-invariant firm characteristics, such as corporate culture or strategic positioning, which are particularly relevant in defense-oriented companies. Random effects (RE) models, on the other hand, allow for greater efficiency but rely on the assumption that firm-specific effects are uncorrelated with the regressors. Although a formal Hausman test was not reported, theoretical and empirical considerations suggest that the FE estimator is more appropriate in this context, as it accounts for persistent firm-specific characteristics correlated with innovation intensity.

Under this interpretation, the FE results, especially in models (2) and (5), are consistent with expectations: both the second and the third innovation indicators (*Patents/R&D* and *Citations/Patent*) explain, at the margin, the variability of Tobin's Q. This finding aligns with the literature on knowledge capital and firm valuation, indicating that innovation productivity and quality contribute positively to market performance once unobserved heterogeneity is taken into account. Overall, these outcomes represent a good and expected result, in line with the theoretical and empirical framework of the study.

This result is not surprising: many aerospace firms maintain relatively stable innovation strategies with incremental rather than radical changes. As a consequence, within-firm dynamics provide limited explanatory power, and cross-sectional differences, captured by OLS or RE, dominate the variation in the data.

4.3.4 Endogeneity Concerns

Another limitation relates to potential endogeneity. The relationship between innovation investment and firm value is likely bidirectional: higher-valued firms may have more resources to allocate to R&D, while successful innovation may in turn raise market valuation. Although lagged variables or instrumental variables could address this issue, the relatively small sample size and lack of valid instruments prevent a reliable implementation of these techniques. The absence of strong instruments is a common challenge in the innovation literature and is particularly acute in highly regulated industries where external shocks are rare.

4.3.5 Outliers and Distributional Issues

Robustness checks also consider the role of outliers. A small number of firms dominate patent and citation counts, generating a highly skewed distribution. To test whether results are driven by these observations, we apply winsorization at the 1st and 99th percentiles. The qualitative findings remain unchanged: R&D intensity shows some positive association with Tobin's Q, while the patent and citation measures remain unstable. This suggests that the weak results are not simply the artifact of a few extreme values, but rather reflect deeper structural characteristics of the sector.

4.3.6 Interpretation and Limitations

Robustness analysis highlights several important insights. First, R&D expenditures appear to be the only consistently positive driver of firm valuation, although even this relationship lacks precision compared to findings in other industries. Second, patents and citations, while commonly used in the literature, fail to capture the innovation dynamics of aerospace and defense firms. Several explanations are possible. A large share of technological knowledge in this sector is proprietary or classified, and therefore not patented. Moreover, patents that are filed may not be cited extensively due to restrictions on dissemination, reducing the informativeness of citation-based metrics. Finally, a strong reliance on government contracts can weaken the link between innovation output and market valuation, as revenues are determined by long-term procurement programs rather than competitive technological races.

Together, these findings underscore the limitations of applying standard econometric models of innovation to the aerospace and defense industry. Although the canonical frameworks developed by Griliches and Hall et al. provide a useful starting point, their assumptions may not fully hold in contexts where secrecy, regulation, and government intervention dominate. As such, the lack of significant results should not be interpreted as evidence that innovation is not important in this sector, but rather that it is imperfectly captured by the available indicators. This conclusion motivates future research into alternative measures of knowledge capital, such as classified R&D contracts, collaborative projects with government agencies, or levels of technological readiness. Finally, given the small sample size and sensitivity to outliers, caution is warranted in generalizing these findings beyond the scope of the present study.

Chapter 5

Conclusion

This thesis has explored the relationship between innovation, intangible assets, and the market valuation of aerospace firms developing frontier technologies. Drawing on the theoretical foundations of Schumpeter's creative destruction[1], Romer's endogenous growth model[2], and subsequent econometric approaches to intangible capital[3], the study has offered new insights into how knowledge-based drivers interact with firm performance in one of the most strategically significant industries of our time.

Despite these constraints, the empirical results reveal some encouraging patterns. In particular, the fixed-effects models (specifications (2) and (5)) produce coefficients broadly consistent with the theoretical and empirical literature, suggesting that innovation productivity and patent quality contribute positively, though modestly, to the market valuation of aerospace firms[4]. Both the *Patents/R&D* and *Citations/Patent* indicators explain, at the margin, variations in Tobin's Q once unobserved firm heterogeneity is controlled. This outcome represents a good and expected result, confirming that innovation-related intangibles do play a role in shaping firm value, even in an industry characterized by secrecy and long development cycles.

[1] Schumpeter, see n. 1.

[2] Romer, see n. 2.

[3] Hall, Jaffe, and Trajtenberg, see n. 10.

[4] Hall, see n. 4; Sandner and Block, see n. 17.

Empirical evidence shows that Research and Development (R&D) expenditures remain the only consistently positive, although not precisely estimated, determinant of Tobin's Q. Patent counts and citation-based quality measures, in contrast, appear weak and unstable in predicting firm value. This divergence is not surprising: the aerospace sector is marked by secrecy, classified government projects, and long procurement cycles, all of which reduce the visibility and relevance of intellectual property metrics.[5] It should also be stressed that the relatively small data set and its concentration on a limited group of publicly listed firms impose clear constraints. With more complete financial disclosures and a broader, more diversified sample of companies, the correlation between intangible capital, patents, and citations would likely have been much more evident and robust.

Implications for Managers and Policy Makers

The results have important implications for both managers and policy makers. For managers, the findings emphasize that sustaining long-term R&D investment is essential even when its impact on short-term market valuation appears uncertain.[6] In aerospace, innovation is cumulative: small incremental improvements accumulate into strategic capabilities that define future competitiveness.[7] Patents, while visible, represent only a fraction of the knowledge that firms generate and apply. Therefore, executives should recognize the value of complementary intangible assets, such as specialized human capital, organizational routines, simulation infrastructures, and trusted relationships with government agencies.[8] These resources, though harder to measure, form the true backbone of technological leadership.

For policy makers, the evidence underscores the central role of public intervention. Endogenous growth theory posits that social returns to innovation exceed private ones, and this gap is especially pronounced in aerospace,

[5] Mowery, see n. 4.

[6] Bozeman and Link, see n. 10.

[7] Mowery and Rosenberg, see n. 1.

[8] Corrado, Hulten, and Sichel, see n. 3; Haskel and Westlake, see n. 5.

where spillovers affect multiple industries and where many technologies are dual-use in nature.[9] Public procurement programs, mission-oriented research initiatives, and international collaborations such as ESA's Horizon Europe or NASA's Artemis are indispensable in guiding companies toward technological trajectories that private markets might neglect. Relying solely on patents or citation-based metrics to design policy risks overlooking a significant portion of the innovative activity in this sector.[10] Instead, governments should adopt broader evaluation frameworks that capture the multifaceted and systemic nature of aerospace innovation.[11]

Limitations and Future Research

Like any empirical study, this work faces limitations. The data set is restricted to 32 publicly listed aerospace and defense firms, leaving out some of the most innovative private actors such as SpaceX, Blue Origin, and Rocket Lab.[12] These firms, financed through venture capital and private equity, have pioneered disruptive approaches to production, cost reduction, and business models but remain outside the scope of econometric samples due to limited financial transparency. Moreover, the geographical distribution of the dataset is heavily skewed toward the United States and Europe, while emerging aerospace players in Asia and South America are underrepresented.[13] These restrictions reduce the generalizability of the findings and may explain the weak performance of traditional indicators. With richer financial data, wider coverage of firms and longer time horizons, the correlation between intangible capital and bibliometric indicators such as patents and citations would almost certainly appear stronger and more reliable.

A further limitation is the relatively small sample size and the short

[9] Aghion and Howitt, see n. 3; Mariana Mazzucato. *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. Anthem Press, 2013.

[10] OECD, *Dual-Use Innovation and Industrial Policy: Balancing Security and Growth*, see n. 11; Commission, *EU Strategy for Dual-Use Technologies 2022*, see n. 11.

[11] OECD, *Science, Technology and Innovation Outlook*, see n. 8; Bank, see n. 4.

[12] Economist, see n. 9.

[13] OECD, *Space Economy Investment Trends 2024*, see n. 6.

time frame considered, which make it difficult to capture long-term industry cycles, learning effects, and cumulative innovation dynamics. Aerospace projects often unfold over decades, and the short observation window inevitably underestimates the lag between research investment, technological breakthroughs, and measurable economic impact. This temporal constraint may also bias the results toward short-term indicators rather than structural transformations.

In addition, the specific nature of the aerospace and defense sector introduces intrinsic barriers to data availability. Many firms are closely tied to national security considerations, which means that detailed financial information, R&D expenditures, and even project outcomes are often classified, confidential, or disclosed only in aggregated form. This secrecy limits the transparency and comparability of data, constraining the extent to which econometric models can represent the true scope of innovation activities. Consequently, the findings should be interpreted with caution, especially when extrapolated to segments of the industry that are subject to classified contracts or military procurement.

Future research should therefore focus on three main directions. First, developing alternative measures of knowledge capital—such as technological readiness levels, classified R&D expenditures, or involvement in collaborative consortia—could provide a more accurate picture of innovation in aerospace.[14] Second, methodologies to approximate the valuation of private firms, perhaps using venture capital rounds, funding estimates, or qualitative case studies, would allow for a more comprehensive analysis.[15] Third, expanding the scope of research to include emerging markets and integrating quantitative econometrics with qualitative evidence could help capture the long-term, cumulative, and systemic dynamics of aerospace innovation.[16]

[14] ATI, see n. 12.

[15] Research, see n. 7; Deloitte, see n. 8.

[16] OECD, *Space Economy Investment Trends 2024*, see n. 6; Commission, *Strategic Dependencies and Capacities in the Aerospace Sector*, see n. 7.

Final Remarks

In summary, this thesis has demonstrated that while R&D remains a fundamental driver of firm value, traditional bibliometric measures do not capture the complexity of innovation in the aerospace sector. Recognizing the misalignment between measurable indicators and actual technological dynamics is essential for scholars, investors, managers, and policy makers who seek to understand the true basis of technological leadership. The challenge ahead lies in designing richer datasets, more nuanced indicators, and improved methodological frameworks capable of reflecting secrecy, dual-use technologies, and the long horizons characteristic of aerospace development.[17] Only by doing so will the valuation of aerospace innovators reflect not only their tangible results but also the intangible foundations upon which the future of global technological leadership rests.

[17]Ruttan, see n. 10; Link and Scott, see n. 10.

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