MASTER IN INDUSTRIAL ENGINEERING

MASTER'S THESIS

VALUATION MODEL OF INDUSTRIAL PROPERTY FROM A GAME THEORY PERSPECTIVE

Álvaro Ferrero Baz

Director
Dr. Antonio García de Garmendia

Madrid
January 2025

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título Valuation Model of Industrial Property from a Game Theory Perspective en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el curso académico 2025/26 es de mi autoría, original e inédito y no ha sido presentado con anterioridad a otros efectos. El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido tomada de otros documentos está debidamente referenciada.

Fdo.: Álvaro Ferrero Baz Fecha: 20/01/2025

Álvaro F.

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: Dr. Antonio García de Garmendia Fecha: 20 enero, 2025

Abstract

The management of industrial property is a cornerstone of corporate strategy in today's innovation-driven global economy. Patents, as key assets within this domain, not only safeguard technological advancements but also serve as critical tools for fostering collaboration, generating revenue, and maintaining competitive advantages. However, challenges such as patent thickets, restrictive competition practices, and the growing complexity of industrial property transactions hinder innovation and complicate market entry. Addressing these issues requires robust frameworks capable of optimizing knowledge-sharing processes and guiding strategic decisions in knowledge management.

This master's thesis develops a comprehensive framework based on game theory to optimize collaboration strategies in the field of industrial property management. By integrating theoretical concepts, contextual factors, and practical applications, the framework evaluates strategic interactions under both perfect and imperfect information scenarios. The model incorporates key parameters such as exclusivity, bargaining power, sectoral fragmentation, and transactional costs, in order to offer actionable insights for firms seeking to maximize the value of their intellectual property portfolios.

The study follows a structured workflow to achieve its objectives, as depicted in Figure 1. The process begins with a foundational analysis of industrial property, its valuation, and collaboration strategies, followed by an exploration of game theory concepts relevant to strategic decision-making. These theoretical insights form the basis for the development of the proposed model, which is validated through simulations and further analyzed for its economic implications.

The workflow is divided into the following steps:

- **Understanding Industrial Property**
  - A detailed review of the legal and structural foundations of intellectual property, with a focus on patents and their role in fostering innovation.
  - An exploration of the most common collaboration strategies, emphasizing their context-dependent nature, pros and cons, and their impact on final payoffs.
- **Review of Game Theory**
  - Introduction to key game theory concepts, such as Nash equilibrium, cooperative strategies, and repeated games.

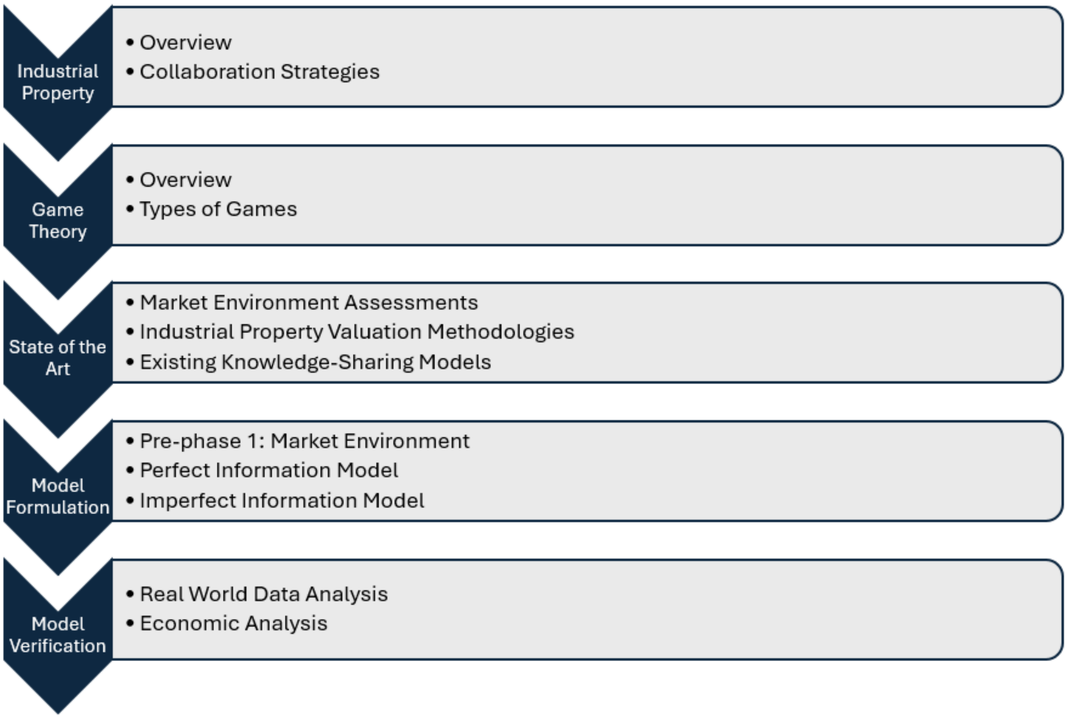
  - Analysis of different types of games and their applicability in modeling strategic interactions in patent management.

- **State of the Art**
  - An evaluation of methodologies for analyzing the market environment, including factors such as competitiveness and market fragmentation.
  - An assessment of diverse industrial property valuation techniques, their requirements, and their applicability in different contexts.
  - A review of available models on knowledge-sharing, focusing on their formulation and practical implications.

- **Model Formulation**
  - Development of a game theory-based mathematical framework that integrates the critical factors influencing patent transactions.
  - Consideration of both perfect and imperfect information scenarios to capture the complexities of real-world interactions.

- **Model Verification**
  - Simulation of real-world-inspired scenarios using representative patent data to evaluate the model's performance.
  - Analysis of strategic decisions under various market conditions, sectoral fragmentation, and firm-specific factors.
  - Assessment of how the proposed framework helps firms optimize resource allocation and maximize profits.
  - Quantification of the financial impacts of adopting different collaboration strategies.

Figure 1: Workflow of the project



Source: Own elaboration. (2025)

This master's thesis provides a comprehensive understanding of industrial property management and collaboration strategies, integrating both theoretical and practical relevance. It highlights how contextual factors, such as exclusivity and bargaining power, influence strategic decisions and demonstrates the model's adaptability to diverse scenarios. By simulating both base collaboration and R&D games, the framework captures the trade-offs inherent in industrial property transactions and offers guidance for achieving mutually beneficial outcomes.

The accompanying economic analysis reinforces the model's value as a tool for firms to assess potential benefits, optimize their strategies, and navigate the complexities of patent transactions. The study not only addresses current challenges in industrial property management but also establishes a foundation for future research, offering a pathway toward more dynamic and cooperative industrial landscapes.

In conclusion, this thesis combines theoretical insights, practical modeling, and real-world analysis to provide a robust framework for optimizing knowledge-sharing processes. Its findings are a valuable resource for firms seeking to enhance their collaboration strategies, foster innovation, and leverage industrial property as a driver of growth and competitiveness.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The management of industrial property has become a cornerstone of corporate strategy in today's competitive and innovation-driven global economy. Companies increasingly leverage industrial property not only to protect their innovations but also as strategic assets to gain competitive advantages, generate revenue, and foster collaboration. This thesis examines the challenges and opportunities in managing these intangible assets, with a particular focus on optimizing knowledge-sharing processes between firms.

In this rapidly evolving global context, patents play a pivotal role by safeguarding technological advancements and incentivizing further development. However, the growing volume of patents has led to significant challenges, such as the emergence of patent thickets—overlapping networks of patents often owned by competing companies. These thickets can create barriers to entry for new firms, hinder innovation, and increase the risk of litigation. Additionally, practices such as patent hold-ups and restrictive licensing conditions can exacerbate these issues, fostering monopolistic behaviors that limit competition and raise additional costs for consumers.

The growing number of industrial property disputes underscores the urgency of addressing these issues. To foster a more dynamic and innovative marketplace, it is essential to facilitate effective knowledge exchange and collaboration among industry players. Without appropriate mechanisms to manage industrial property, the very systems designed to promote innovation risk inadvertently obstructing it.

One of the most effective approaches, and the one to be analyzed in this master's thesis, is fostering collaboration between companies. Effective knowledge-sharing mechanisms and collaborative strategies between firms can help reduce barriers to innovation and mitigate conflicts. Companies have several options to facilitate collaboration, including selling, licensing, joint ventures, and strategic alliances. Each of these approaches offers unique benefits depending on factors such as the asset's market value and the strategic objectives of the parties involved.

This study adopts a game theory-based approach to explore collaboration strategies and identify optimal solutions for industrial property management. Game theory provides a structured and robust framework for analyzing strategic interactions between parties, particularly in contexts involving shared interests and potential conflicts. By modeling the dynamics of cooperation under different conditions, such as perfect and imperfect information, this master's thesis aims to identify optimal strategies for knowledge-sharing and industrial property management.

The primary motivation for this project stems from the economic and innovation benefits of effective knowledge-sharing agreements. By enabling firms to collaborate on industrial property, these agreements can reduce barriers to innovation, mitigate conflicts, and foster mutual growth. However, the complex process of managing intangible assets and the strategic considerations involved pose significant challenges. Developing a practical model that addresses these complexities is essential for enhancing innovation and market competitiveness.

To effectively design an adequate model it is important to consider that the value of industrial property and the optimal strategies for knowledge-sharing are highly dependent on their context. Factors such as exclusivity, bargaining power, market conditions, and transactional costs significantly influence the dynamics of intellectual property management and collaboration. Recognizing this, a primary focus of this thesis is to identify the key factors that define the landscape of these transactions, develop methodologies to measure or estimate them and incorporate them into a comprehensive model that accurately reflects the complexities of these processes.

To develop a robust framework for optimizing collaboration strategies, this thesis delves into the fundamental concepts of industrial property and the mechanisms that govern its management. The analysis begins in chapter 2 by exploring the legal and structural foundations of intellectual property, including its historical origins, the rationale for its protection, and the frameworks that regulate its use. Particular attention is given to patents, their conditions of patentability, and their strategic importance as tools for innovation and competition.

Beyond the legal context, this master's thesis also examines the valuation of industrial property, a critical yet complex aspect of industrial property management.

Patent value is highly context-dependent, influenced by factors such as market conditions, technological applications, and the strategic goals of the owning firm. This variability underscores the importance of selecting appropriate valuation methodologies, ranging from income-based to market-based approaches. Chapter 4 focuses on analyzing the state of the art in knowledge sharing and collaboration, exploring existing models and methodologies to understand how the exchange of information can be effectively modeled. Additionally, the chapter addresses two key factors critical to collaboration strategies: measuring patent entanglement and valuing industrial property. By examining prior research, this chapter provides a comprehensive overview of the current landscape and lays the foundation for the development of a robust framework to model and optimize industrial property collaboration strategies.

Collaboration strategies themselves form the core of this thesis. By analyzing mechanisms such as selling, licensing, joint ventures, and patent pooling, the model developed in this work seeks to provide actionable insights into how firms can optimize the exchange of intellectual property. These strategies, and the trade-offs they involve, shaped by factors such as exclusivity, bargaining power, and transaction costs, are introduced in chapter 2 and are further integrated into the game theory-based framework proposed in chapter 5.

Game theory serves as a powerful tool for modeling the strategic interactions between firms, particularly in the context of patent management. Chapter 3 introduces key concepts of game theory, such as Nash equilibrium, cooperative games, and repeated interactions, which are applied in chapter 5 to design a model that accurately captures the dynamics of knowledge-sharing under both perfect and imperfect information scenarios. By simulating real-world conditions, the model aims to provide a comprehensive understanding of how firms can navigate the complexities of industrial property and achieve mutually beneficial outcomes.

The methodology described in chapter 5 is further validated through real-world simulations presented in chapter 6, using representative patent data to test the model's applicability and effectiveness. These simulations evaluate scenarios that involve firms with differing market positions and patent portfolios, offering insights into how factors such as sectoral fragmentation and exclusivity considerations influence strategic decisions.

In addition to the model validation, this thesis includes an economic analysis presented in chapter 7, which evaluates the economic benefits and potential impacts based on the developed framework. This analysis builds upon the model outlined in chapter 5 and the simulation results detailed in chapter 6, offering insights into how the proposed strategies can enhance collaboration efficiency, optimize resource allocation, and foster innovation. By quantifying the financial implications of optimal knowledge-sharing strategies, this chapter aims to prove the practical relevance and applicability of the framework in real-world industrial contexts.

Finally, chapter 8 concludes the master's thesis by summarizing the key takeaways and achievements of the project, reflecting on the most significant advancements made in understanding and optimizing industrial property collaboration. The final chapter also explores potential improvements and future research directions, highlighting areas where the model could be further expanded or refined, such as incorporating additional factors or scaling the framework for more complex industrial scenarios. These forward-looking insights aim to guide and promote further exploration of this critical area, ensuring the continued development of innovative strategies for knowledge-sharing and intellectual property management.

In conclusion, this project aspires to serve as a comprehensive framework for fostering collaboration and innovation among companies. By integrating key contextual, sectoral, and strategic factors, the developed model moves beyond simplistic solutions, offering a nuanced approach to optimizing knowledge-sharing processes. Its ability to evaluate the unique conditions of each scenario ensures that the most effective collaboration strategies are identified, promoting mutual growth and innovation. This framework not only addresses the complexities of industrial property management but also sets a foundation for creating a more dynamic and cooperative industrial landscape, where industrial property can be leveraged to its fullest potential.

Chapter 2

The Basics of Industrial Property

"Everyone has the right to the protection of the moral and material interests resulting from any scientific, literary or artistic production of which he is the author."[1].

On December 10, 1948, the United Nations General Assembly accepted in Paris the Universal Declaration of Human Rights (UDHR)[1]. This foundational text settled the basis of human and civil rights and freedoms. Within this text, the second statement of Article 27 recognized industrial property rights as fundamental human rights.

This chapter serves as an introduction to the fundamental ideas of industrial property, focusing on understanding what it is, its most relevant types, and the reason for protecting it. Among the main forms of industrial property, particular emphasis will be placed on patents, assessing the key patentability criteria, and the procedural complexities that inventors have to cope with while aiming to protect their innovative ideas, among other topics. Furthermore, this chapter will also examine the current landscape of industrial property in a globalized marketplace characterized by rapid technological advancements and continuous innovation.

By the end of this chapter, a comprehensive understanding of key industrial property concepts will be established, serving as the cornerstone for the rest of this study.

[1]United Nations General Assembly (1948)

2.1 Contextualizing Industrial Property

Industrial property is typically regarded as one of the two main branches within the broader concept of intellectual property, the other being copyright. However, it is important to note that in certain countries, such as Spain, the term ”intellectual property” may be understood to refer exclusively to copyrights[2]. As its name suggests, industrial property focuses on industry-related creations, while copyright primarily deals with artistic, literary, and creative works.

Although this project will center on industrial property intending to optimize knowledge exchange within the industrial value chain, this section will provide a general context for all types of protection. , encompassing all legal rights that arise from intellectual activity in the industrial, scientific, literary, and artistic fields. These protections play a crucial role in fostering innovation by granting creators and inventors exclusive rights to their creations for a limited time, allowing them to control the use of their ideas and innovations[3].

This section explores the origins of industrial and intellectual property and the principles that regulate their protection. It will define intellectual property and discuss the rationale behind protecting these intangible assets.

2.1.1 Origins

The origins of industrial property and copyright can be traced back to ancient times, with one of the earliest known examples dating to around 500 B.C.E. in the Greek colony of Sybaris, where chefs were granted year-long monopolies for creating unique culinary dishes[4]. Although specific laws did not exist in Ancient Greece or Rome, the author Bruce Bugbee compiles in his book 'The Genesis of American Patent and Copyright Law'[5] some notable property disputes in ancient times. In the first century B.C.E., the Roman architect Vitruvius exposed literary theft during a contest in Alexandria, where false poets were tried and convicted for plagiarism. Similarly, the Roman poet Martial accused Fidentinus of reciting his works without proper attribution. While these cases highlight early recognition of intellectual ownership, the lack of formal institutions or legal frameworks in ancient societies demonstrates that the protection of creative works remained informal and situational during this era.

[2]Spanish Institute for Foreign Trade (ICEX)
[3]Kalanje, C.M. (2006)
[4]Moore, A. & Himma, K. (2022)
[5]Bugbee, B. (1967)

Since ancient times, when industrial property and copyright protection were rare and largely informal, property rights have expanded remarkably. Today, exclusive legal rights are claimed over a wide range of intangible assets, covering not only inventions and artistic works but also other intangibles, including the triangular prism shape of Toblerone's chocolate bars[6], the signature blue color of Tiffany & Co.[7] or the roar of the Metro-Goldwyn-Mayer lion[8].

How did the legislation on industrial property and copyright evolve from being considered atypical to the current scenario, where property laws can protect shapes, sounds, or even colors? This section will explore the origins of these laws and trace their evolution, examining how they developed into the legal frameworks that exist today.

The history of industrial and intellectual property law traces back centuries, with the first recorded modern patent being granted in the year 1421 by the city-state of Florence to Filippo Brunelleschi, an architect renowned for designing the dome of Florence's cathedral[9]. A more lasting foundation came in 1474 with the Venetian Republic's statute, which is considered the basis for the first institutionalized patent protection[10]. This statute came 150 years before England's Statute of Monopolies, a key law introduced in 1624 that granted fourteen-year exclusive rights to authors and inventors for their creations[11].

In 1710, the Statute of Anne further advanced intellectual property regulation by establishing what scholars recognize as the first modern copyright statute, shifting the focus toward protecting authors' rights[12]. Around this period, the term "intellectual property" first appeared in the Oxford English Dictionary in a 1769 issue of the Monthly Review.[13].

Global efforts to formalize industrial property and copyright protection continued into the 19th century with the signing of the Paris Convention for the Protection of Industrial Property[14] in 1883, which established a framework for the protection of industrial property and remains in effect today. Shortly after, the Berne Convention

[6] Metida (2023)
[7] Tiffany & Co. (2024)
[8] Daniel, L. (2012)
[9] Willson Gunn (2014)
[10] May, C. (2010)
[11] Brown, M. & Evans, A. (2024)
[12] Intellectual Property Rights Office (IPRO)
[13] Mehmood, S. (2016)
[14] World Intellectual Property Organization (WIPO)

for the Protection of Literary and Artistic Works[15] was signed in 1886 by ten European countries to safeguard original creative works. In 1893, these two conventions were merged under the title United International Bureaux for the Protection of Intellectual Property[16], marking a unified approach to intellectual property protection. This organization later moved to Geneva in 1960 and was succeeded by the World Intellectual Property Organization (WIPO) in 1967,[17].

Today, the WIPO remains the United Nations agency dedicated to helping creators, innovators, and entrepreneurs protect and promote their intellectual property, while also serving as a key forum for addressing emerging intellectual property issues[18]. Since its establishment, the WIPO has worked toward a harmonized global intellectual property system, facilitating agreements such as the Patent Cooperation Treaty in 1978, which allows applicants to seek patent protection in multiple countries simultaneously[19].

In line with this drive for international unification, the World Trade Organization (WTO) introduced in 1994 the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). This multilateral agreement plays a crucial role in promoting global trade in knowledge and creativity, resolving intellectual property disputes, and ensuring that WTO members can balance international obligations with their domestic policy needs[20].

As highlighted in this analysis, industrial property and copyright regulations have progressively become stricter over time, while simultaneously evolving into a more globalized system aimed at ensuring robust protection for creators and innovators. This framework has helped provide security and encourage investment in innovation by safeguarding industrial property and copyright across borders. However, as will be explored in later sections, this increasing restrictiveness and the limitation of free access to knowledge can have negative consequences.

2.1.2 Definition

Defining the concept of intellectual property is a complex topic. Thus, most definitions available focus on listing the different types of property protected by

[15] World Intellectual Property Organization (WIPO)
[16] Encyclopedia Britannica (2024)
[17] World Intellectual Property Organization (WIPO)
[18] World Intellectual Property Organization (WIPO)
[19] World Intellectual Property Organization (WIPO)
[20] World Trade Organization (WTO)

intellectual property rights or simply on providing examples, rather than trying to provide a meaningful description of the subject. Moreover, the idea of intellectual property comes from a philosophical and ethical background, which only makes providing a concrete definition harder[21].

What is intellectual property then? Oxford's dictionary defines intellectual property as "an idea, a design, etc. that somebody has created and that the law prevents other people from copying"[22], whereas the University of Oxford adds that it "is intangible property that is the result of creativity and innovation and which can be owned in a similar way to physical property"[23]. The WIPO, for its part, defines intellectual property as "creations of the mind, such as inventions; literary and artistic works; designs; and symbols, names and images used in commerce."[24]

In 1998, the Office of the United Nations High Commissioner for Human Rights (OHCHR) organized the Fiftieth Anniversary of the Universal Declaration of Human Rights. During this event, the WIPO led a panel discussion on "Intellectual Property and Human Rights"[25]. Among the topics of discussion explored during this conference was the intricacy of defining intellectual property. The conclusion raised by the WIPO was that a proper definition of intellectual property has to focus on two elements: the property element and the object to which the property element relates.

Based on the analysis in this chapter and the sources consulted intellectual property will be understood, for this and subsequent chapters, as the set of intangible assets subject to legal rights that provide individuals or entities with ownership, control, and exclusive rights over the creative and intellectual works they produce. In simpler terms, intellectual property rights can be understood, as stated by the WIPO, as "the rights of exploiting information."[25]

2.1.3 Rationale for Protection

In the previous sections, the definition of intellectual property was established, along with an analysis of its origins and evolution leading to the present context. However, a significant question remains to be addressed to fully understand and

[21] George, A.(2012)
[22] Oxford English Dictionary
[23] University of Oxford
[24] WIPO, (2004)
[25] Holmes, W.C. (1998)

contextualize the concept: Why is it necessary to protect intellectual assets?

As previously mentioned, strict protection can harm economic development. In fact, theoretical economists are far from united when it comes to defending strong protections. Since the beginning of the century, many authors have pointed out that strict intellectual property rights are a double-edged sword as they stimulate innovation and cultural advancement by rewarding inventors and artists, but only at the cost of inhibiting the dissemination of their inventions and creative works[26] [27]. One of the most notable writings in this area is the book 'Against Intellectual Monopoly'[28] by Michele Boldrin and David K. Levine, where they argue that, in most cases, the protection of intellectual assets causes more economic harm than good and should be eliminated.

Given all of this, one could wonder: What are the true benefits of protecting intellectual assets? Why is it important to enforce such protections? And, how strict should the regulations be to strike the right balance between promoting innovation and ensuring access to knowledge? This section aims to bring light to these questions.

Discussions surrounding the rationale for protecting intellectual property have been a recurring theme in the field since the late twentieth century. In 1988, Justin Hughes published 'The Philosophy of Intellectual Property'[29], in which he presented some justifications for assigning ownership to intellectual property from a philosophical point of view. Hughes revised two theories he viewed as complementary and essential for justifying intellectual property rights: the Lockean Justification and the Hegelian Justification, or Personality Theory.

The Lockean theory, based on Locke's 'Two Treatises of Government'[30], argues that labor should be rewarded and that individuals can claim ownership through their work as long as "there is still enough, and as good left; and more than the yet unprovided could use". Hughes contends that this theory aligns with intellectual property but is incomplete. To complement it, he adds Hegel'philosophy[31], which emphasizes that property allows for personal expression and recognition. In this view, ideas belong to their creators as expressions of their personalities, making intellectual property a matter of personal identity.

[26] Chang, H. (2001)
[27] Boldrin, M. & Levine, D. (2002)
[28] Boldrin, M. & Levine, D. (2008)
[29] Hughes, J.
[30] Locke, J. (1689)
[31] Hegel, G.W. (1820)

Another philosophical justification and one of the most popular frameworks used to support these kinds of protection is the utilitarian perspective. The utilitarian arguments hold that the protection of intellectual assets incentivizes innovation by rewarding creators, ultimately benefiting society by fostering a continuous stream of new inventions, works, and creative expressions[32].

Given its popularity, the utilitarian justification has been one of the most discussed in academic literature. However, despite a substantial amount of theoretical and empirical research, the evidence regarding the impact of industrial property and copyright protection on innovation and economic growth remains mixed, as the reported effects often vary significantly depending on the specific methodological approaches of individual studies. Nonetheless, more recent papers analyzing the relationship between these rights, innovation, and growth suggest that protecting intellectual assets generally has a positive impact on innovation and economic growth, particularly in developed countries[33]

Some other key arguments for protecting intellectual assets are grounded in ethical considerations. Every creation requires considerable time, energy, effort, real capital, and specialized knowledge. Given the efforts involved in producing creative works, protecting the result can serve as a way to acknowledge and respect the intellectual contributions of creators, while ensuring they receive proper recognition and financial returns for their work[34].

As discussed throughout this section, there is no clear consensus on the necessity or degree of strictness with which intellectual property rights should be enforced. However, a common theme in the literature on the matter is the need for regulation that effectively incentivizes innovation. Nevertheless, finding the right balance between protecting intellectual assets and ensuring access to knowledge is a highly complex issue that remains a subject of ongoing debate. In this regard, this thesis aims to tackle the problems stemming from overly strict legislation by developing a model that fosters collaboration and knowledge exchange between companies.

2.1.4 Legislation

Industrial property and copyright are governed by a range of different national, regional, and international laws, each contributing to the legal framework. This

[32]Paul, R. (2021)
[33]Neves, P. et al. (2021)
[34]Shara, D.K. (2014)

multilayered governance structure is complex, involving numerous overlapping institutions and forums without a single, overarching rule-making body. As a result, navigating the sets of regulations can be considerably challenging, with varying standards and approaches across different jurisdictions. Therefore, this section will provide an overview of some of the most relevant laws and institutions with broad applicability, as well as a summary of common or typical aspects of the legal framework across various countries.

In the European Union, intellectual property rights are not only subject to national laws but also governed by EU legislation. Article 118 of the Treaty on the of the European Union (TFEU)[35] empowers the European Parliament and the Council to create measures for establishing EU intellectual property law. These laws aim to provide uniform protection of intellectual property across the single market and develop centralized, EU-wide systems for authorization, coordination, and supervision[36].

On a worldwide level, the WIPO plays a significant role in promoting and protecting intellectual property across borders through cooperation among its 193 member states and collaboration with various international organizations. WIPO aims to facilitate the harmonization of IP rights and standards worldwide. Additionally, the TRIPS Agreement is another key component of global intellectual property governance, establishing minimum international standards that all WTO members must adhere to. Non-compliance with TRIPS can lead to legal actions through the WTO's Dispute Settlement Mechanism, ensuring consistent enforcement of intellectual property standards globally.

The TRIPS Agreement defines some general principles for intellectual property rights, focusing on providing minimum standards for protection across various forms of intellectual property. The agreement also sets out rules for enforcement, emphasizing transparency and fair procedures. Additionally, it includes provisions for non-discrimination, requiring that intellectual property rights be applied equally to both domestic and foreign nationals[37].

[35] European Union (1957)
[36] European Parliament
[37] World Trade Organization (WTO)

2.2 Principal Forms of Industrial Property

Industrial property, as defined in the Paris Convetion[38], includes patents for inventions, industrial designs, trademarks, geographical indications, commercial names, and protection against unfair competition among others. Its regulation aims to safeguard signs and creations related to industrial products and services, preventing unauthorized use or misleading practices that could confuse consumers.

These various forms of industrial property provide tailored protection for different types of creations and innovations. This section will focus on the principal forms of industrial property identified by the WIPO[39]: patents, trademarks, industrial designs, geographical indications, and trade secrets.

- **Patents[40].** A patent is an exclusive right granted for an invention, offering legal protection to the inventor. This not only safeguards the invertor's interests but also benefits society by making technical details of the invention publicly accessible, promoting further innovation. Patents can be awarded for inventions across various fields, covering both products and processes. Patent protection prevents others from commercially exploiting the invention without the owner's consent, ensuring the creator's rights are upheld for a limited period within the relevant jurisdiction.

- **Trademarks[41].** A trademark is a sign that distinguishes the goods or services of one enterprise from those of others. Trademark registration grants the owner exclusive rights to use the mark and the option to license it to others for compensation. Various types of trademarks can be registered, including words or combinations of words, letters and numerals, symbols, logos, three-dimensional features such as the shape or packaging of goods, non-visible signs like sounds or fragrances, or color shades used as distinctive features.

- **Industrial designs[42]** Legally, industrial design refers to the ornamental aspect of an article, which can include three-dimensional features, like shape, or two-dimensional features, such as patterns, lines, or colors. The owner of a registered industrial design has the right to prevent third parties from making, selling, or importing products that copy or substantially replicate

[38] WIPO, (1967)
[39] World Intellectual Property Organization (WIPO)
[40] World Intellectual Property Organization (WIPO)
[41] World Intellectual Property Organization (WIPO)
[42] World Intellectual Property Organization (WIPO).

the protected design for commercial purposes. Industrial design protection can be applied to a wide range of goods, including packaging and containers, furniture and household products, lighting equipment, jewelry, electronic devices, textiles, or graphic symbols.

- **Geographical indications[43].** A geographical indication (GI) is a sign used on products that originate from a specific geographical location and possess qualities or a reputation attributable to that origin. To qualify as a GI, a sign must indicate that a product originates from a particular place, and its qualities, characteristics, or reputation should be primarily due to this geographical origin. This creates a direct link between the product and its place of production. GIs are commonly associated with agricultural products, foodstuffs, wines, spirits, handicrafts, and industrial products. The term "geographical indications" encompasses various concepts found in international treaties and national jurisdictions, such as appellation of origin (AO), protected designation of origin (PDO), and protected geographical indication (PGI).

- **Trade secrets[44].** Trade secrets refer to confidential business information that provides a competitive edge, protected as long as it remains secret and valuable. To qualify, the information must be unknown to the public, offer commercial value, and be safeguarded by its owner through measures like confidentiality agreements. Trade secrets can include technical details, such as manufacturing processes or software source codes, as well as commercial strategies, like client lists or marketing methods. Unauthorized disclosure or acquisition is considered unfair practice, but independent discovery or reverse engineering does not violate trade secret protection.

2.3 Patents: Cornerstones of Industrial Property

Among the different types of industrial property, this project will place special emphasis on patents, as they are not only the most widely used mechanism for protecting technical inventions but also the form of protection most focused on safeguarding knowledge. Unlike trademarks or industrial designs, which primarily concern the distinctive features or aesthetic aspects of a product, patents are directly tied to the safeguarding of technical know-how, playing a crucial role in protecting specialized knowledge and creative solutions.

[43] World Intellectual Property Organization (WIPO).
[44] World Intellectual Property Organization (WIPO).

As previously mentioned, a patent is an exclusive right granted for an invention, offering legal protection to the invention. So, in sectors driven by technology and research, patents are essential tools for safeguarding new inventions and technical expertise. This makes them central to the objectives of this master's thesis, which aims to optimize knowledge exchange within the industrial value chain.

Patents, by their nature, are a type of intellectual property that frequently gives rise to some of the most significant challenges in today's innovation landscape. Consequently, they play a pivotal role in optimizing the knowledge exchange between companies, making them a crucial area to address in this project.

This section will focus on key requirements for securing patent rights and the advantages they offer. Aiming to provide a comprehensive understanding of the significance of patents within the realm of industrial property.

2.3.1 Innovation as a Fundamental Element of Patenting

Innovation is a key concept across all areas of intellectual property, but it holds particular importance within the realm of industrial property, particularly for patenting. The innovative character of an idea or product is a fundamental requirement for claiming rights and protection under industrial property law. Without a novel or inventive element, inventions, designs, or processes cannot be legally safeguarded. This focus on innovation serves not only as a foundation for granting protection but also as a driving force behind the continued development of new technologies and solutions. In essence, innovation lies at the very core of patenting. But what exactly qualifies as innovation? What turns an intangible asset into something innovative? These questions, key to understanding how industrial property functions, will be explored in this section.

Innovation in the context of patenting is often linked to the development of novel solutions to technical challenges. While many industrial property laws don't provide a strict definition of what constitutes an invention, some countries describe it as the creation of new answers to technical problems. The problem itself could be old or new, but the solution must be original. Simply discovering something that already exists in nature doesn't typically qualify; there must be a significant degree of human creativity and inventiveness. Importantly, inventions don't need to be highly sophisticated—a simple innovation, like the safety pin, is a perfect example of solving a technical issue in a unique way[45].

[45]WIPO, (2016)

This focus on originality and problem-solving is crucial when determining what qualifies as innovation under industrial property. To be protected, inventions must not only be new but also demonstrate practical solutions to specific problems, regardless of their complexity.

2.3.2 Conditions of patentability

Not all inventions are patentable. Patent laws typically stipulate that an invention must meet the following five specific conditions[46], commonly referred to as conditions of patentability:

- **Patentable subject matter.** An invention is patentable if it falls within the scope of patentable subject matter as defined by national law. As a result, this varies from one country to another but typically encompasses processes, machines, manufactured items, compositions of matter, and their improvements, or even business methods. On the other hand, laws of nature, discoveries of natural substances, physical phenomena, varieties of plants or animals, abstract ideas, scientific theories, mathematical methods, and medical treatment methods (as opposed to medical products) are generally excluded from patentability. Additionally, it must be noted that any invention that requires restrictions on commercial exploitation to safeguard public order, morality, or public health may also be deemed non-patentable.

- **Utility.** For a patent to be granted, the invention must demonstrate utility, meaning it must have a credible, specific, and substantial purpose. The utility should be specific to the invention itself rather than a general benefit applicable to a wide range of items. Additionally, the invention must have practical use or be capable of some form of industrial application.

- **Novelty.** The invention must exhibit a unique characteristic that is not already known within the existing body of knowledge, referred to as prior art, in its technical field. This requirement is closely tied to the concept of innovation discussed in section 2.3.1.

- **Non-obviousness.** Patents must exhibit non-obviousness, meaning that the improvement should extend beyond the predictable use of existing knowledge (prior art) according to its established functions. The invention must show an inventive step that would not be easily deduced by a person with average knowledge in the relevant technical field.

[46]Christensen Fonder Dardi

- **Enablement.** The patent application must contain a comprehensive written description of the invention, detailing the method of making and using it. This description must be clear, concise, and thorough enough for individuals with ordinary skills in the relevant field to reproduce the invention without excessive experimentation. Additionally, the application must disclose the best mode for practicing the invention, making sure that it is sufficiently detailed for someone skilled in the art to understand and implement it.

2.3.3 Rights of a Patent Holder

The rights of a patent holder vary from one country to another, depending on national laws and regulations. The individual or entity to whom the patent is granted, known as the patentee or patent owner, gains exclusive rights over the invention in the country where the patent is issued. This means that anyone wishing to commercially exploit the invention within that country must first obtain the patentee's authorization. Without such authorization, any commercial use of the patented invention is considered illegal. Patent protection is granted for a limited period, typically 20 years. After this period, the protection expires, and the invention enters the public domain, commonly referred to as being "off patent".

Inventions are typically categorized into two main groups based on their nature: product inventions and process inventions. For instance, creating a new device is an example of a product invention, while developing a new method for producing a device is considered a process invention. These are commonly referred to as product and process patents, respectively.

The rights conferred by a patent vary depending on the type of invention and are defined in the patent law where the patent is issued. However, there are some common exclusive rights granted to patent holders across most jurisdictions[46]. These include:

- For product patents, the patentee has the right to prevent third parties from making, using, offering for sale, selling, or importing the product for commercial purposes without their consent.

- For process patents, the patent holder has the right to stop third parties from using the process without permission, as well as from using, offering for sale, selling, or importing products that are directly obtained through the patented process.

It is important to note that while the patentee has the exclusive right to prevent others from exploiting the invention commercially, this does not automatically grant them the right to commercially exploit the invention themselves. They still need to comply with other relevant laws and regulations in the country of interest.

2.4 Current Landscape of Industrial Property

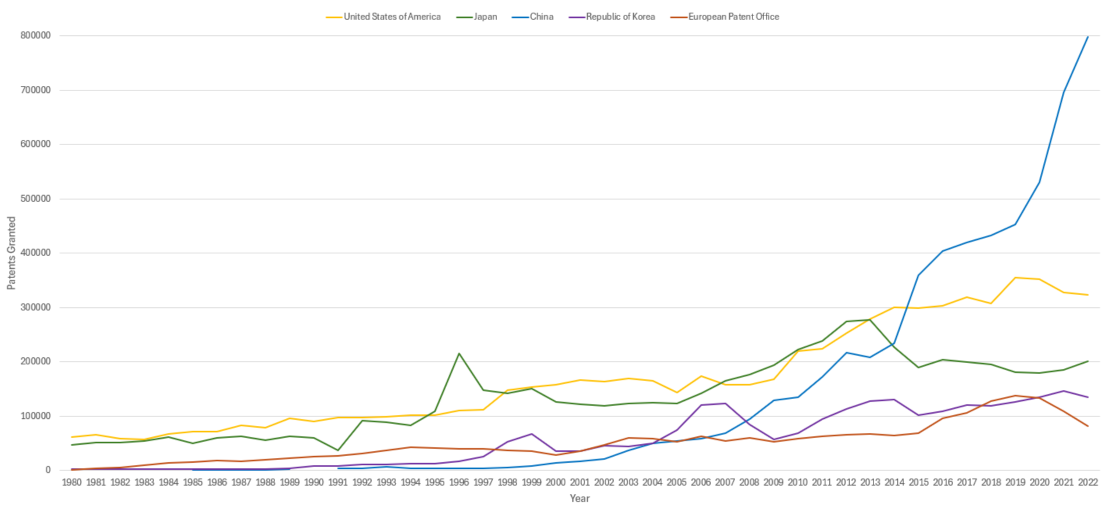
As mentioned throughout this chapter, one of the primary goals of intellectual property protection and consequently, of industrial property protection as well, has always been to encourage innovation by safeguarding the interests of inventors[47]. However, today's rapid advancement of new technologies alongside the continuous development of innovative products, driven by increasing globalization, has brought to light the growing issues that industrial property rights can present. This is why, as noted in section 2.1.3, many authors question the efficiency of industrial property rights, particularly if applied too strictly. Excessively rigid enforcement of industrial property protection may create barriers that obstruct others from building upon or improving existing ideas.

One of the most common scenarios observed in the past decades involves the existence of numerous overlapping patents, frequently owned by different industries, which complicates innovation processes[48]. This issue is particularly prevalent in the case of patents, leading to the phenomenon known as the "patent thicket." Patent thickets pose a significant challenge by creating complex webs of overlapping patents, which can hinder the patentability of new inventions and ultimately restrain innovation[49].

These thickets are commonly found among companies competing within the same sector and often reflect the cutting-edge technologies in that industry. Patent thickets are closely linked to the volume of patents, which, as illustrated in Figure 2.1, has notably increased since the 1980s, although recent trends indicate a slowdown in this growth rate, with some exceptions like China, where the growth rate continues to increase significantly. Consequently, driven by existing legislation and the rising number of patents granted, patent thickets have been steadily growing since the late 20th century[50].

[47] World Intellectual Property Organization (WIPO)
[48] Wagner, S. (2015)
[49] Saphiro, C. (2000)
[50] Hall, B.H. et al. (2013)

Figure 2.1: Number of patents granted per year



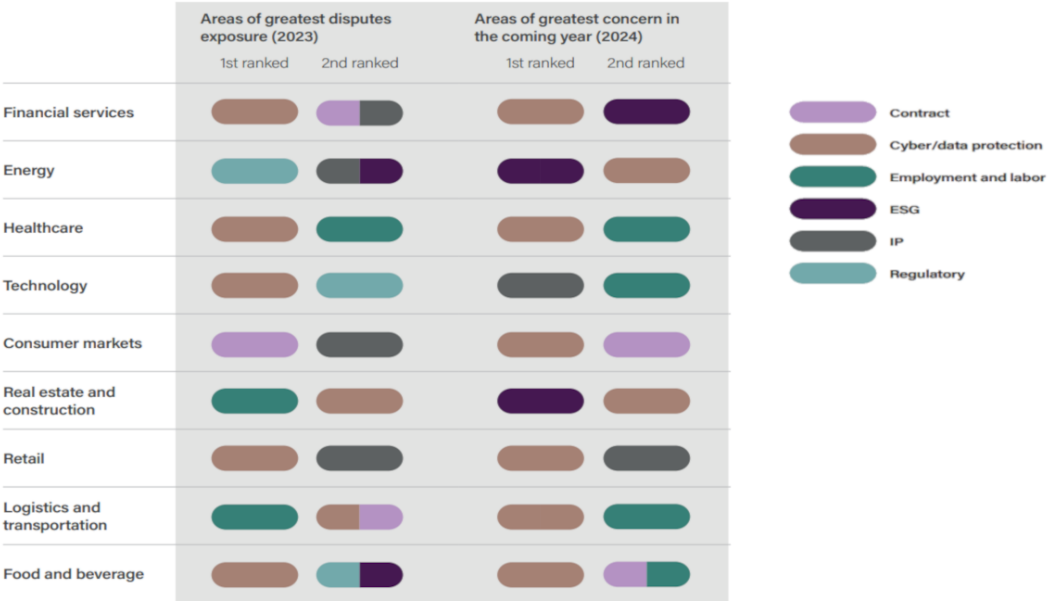
Source: WIPO IP Statistics Data Center. (2023)

The high costs associated with navigating the existing patent thickets create barriers to market entry, particularly for emerging companies[51]. These companies, which could bring fresh ideas to the market, are frequently unable to compete due to the prohibitive costs, leading to a decline in inventive activity. In fact, complex technologies, while attracting interest from numerous companies often see reduced competition due to these exorbitant entry costs, consequently resulting in market consolidation among already existing companies[52]. Moreover, these established companies, with their greater resources, may exacerbate this issue by creating patent thickets to protect their market dominance, even if they possess less creative capacity.

Additionally, since patents are intangible assets, their presence in a particular field is difficult to trace, making it easier for companies to infringe on industrial property rights[53]. As a result, the violation of these rights has become a common issue, often leading to costly legal disputes. As shown in Figure 2.2, studies indicate that intellectual property is one of the areas with the greatest dispute exposure across various business sectors[54], including financial services, energy, technology, consumer markets, and retail.

[51] Entezarkheir, M. (2016)
[52] Bessen, J. (2003)
[53] von Graevenitz, G.et al. (2013)
[54] Roosa, S. (2024)

Figure 2.2: Industrial litigations: concerns and exposures



Source: Norton Rose Fulbright. (2024)

However, the presence of patent thickets is not the only problem stemming from the significant growth in the volume of patents within industries. Patent holders may also use their rights to block access to their inventions by new creators, either by outright refusal or by imposing excessively restrictive conditions, creating what is known as a "patent hold-up."[55] This practice, when carried out in bad faith, is considered an act of unfair competition and poses a major threat to progress.

By preventing unauthorized use of their inventions, patent holders can establish monopolies[56]. As a result, this monopoly can act as a significant barrier to new companies entering the market, leading to reduced product variety and higher prices for consumers. Ultimately, this situation impacts consumers through reduced purchasing power and a potential decline in the quality of products.

Beyond the misuse of patents to block competition, unfair competition practices have become relatively prevalent, particularly in industries driven by innovation[57]. These practices, often bordering on or violating legal and ethical standards, pose a growing concern for both businesses and regulators. Unfair competition practices

[55] Galetovic, A. & Ross Levine, S.H. (2015)
[56] Lemley, M.A. & Shapiro, C. (1991)
[57] Elizabeth, Y.N. et al. (2021)

have not only triggered an increase in litigations but have also caught the attention of antitrust authorities[58]. These agencies, particularly in the U.S., are increasingly focused on how patent-related practices intersect with antitrust laws.

The concept of "patent hold-up" is especially controversial, as it allows patent holders to demand abusive royalties after their technology becomes an industry standard, undermining competition and driving up costs for consumers[59]. Antitrust regulators, including the Antitrust Division and the Federal Trade Commission, have taken steps to scrutinize these practices while trying to strike the perfect balance between protecting IP rights and preventing monopolistic behaviors that can stifle innovation and harm the broader economy.

As a result of the challenges discussed, resolving patent disputes more efficiently, reducing litigation, and accelerating progress has become increasingly necessary in recent decades. To achieve this, facilitating the exchange of knowledge and expertise between companies is essential. By doing so, the final objective is not only to help address the complexities of the current landscape but also to foster greater cooperation. Ultimately, this collaboration will create a more innovative marketplace, where industry growth is driven by shared knowledge.
Given the current competitive issues caused by industrial property regulation, this master's thesis will focus on exploring strategies that not only help companies overcome existing barriers but also encourage collaboration for maximizing mutual benefit. Instead of focusing solely on rivalry, the aim is to identify solutions that promote knowledge and resource sharing, enabling firms to navigate the complexities of today's landscape better.

2.5 Collaboration Strategies for Industrial Property Management

The sharing of value in intellectual property is critical to ensuring that its protection does not hinder innovation. Effective collaboration between companies plays a key role in facilitating knowledge exchange while safeguarding intellectual assets. Various methods of collaboration have been explored in the literature to strike a balance between protecting property rights and promoting progress. This section will explore some of the most widely adopted strategies for knowledge sharing, illustrating how companies can collaborate to foster innovation without

[58] Lemley, M.A. & Shapiro, C. (2019)
[59] Cotter, T.F. (2009)

compromising the security of their intellectual property.

The four most common forms of collaboration, which will be analyzed in this section, are Sale, Licensing & Cross-licensing, Cooperation (patent pools, alliances, and joint ventures), and Donation & Abandoning. These four approaches represent different strategies that companies can adopt to share knowledge, protect their intellectual assets, and foster innovation.

2.5.1 Sale of Industrial Property

The sale of intellectual property assets can be a beneficial strategic decision for companies when the value of the assets is greater to the buyer than to the original owner[60]. This scenario often arises when the current owner lacks the necessary resources to effectively produce or market the protected goods. In such cases, transferring ownership can unlock the full potential of the innovation, allowing the buyer to leverage their to bring the product to market successfully while also giving the seller financial gains from an asset they were not fully utilizing.

In fact, some academic studies[61] highlight that patented technologies acquired through purchase tend to be more complex, technologically advanced, and better legally protected than those developed internally. Additionally, these purchased technologies are often closer to foundational research, presenting an opportunity for the buyer to capitalize on advancements that they might not have otherwise accessed.

However, the sale of intellectual property is not without its challenges. A key concern lies in the disclosure of information regarding the invention. Insufficient information can hinder a potential buyer's ability to accurately assess the value of the asset, while overly detailed disclosure might jeopardize the negotiations[62]. In some instances, revealing too much could enable competitors to exploit the acquired knowledge independently, undermining the seller's interests.

To navigate these complexities, establishing a "patent fence" can be an effective strategy[63]. A patent fence is a defensive patent strategy where a company acquires patents on near substitutes for its core innovation, thereby creating a robust protective barrier around its intellectual property. This approach not only secures

[60] Chesbrough, H. (2007)
[61] Caviggioli, F. et al. (2016)
[62] Fisher, W.W. & Oberholzer-Gee, F. (2013)
[63] Grzegorczyk, T. & Glowinski, R. (2019)

the core invention but also encompasses associated processes and complementary or substitute products. By broadening the scope of protection, a patent fence can increase the costs for competitors attempting to circumvent the patents, thereby enhancing the security of any disclosure made during the negotiation process[64].

Ultimately, the sale of IP can serve as a powerful mechanism for value creation, benefiting both the seller and the buyer while fostering innovation in the market. This strategy is particularly well-suited when the sale value of the intangible asset exceeds the economic return that the selling company can derive from it while being less than the expected value that the buyer anticipates gaining. In other words, as mentioned at the beginning of this section, this approach is most effective when the value of the asset is greater to the buyer than to the original owner.

2.5.2 Licensing & Cross-Licensing

Licensing is a strategic alternative for firms seeking to leverage their intellectual property while addressing the challenges of market competition. While companies may hesitate to license patents that they are actively using to pursue market power[65], exclusive licensing to partners with complementary assets can facilitate the commercialization of their technology[66]. In fact, firms often do not patent technologies they do not intend to commercialize directly[67].

Licensing can also provide a lucrative alternative for companies when they lack the resources to defend their rights in the market. Additionally, another key advantage of licensing is that it can discourage competitors from developing alternative inventions by imposing low license fees[68]. Start-ups, in particular, often license technology from established companies to enhance their technological capabilities.

Although licensing agreements may not always provide full access to the knowledge and all organizational routines necessary for effective implementations[69], research indicates that firms typically transfer a significant degree of knowledge alongside their partner. Such agreements usually include enough comprehensive technology development reports, supporting documentation, and even ongoing collaboration with R&D staff.

[64] Reitzig, M. (2004)
[65] Somaya, D. (2012)
[66] Arora, A. & Ceccagnoli, M. (2006)
[67] Carlsson, B. et al. (2008)
[68] Belingheri, P. & Leone, M.I. (2017)
[69] Al-laham, A. et al. (2010)

When considering licensing arrangements, firms must decide between two types of agreements: exclusive and broad licensing[70]. Exclusive licenses are particularly beneficial for technologies in the early stages of development, while broad licenses can be more suitable for establishing industry standards. Additionally, firms should assess whether to license within their own industry or beyond. While partnering with industry peers may offer a more straightforward approach, it often comes with increased competitive risks.

Cross-licensing agreements present another effective strategy, particularly when both parties seek to mutually benefit from their respective inventions without incurring significant costs or risking litigation[71]. This approach enables companies to secure freedom of operation while gaining access to external knowledge[72]. It is especially advantageous in cumulative industries, where innovations often arise from interrelated technologies. Additionally, smaller high-tech firms frequently utilize cross-licensing agreements to ensure their ability to operate freely within their respective markets[73].

In conclusion, by engaging in licensing agreements, firms can unlock additional revenue streams while ensuring their intellectual property is optimized. On the other hand, cross-licensing allows businesses to share complementary technologies, facilitating collaboration and reducing the risk of costly legal disputes. These strategies not only enhance competitive advantage but also contribute to a more interconnected marketplace, where knowledge and resources are shared, ultimately accelerating technological progress and fostering innovation.

2.5.3 Cooperation in Industrial Property

In the realm of industrial cooperation, three primary strategies will be examined: strategic alliances, joint ventures, and patent pools. These three approaches can significantly enhance collaborative efforts among companies, particularly in the context of R&D.

Strategic alliances are particularly beneficial in the early phases of R&D projects, as they allow partners to leverage complementary knowledge and patents, leading to more effective execution and potentially increasing market share[74]. However,

[70] Ziegler, N. et al. (2010)
[71] Grimaldi, M. et al. (2018)
[72] Grindley, P. & Teece, D.J. (1997)
[73] Kohler, F. (2011)
[74] Lichtenthalter, U. (2005)

while alliances facilitate access to partner technologies, they can also limit a firm's ability to develop its own technological capabilities.

On the other hand, joint patenting can be used to create a form of leverage that ensures the continuity of the partnership, reinforcing mutual interests[75]. This form of cooperation fosters long-term partnerships, as the shared patent requires ongoing coordination for management, licensing, or further development. Moreover, joint patents are more commonly found when alliance partners have had prior collaborations, as these existing relationships tend to enhance trust and communication[76].

By aligning mutual interests, both strategic collaboration and joint patenting agreements reduce the risk of opportunistic behavior and strengthen the stability of the collaboration, particularly in industries where innovation is costly and complex.

An increasingly popular method of collaboration is the establishment of patent pools, which aggregate the licensed patents of various companies. This approach addresses the challenges posed by fragmented patent rights, particularly in high-tech sectors where network externalities tend to favor widely adopted technologies[77]. By collaborating to create a shared technology platform, companies can outcompete rival technologies while simplifying the complex patent landscape.

In recent years, successful instances of patent pools have demonstrated their utility in simplifying the problems caused by patent thickets, with notable examples being the CD and MP3 technologies[78]. These collaborations have proven effective in fostering industry ecosystems, promoting market adoption, and supporting innovation by streamlining access to essential patents and reducing the complexity of overlapping rights.

Although not the focus of this master's thesis, another compelling motive for cooperation is the co-creation of technical standards applicable to specific industries. Establishing a patented standard can provide a sustainable competitive advantage[79]. Moreover, sharing technologies among different companies can enhance the overall competitiveness of the technological landscape.

[75] Delerue, H. (2018)
[76] Kim, C. & Song, J. (2007)
[77] Di Minin, A. & Faems, D. (2013)
[78] den Uijl, S. et al. (2013)
[79] Leiponen, A. (2013)

2.5.4 Donation & Abandonding of Industrial Property

In 2012, the European Commission published a survey analyzing innovation indicators[80], which included an analysis of the percentage of patents that remain unused. The survey differentiated between patents that were strategically kept unused, often to block other patents—to prevent others from patenting similar inventions, complements, or substitutes—and those without strategic motives, referred to as "sleeping patents." The study, which included data from 20 European countries, the US, Japan, and Israel revealed that over 40% of patents were unused, highlighting a significant portion of intellectual property not being actively commercialized. Notably, more than 15% of these patents were "sleeping". More recent studies[81] on this share show that the trend has persisted, with approximately 40% of patents in Europe, the U.S., and Japan still remaining unused.

Donating or abandoning patents can be a practical solution for companies dealing with unused intellectual property. These inactive patents not only fail to generate revenue but also incur ongoing costs, such as renewal fees and taxes. In cases where the technology has become obsolete or external exploitation is not feasible, donation or abandonment can provide significant financial relief. Despite the potential benefits, patent donations remain relatively rare. Different factors such as uncertainty about tax advantages and the costs associated with valuing the patents may dissuade companies from pursuing this option.

2.6 Conclusions

In conclusion, the current landscape of industrial property is marked by notable challenges that can hinder innovation and market entry. The rising volume of patents, while intended to promote innovation, has led to the emergence and growth of patent thickets, along with unfair competition practices such as patent hold-ups.

Patent thickets as complex networks of overlapping patents, frequently held by competing companies, complicate the innovation process and create high barriers to entry for emerging firms. On the other hand, unfair competition practices like imposing restrictive conditions that prevent new creators from accessing essential technologies, lead to the establishment of monopolies that hinder competition and ultimately reduce product variety while increasing consumer prices.

[80] European Commission (2012)
[81] Torrisi, S. et al. (2016)

Moreover, the increasing number of litigations surrounding industrial property disputes underscores the urgency of resolving these issues efficiently. To foster a more innovative marketplace, it is crucial to facilitate knowledge exchange and cooperation among industry players. Given the current landscape, it is necessary to develop solutions that ensure industrial property protection, intended primarily to foster innovation, does not inadvertently hinder it.

One way to address these challenges is by fostering collaboration between companies. To facilitate this, there are four main strategies: sale, licensing & cross-licensing, cooperation (including alliances, joint patenting, and patent pools), and donation & abandonment. These strategies allow firms to tailor their approach based on their industrial property, market position, and innovation goals.

Each strategy has a specific context in which it is most applicable. Sale is ideal for instances where the buyer can derive greater value than the original owner, while licensing is well-suited for firms seeking revenue without renouncing ownership. Cooperation strategies enable shared access to technology, making them suitable for R&D partnerships and industry-wide standards. Donation and abandonment can provide an economical relief for unused assets.

By selecting the right collaboration strategy, companies can strategically optimize their competitive advantage, enhance the economic performance of their industrial property assets, foster innovation, and contribute to a more interconnected and cooperative industry landscape.

The objective of this master's thesis is to develop a model that employs game theory to assess the optimal ways of collaboration among the aforementioned alternatives, ultimately aiming to provide a framework for enhancing knowledge exchange and innovation within the industrial value chain. By doing so, this model seeks to address and help mitigate the current challenges posed by industrial property, such as barriers to innovation and market entry, thus supporting a more dynamic and accessible landscape for emerging technologies and competitors.

Chapter 3

The Basics of Game Theory

Understanding the basic principles of game theory is fundamental for this project, as the model to be developed will apply game theory to optimize knowledge exchange between companies. Game theory is particularly suited for this purpose because it provides tools to analyze strategic interactions and incentives among independent players, making it possible to assess cooperative and competitive behaviors. This approach can help identify optimal collaboration strategies that align with individual and shared interests, ultimately facilitating more effective knowledge sharing.

This chapter will provide a general overview of the main concepts related to game theory, establishing a foundation for the rest of this project. Key ideas Nash equilibrium, different types of games, and other fundamental aspects will be explored, setting the stage for applying game theory to enhance collaboration strategies in industrial property management.

3.1 What is Game Theory?

Game theory is the study of strategic decision-making among independent and competing entities, known as players, within a structured setting[82]. It provides a theoretical framework to analyze and predict interactions in social and economic scenarios where individual choices impact the outcomes for all participants involved. In essence, game theory is often considered the "science of strategy," focused on optimizing the decisions of rational players in competitive or cooperative contexts.

[82] Hayes, A. (2024)

Born in the 1920s as a branch of mathematics, the concept of game theory exploded significantly with the foundational contributions of John von Neumann and Oskar Morgenstern in their 1944 work, 'Theory of Games and Economic Behavior'[83]. Since then, it has become a vital tool for understanding complex interactions in fields as diverse as economics, political science, evolutionary biology, and business. Game theory helps predict likely outcomes for strategic situations such as pricing competition, merger decisions, or legal disputes.

Key elements of game theory include:

- **Players.** The decision-makers in a game, can be individuals, firms, or other entities.

- **Strategies.** The set of possible actions each player can take. Pure strategies involve specific, predetermined acts, while mixed strategies combine actions probabilistically.

- **Payoffs.** The outcomes or utilities players receive based on chosen strategies, reflect the benefits or losses of each action.

- **Information sets.** Knowledge available to players at each decision point. In perfect information games, like chess, players know all past moves, while imperfect information games, like poker, involve uncertainty regarding other players' actions or private information.

A fundamental assumption in game theory is that players act rationally, aiming to maximize their expected payoffs based on available information. Moreover, the concept of common knowledge is central, implying that all players are aware of the game's structure, strategies, and mutual awareness among players. Through these elements, game theory enables a structured approach to predicting the dynamics of strategic interactions across multiple real-world applications[84].

By focusing on how players' decisions influence each other's outcomes, game theory provides insights into the challenges and opportunities that arise in scenarios of both conflict and cooperation.

[83] Morgenstern, O. & von Neumann, J. (1944)
[84] Hayes, A. (2024)

3.2 The Nash Equilibrium

The Nash equilibrium is a foundational concept in game theory that describes a situation in which each player's strategy is optimal given the strategies chosen by all other players. Once a Nash equilibrium is reached, no player can improve their payoff by unilaterally changing their strategy[85]. This outcome reflects what is often called a "no regrets" position: each player has made a choice they won't regret, given the decisions of others, because no alternative choice could yield a better outcome under the existing conditions[86].

A Nash equilibrium typically emerges over time, especially in games that involve repeated interactions. In many cases, players engage in trial and error, adjusting strategies iteratively until reaching a stable equilibrium. Once this point is achieved, the equilibrium becomes self-sustaining since any deviation from it by a single player would not make sense, as it would not improve their position[87]. Therefore, the equilibrium outcome will remain robust, even when external conditions or individual preferences might change.

Nash equilibrium can exist in both pure and mixed strategies. In a pure strategy equilibrium, each player consistently chooses the same strategy. In a mixed strategy equilibrium, players may randomize over several strategies, reaching equilibrium through probabilistic choices. The stability of Nash equilibria, whether pure or mixed, provides a predictive framework for outcomes in competitive situations and helps in analyzing the strategic stability of decisions[88].

In games with relatively straightforward scenarios. such as those involving only two players with two choices each, finding a Nash equilibrium is often easier. However, in more complex games, especially those involving multiple players or dynamic interactions over time, multiple Nash equilibria may exist. This multiplicity of equilibria can present coordination challenges, as players may need to align their strategies across different potential outcomes[89].

In this project, the model will aim to achieve a Nash equilibrium in the exchange of information between industrial companies. The goal is to ensure that all parties involved in this collaborative process find an optimal balance in sharing knowledge and maximizing their mutual benefits.

[85] Nash, J. (1950)
[86] Flokas, L. et al. (2020)
[87] Kranton, R.E. (1996)
[88] Reny, P.J. (2003)
[89] Chatterjee, K. (2002)

3.3 Types of Games

Game theory encompasses various types of games, each of them with unique characteristics and implications for strategic decision-making. This section will focus on understanding these different types of games to assess which characteristics and classifications best align with the challenges presented in this master's thesis. Understanding these different categories will help identify the mechanisms that drive collaboration, competition, and overall decision-making processes relevant to this project.

3.3.1 Cooperative vs Non-Cooperative Games

Cooperative games focus on the dynamics of coalitions, where groups of players collaborate to achieve collective outcomes. In this framework, the primary concern is how these groups form and how they allocate the resulting payoffs among their members. The emphasis lies on collective interests rather than individual strategies[90].

Conversely, non-cooperative game theory examines interactions between rational agents striving to maximize their own payoffs. In these scenarios, players make strategic choices based on the available options and the anticipated actions of others. A simple illustration of a non-cooperative game is rock-paper-scissors, where players independently choose their actions without collaboration.

3.3.2 Zero-Sum vs Non-Zero-Sum Games

The distinction between zero-sum and non-zero-sum games is crucial in order to understand competitive interactions. In a zero-sum game, one participant's gain is precisely balanced by another's loss, resulting in a net benefit of zero[91]. Sports games like tennis, where there is one winner and one loser, exemplify this structure.

In contrast, non-zero-sum games allow for outcomes where all participants can benefit or suffer simultaneously. Business partnerships often reflect this scenario, as both entities can create mutual value rather than competing at each other's expense.

[90]Chatain, O. (2016)
[91]Barron, E.N. (2008)

3.3.3 Static vs Dynicam Games

Games can also be classified based on the timing of players' decisions. Static or simultaneous move games involve participants making choices concurrently, which is common in competitive business environments[92]. One of the most typical examples of this type of game is the Prissoner's Dilemma[93].

In contrast, dynamic or sequential move games allow one player to observe the other's actions before making a decision. This is often seen in negotiation settings, where one party articulates its demands first, allowing the other side to respond based on the revealed information. A classic example of a dynamic game is chess. In such games, the ability to respond to earlier moves adds a layer of complexity, as players can adapt their strategies to gain an advantage.

3.3.4 One Shot vs Repeated Games

One-shot games consist of a single interaction, making decisions irreversible. An example of this would be the aforementioned Prisonner's Dilemma, where players must choose carefully, knowing their decisions are final.

Repeated games, however, involve ongoing interactions among the same players. Each round allows participants to learn from previous outcomes, leading to strategic adjustments over time. A common scenario is rival firms adjusting their pricing in response to each other, creating a cycle of competition that reflects ongoing market dynamics[94].

3.4 Types of Strategies

In game theory, participants can choose from a range of strategies to navigate their competitive environments. The selection of a strategy typically indicates the level of risk a player is willing to take and their objectives in seeking the most favorable outcome. This section will analyze the most common strategies that players might employ, assessing which of these best aligns with the problem discussed in this master's thesis.

[92] Bencherkroun, H. & van Long, N. (2011)
[93] Kuhn, S. (2019)
[94] Scheve, T. (2024)

3.4.1 Maximax Strategy

The 'Maximax' strategy is characterized by a high-risk approach, where the participant commits fully to the possibility of achieving the best possible outcome. This strategy does not involve hedging against losses; instead, the player is all in or all out. A classic example is a startup launching a new product, which could significantly increase its market capitalization. However, if the launch fails, the company risks bankruptcy. Participants using this strategy are willing to face significant consequences for the chance of substantial rewards[95].

3.4.2 Maximin Strategy

In contrast to the previously described 'Maximax' strategy, the 'Maximin' strategy focuses on minimizing the worst possible outcome. Participants adopting this strategy are risk-averse and are willing to settle for a less favorable result to avoid the worst-case scenario. For instance, companies may choose to settle lawsuits out of court, accepting a less-than-ideal outcome to prevent potentially devastating consequences associated with a public trial[96].

3.4.3 Dominant Strategy

A dominant strategy is one that yields the best outcome for a player, regardless of the choices made by other participants. In business contexts, this may involve a firm expanding into a new market without concern for the actions of competitors. In the classic example of the Prisoner's Dilemma, the dominant strategy for both players is to confess, as it leads to a more favorable outcome than remaining silent, regardless of the other's decision[97].

3.4.4 Pure Strategy

A pure strategy involves making a specific, defined choice, without regard to the actions of others. This strategy requires minimal strategic decision-making. An example is a game of rock-paper-scissors in which a player consistently throws the same shape. The outcome is predetermined based on this consistent choice,

[95] Zagare, F.C. (1984)
[96] Mehmet, I. (2014)
[97] Hayes, A. (2024)

leading to predictable results[98].

3.4.5 Mixed Strategy

A mixed strategy combines various elements of randomness with calculated decision-making. While it may appear arbitrary, considerable thought goes into its execution. An illustration of this is seen in the relationship between a baseball pitcher and a batter. The pitcher must vary their pitches to prevent the batter from predicting their next move. By mixing strategies, the pitcher can create unpredictability, enhancing their chances of success[99].

3.4.6 Cooperative Strategy

The cooperative strategy is centered on collaboration among participants to achieve mutually beneficial outcomes. In this approach, players work together to optimize their collective payoffs rather than competing against each other. This strategy is particularly relevant in scenarios involving negotiations or partnerships, where parties may form coalitions to pool resources, share risks, or leverage their strengths for shared gain[100].

3.5 Conclusions

In conclusion, the exploration of game theory within this thesis has provided valuable insights into the dynamics of strategic interactions among participants in various contexts. Cooperative games, in particular, foster alliances and partnerships that enhance collective payoffs, making them highly relevant to this project. This is particularly crucial in scenarios where shared interests align, allowing participants to work together rather than in opposition.

The selected game model for this project is a non-zero-sum game, which signifies that the interests of the involved parties do not directly oppose each other. In non-zero-sum situations, all participants can benefit simultaneously, emphasizing the potential for mutual gains through collaboration. This characteristic aligns well intending to facilitate information exchange and innovation, which can benefit all parties involved.

[98] Pavel, L. (2011)
[99] Limaei, S.M. (2010)
[100] Suris, J.E. et al. (2007)

Furthermore, the design of this game will be static, as it aims to reach agreements simultaneously rather than through a sequential process. Additionally, the game will be framed as a repeated interaction, meaning that the participants will engage in multiple rounds of decision-making until they achieve an optimal outcome.

As the game is developed, it will evaluate various strategies that the involved parties might adopt. These strategies may include maximax, maximin, dominant, pure, mixed, and cooperative approaches. By analyzing how these strategies influence the outcomes, the model aims to identify pathways toward achieving optimal outcomes that enhance overall collaboration among firms.

Chapter 4

State of the Art

This chapter will delve into the existing body of research and models focused on knowledge sharing and collaboration. While Section 2.5 has already explored collaboration alternatives, the primary objective in this chapter is to investigate how the exchange of information can be effectively modeled, examining prior work in this area and identifying any existing models that can serve as references.

Additionally, this chapter will also address two critical factors: measuring the entanglement of patents across companies and valuing industrial property, as both factors are key to determining the optimal collaboration strategy.

The phenomenon of patent thickets, characterized by overlapping patents that complicate innovation, presents substantial challenges for firms. Moreover, the degree of entanglement among different companies can strongly influence the choice of certain collaboration alternatives, such as cross-licensing. For this reason, this chapter will examine methodologies and models for quantifying patent thickets, offering insights into how the level of entanglement can be assessed.

Furthermore, understanding the economic potential of each alternative is essential for optimizing knowledge exchange. Understanding how to evaluate industrial property will provide insights into how organizations can better leverage their assets in collaborative efforts. Therefore, this chapter will discuss key methods and models for valuing industrial property.

Through this comprehensive analysis, the chapter aims to present an informed view of the current landscape of collaboration models, patent entanglement measurement, and industrial property valuation. By synthesizing existing research, models, and methodologies, this chapter will lay the groundwork for developing a model that facilitates knowledge sharing and innovation in today's industrial landscape.

4.1 Patent Thickets Measurement

The concept of patent thickets has attracted significant academic attention, especially since Carl Saphiro introduced his theory in the book 'Innovation Policy and the Economy'[101]. Over the past two decades, patent thicket discussions have become a regular topic in industrial property court cases, and various public entities have published several policy reports and recommendations to address this issue[102].

Given the increasing relevance of the patent thicket problem in the last decades, numerous studies and reports have been issued analyzing potential solutions. Many of them agree that it is crucial to measure patent thickets in specific technology fields to address these issues. For this purpose, several methods have been proposed in the existing literature, some of the most relevant and widely accepted will be presented in this section.

Moreover, as discussed in the introduction of this chapter, measuring the level of patent entanglement among companies is highly relevant to this project's model, since a high degree of entanglement can make certain strategies, such as patent pooling or cross-licensing, more advantageous or even optimal.

4.1.1 Fragmentation Index

One of the initial methods for assessing patent thickets is the Fragmentation Index[103], proposed by Ziedonis, which builds upon the Herfindahl-Hirschman index to evaluate the distribution of patent rights at the firm level. This index serves as a tool to determine whether patents are primarily concentrated within a limited number of firms or are widely distributed among many patent holders.

The Fragmentation Index is designed to measure patent thickets by indicating the extent of fragmentation of patent rights. Originating from a normalized version of the Herfindahl-Hirschman index, commonly used to measure market concentration, this index can reveal patterns of patent ownership in specific technology domains.

While the Fragmentation Index is valuable for investigating patent fragmentation, it faces challenges when applied to larger datasets due to data collection difficulties.

[101]Shapiro, C. (2000)
[102]Egan, E.J & Teece, D.J. (2015)
[103]Ziedonis, R.H.(2004)

Therefore, when calculating this index, some studies[104] had to establish a threshold for the number of patents held by firms to ensure meaningful results, excluding many patentees with fewer patents. As a result, companies with fewer than 100 patents were often omitted from the analysis. Consequently, relying solely on large firms for this measurement may lead to skewed or inaccurate conclusions about the extent of patent thickets.

The mathematical calculation of the Fragmentation Index relies on the number of backward citations within a company's patent portfolio. For any given technology field *j*, the formula accounts for the references made by a company *i* to patents held by other companies *k*.

$$Fragmentation = \frac{1}{N}\sum_{i=1}^{N}\{(1-\sum_{k=1}^{k}(\frac{references_{ijk}}{references_{ij}})^2)(\frac{references_{ij}}{referencesij-1})\} \qquad [1]$$

During a specific timeframe, references$_{ij}$ indicates the number of citations of company *i* within technology *j*, whereas references$_{ijk}$ represents the overall number of citations of accompany *i* that cite patents owned by company *k* in the same technology *j*.

Overall, while the Fragmentation Index is useful for providing insights into patent distribution, it is more suited for smaller sample sizes within specific technology fields rather than for extensive network analyses. Additionally, it serves as a valuable indicator of the ease of patenting within a particular field or technology. Nonetheless, it may not be as effective for assessing the level of entanglement or overlapping patents among specific companies.

4.1.2 Patent Informatics for Patent Thicket Detection

The Patent Informatics Approach for Patent Thicket Detection[105], proposed by Clarkson in 2005, utilizes citation networks to assess the density of patent thickets through network analysis. This approach measures the "outdegree" or "indegree" within citation networks, where each citation from one patent to another represents a tie. The density within these networks serves as an indicator of the level of entanglement or thicket formation.

The method uses a modified version of the standard network density equation[106], which measures connections within a directed network and is commonly used in

[104] Cockburn, I.M. (2010)
[105] Clarkson, G. (2005)
[106] Wasserman, S. & Faust, K. (1994)

network analysis. This equation provides a measure of how densely connected a network with g is by summing the present links ties among nodes, where x_{ij} is the value of the from node i to node j, and then dividing that total by the maximum number of possible links.

$$\Delta = \frac{\sum_{i=1}^{g} \sum_{j=1}^{g} x_{ij}}{g(g-1)} \qquad [2]$$

In a patent context, each node (representing a patent) can potentially cite only previously issued patents, making it necessary to adjust the network density formula to account for the chronology of patents. Generally, newer patents have more potential citations to make, while the earliest patents in a field, having no predecessors, provide no citations. To address these variations, Clarkson proposed two equations: one based on outdegree [3] (citations made) and the other on indegree [4] (citations received).

$$\Delta_{p-out} = \frac{\sum_{n=2}^{g} \sum_{j=1}^{g} \frac{x_{nj}}{n-1}}{g-1} \qquad [3]$$

$$\Delta_{p-in} = \frac{\sum_{j=1}^{g} \sum_{n=2}^{g} \frac{x_{jn}}{n-1}}{g-1} \qquad [4]$$

Ultimately, Clarkson introduced a final formula for this methodology that focuses on all the system's outgoing or incoming citations, simplifying the calculation while preserving accuracy for a fully connected network. However, this approach assumes that circular citations do not exist, meaning a given patent i cannot both cite and be cited by another specific patent j. Consequently, for a network of g patents, the total number of possible citations is effectively halved compared to the original network case, as citations in both directions are not allowed.

$$\Delta_p = \frac{\sum_{n=1}^{g} \sum_{j=1}^{g} x_{nj}}{g(g-1)/2} \qquad [5]$$

This approach is particularly useful for analyzing patent density within smaller networks or specific technological fields, although it is limited in capturing trilateral relationships and large-scale networks. As a result, it proves valuable in evaluating patent thicket density, especially in the context of patent pool assessments or policy development.

4.1.3 Triples Indicator

The triples indicator, developed by Graevenitz et al.[107], provides a methodology for measuring patent thicket density across technology fields. In this model, a "triple" refers to a set of three firms, each of which holds forward citation-limiting claims on patents owned by the other two. This configuration reflects a situation where each firm can effectively block the other two, forming a mutually obstructive network of patent claims. Forward citations, in this context, represent instances where an older patent is cited by subsequent patents, indicating its relevance to current innovations and potentially its blocking effect on new patent claims.

Graevenitz and colleagues utilized European Patent Office (EPO) citation data, particularly focusing on critical citations classified as "X" or "Y," which are specifically recognized as blocking prior art. These classifications are established within the EPO's search reports for each patent application. Documents labeled as type X indicate prior art of particular relevance, potentially posing a direct obstacle to patentability. In contrast, type Y documents refer to prior art that, while not independently blocking, could collectively limit patentability when considered in combination with other patents. The presence of multiple triples within a technology area thus suggests a dense patent thicket, with significant mutual blocking across companies.

The triples indicator is particularly effective for evaluating thicket density within complex technological fields. In 2015, Fischer and Ringler[108] further refined the triples indicator by disregarding the distinction between critical and non-critical citations, thereby assessing variations in patent thicket density across different patent systems. Additionally, this model has proven useful for examining the behavior of patent entities, such as patent trolls, within densely patented fields.

In conclusion, the triples indicator algorithm involves partitioning patents into technology-specific subsets, identifying existing blocking relationships through X or Y references, and then analyzing mutual blocking pairs to form groups of three (or triples) where blocking is reciprocal across all three firms. This algorithm provides a systematic count of triples within a given technology area, highlighting the density of blocking relationships.

[107] von Graevenitz et al. (2011)
[108] Fischer, T. & Ringler, P. (2015)

4.2 Industrial Property Valuation

This master's thesis also seeks to explore and analyze various approaches to evaluating industrial property. Accurate valuation of industrial property assets is essential, as they represent a considerable portion of a company's intangible assets. Properly assessing these assets not only enables fair and strategic transactions but also informs company decisions around the management and growth of their capital. Given its to provide both competitive advantages and economic value, understanding its worth allows companies to capitalize on their assets to drive innovation, increase market leverage, and achieve sustainable growth[109].

Valuing industrial property is complex, as these assets lack physical form and are challenging to quantify objectively. Unlike tangible assets, industrial property value is largely dependent on the circumstances surrounding its use, resulting in a subjective valuation process. Typically, the value of industrial property is based on its contribution to additional revenue or cost savings, and the resulting economic impact for the company[110]. In a fully efficient market, the price of industrial property would ideally align with its expected net present value. However, limited holders of specific technologies, information asymmetries around technological development, uncertainties regarding the economic performance of the industrial property, and the considerable costs involved in transactions all contribute to a less-than-perfect market environment in real-life scenarios.

This chapter will analyze the most frequently discussed valuation methods in the literature, highlighting their key features, applicability, and limitations to provide a robust framework for understanding industrial property valuation techniques.

4.2.1 Fair Market Value

When two companies decide to collaborate one of the main objectives is to establish a fair and reasonable valuation, aligning with the concept of Fair Market Value. This standard ensures that both parties reach an equitable understanding of the asset's worth, fostering transparency and trust in the valuation process.

Fair Market Value[110] represents the price at which an asset would exchange hands between a willing buyer and a willing seller, each possessing reasonable knowledge of all relevant information and neither under compulsion to act.

[109] Farre-Mensa et al. (2020)
[110] Martin, D. & Drews, D. (2010)

In the context of industrial property valuation, the Fair Market Value standard assumes a hypothetical transaction that accurately reflects the asset's value based on the conditions of a competitive and informed market. Key to this definition is the absence of any compulsion on either party to participate in the transaction, which means neither the buyer nor the seller is under financial or legal duress, such as bankruptcy or court mandate, that would otherwise force the transaction.

Another crucial aspect of Fair Market Value is the assumption of a typical, rather than a specific, participant. Unlike valuations that may reflect unique strategic advantages for a particular buyer or seller, this standard seeks to identify the value that would be recognized by an average market participant. This requires that both parties in the transaction are acting in their own best interests, considering the broader economic climate, the characteristics of the relevant industry, and the unique qualities of the asset itself.

Furthermore, the Fair Market Value standard stipulates that both parties possess a reasonable knowledge of all relevant facts. While this standard doesn't require exhaustive insider knowledge, it does necessitate an informed understanding of available public information and industry norms. In practice, buyers and sellers may not have access to every detail about the asset; however, Fair Market Value is determined on the premise that they possess enough information to make a well-informed decision consistent with the general market.

4.2.2 Cost-Based Approach

The cost-based approach[111] is centered on the expenditures required to create or acquire the asset, offering a backward-looking valuation tied to historical costs. This method estimates the value of an asset based on the costs invested in its development rather than on potential future revenues. Typically, these models include adjustments for asset depreciation, which may vary based on company or industry-specific standards. Cost-based valuations are particularly useful for regulatory purposes, such as accounting and taxation, due to their simplicity and regulatory acceptance. However, they do not typically capture the economic value that might be derived from the asset, nor do they account for any future revenue-generating potential.

[111] Pitkethly, R. (1997)

The cost-based approach encompasses two distinct models[112]: the Reproduction Cost and the Replacement Cost. The Reproduction Cost method calculates the expenses necessary to replicate the asset exactly as it is, making it suitable for legal contexts, such as litigation. Conversely, the Replacement Cost estimates the cost to create a functionally equivalent asset rather than an exact duplicate, which can be useful for setting target prices before negotiations or determining royalty rates.

Cost-based approaches are particularly effective for early-stage technologies or assets with limited market data[113], where it may be more practical to calculate their cost basis than to project market revenues. Nonetheless, these models can overlook key economic indicators such as revenue and profitability potential. A robust cost-based valuation should therefore carefully account for opportunity costs, obsolescence risks, and direct expenses, ensuring that all relevant costs are factored in to provide a comprehensive, although historically oriented, perspective on the asset's value.

4.2.3 Market-Based Approach

The market-based approach[114] evaluates the worth of assets by comparing them to similar assets that have been recently traded in the marketplace. This approach derives value by identifying comparable assets and referencing their licensing revenues or sales prices. When a robust market of recent transactions exists, a market-based approach can provide a straightforward and reliable estimate, as it leverages real-world data to reflect the asset's perceived value under prevailing economic and industry conditions.

However, finding comparable intangible assets can be challenging due to the unique nature of industrial property and the limited public availability of transaction data. Key aspects, such as industry, geographic scope, exclusivity rights, and payment terms, must align closely with those of the industrial property being valued to ensure accuracy. Additionally, external factors, such as bankruptcy or forced divestitures, can distort transaction terms, potentially making these comparisons less reliable. An active, transparent market is ideal but uncommon in the industrial property field, where fewer transactions and a lack of widely published data make it difficult to gather adequate, comparable transaction information.

[112] Tobin, J. & Brainard, W.C. (1976)
[113] Razgaitis, R. (2008)
[114] Matsuura, J.H. (2004)

The market-based approach is highly effective when reliable comparison data is available. However, it can sometimes require supplementation with additional valuation techniques. Nevertheless, when sufficient information is available, the market-based approach remains one of the most commonly applied methods for industrial property valuation[115].

4.2.4 Income-Based Approach

The income-based approach[116] evaluates the value of industrial property by projecting future revenue or cash flows generated from its use and then discounting these anticipated earnings to a present value. This approach is widely applicable and particularly suited to intangible assets with clear revenue-generating potential, such as patented technologies or licensed trademarks. Unlike cost-based methods, which focus on past costs, income-based models are inherently forward-looking, estimating the industrial property's potential financial returns over its economic life. The primary components of this approach include forecasting income linked to the industrial property, projecting growth rates, determining the expected revenue duration, assessing risk factors, and isolating the revenue portion attributable to the asset.

One of the essential elements in the income-based approach is the discount rate, which adjusts future cash flows for both the time value of money and the uncertainty in revenue projections[117]. Selecting an appropriate discount rate is crucial as it reflects risks like market fluctuations, industry-specific challenges, and potential industrial property obsolescence. Techniques such as the Capital Asset Pricing Model (CAPM), Weighted Average Cost of Capital (WACC), and the Build-up Method are often applied to refine this rate.

The income-based valuations are highly versatile and widely used. However, they rely on accurate forecasting, making them less effective in uncertain or nascent markets where revenue projections may be speculative.

4.2.5 Relief from Royalty

The Relief from Royalty method is a hybrid valuation approach that combines elements of both the market and income methods. It estimates the value of an

[115] Ignat, V. (2016)
[116] Lopes, I.T. (2011)
[117] Michel-Schneider, U. (2022)

intangible asset by calculating the hypothetical cost savings the company achieves by owning the asset rather than paying royalties to a third party for its use. This avoided cost forms the basis of the valuation, as it represents the "relief" from not having to pay a royalty fee[118].

To apply this method, a forecast of revenue associated with the asset is established over its projected useful life. An appropriate royalty rate, based on comparable licensing deals from similar industries, is then applied to this revenue estimate. The selected royalty rate is crucial and should reflect the relative strength, market share, and risk factors specific to the asset, such as market growth, obsolescence potential, and legal protections. Factors like exclusivity, geographic scope, and advertising restrictions within comparable agreements also help refine this rate, as it must accurately represent the fair market value.

After determining the royalty rate, the present value of these hypothetical royalty payments is calculated by applying a discount rate. This discount rate incorporates relevant risks and may include an asset-specific premium to reflect the unique uncertainties tied to the industrial property. As a straightforward method that combines transparency with elements of both the market and income approaches, the Relief from Royalty method is widely used for brands, patents, and software. However, due to its reliance on market-comparable royalty rates, it often requires additional validation and may not be as commonly used as the more established market, cost, or income-based methods when highly reliable data isn't readily available.

4.3 Knowledge-Sharing Models

This section will not focus on knowledge-sharing methodologies, as they have been already analyzed in section 2.5. Instead, it will concentrate on identifying, analyzing, and reviewing the current state of research directly related to the primary goal of this master's thesis: developing a model to optimize information exchange between industrial companies.

A thorough review of the existing literature has led to two main conclusions: First, studies evaluating the effectiveness of knowledge-sharing mechanisms in industrial contexts are primarily ex-post analyses, meaning they examine past decisions but do not aim to aid in decision-making. Second, most existing models focus on a

[118] Hübscher, M.C. & Ehrhart, S. (2021)

single collaboration strategy and analyze its potential effectiveness rather than providing a complete integrated, decision-support tool.

This section will therefore present and analyze some of these models that could serve as a foundation or provide insights for developing the knowledge-sharing optimization model in this thesis. Given that the majority of existing models focus on a single collaboration strategy, this section will be divided into five parts, each dedicated to one of the different collaboration strategies outlined in Section 2.5: sale, licensing & cross-licensing, cooperation, and abandoning & donating. Additionally, a final subsection will examine more general models that provide broader perspectives on collaboration.

4.3.1 Sale Models

There are several models that use game theory to analyze asset sales strategies, though relatively few focus specifically on the sale of intangible assets like industrial property. This distinction is essential, as industrial property sales involve unique challenges, such as the risk of information diffusion and value depreciation as more entities gain access to the asset.

One study that analyzes sale strategies for industrial property is the one published by Yoshiaki Todoroki and Naoki Watanabe in 2018[119]. This study presents a game-theoretic model aimed at determining optimal pricing strategies for resalable intellectual property, which does not have the legal protections afforded by patents. The model considers a sequence of trades in which the initial owner strategically decides to sell to select players, balancing the maximization of profit with control over information diffusion.

To model this, the authors use backward induction to assess how an initial industrial property holder should optimally price and control the resale process. The model explores different outcomes, where the initial holder may either maximize profits through controlled resales or retain exclusivity if the marginal benefit of resale falls below the profit from exclusivity.

[119] Todoroki, Y. & Watanabe, N. (2018)

4.3.2 Licensing & Cross-Licensing Models

Licensing and cross-licensing represent some of the most common and widely studied methods for knowledge sharing between companies. Due to their frequent application in industry, numerous models have been developed to explore and optimize these strategies. This section will therefore focus on presenting a selection of the most complete or relevant models within this area.

In 2013, Shin Kishimoto published a study[120] examining stable bargaining outcomes for patent licensing under oligopolistic market conditions. This study models licensing negotiations as cooperative games without side payments, focusing on cost-reducing technologies in markets with Cournot competition. Additionally, the paper investigates two main licensing approaches, fixed-fee and per-unit royalty licensing, assessing their outcomes through core and bargaining set solutions. The analysis emphasizes how these licensing structures impact coalition formation and stable bargaining outcomes, as firms negotiate either a fee or royalty rate through coalition-based strategies.

Alineas Mallios in 2018[121] expanded on this approach, publishing another thorough study examining patent licensing dynamics in an oligopolistic setting, with a focus on cost-reducing technology within Cournot competition among firms. This study also evaluated the two distinct licensing methods, fixed-fee, and per-unit royalty licensing, analyzing their effects on profits, competition, and consumer surplus. The model assumes that one firm holds a patent for a cost-saving technology, which it may license to competitors, addressing cases where competitors can either perfectly duplicate the technology or not.

Both these studies provide significant insights into how patent holders strategically make licensing decisions in industrial settings, balancing competition with the benefits of licensing. As evidenced by these studies, models addressing licensing agreements also place particular emphasis on payment structure, examining the effects of fixed fees versus per-unit royalties in determining the most beneficial approach for patent holders and licensees.

Another study of particular interest for this section is the one issued by Dan Zhao in 2017[122], which models how firms decide whether to license their technologies unilaterally, engage in cross-licensing, or avoid licensing altogether. This study models strategic cross-licensing behaviors between firms in an oligopoly, focusing

[120] Kishimoto, S. (2013)
[121] Mallios, A. (2018)
[122] Zhao, D. (2017)

on the impact of cost-reducing and quality-improving innovations. The model mainly addresses four major issues: antitrust and welfare implications, incentive compatibility, the role of firms' bargaining power, and the relative importance of cost versus quality improvements in shaping licensing decisions.

In the game presented in this paper, two firms possess different innovations, one has quality-enhancing technology, while the other has a cost-reducing innovation. These firms engage in Cournot competition, where they determine output quantities based on their chosen licensing strategies. The model considers several potential outcomes: unilateral licensing by either firm, cross-licensing or no licensing. By examining these scenarios, Zhao explores how each firm's strategic incentives change based on innovation intensity (drastic vs. non-drastic), product quality differentiation, and production cost differences.

4.3.3 Cooperation Models

Patent pooling is one of the most extensively explored collaboration strategies in the literature, with analyses conducted both ex-ante, to assess the decision to form a pool, and ex-post, to evaluate its efficiency. Various models, based on game theory, explore the incentives and dynamics involved in creating patent pools.

One of these models was presented in 2010 by Jay Pil Choi[123]. This study develops a model to analyze the dynamics of patent pool agreements under the uncertainty of patent validity, which is treated as probabilistic. Choi emphasizes that patents are often contested, as firms may challenge the scope and validity of each other's patents, with litigation becoming an essential part of managing intellectual property rights. This uncertainty creates incentives for firms to form patent pools as a strategy to reduce litigation costs and resolve or prevent disputes over overlapping patent claims.

The model uses a game-theoretic approach to assess firms' decisions to litigate or form pools, taking into account factors like the complementary or substitutable nature of patents, which influence whether patent pooling is welfare-enhancing or anticompetitive. For instance, patent pools are generally seen as pro-competitive when patents are complementary, as they reduce overall royalty rates for consumers. However, when patents are substitutes, pools may elevate royalties and reduce competition, thus potentially harming social welfare.

[123]Choi, J.P. (2010)

Choi also distinguishes between ex-ante and ex-post patent pools, formed before or after a court validation, respectively. The model suggests that ex-ante patent pools should be restricted, especially if firms are likely to litigate to challenge patent validity. In contrast, ex-post patent pools can be more beneficial, particularly when patents have been confirmed as valid and are complementary, allowing for more efficient use of combined technologies.

The model developed by Choi was preceded by the study conducted by Lerner and Tirole in 2002, which also explored patent pools. The authors develop a theoretical model to evaluate patent pools, particularly focusing on conditions under which these pools enhance welfare. The model aims to clarify the role of patent pools in licensing by identifying necessary and sufficient conditions for a patent pool to be beneficial for social welfare. The researchers apply game-theoretic concepts to analyze both the incentives for forming pools and the antitrust implications, especially regarding patents that are either complements or substitutes.

Key elements of the model include examining the "independent licensing provision," which allows pool members to license patents separately. This provision serves as a tool for antitrust authorities to prevent welfare-reducing pools. The model also addresses the inclusion of future related patents in pools, analyzing how such arrangements might affect members' incentives to innovate or circumvent patents. Additionally, the study explores the concept of "essential patents," defining patents critical to the technology and lacking substitutes.

4.3.4 Donation & Abandoning Models

As previously mentioned, abandonment and donation of licenses represent relatively uncommon strategies in industrial property management, and as a result, there are fewer studies dedicated to analyzing and modeling these alternatives.

The study by Wen Zheng explores the role of patent abandonment in promoting cumulative innovation[124]. This study explores the role of patent abandonment in promoting cumulative innovation. By applying a strategic framework, Zheng models how a firm's decision to abandon a patent can foster subsequent inventions by external innovators who no longer face the transaction costs associated with accessing proprietary technology. This decision, according to the model, broadens the potential for innovation spillovers, as external inventors can freely build on the abandoned patent to create new technologies.

[124] Zheng, W. (2019)

The study suggests that, under certain conditions, patent abandonment serves as a positive-sum strategy that allows the original firm to learn from the developments made by external inventors and potentially reabsorb this knowledge in future innovations. Through a two-stage model, Zheng examines the firm's decision-making process, analyzing both the conditions under which firms may benefit from creating a "knowledge spillover pool" and the strategic value that abandonment can generate over time.

4.3.5 General Collaboration Models

Although less common, some models analyze various collaborative alternatives for knowledge sharing without focusing on a specific strategy. This section will review some of the most relevant models that take a broader approach to industrial collaboration, exploring mechanisms that can be applied across different strategies.

Some models identified in the literature do not focus on optimizing the method of collaboration itself but instead provide a framework that helps firms decide whether to adopt a collaborative or opportunistic strategy, analyzing the general incentives for collaboration. One such model, developed by Mingxing et al. in 2024[125], examines strategic dynamics within patent alliances, particularly focusing on how to mitigate opportunistic behavior that may arise from contractual gaps. Leveraging Evolutionary Game Theory (EGT), the research explores the incentives for forming alliances, the effectiveness of anti-opportunism strategies, and the impact of these measures on alliance stability. The model identifies two main strategies that alliance members may adopt: "reciprocity" (genuine collaboration through knowledge and technology sharing) and "opportunism" (contributing lower quality patents while accessing high value patents from other alliance members).

Another model that may be useful for this thesis is the study published by Shyama V. Ramani in 1995[126], which, while not specifically focused on industrial property, models collaboration strategies for research and development (R&D), involving knowledge-sharing alternatives that are relevant to this project. Ramani's study investigates the strategic rationale behind R&D alliances and examines various models of cooperative R&D through game theory. This study categorizes alliances based on specific goals, such as cost-sharing, information-sharing, R&D cartels, and joint ventures.

[125] Mingxing, L. et al. (2024)
[126] Ramani, S.V.(1995)

The study models each alliance type in terms of firms' motivations to engage in R&D collaboration, assessing factors like cost reduction, profit maximization, and market competition. Using a game-theoretic framework, Ramani highlights how different collaboration structures, such as cost-sharing alliances or research joint ventures, impact R&D investment, market outcomes, and profit distribution. For instance, it models scenarios in which firms might choose to enter a cost-sharing alliance to minimize expenses or an information-sharing alliance to leverage shared knowledge without duplicating efforts.

The study also explores the incentive structures within these alliances, identifying potential barriers to optimal collaboration, such as information asymmetries and risks of "free-riding." By simulating scenarios where firms decide between in-house development and various alliance types, this research provides insights into how market dynamics, R&D spillovers, and strategic behavior influence firms' decisions to collaborate. The paper offers a comprehensive game-theoretic foundation for understanding R&D alliances, highlighting the importance of economic incentives and strategic considerations in fostering successful and beneficial collaborative innovation.

Lastly, a research article on knowledge-sharing using game theory was published by Mingyu Xu et al. in 2024[127]. This model applies stochastic evolutionary game theory to simulate decision-making under environmental uncertainty. In this framework, participants first choose between active or negative fulfilling strategies, reflecting their initial commitment level to the commercialization process. They then select between two different sharing strategies, active or passive sharing, here active sharing represents a high level of engagement to support effective knowledge transfer, while passive sharing implies minimal involvement, potentially limiting commercialization success.

The model's simulations assess how changing external conditions, like reputation, economic incentives, or contractual structures, can impact the stability of these strategies, providing insights into conditions that optimize tacit knowledge sharing under uncertainty. This structured approach enhances understanding of how varying commitment and sharing strategies can influence the outcomes of patent commercialization.

[127] Xu, M. et al. (2024)

4.4 Conclusions

In conclusion, this chapter has reviewed key research, methodologies, and models that form the basis of patent thicket measurement, industrial property valuation, and knowledge-sharing strategies, highlighting both advancements and ongoing challenges in optimizing knowledge exchange.

As reviewed in this chapter, considerable work has been conducted on methods to measure the complexity of patent entanglements, particularly within specific technologies or industries. These methods rely heavily on patent citations to assess interconnectedness and often require extensive patent data for accurate assessment. However, as the number of patents increases, so does the complexity of analysis, making it challenging to quantify entanglements comprehensively across industries.

The three methodologies analyzed in Section 4.1 of this chapter offer effective ways to measure entanglement levels within patent networks. As previously mentioned, this information is particularly valuable for assessing the viability of collaboration strategies like cross-licensing or patent pooling, since these approaches' optimality relies heavily on the the degree of entanglement between the intellectual property of the parties involved in a knowledge-sharing process.

Moreover, these methodologies also allow for calculating additional factors, such as the concentration of intellectual property among the involved parties, which is highly relevant to this project's analysis. By incorporating both entanglement and concentration factors, these measurement methodologies contribute significantly to understanding the strategic landscape for optimizing knowledge-sharing.

Another widely discussed yet complex topic is how to evaluate industrial property. One of the most critical aspects to consider is that the value of these intangible assets depends significantly on context. This contextual dependency implies that the worth of industrial property can vary greatly based on its intended application and market setting, which makes its valuation particularly challenging.

Moreover, as nearly all of the valuation methodologies examined (except for the cost-based approach, which is less applicable and effective for this project) also rely heavily on future projections, their assessments largely depend on the available information about the asset. The anticipated revenue and market conditions surrounding the property can lead to vastly different valuations depending on who assesses it. This dependency on future expectations introduces inherent risks and uncertainties, as market dynamics, technological advancements, and competitive landscapes may evolve unpredictably. To address this, methods like the market-based approach often incorporate benchmarking, evaluating the asset's value in comparison to similar assets in the market whenever possible. This can help mitigate some of the uncertainties by grounding the valuation in observable market data.

Selecting an optimal valuation approach is thus highly context-sensitive, with the economic worth of industrial property closely tied to its intended use and market potential. This emphasizes the importance of carefully choosing the appropriate valuation method when assessing the economic potential of intellectual assets in collaborative environments.

For this project, another essential factor is that the value of an asset can differ greatly between companies, depending on their resources and strategic goals. This is particularly relevant for strategies like sale or donation, where an asset that holds limited value for one entity could have substantial potential for another.

Lastly, the research reviewed confirms that there is extensive work on modeling the benefits and strategies of knowledge sharing and collaboration. Other models focused on knowledge-sharing, although not specifically on industrial property, provide insights that are particularly useful for planning this project's model structure. Moreover, numerous models analyze specific strategies evaluating their characteristics and effectiveness.

Indeed, for each strategy, there are relevant studies that examine the dynamics of collaboration, often applying game theory to determine optimal structures. For example, several models address the best payment structures for licensing, comparing fixed-fee versus per-unit royalties, and offering valuable insights for structuring compensation within this framework. Additionally, there is extensive work on models that analyze whether or not to engage in knowledge sharing or collaboration in the first place; these are useful for establishing the overall collaboration framework within this project.

In conclusion, while notable progress has been made in examining the advantages, challenges, and optimal structures for various collaboration strategies, there is still significant potential to refine further and optimize collaborative processes, which is the focus of this master's thesis.

The methodologies and models reviewed in this chapter, including those for patent thicket measurement, industrial property valuation, knowledge-sharing strategies, and collaboration frameworks, provide a strong foundation for developing a model based on game theory that optimizes knowledge-sharing within the industrial value chain. Many of the formulations, methodologies, and assumptions explored here will serve as a framework for the model to be developed in subsequent chapters.

Chapter 5

Model Formulation

This chapter presents the formulation and structure of the code, written in Python and presented in Appendix A. The formulation is designed to optimize the exchange of information between companies for a given set of patents. The code aims to evaluate various strategic decisions regarding the management of industrial property, including abandoning, selling, or licensing patents, as well as forming a strategic alliance or establishing a joint venture between the parties involved.

The chapter begins with an overview of the problem, outlining the key parameters, variables, and assumptions considered in the solution approach. Following this, the methodology and formulation implemented to analyze the different strategies are explained in detail, including the application of game theory to identify an optimal solution. Finally, key computational aspects, such as the selection of Python libraries, data handling techniques, and optimization strategies, are also addressed.

5.1 Problem Definition

This chapter focuses on the definition and context of the problem, outlining the key parameters, and variables considered in the solution approach. The objective is to establish a clear foundation for the subsequent formulation and implementation of strategies aimed at optimizing the exchange of information between companies. By understanding the problem's structure and constraints, the chapter provides a roadmap for the analysis and decision-making process that follows.

5.1.1 Patent Information

This section focuses on the specific characteristics of the patents involved in the analysis. Key attributes such as ownership, technological field, and type are primary inputs for evaluating strategic decisions. Understanding the patents' unique features is essential for assessing their role in the optimization process.

Globally, patents are administered and recorded by several patent offices, which act as regulatory bodies for intellectual property. These offices, such as the European Patent Office (EPO)[128] and the United States Patent and Trademark Office (USPTO)[129], among other institutions, are responsible for granting patents and maintaining comprehensive databases of public information about them. This information typically includes ownership, technological classifications, publication dates, specific details about the patent, remaining protection time, publication numbers, and the current legal status of the patents.

Among this information, ownership, technological field, and remaining protection time are particularly critical for the current problem. These attributes allow the code to assess the type of each patent and optimize the exchange of information between companies.

A patent's technological field, as defined by the classifications of the corresponding patent office, provides a useful framework for distinguishing between two broad categories of patents:

- **Revenue-Generating Patents.** These are patents oriented toward direct commercialization or quality improvement. For instance, patents covering new products, advanced features, or unique commercial offerings are often used to generate significant revenue streams for their owners[130].
- **Cost-Reduction Patents**. These types of patents aim to improve efficiency through better manufacturing processes, operational tools, or supply chain optimizations. Their value lies in reducing production costs or enhancing productivity rather than in direct market sales[131].

The categorization of patents into these types is crucial for assessing their strategic value and optimizing decisions such as retention, licensing, or sale, as the patent type directly affects factors like how exclusivity impacts the asset's value[131]. The

[128] European Patent Office (EPO)
[129] United States Patent and Trademark Office (USPTO)
[130] Almeida, L. & Dierickx, I. (2005)
[131] van Triest, S. & Vis, W. (2007)

categorization process in the code relies on the information provided by the patent office databases, such as technological classifications.

In addition to categorizing patents based on their purpose, the code evaluates whether a patent would have a direct application or would instead be utilized for research and development (R&D). Patents intended for R&D require additional considerations, as they are integral to innovation processes but introduce some additional uncertainties regarding success and commercialization[132].

When a patent is used for R&D, two additional factors must be considered:

- **Success Rate of the R&D Process.** This refers to the probability that the research will yield viable outcomes, such as new products or processes that can be commercialized effectively. The likelihood of success depends on the nature of the patent and the field of application[133]. Additionally, it is crucial to achieve these results before a competing company patents a similar product, as this could limit or even prevent the ability to patent the outcomes. This scenario is known as a "patent race"[134].

- **Subsequent Application or Commercialization.** Even if R&D efforts succeed, it is necessary to estimate the feasibility of applying the discoveries and their potential for market success[135].

Finally, it must be noted that while the type of patent is determined based on the available data from patent offices, the decision to use a patent for R&D is treated as an external parameter in the model. This parameter is influenced by the decisions of the players involved in the game, reflecting their strategic preferences and resource allocations. By explicitly incorporating this flexibility, the code ensures that the scenario aligns with the expectations and objectives of each player.

5.1.2 Market Environment and Competitive Landscape

This section examines external factors influencing the optimal strategy for the patents. These include the competitive dynamics of the industry, and the size and capabilities of the companies involved, as both may impact collaboration or

[132] Merges, R.P. (1988)
[133] Hodge, J. and Hakkio, C. (1990)
[134] Denicolò, V. (1996)
[135] Sevensson, R. (2007)

licensing decisions. Such factors provide critical context for decision-making and help optimize the knowledge-sharing process.

The analysis of the market environment and competitive landscape will rely on the methodology outlined in section 4.1. Among the various approaches discussed, the Fragmentation Index, detailed in subsection 4.1.1, has been chosen for its ability to provide a robust measure of competitiveness within the patent landscape. This index, derived from the Herfindahl-Hirschman Index (HHI), captures the degree of concentration within the sector and provides insight into the distribution of ownership among key players based on the size of their patent portfolios[136].

The Fragmentation Index is particularly well-suited for understanding the dynamics of patent ownership within a specific technological domain[137]. By quantifying the number of players and the amount of patents they hold, the index provides valuable insights into the technology's market environment. A highly fragmented market, with numerous players holding small shares of patents, indicates a competitive landscape. Conversely, a low fragmentation score suggests a concentrated market where a few entities dominate patent ownership.

In this context, the Fragmentation Index can serve as a key indicator of the technological landscape, addressing aspects such as:

- **Number of Players.** The index reflects the number of entities active in the sector, offering a clear picture of how competitive or monopolistic the market is.

- **Ownership Concentration.** By analyzing the ownership distribution of patents, the index highlights whether a handful of companies control key technologies or are evenly distributed among many players.

This measure is especially relevant when considering strategic decisions around licensing or selling patents[138]. In a highly competitive landscape, where many players are involved, granting an additional player access to a patent through licensing is less likely to significantly impact the revenue the owner can generate. In contrast, in a less competitive landscape, where exclusivity is a key driver of revenue, granting access to the patent may result in a substantial reduction in potential gains for the owner. The degree of competitiveness, therefore, plays a

[136]Entezarkheir, M. (2019)
[137]Gambardella, A. & Giarratana, M.S. (2013)
[138]Noel, M. & Schankerman, M. (2013)

critical role in determining whether licensing or selling is the optimal strategy[139].

Additionally, the level of competition greatly affects the dynamics of research and development (R&D)[139]. In highly fragmented sectors, achieving a first-mover advantage in patenting and commercializing a new asset becomes significantly more challenging due to the increased number of players involved. A larger number of competitors intensifies the "patent race," where multiple entities may be simultaneously working towards similar innovations[140]. This elevated competition increases the likelihood that other players may secure a patent first, diminishing the benefits of exclusivity and the potential for market leadership.

The Fragmentation Index thus serves as a key indicator for assessing technological and market landscapes. By addressing factors such as the number of active players, the degree of ownership concentration, and the strategic implications of competition, this measure enables informed decisions regarding patent management and collaboration strategies. It also highlights the complexities of innovation in highly competitive environments, where the interplay of exclusivity, licensing, and R&D success becomes particularly critical.

In the code, this index will be calculated as a preliminary phase to the optimization process, using a representative sample of patents within the same technology domains as those involved in the game.

5.1.3 Patent Value

This section addresses the methods and decisions that could be used to estimate the economic value of each patent. Factors such as the potential revenue generated, market power, exclusivity, and technological relevance are analyzed. Accurate valuation is a cornerstone for determining optimal strategies, including licensing, selling, or joint ventures.

The methodology applied in this project to assess the value of patents is based on the information presented in section 4.2. To maintain flexibility within the model, the patent value will be treated as an external variable that the players involved must provide. This ensures that the optimization process remains adaptable to the specific context and circumstances of the companies participating in the analysis while remaining coherent with their internal expectations and assessments.

[139] Entezarkheir, M. (2016)
[140] Jell, F. et al. (2017)

For this optimization process, the income-based approach is selected to value patents. This method evaluates the patent's value based on the income it is expected to generate[141]. This income can take the form of revenue generation, where the patent directly contributes to the creation or commercialization of products, or cost reduction, where the patent improves efficiency, reduces production costs, or enhances operational processes.

While theoretically, a market-based approach could be considered optimal for determining a patent's value by benchmarking against comparable transactions, in practice, this method is limited. Patent transactions are often private, and the prices involved are rarely disclosed, making it challenging to obtain reliable and representative data for market-based valuations. This lack of information diminishes the feasibility of using market-based methods as a consistent valuation tool in the optimization model[142].

The income-based approach offers additional advantages over the market-based alternative. As discussed previously in this master's thesis, the value of a patent is highly dependent on the company assessing it, including its specific context, strategic goals, and circumstances. For instance, a patent's value may significantly vary based on its integration into a company's existing portfolio, its ability to complement current technologies or its alignment with the company's long-term objectives. Unlike the market-based approach, the income-based method accounts for these individual factors by directly linking the patent's value to the company's expectations and business model.

This flexibility allows the model to accommodate the unique characteristics of each player and their strategic priorities. By incorporating patent values as external variables and leveraging an income-based methodology, the optimization process ensures a practical, context-sensitive, and robust framework for evaluating patents.

5.1.4 Other Variables and Parameters

This section addresses additional variables that, while not falling under the primary categories, play a critical role in the analysis by influencing the outcomes of the decision-making process. These variables primarily relate to the costs associated with patents and knowledge-sharing activities, which are often decisive in determining the optimal strategy for managing intellectual property.

[141] Oh, J.W. & Park, H.W. (2022)
[142] da Cruz, G. et al. (2017)

Maintaining a patent involves recurring legal and administrative expenses, such as renewal fees, regulatory filings, and compliance requirements[143]. These costs tend to rise over time, particularly in jurisdictions where renewal fees increase with the age of the patent. For patents that no longer align with a company's strategic objectives or fail to generate sufficient value, the cumulative maintenance costs may outweigh their benefits, prompting companies to consider abandoning or donating the patent to reduce financial burdens[144].

Additionally, the costs associated with patent-related transactions are significant factors that significantly influence decision-making[145]. Selling or buying patents involves expenses such as valuation, negotiation, legal transfer of ownership, and due diligence. Licensing agreements will incur separate costs for both parties: licensors must manage licensing contracts, enforce royalty agreements, and monitor compliance, while licensees face initial fixed fees and ongoing royalty payments. On the other hand, collaborative strategies such as forming strategic alliances or joint ventures raise even more complexity. Strategic alliances frequently require resource alignment, integration of R&D processes, and shared intellectual property agreements, whereas joint ventures entail the highest transactional costs due to the need for creating a new entity, managing shared operations, and balancing ownership interests.

These costs can be decisive in determining the most viable strategy[146]. For instance, when the costs of registering or maintaining a patent exceed its expected value, abandoning or donating the patent may be a rational choice. Similarly, the elevated costs of forming a joint venture make this option justifiable only when both companies expect substantial mutual benefits, such as pooling complementary patents or accessing new markets. On the other hand, licensing or selling patents may be preferred in situations where lower transactional costs and quicker returns are prioritized.

By incorporating these variables, the model takes into account the financial and operational realities that shape strategic decision-making. This ensures that the proposed solutions are not only theoretically optimal but also practical and aligned with the constraints and priorities of the companies involved.

[143] European Patent Office (EPO)
[144] Zheng, Y. & Huang, J. (2022)
[145] Chen, Y.M. et al. (2016)
[146] Caviggioli, F. et al. (2017)

5.2 Assumptions

This section outlines the key assumptions considered in the development of the model. These assumptions provide the foundation for the analysis, defining the scope, constraints, and conditions under which the optimization process operates. By explicitly stating these assumptions, the model ensures clarity and transparency, enabling a better understanding of its structure and limitations. These premises are critical for simplifying complex scenarios, establishing a consistent framework, and guiding the interpretation of the results.

1. For the calculation and assessment of the sector's Fragmentation Index, it is assumed that patents with multiple owners are evenly shared among them. For instance, if there are two owners, the ownership is assumed to be split 50/50.

2. The type of patent will be automatically assigned as either benefit-generating or cost-reducing based on its technological classification unless otherwise specified by the players involved.

3. Exclusivity is assumed to affect only benefit-generating patents, including quality-improving patents.

4. The degree to which exclusivity impacts the value of a patent is assumed to be directly proportional to the Fragmentation Index (ranging from 0 to 10,000 by definition). Higher Fragmentation Index values (indicative of less competitive markets) will amplify the exclusivity effect on patent value.

5. The bargaining power of each player is assumed to be proportional to their percentage of ownership within the analyzed patent sample. Therefore, players with larger patent portfolios will have greater negotiating power than those with smaller portfolios.

6. The sale value and license fee of a patent are calculated based on the valuation provided by each player, incorporating the effect of exclusivity and the bargaining power of each party.

7. In cross-licensing processes, it is understood that each patent has its license fee. Cross-licensing is any process where two players license at least one patent to each other.

8. When more than two players are involved in cross-licensing patents, the process is considered a patent pool.

9. Licensing, cross-licensing, and patent pooling are assumed to follow the same dynamics, differing only in the number of patents and players involved.

10. Cooperative processes, such as strategic alliances and joint ventures, are assumed to incur only legal and administrative costs to establish and define the cooperation. These processes do not involve costs derived from licensing or selling patents.

11. In a strategic alliance, each player conducts the R&D process independently. As a result, their success chance and commercialization capacity remain unchanged.

12. In the case of a joint venture, both companies conduct the R&D process jointly. Therefore, their combined success chance and commercialization capacity increase.

13. The success chance and commercialization capacity of a company in a patent race are assumed to be proportional to its presence in the market, defined as the percentage of ownership it represents within the analyzed group of patents.

14. For simplicity, it is assumed that in R&D processes, all players involved will choose to use the same patents for R&D and that all these patents will be required for the process.

15. The annual costs of maintaining a patent are assumed to align with those provided by the European Patent Office (EPO). In Europe, maintenance fees are annual and increase significantly over time:
    - Years 1-5: 500€/year
    - Years 6-10: 1000€/year
    - Years 11-20: 3000€/year

16. Transactional costs associated with each strategy are assumed to fall within predefined ranges based on typical costs for similar transactions. Selling a patent is considered the least expensive option in terms of transactional costs while creating a joint venture is the most expensive.

17. For the optimization process, perfect information is assumed, given the collaborative nature of the project. However, an additional function has been developed to evaluate the viability of different strategies for collaborating on a specific patent with a known counterpart but with an unknown patent value.

5.3 Model and Mathematical Formulation

This section presents the model and its mathematical formulation, providing a structured framework to address the optimization problem defined in previous sections. The model integrates the key parameters, variables, and assumptions previously outlined, translating them into a formal mathematical representation. The objective is to create a robust and adaptable structure that captures the complexity of patent management and strategic decision-making.

5.3.1 Model Inputs and External Parameters

As section 5.2 about assumptions outlines, the model operates under perfect information, where all relevant data is known and accessible to the players involved. To achieve this, the following inputs must be provided as external parameters:

- **Game Data**. A parameter table detailing the patents involved in the optimization process and associated information to be optimized during the exchange. This table includes:
  - The patent name (publication number).
  - The owner of the patent.
  - The expiring date of the patent.
  - The type of the patent (benefit-oriented or cost-reduction-oriented).
    * The type can be provided directly or calculated in a pre-phase of the code, as described earlier, based on the available technological information.
  - Whether the patent is expected to be utilized for R&D purposes.
- **Sample of patents.** A representative sample of patents within the same technological domain. This data will be used during the pre-phase of the code to estimate the sector's Fragmentation Index and to calculate the bargaining power and the percentage of ownership of patents held by the players participating in the game.
- **Players.** The companies involved in the exchange of information.
- **Player-Specific Information.** A detailed table for each player, specifying:
  - Ownership. Whether each patent belongs to the player (ownership = 1 if yes, ownership = 0 if not).

- The value of each patent for the respective player. This value reflects the strategic importance or expected utility of the patent from the player's perspective.

These inputs serve as the foundation for the model's optimization process, ensuring that all relevant factors influencing patent management and strategic decisions are accounted for. By integrating these parameters, the model becomes capable of evaluating complex scenarios and identifying optimal solutions tailored to the specific context of the game.

5.3.2 Pre-Phase 1: Assessing Market Environment and Competitive Landscape

The first pre-phase focuses on calculating the Fragmentation Index, which evaluates the distribution of patent ownership within the sector. This metric provides critical insights into the market environment by determining whether the industry is dominated by a few players holding a large share of patents or fragmented among many players with relatively small shares. This analysis is essential for understanding the competitive landscape and its implications for strategic decisions regarding patent management and collaboration.

In addition to the Fragmentation Index, the function also calculates the percentage of patent ownership for each company operating in the sector. This metric helps quantify the influence and bargaining power of individual players based on their share of patents. Consistent with Assumption 1 in Section 5.2, if a patent is jointly owned by multiple companies, ownership is assumed to be distributed equally among the owners.

The first step in the process is to analyze the sector's patent data by creating a representation of the market's concentration and ownership distribution. Let P be the sample of patents in the sector, and for any given patent $p \in P$, let $A(p)$ denote the set of applicants (owners) associated with p. The sample of patents table includes a table that links each patent to its respective applicants.

To ensure accuracy, applicant names are first standardized by converting them to a uniform format, such as uppercase. This eliminates inconsistencies that might arise from formatting differences and ensures that each applicant is uniquely identified across the dataset.

For patents owned by multiple applicants, the ownership is divided equally among all associated entities. Specifically, for a patent p with $|A(p)|$ applicants, the ownership fraction allocated to each applicant $a \in A(p)$ is calculated as:

$$O(p,a) = \frac{1}{|A(p)|} \quad [6]$$

This approach ensures a homogeneous distribution of ownership for patents with multiple owners.

Next, the total number of patents p owned by each applicant a is determined by summing their fractional ownership across all patents in P. Mathematically, this is expressed as:

$$T(a) = \sum_{p \in P} O(p,a) \quad [7]$$

Where *T(a)* represents the total number of patents owned by applicant a across the sector.

The ownership percentage for each applicant is then calculated relative to the total number of patents in the dataset, $|P|$. This percentage is computed as:

$$\%T(a) = \frac{T(a)}{|P|} \cdot 100 \quad [8]$$

This metric quantifies each applicant's share of the patent landscape as a percentage of the total.

The final step involves calculating the Concentration Index (CI), a measure derived from the Herfindahl-Hirschman Index (HHI) that assesses the degree of concentration in the sector. The index is calculated as the sum of the squares of ownership percentages for all applicants:

$$CI = \sum_{a \in A} (\%T(a))^2 \quad [9]$$

The value of CI is then interpreted to assess the level of market concentration:

- $CI > 2500$: The market is classified as highly concentrated, indicating that a few players dominate the sector.
- $1500 < CI \leq 2500$: The market is classified as moderately concentrated, with some balance between dominant players and smaller ones.
- $CI \leq 1500$: The market is classified as low concentration, reflecting a fragmented landscape with numerous players holding relatively small shares.

This pre-phase plays a pivotal role in the optimization framework by providing essential insights into market dynamics and player influence. By analyzing the concentration of patents, it identifies the competitive structure of the market, highlighting whether it is fragmented or dominated by a few key players. In fragmented markets, strategic decisions such as licensing or collaboration often involve lower risks of exclusivity loss. Conversely, in highly concentrated markets, ownership becomes a critical factor in revenue generation, necessitating more cautious and strategic decision-making.

Additionally, the calculation of ownership percentages serves as a direct input to the optimization process, enabling the estimation of each player's bargaining and commercialization power. This ensures that strategic decisions are not only data-driven but also contextualized within the competitive landscape, reflecting the relative influence and leverage of each company. By incorporating these insights, the model is better equipped to navigate the complexities of patent management and collaboration.

5.3.3 Pre-Phase 2: Assessing Patent Value and Calculating Transaction Metrics

The second pre-phase is divided into two main components. The first involves an external process where each player independently assesses the value of their patents using the Income-Based Method. This step is internal to each company, as stated in Assumption 17 from Section 5.2, and reflects the premise that the valuation of patents is highly contextual, depending on the specific circumstances, resources, and expectations of the company owning the patent. By delegating this step to the players, the model ensures that the input values align with each company's internal assessment and strategic outlook.

The second component uses the outputs from the first pre-phase (Fragmentation Index and ownership percentages) and the internally derived patent values to calculate the sale value and licensing value of each patent involved in the game. These calculations are performed within the model and rely on a combination of the players' patent values, their bargaining power, and the expected variation in profits from licensing or selling the patents.

First, the bargaining power of each player involved in the game i is calculated based on their representation in the sector, as determined in Pre-Phase 1. Specifically, the share of patents held by each player $\%T(i)$ is divided by the total patent ownership across all players involved in the game to compute the relative power of each company:

$$power(i) = \frac{\%T(i)}{\sum_j \%T(i)} \quad \forall i, j \in players \tag{10}$$

This metric ensures that players with a larger share of patents in the sector have greater influence in determining transaction terms.

The sale value of a patent is derived by combining the patent values provided by each player with their respective bargaining power. For a patent p, the sale value is calculated as:

$$sale\_value(p) = \sum_i value_i(p) \cdot (1 - power_i) \tag{11}$$

Where $value_i(p)$ represents the value assigned to patent p by player i, and $power_i$ is the bargaining power of player i. This formula reflects the assumption that the sale price will be more favorable to the player with greater bargaining power, aligning with the notion that stronger players can negotiate better terms.

A patent is likely to be sold when the value assigned by the buyer exceeds the value assigned by the seller. In this case, the sale price is determined as a compromise weighted by the relative bargaining powers of the players involved.

On the other hand, the licensing value of a patent p will be determined by evaluating the expected variation in profits for both the licensor and the licensee. For the licensor, the variation depends primarily on the exclusivity factor (e), which quantifies how much exclusivity is lost when the patent is licensed to another player. The change in profits is calculated as:

$$\Delta profit_{licensor}(p) = value_{licensor}(p) \cdot e \tag{12}$$

For the licensee, the variation in profit is simply the value they expect to gain from the patent, adjusted for exclusivity:

$$\Delta profit_{licensee}(p) = value_{licensee}(p) \cdot (1 - e) \tag{13}$$

Once the profit variations for both parties are determined, the license fee is calculated based on these values and the bargaining power of the players involved. The license fee for a patent is derived as:

$$license\_fee(p) = \sum_i (\Delta profit_i(p) \cdot (1 - power_i)) \quad [14]$$

Licensing occurs when the license fee compensates the licensor for the loss of exclusivity while remaining lower than the profit the licensee expects to generate from accessing the patent.

Based on the formulation, it can be concluded that the exclusivity factor plays a central role in determining whether licensing or selling is more appropriate. In highly competitive markets, where the exclusivity factor has a smaller impact on revenue, licensing is often preferred, as the loss of exclusivity is less detrimental. Conversely, in less competitive markets, where exclusivity is a critical driver of revenue, the effects of licensing are more significant, making patent sales or retention the favored strategies.

This pre-phase bridges the internal patent valuations provided by the players with the external market dynamics captured in Pre-Phase 1. By calculating sale and licensing values based on bargaining power and profit variations, the model provides a structured and transparent framework for evaluating transaction strategies. Furthermore, considering the exclusivity factor highlights its importance in guiding strategic decisions, particularly in balancing the trade-offs between maintaining exclusivity and sharing knowledge through licensing.

5.3.4 Optimization model

This section presents the optimization model developed to evaluate strategic decisions in the exchange and management of patents. The model integrates the parameters, variables, and assumptions outlined earlier to construct a mathematical framework that captures the complexity of patent transactions. By analyzing the potential strategies available to each player the model seeks to identify optimal outcomes for all participants.

The core objective of the optimization model is to determine the Nash Equilibrium, where no player has an incentive to unilaterally change their strategy. This ensures that the selected strategies are mutually beneficial and stable within the competitive landscape. The formulation accounts for critical factors, including the type and value of each patent, bargaining power, transaction costs, and the exclusivity dynamics associated with the knowledge-sharing process.

Through this model, a structured and data-driven approach is applied to optimize decision-making, providing insights into the strategic interplay between players and their patents. This section details the formulation of the payoff matrix, the calculation of payoffs, and the methodology used to identify equilibrium strategies.

In a base case, where no patents are used for R&D, the optimization model generates a payoff matrix that captures the strategic options available to each player for their respective patents. Each player can adopt different strategies for every patent, including keeping, abandoning, selling, or licensing the patent. The matrix also considers all possible combinations of these strategies. For instance, if Player 1 owns two patents, A and B, their strategies would include combinations such as KeepA+KeepB, SellA+KeepB, LicenseA+AbandoneB, and so on.

As outlined in Assumption 7 of Section 5.2, if two players mutually license multiple patents, this will be considered a cross-licensing agreement, where the players exchange rights to use their patents without additional payments. Consequently, in the absence of R&D, the model focuses solely on three strategic options: sale, license, and cross-license, reflecting the primary transactions that occur in such scenarios.

The payoffs for each strategy combination are calculated based on several factors:

- The type of patent (revenue-generation or cost-reduction).
- The sale value and license fee associated with the patents.
- The costs outlined earlier in this chapter, including maintenance costs and transaction costs for selling or licensing patents.

The payoff for each strategy is derived from the following components:

- **Benefit from Revenue-Generating Patents B_i:**

Additional revenue obtained by each player i from each patent p involved in the game and classified as revenue-generating (RP). This benefit depends on the players' value for each patent $value_i(p)$, whether the player holds the use rights (a binary variable indicating access to the patent's usage), and the potential effect that exclusivity e may have on such value for each strategy. In the case of sale transactions, exclusivity is not affected, and $e = 0$, ensuring no loss in patent value due to reduced exclusivity. Conversely, for license transactions, the impact of exclusivity is proportional to the Fragmentation Index calculated during Pre-Phase 1, reflecting the competitive dynamics of the market. This ensures that the reduction in exclusivity accurately captures the broader market environment in which the patent operates.

$$B_i = \sum_{p \in RP} value_i(p) \cdot use\_rights \cdot (1 - e) \qquad [15]$$

- **Cost Reduction from Cost-Reducing Patents C_i:**

Operational savings for each player i resulting from each patent i classified as cost-reducing (CP) based on players' value for each patent $value_i(p)$, and whether the player holds the use rights (a binary variable indicating access to the patent's usage). In this type of patents, and as outlined in assumption 3 of section 5.2 exclusivity is assumed to have no effect.

$$C_i = \sum_{p \in CP} value_i(p) \cdot use\_rights \qquad [16]$$

- **Sale Value Income/Cost SV_i:**

Determined by the value $sale\_value(p)$ calculated during Pre-Phase 2 for each patent p, whether the patent is marked as being for sale (a binary variable indicating the strategy), and the transactional role of the player. Specifically, the sale value is assigned a positive value (+1) if the player takes the role of the seller, and a negative value (−1) if the player takes the role of the buyer.

$$SV_i = \sum_{p} sale\_value(p) \cdot sale\_transaction \cdot role \qquad [17]$$

- **License Fees Income/Cost LF_i:**

Determined by the value $license\_fee(p)$ calculated during Pre-Phase 2 for each patent p, whether the patent is being licensed (a binary variable indicating the strategy), and the transactional role of the player. Specifically, the license fee is assigned a positive value (+1) if the player takes the role of the licensor, and a negative value (−1) if the player takes the role of the licensee.

$$LF_i = \sum_{p} license\_fee(p) \cdot license\_transaction \cdot role \qquad [18]$$

- **Maintenance Costs MC_i:**

The total costs required to player i to retain each patent p it owns. These costs, as outlined in assumption 15 of section 5.2, depend on the patent's remaining years of validity $remaining_years_y(p)$, calculated based on the expiration date and the current year. Additionally, the costs $annual_maintenance_fee_y$ increase with the age of the patent, reflecting the standard fee structure for maintenance by year as

$$MC_i = \sum_y \sum_p annual\_maintenance\_fee_y \cdot remaining\_years_y(p) \cdot ownserhip_i(p) \quad [19]$$

defined by patent offices. The variable $ownership_i(p)$ is used to determine whether the player is responsible for these costs, ensuring that only the patent owner at a given time incurs the associated expenses, considering if ownership is transferred through a sale or purchase agreement.

- **Transaction Costs TC_i:**

Costs incurred by player i during transactions involving patent p depend on the type of transaction (e.g., selling or licensing) and the player's role as either the owner of the patent or the counterparty. These costs, as outlined in Assumption 16 of Section 5.2, vary across predefined ranges that are based on typical costs for similar transactions observed in industry practices. The ranges for these costs are summarized in Table 5.1.

Table 5.1: Transaction Costs Range

Type of transaction	min.	max.
Sale - Seller	8000	35000
Sale - Buyer	16000	70000
License - Licensor	12000	45000
License - Licensee	7000	30000

These ranges reflect the costs typically associated with patent transactions, such as legal fees, administrative expenses, and due diligence efforts. For sales transactions, sellers generally incur lower costs due to the straightforward nature of relinquishing ownership, whereas buyers face higher costs due to the need for detailed patent evaluations and regulatory compliance. Similarly, licensors often bear higher costs compared to licensees, as they are responsible for contract negotiations and compliance monitoring over time.

Considering all these calculations, the total payoff for player i, based on the strategies adopted for each patent p and their various combinations, is determined as:

$$payoff_i = SV_i + LF_i + B_i - (-C_i + MC_i + TC_i) \quad [20]$$

Once the payoff matrix is designed and calculated, the model seeks to identify the Nash Equilibrium, a state in which no player has an incentive to unilaterally change their strategy. In this equilibrium, each player's strategy is optimal given the strategy of the other player.

Once the Nash Equilibrium is identified, the model outputs:

- The **equilibrium strategies for each player**, specifying whether they keep, sell, or license their patents.
- The **associated payoffs for each player**, showing the total benefits or costs resulting from the selected strategies.

When patents are designated for R&D, the optimization model performs three parallel analyses, each generating a separate payoff matrix. These matrices account for varying levels of cooperation between the players and incorporate additional factors related to the success probability of R&D efforts. The structure and assumptions for each matrix are described below:

1. Non-Cooperation

In the first scenario, no cooperation occurs between the players. The payoff matrix retains the same structure as the base case, where strategies for each patent include keeping, selling, abandoning, or licensing. For patents designated for R&D, the payoff calculations are adjusted to account for the probability of successfully completing the research and implementing or commercializing the resulting innovation before competitors.

As outlined in assumption 13 of section 5.2, the probability of obtaining a new patent before other companies in the sector is proportional to the player's presence in the industry. This is measured by the number of patents owned or the player's patent share, with companies operating in less competitive sectors having a higher probability of success.

The formulas for calculating payoffs in this matrix are based on those presented earlier (from Formula [15] to Formula [29]). However, for patents designated for R&D RDP, formulas [15] and [16] are modified to incorporate the success probability of each player i $success\_chance_i$, reflecting both the research outcome and subsequent implementation. Specifically:

$$B_i = \sum_{p \in RDP} value_i(p) \cdot use\_rights \cdot (1 - e) \cdot success\_chance_i \qquad [21]$$

$$C_i = \sum_{p \in RDP} value_i(p) \cdot use\_rights \cdot success\_chance_i \quad [22]$$

This matrix evaluates the individual strategies of each player without collaboration, assessing the costs and benefits of pursuing R&D independently.

2. Strategic Alliance

The second matrix considers the option of a strategic alliance, where both players share all patents designated for R&D. As outlined in assumption 14 of section 5.2, the payoff matrix in this case evaluates strategies for patents not designated for R&D, including keeping, selling, abandoning, or licensing. The strategies for patents used in R&D are fixed, as they are shared between players under the alliance.

For patents involved in R&D, payoffs are calculated using the adjusted Formulas [21] and [22], assuming that all players within the alliance have access to the shared patents. Finally, as stated in assumption 11 of section 5.2 each player's success probability in R&D efforts remains unchanged, based on their presence in the sector as calculated in the first matrix.

Additionally, the transactional costs associated with forming a strategic alliance are included in the payoff calculation. These costs are similar to those for sales or licensing transactions and are presented in Table 5.2. This ensures that the model accounts for the financial implications of creating a strategic alliance alongside its strategic benefits.

Table 5.2: Strategic Alliance Costs Range

Type of transaction	**min.**	**max.**
Strategic Alliance	15000	80000

3. Joint Venture

The third matrix evaluates the option of forming a joint venture, where players fully integrate their efforts in R&D. Similar to the strategic alliance, all patents designated for R&D are shared, and strategies for the remaining patents include keeping, selling, abandoning, or licensing.

In this scenario, the success probability of the R&D process and subsequent commercialization is increased, as outlined in assumption 12 of Section 5.2. The joint venture's success probability is calculated as the sum of each particular success probability of all players involved, reflecting the combined expertise and resources of the partnership. This adjustment ensures that the joint venture's payoff captures the enhanced likelihood of innovation and market entry.

As with the strategic alliance, transactional costs specific to forming a joint venture are included in the payoff calculations. These costs are presented in Table 5.3, accounting for the legal, administrative, and operational expenses of establishing the joint venture.

Table 5.3: Joint Venture Costs Range

Type of transaction	**min.**	**max.**
Joint Venture	150000	1000000

Finally, the model determines the Nash Equilibrium for each of the three payoff matrices independently. For each of the matrices, the equilibrium represents the combination of strategies where neither player has an incentive to unilaterally change their decision, ensuring stability within that specific cooperation scenario.

Once the Nash Equilibria for the Non-Cooperation, Strategic Alliance, and Joint Venture scenarios have been identified, the model performs a comparative analysis to determine the definitive equilibrium across the three scenarios. This step evaluates the payoffs from each cooperation level to identify the strategy that provides the greatest benefit to both players simultaneously.

In this final step, the model ensures that:

- All players agree to cooperate if either a Strategic Alliance or a Joint Venture offers a higher payoff for both compared to the Non-Cooperation scenario.

- Among cooperation strategies, players will favor the Joint Venture if the combined payoff exceeds that of the Strategic Alliance.

By identifying the definitive equilibrium, the model determines whether cooperation is optimal and, if so, the form of cooperation that maximizes mutual benefits while accounting for the trade-offs and costs associated with each strategy. This approach provides a structured and rigorous framework for evaluating strategic decisions in the context of R&D and patent management.

5.3.5 Evaluating Patent Strategies Under Imperfect Information

This section introduces a computational approach designed for scenarios where companies operate under imperfect information. Instead of relying on complete data for all players, the model focuses on analyzing different strategies for a specific patent by varying the counterparty value and considering the ranges of transactional costs associated with each strategy, as presented in Tables 5.1, 5.2 and 5.3. This method allows a company to evaluate the potential payoffs of its strategic choices while accommodating uncertainty in its counterparty's valuation.

In an environment of imperfect information, companies must often make decisions about patent management without fully knowing the counterparties' valuations or strategic preferences. To address this issue, the model also provides a framework for analyzing strategies for a specific patent, such as sale, license, strategic alliance, and joint venture, by simulating varying levels of counterparty value.

The tool evaluates payoffs based on the formulas presented in the previous sections ([6]-[22]) incorporating relevant factors such as the bargaining power derived from the company's market presence and the patent's sector concentration (Frag. Index), adjusting for transactional costs associated with each strategy drawn from the predefined ranges and considering factors like exclusivity, success probability in R&D, and the patent's direct value to the player and counterparty.

This model employs the following inputs:

- **Patent Value (*value*):** The value of the patent to the owner.
- **Counterparty Value (*counterparty_value*):** A variable representing the potential value of the patent to the counterparty, simulated over a continuous range.
- **Exclusivity Factor (e):** A measure of the competitive impact of licensing, proportional to the Fragmentation Index calculated in Pre-Phase 1.
- **Bargaining Power (*power*):** Derived from the proportion of patents owned by the player relative to the total market.
- **Success Chance (*success_chance*):** The probability of successful R&D and implementation, influenced by market presence and competition.
- **Transactional Costs (TC):** Fixed cost ranges for each strategy, as outlined in Tables 5.1, 5.2 and 5.3.

- **Maintenance Costs (MC):** Costs required to retain a patent, as presented in assumption 15 of section 5.2.

The model assesses all the strategic options outlined in this project, including Sale, License, Strategic Alliance, Joint Venture, and No Action. The sale value of a patent and the license fee are calculated using formulas [11] and [14], respectively, with adjustments made to account for the counterparty value.

$$sale\_value = value \cdot (1 - power) + counterparty\_value \cdot power \qquad [23]$$

$$license\_fee = value \cdot e \cdot (1 - power) + counterparty\_value \cdot e \cdot power \qquad [24]$$

The payoff for sale is calculated considering the estimated sale value and subtracting the transactional costs:

$$SalePayoffRange = [sale\_value - TC^{min}_{Sale}, \quad sale\_value - TC^{max}_{Sale}] \qquad [25]$$

Licensing payoffs incorporate the exclusivity factor (e) and the adjusted patent value for the licensor and licensee:

$$LicensePayoffRange = [license\_fee + value \cdot (1 - e) \cdot success\_chance - TC^{min}_{License} - MC, \quad license\_fee + value \cdot (1 - e) \cdot success\_chance - TC^{max}_{License} - MC] \qquad [26]$$

Payoffs for a strategic alliance assume shared R&D access and fixed success chances, reduced by alliance costs:

$$StrategicAlliancePayoffRange = [value \cdot success\_chance - TC^{min}_{Alliance} - MC, \quad value \cdot success\_chance - TC^{max}_{Alliance} - MC] \qquad [27]$$

In a joint venture, combined success chances from all players improve payoffs, offset by higher transactional costs:

$$JointVenturePayoffRange = [value \cdot success\_chance_{combined} - TC^{min}_{JV} - MC, \quad value \cdot success\_chance_{combined} - TC^{max}_{JV} - MC] \qquad [28]$$

Lastly, the payoff for no action is determined solely by the patent value and maintenance costs:

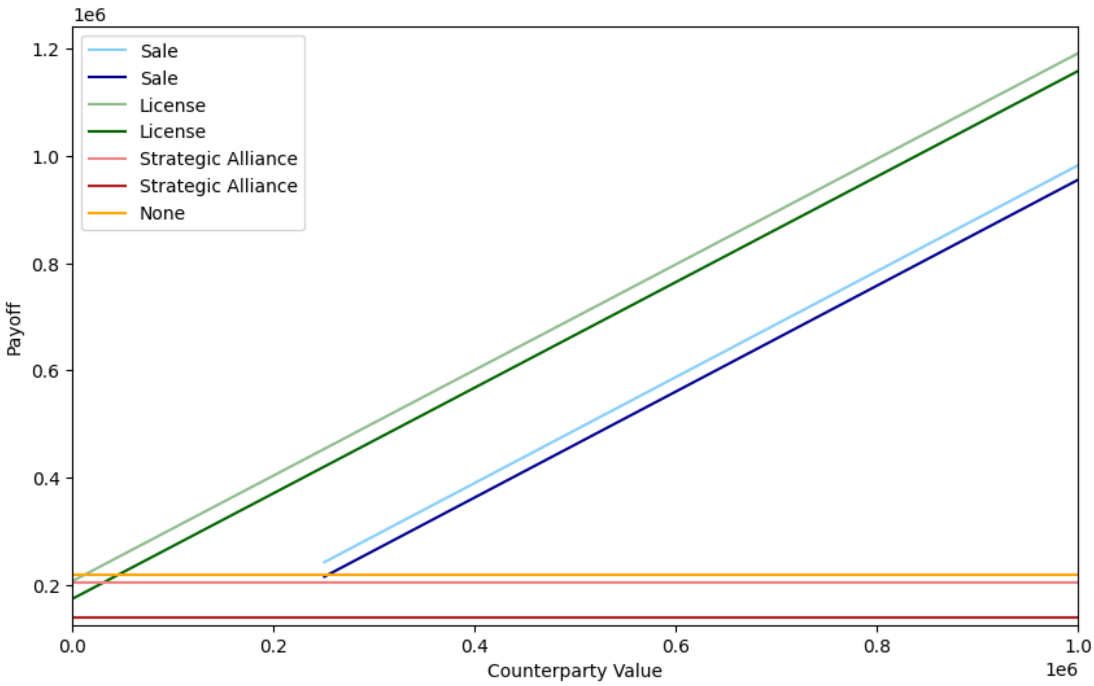
$$NoActionPayoff = value \cdot success\_chance - MC \qquad [29]$$

Once the different payoffs are calculated, the model plots the payoff ranges for each strategy as a function of the counterparty value. This representation provides a clear visual illustration of the trade-offs involved. This enables companies to identify the potential profitability of different strategies for a specific patent under different counterparty value scenarios.

The resulting graph, as presented in Figure 5.1, highlights:

- The minimum and maximum payoffs for sale, license, strategic alliance, and joint venture strategies, if positive for both parties.
- The payoff for no action as a baseline comparison.
- The influence of transactional costs and bargaining power on each strategy.

Figure 5.1: Strategic Evaluation Under Perfect Information - Example



Source: Own elaboration. (2024)

This tool provides a flexible and data-driven approach for evaluating different patent strategies under conditions of imperfect information. By simulating a range of counterparty valuations and incorporating key factors such as bargaining power, exclusivity, and transactional costs, the model empowers companies to make informed decisions tailored to their specific patent and market context.

5.4 Conclusions

This chapter has presented a comprehensive framework for the mathematical formulation behind modeling the strategic management of patents, addressing theoretical foundations, assumptions, scenarios, and information requirements. Moreover, by integrating key assumptions, external parameters, pre-phase analyses, and optimization techniques, the model provides a structured and robust approach for evaluating various strategies related to patent ownership and collaboration.

The Assumptions section established the foundational premises underlying the model, ensuring clarity and consistency in addressing the complexities of patent transactions. Most of these assumptions were introduced to estimate values or parameters using readily accessible data, as much of the information related to patent characteristics is unknown, and knowledge-sharing transactions between companies typically remain private.

Many of the assumptions rely on sectoral analysis based on the sample of patents considered. Therefore, the sample must be representative, as parameters such as bargaining power, exclusivity, or the success chance of an R&D process and subsequent commercialization depend heavily on the results of this analysis.

However, thanks to the design and flexibility of the code, these parameters can easily be adjusted and introduced as external inputs rather than being calculated during the pre-phase of the model. This approach may be particularly useful if one of the players involved in the game believes that their patent, despite being in a highly competitive sector (where exclusivity typically has less influence on patent value), holds such strategic importance to their business that exclusivity does have a significant effect on decision-making. Similarly, if a player considers that their R&D process is sufficiently advanced and that few competitors remain in the "patent race," they may choose to assign a higher success chance to their research efforts.

Additionally, some assumptions were made regarding how the different dynamics of each strategy are represented or how certain scenarios were simplified to optimize and reduce computation time. These simplifications can also be easily reversed, allowing the code to be adapted to analyze each cooperative strategy individually for every R&D variable or to enable each company to apply different criteria for deciding whether a patent will be used for R&D.

These premises not only ensure the model's functionality and efficiency but also maintain the flexibility needed to accommodate specific contexts, external inputs, or strategic considerations from the players involved.

The Model Inputs highlighted the critical data required to operationalize the model, including patent-specific characteristics, player-specific information, and industry-level data. These inputs ensure that the model is grounded in real-world variables, enhancing its relevance and adaptability to different contexts.

The Pre-Phase 1 analysis provided insights into the competitive landscape through the calculation of the Fragmentation Index and patent ownership percentages. This step is instrumental in quantifying the bargaining power of each player and contextualizing strategic decisions within the broader market environment.

This pre-phase relies on the selected sample of patents and aims to represent the sector realistically using appropriate information. However, if the players involved deem it necessary, some parameters calculated during this pre-phase can be introduced as external inputs, as previously mentioned in this section. This flexibility ensures that the model remains adaptable to specific contexts and player-defined considerations.
On the other hand, Pre-Phase 2 defines the player-specific patent valuations and introduces the formulation of key metrics such as sale value and license fee, taking into account the bargaining power and exclusivity factors.

As previously mentioned, an alternative approach for assigning patent value would involve using a market-based approach, which could determine the fair value of the asset based on real market transactions. This calculation could theoretically be included internally in the code. However, due to the lack of publicly available information on such transactions, the model adopts an income-based approach instead. This valuation method requires data that the model itself cannot provide, such as the expectations and estimates of each player. For this reason, the value assigned to each patent is treated as an external input, provided directly by the players.

A key advantage of this approach is its flexibility and contextual relevance. As highlighted throughout this text, the value of a patent depends significantly on its context, and the income-based method inherently accounts for this by relying on player-specific valuations. This allows the model to reflect the strategic priorities and unique circumstances of each player, ensuring a more realistic and adaptable framework.

To apply this methodology, it must assume a scenario of perfect information, which is plausible given the collaborative nature of the model. Nevertheless, to develop a more robust framework, additional code was implemented to analyze alternative strategies under imperfect information, where the counterparty value is treated as a variable. This extension enhances the model's applicability, providing insights into a broader range of potential scenarios.

This chapter also presents the formulation of the Optimization Model that aims to assess how strategic decisions are evaluated under perfect information. The payoff matrices in this model are constructed to capture the trade-offs between keeping, selling, licensing, or collaborating on patents, with the Nash Equilibrium identifying the most stable and mutually beneficial outcomes.

Extending the optimization model to include R&D scenarios, the model also allows for introducing new complexities, such as success probabilities and enhanced cooperation through strategic alliances and joint ventures. By comparing these scenarios with non-cooperative strategies, the model highlights the conditions under which collaboration yields the greatest mutual benefit.

Chapter 6

Model Verifitcation

This chapter focuses on verifying and testing the effectiveness and applicability of the model developed in Chapter 5 by using real-world data to perform realistic simulations. The aim is to assess how well the model captures the dynamics of patent transactions and strategic decision-making in a realistic context.

Both components of the code will be analyzed in this chapter: the module that assumes perfect information, and the extension designed to evaluate different patent strategies under imperfect information, which includes uncertainties about key variables are incorporated into the analysis. By testing these scenarios, the robustness and flexibility of the proposed model are evaluated, ensuring that it can accommodate a wide range of practical situations and strategic environments.

6.1 Selected Patent Sample

This section provides an overview of the patent sample selected for the model verification process, including a detailed description of the dataset and an analysis of the chosen sector. The sectoral analysis builds upon the patent sample described in Section 6.1.1 of this chapter and applies the Pre-Phase 1 framework outlined in Section 5.3.2.

The selected patent sample serves as the foundation for evaluating the model's performance and applicability in a realistic context. By leveraging this dataset and conducting a thorough sectoral analysis, the model's ability to capture competitive dynamics, patent valuation, and strategic interactions is tested under practical conditions.

6.1.1 Description of the Selected Patent Sample

The data used for this verification process was obtained from the European Patent Office (EPO), which classifies patents according to the Cooperative Patent Classification (CPC) system[147]. The CPC is an extension of the International Patent Classification (IPC) and is jointly managed by the EPO and the United States Patent and Trademark Office (USPTO). It is structured into nine main sections (A-H and Y), which are further divided into classes, subclasses, groups, and subgroups. The system currently contains approximately 250,000 classification entries, offering a comprehensive framework for organizing patents.

The nine CPC sections are presented in Table 6.1. For this study, data was selected from Section H, which pertains to Electricity.

Table 6.1: CPC Sections

Symbol	**Classification and description**
A	Human Necessities
B	Performing Operations; Transporting
C	Chemistry; Metallurgy
D	Textiles; Paper
E	Fixed Constructions
F	Mechanical Engineering; Lighting; Heating; Weapons; Blasting
G	Physics
H	Electricity
Y	General Tagging of New Technological Developments; General Tagging of Cross-Sectional Technologies Spanning over Several Sections of the IPC; Technical Subjects Covered by Former USPC Cross-Reference Art Collections and Digests

Source: European Patent Office (EPO)[148].

Section H is further subdivided into seven subsections, as shown in Table 6.2. Within this section, a sample of 10,000 patents was chosen from Group H02, which focuses on the generation, conversion, or distribution of electric power.

[147]European Patent Office (EPO)

Table 6.2: CPC-H Sub-sections

Symbol	Classification and description
H01	Electric Elements
H02	Generation; Conversion or Distribution of Electric Power
H03	Electric Circuitry
H04	Electric Communication Technique
H05	Electric Techniques not Otherwise Provided for
H10	Semiconductor Devices; Electric Solid-State Devices not Otherwise Provided for
H99	Subject Matter not Otherwise Provided for in this Section

Source: European Patent Office (EPO)[149].

The data from Group H02 is categorized into nine specific subgroups, detailed in Table 6.3. This categorization provides granularity to the analysis, ensuring that the selected sample represents a diverse range of patents within a specific sector of electric power systems.

Table 6.3: CPC-H02 Categories

Symbol	Classification and description
H02B	Generation; Conversion or Distribution of Electric Power
H02G	Installation of Electric Cables or Lines, or of Combined Optical and Electric Cables or Lines
H02H	Emergency Protective Circuit Arrangements
H02J	Circuit Arrangements or Systems for Supplying or Distributing Electric Power; Systems for Storing Electric Energy
H02K	Dynamo-Electric Machines
H02M	Apparatus for Conversion between AC and AC, between AC and DC, or between DC and DC, and for Use with Mains or Similar Power Supply Systems; Conversion of DC or AC Input Power into Surge Output Power; Control of Regulation Thereof
H02N	Electric Machines not Otherwise Provided for
H02P	Control or Regulation of Electric Motors; Electric Generators or Dynamo-Electric Converters; Controlling Transformers; Reactors or Choke Coils
H02S	Generation of Electric Power by Conversion of Infrared Radiation, Visible Light or Ultraviolet Light

Source: European Patent Office (EPO)[150].

As outlined in assumption 2 in Section 5.2, patents in this sample will be classified by default as either revenue-generating or cost-reducing, depending on the type of technology. This categorization will follow the criteria presented in Table 6.4 and unless otherwise specified by the parties involved in the simulation, these classifications will remain as assigned by default.

Table 6.4: CPC-H02 Types of Patents

Symbol	**Type of Patent**
H02B	Revenue-Generating
H02G	Cost-Reducing
H02H	Revenue-Generating
H02J	Revenue-Generating
H02K	Revenue-Generating
H02M	Revenue-Generating
H02N	Revenue-Generating
H02P	Revenue-Generating
H02S	Revenue-Generating

Source: Own elaboration (2024)

This carefully selected patent sample provides a robust foundation for testing the applicability and effectiveness of the model across different technological and strategic contexts.

6.1.2 Sectoral Analysis

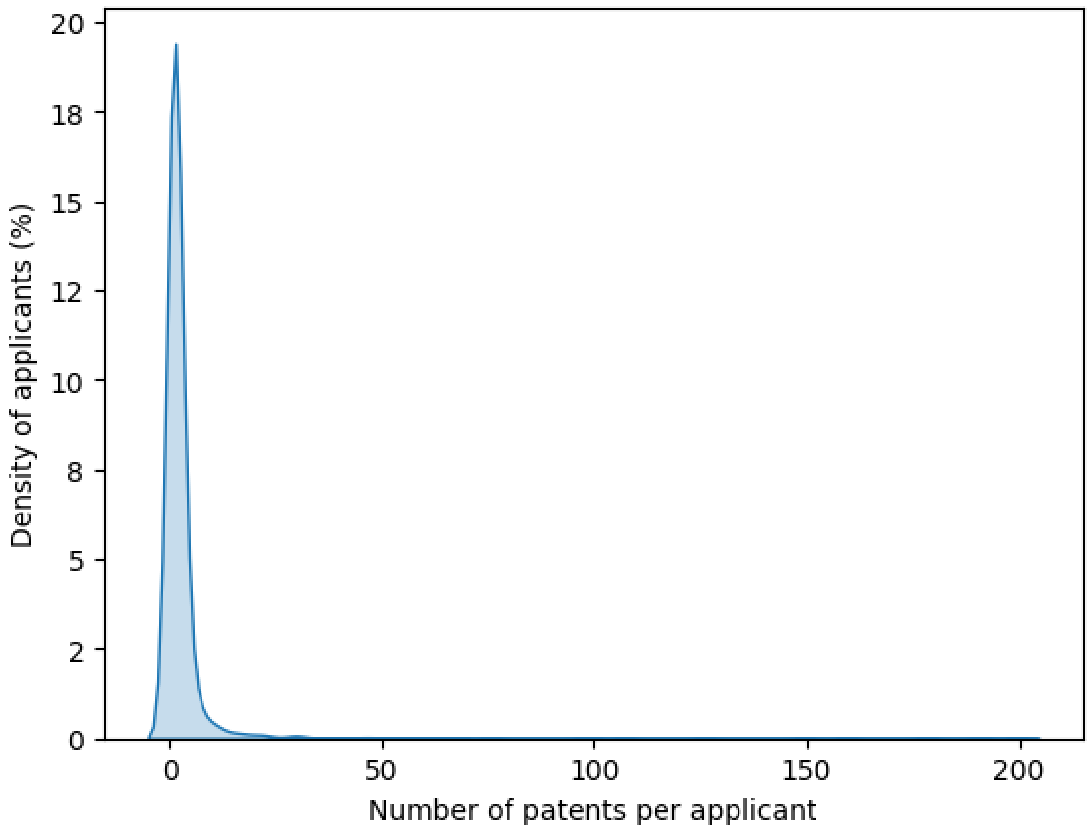
The sectoral analysis is based on the patent sample described in section 6.1.1 and applies the methodology outlined in section 5.3.2. This analysis constitutes the first pre-phase of the overall objective model, providing critical insights into the competitive landscape and ownership distribution within the selected sector.

From the dataset of 10,000 patents, a total of 3,755 distinct applicants were identified. The range of ownership among these applicants varies significantly, from Mitsubishi Electric Corporation, which owns 200 patents, to individual applicants sharing a single patent with up to eight other co-applicants. The average number of patents per applicant is 2.66, with the most common case (mode) being a single patent, highlighting the prevalence of smaller players within the sector.

Further examination reveals that 2,003 applicants, representing more than half of the total, own just one patent. Among these, 598 applicants share their single patent with one or more additional co-applicants. The remaining 1,154 applicants hold ownership in two or more patents, meaning that just over 30% of the applicants control multiple patents within the sample.

To visualize the distribution and density of patent ownership, a violin plot is provided and displayed in Figure 6.1. This plot underscores the substantial variability in ownership levels, from applicants with minimal holdings to a small group of players with relatively high concentrations of patents.

Figure 6.1: Density of Patent Ownership



Source: Own elaboration. (2024)

A key finding of the analysis is that a mere 32 applicants, representing only 0.85% of the total, control 25% of the patents, while 27% of the applicants hold 75% of the patents. This distribution highlights a dual characteristic of the sector: on the one hand, a large number of small-scale applicants with minimal holdings, and on the other, a concentrated group of key players with significantly higher patent ownership. However, it is worth noting that even among these key players, their percentage of ownership is not overwhelmingly dominant, as the applicant with the largest share of patents holds less than 2% of the total.

The calculated Fragmentation Index for the sector is 32.26, a value of particular relevance to the model, as it directly influences the impact of exclusivity on decision-making. As detailed in section 5.3.2, this value reflects a low level of concentration, consistent with a highly fragmented sector.

These findings lead to several important conclusions. The high number of unique applicants, combined with a low average (2.66 patents) and mode (1 patent) for ownership, indicates notable dispersion and suggests that this is a sector with relatively low barriers to entry. At the same time, the presence of a small subset of applicants with ownership significantly above the average demonstrates that, while the sector is competitive, certain players hold influential positions in the landscape.

6.2 Analysis Under Imperfect Information

This section applies the methodology described in section 5.3.5 to analyze scenarios under conditions of imperfect information. Two distinct cases involving players with different characteristics will be evaluated to test the model. Specifically, the analysis focuses on a patent held by Siemens, one of the applicants with the highest number of patents in the dataset, and another patent held by ACE, which owns only two of the 10,000 patents analyzed. This comparison aims to assess how effectively the model captures scenarios involving companies with varying levels of bargaining power and presence in the sector.

The analysis will be conducted using a hypothetical patent denoted as A for Siemens and another as B for ACE. To carry out the analysis, the results of Pre-Phase 2 are required, as they provide the valuations of patents A and B for each company using the income-based approach. However, in this case, to deepen the evaluation of the model, multiple scenarios with hypothetical results of Pre-Phase 2 will be analyzed by varying the value of patents A and B, considering cases where they are of low, moderate, or high value to the respective companies.

Additionally, to explore the model's sensitivity and the effect of exclusivity on decision-making, further analyses will be performed. These will consider not only the exclusivity factor derived from the Fragmentation Index—calculated as 32.26 in Pre-Phase 1—but also alternative scenarios where the patent owner perceives exclusivity to have a significantly different impact. For example, situations where the value of the patent is highly dependent on exclusivity and is considerably reduced when access to the patent is shared with more players will be evaluated.

This approach allows for a thorough examination of the model's robustness and adaptability across a range of conditions, ensuring its capability to represent nuanced decision-making processes in varying competitive and strategic contexts.

6.2.1 Analysis for a Major Player

The analysis presented in this section focuses on the hypothetical scenario of a patent held by a major industry player, Siemens, one of the applicants with the highest number of patents in the dataset. By analyzing a patent denoted as A, this section explores the decision-making process of a player with significant bargaining power and a dominant position in the sector.

The analysis considers three hypothetical patent values provided by the company during Pre-Phase 2: low value (25,000), moderate value (400,000), and high value (850,000). For each scenario, two cases will be evaluated:

1. A default scenario, assuming the patent operates within a sector characterized by low concentration, as indicated by the Fragmentation Index of 32.26.
2. An alternative scenario, where the company specifies externally that the value of the patent is highly dependent on exclusivity. In this case, the patent would lose 45% of its value if an additional player gains access to the information.

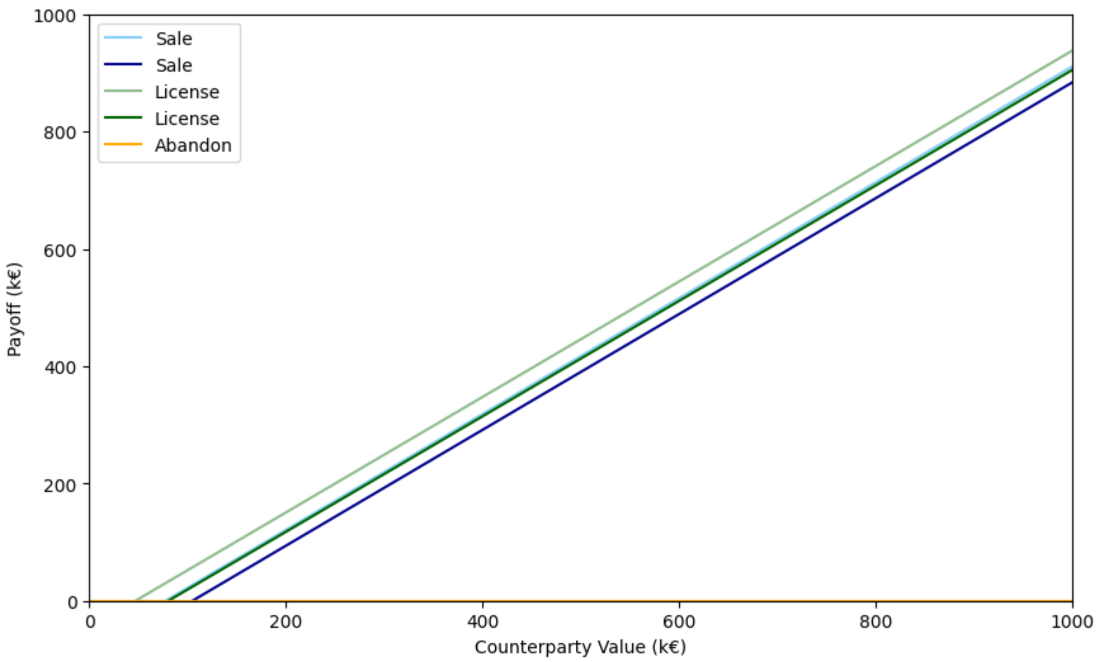
For each of the six scenarios, the code generates a visual representation, as detailed in section 5.3.5. Each graphic presents the payoffs associated with the collaboration strategies available to the company for patent A, based on a range of counterparty values. By examining the six distinct proposed scenarios, the visualizations provide insights into how varying patent values and exclusivity considerations influence the company's strategic decisions. Predefined limits have been applied to both axes across all scenarios, with the x-axis and y-axis sharing the same upper bounds to represent an elevated value. This unified approach highlights the alignment between the counterparty value and the corresponding payoff, ensuring coherence, simplifying interpretation, and facilitating the comparison between the different analyzed scenarios.

Figures 6.2, 6.3, and 6.4 present the results for the default scenario, where the Fragmentation Index is set at 32.26. While each of the three graphs has its specific nuances, a common conclusion emerges. In this scenario, where exclusivity has a minimal impact on the final value of the asset, Siemens would only opt for non-collaborative strategies if the counterparty value is expected to be significantly low.

For virtually any counterparty value, Siemens is likely to benefit from sharing the knowledge with the counterparty, whether through a sale or licensing arrangement, depending on the patent's value to the company. This is because the license fee can easily outweigh the relatively small loss of value caused by the presence of an additional player in the market, given the fragmented nature of the sector.

In the first scenario (Figure 6.2), where the patent has a low value to Siemens, one key observation is that the expected income from the patent is insufficient to cover its maintenance fees. As a result, for very low counterparty values, all payoffs are negative, making the optimal strategy to abandon the patent.

Figure 6.2: Siemens patent: Low value, default scenario

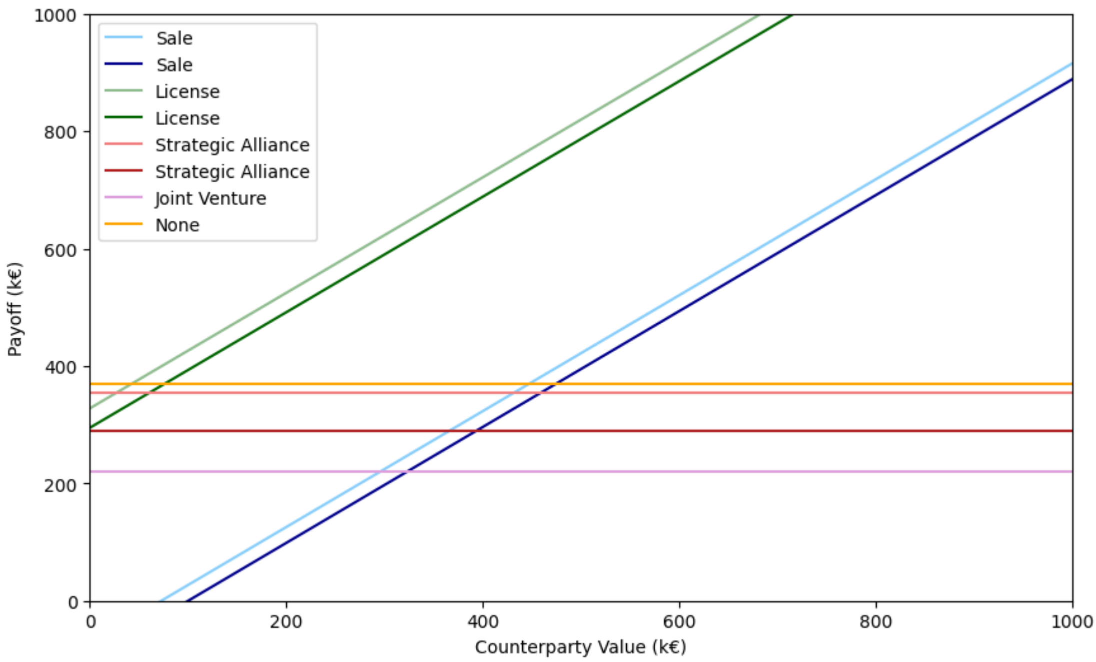


Source: Own elaboration. (2024)

As the counterparty value increases slightly, the optimal strategy shifts to either selling or licensing the patent, with both strategies yielding similar payoffs. In this case, the decision between the two would likely depend on the associated transaction costs. This behavior arises because the expected benefits are so low that even with an additional license fee, Siemens could negotiate a sale value, leveraging its bargaining power, which surpasses the benefits of retaining the patent and collecting licensing fees.

In contrast, Figures 6.3 and 6.4 represent scenarios where the patent holds moderate and high value for Siemens, respectively. In both cases, a common conclusion is that, even with low counterparty values, Siemens should opt for collaborative strategies. The graphs indicate that the benefits of collaboration, through a licensing arrangement, tend to outweigh the costs associated with exclusivity loss.

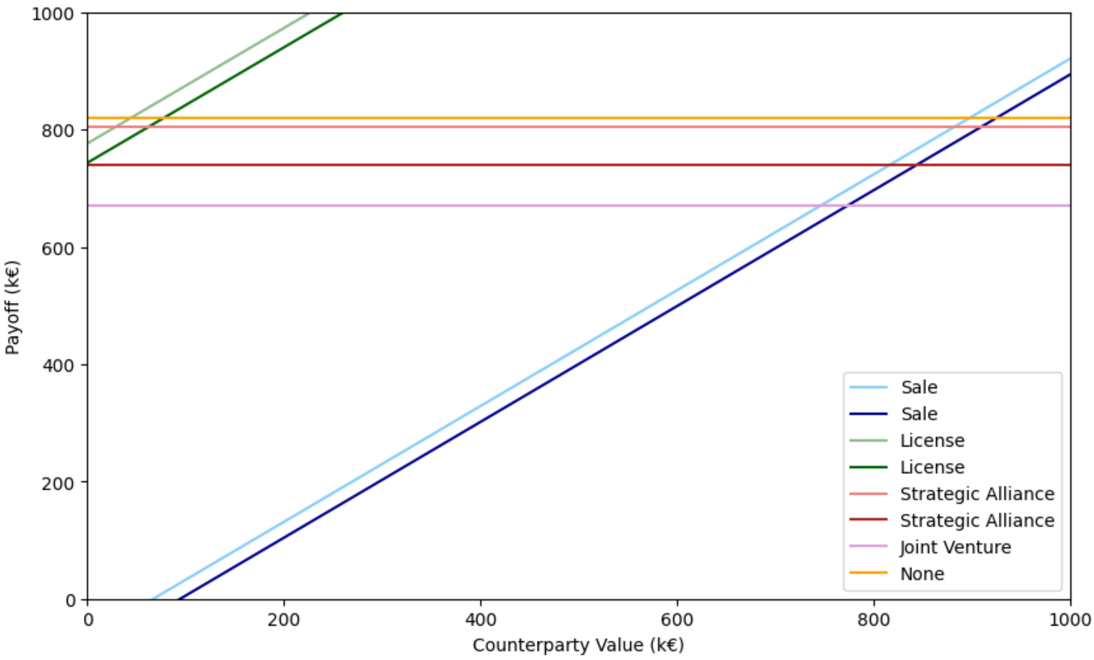
Figure 6.3: Siemens patent: Moderate value, default scenario



Source: Own elaboration. (2024)

Another key observation is that as the patent value increases, so does the difference between the expected payoffs from licensing versus selling. This trend is particularly evident in the high-value scenario (Figure 6.4). This result is consistent with the expectation that a company would prefer to retain a highly valuable patent rather than sell it outright. The additional income generated from licensing fees is sufficient to offset potential exclusivity losses, especially in a highly fragmented sector where such losses have minimal impact.

Figure 6.4: Siemens patent: High value, default scenario



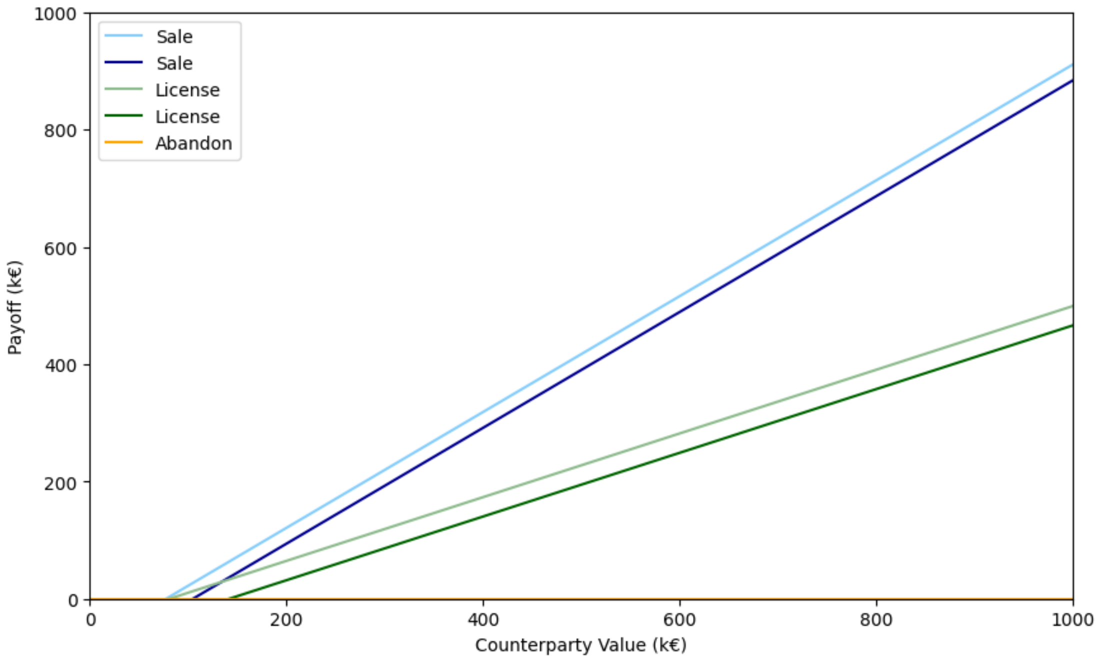
Source: Own elaboration. (2024)

The following three scenarios examine cases where exclusivity has a significantly greater effect on the value of the patent. As illustrated in Figures 6.5, 6.6, and 6.7, the results vary notably depending on the exclusivity factor, as expected. In this context, the option of not collaborating becomes considerably more relevant since maintaining exclusivity over the knowledge holds greater value for the company.

In the first case, where the patent has low value for Siemens, the sale strategy emerges as the optimal choice for most counterparty values, except for very low values where abandonment remains the best option, as it can be observed in Figure 6.5. This last situation is caused because neither party would foresee sufficient benefit from the patent to even cover maintenance costs.

However, as the exclusivity effect is increased in this scenario the payoff from selling becomes significantly higher across most counterparty values compared to the results observed in Figure 6.2. This is driven by the buyer's willingness to pay a higher sale value to benefit from exclusivity. Conversely, even with the license fee, the low inherent value of the patent for Siemens, combined with the loss of exclusivity caused by granting another player access to the information, makes direct sales more advantageous for the company.

Figure 6.5: Siemens patent: Low value, higher exclusivity

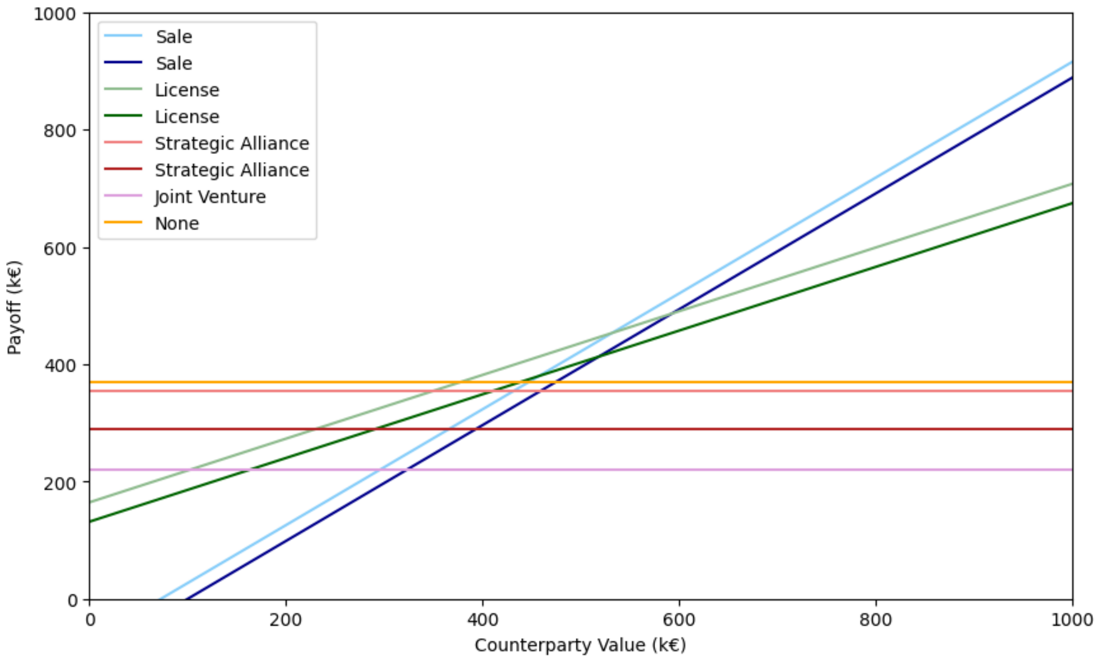


Source: Own elaboration. (2024)

As the patent value increases, the non-collaborative option gains importance, as selling a patent becomes less appealing if the seller does not expect to receive greater benefits than the current owner. As already mentioned within this master's thesis, for collaboration to be viable, the counterparty value must exceed the patent value of the owner.

In the case of a moderate patent value, as shown in Figure 6.6, licensing could become a feasible strategy for higher counterparty values, particularly those close to the valuation Siemens assigns to the patent. In such cases, it may be possible to negotiate a license fee sufficient to offset the loss of exclusivity. However, for counterparty values that are moderately or significantly higher than the patent value, selling the patent becomes the optimal strategy. This happens because the counterparty would be willing to pay a higher purchase price to secure exclusivity. Lastly, the case of a high-value patent, where exclusivity is deemed highly significant, is presented in Figure 6.7. In this scenario, non-collaboration becomes the optimal strategy for almost all counterparty values. Once again, licensing is an interesting option only for counterparty values close to the patent value, where a sufficiently high license fee could be negotiated to compensate for the loss of exclusivity.

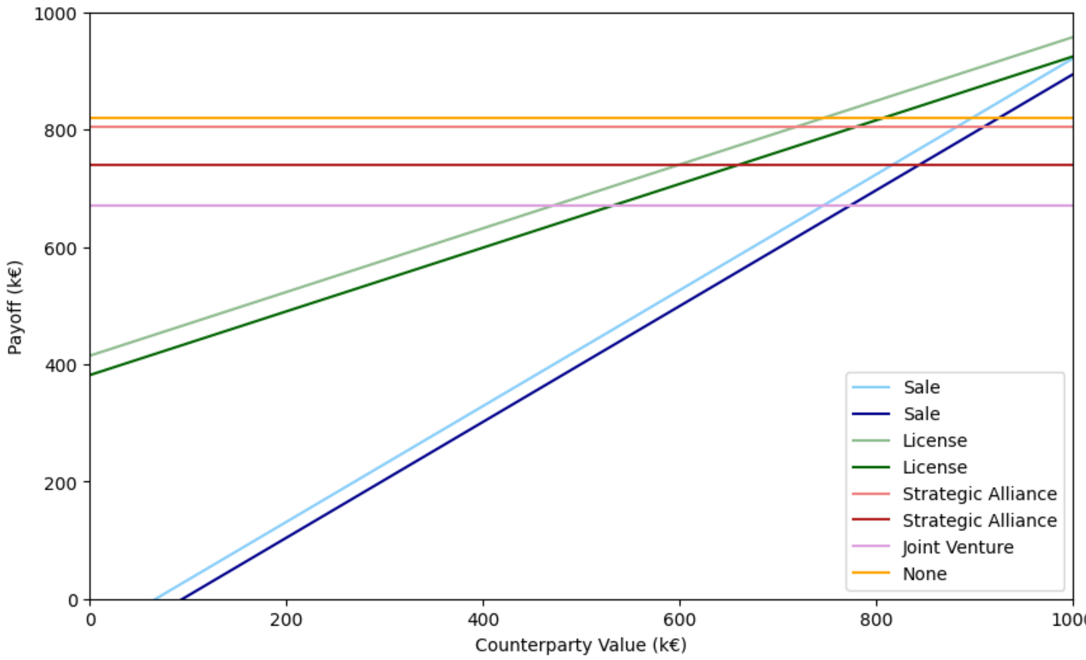
Figure 6.6: Siemens patent: Moderate value, higher exclusivity



Source: Own elaboration. (2024)

Direct sale, on the other hand, is a viable option only if the counterparty places an exceptionally high valuation on the patent and is willing to offer a substantial purchase price to secure exclusive ownership. For most realistic counterparty values, the inherent high value of the patent and the significant exclusivity effect make non-collaboration or even licensing the most advantageous strategic choice for Siemens.

Figure 6.7: Siemens patent: High value, higher exclusivity



Source: Own elaboration. (2024)

When comparing the six scenarios illustrated in Figures 6.2, 6.3, 6.4, 6.5, 6.6, and 6.7, it becomes evident that the payoff for the non-collaboration strategy increases as the internal valuation of the patent rises. This relationship is consistent with the underlying logic that the payoff from retaining the patent equals the company's internal valuation of the asset minus its maintenance costs. In this sense, the value of the patent is highly dependent on the firm's perception of its strategic or economic potential, which directly impacts the desirability of retaining it.

In contrast, licensing strategies are influenced both by the internal valuation of the patent and by exclusivity considerations. Since licensing allows the company to retain ownership of the patent while generating income, higher internal valuations lead to higher payoffs. This is because the retained patent continues to contribute to the firm's portfolio value while generating additional revenue. However, licensing is also impacted by exclusivity: the slope of the licensing payoff curve decreases as exclusivity becomes more critical. A higher dependency on exclusivity means that allowing another player access to the patent reduces its overall value for the original owner, resulting in lower payoffs and flatter curves in these scenarios.

Conversely, the sale strategy remains largely unaffected by variations in the patent's internal valuation or exclusivity. The key factor determining the payoff from a sale is the company's bargaining power. In this initial analysis, the major player, with its significant market power, acts as a price maker. This allows the firm to set an optimal sale price that maximizes its revenue, regardless of its own valuation of the patent. The company's dominant position enables it to secure favorable terms that are less influenced by exclusivity or internal valuation considerations.

However, while exclusivity does not directly impact the payoff from selling the patent, it plays a role in making this strategy optimal. Reduced exclusivity lowers the expected payoffs from licensing, potentially making the sale strategy more appealing by comparison. This dynamic highlights how changes in exclusivity can shift the strategic balance, favoring strategies like sales.

6.2.2 Analysis for a Minor Player

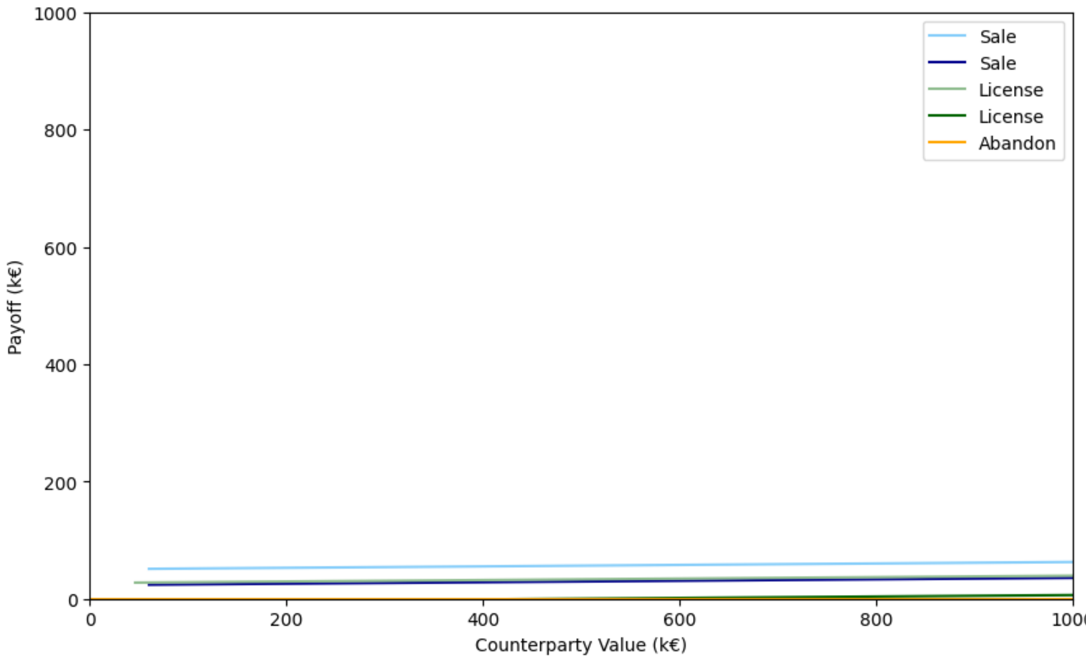
This section focuses on the hypothetical case of the patent being owned by ACE, a company with significantly less influence and market power compared to Siemens. This section will analyze a patent denoted as B, simulating the same six scenarios evaluated in the previous section.

The goal is to test how the model represents and evaluates strategies for companies with distinct characteristics operating within the same sector. This analysis offers insights into how the code adapts to variations in player size, patent portfolio, and bargaining power, highlighting the flexibility and robustness of the framework.

In the default scenario, illustrated in Figures 6.8, 6.9, and 6.10, the expected payoffs for ACE are significantly smaller compared to those obtained by the major player. This disparity is primarily due to the company's lower bargaining power, which results in reduced potential sale values and license fees.

For the low-value patent, as shown in Figure 6.8, the expected income is insufficient to cover the costs associated with maintaining the patent. Consequently, in the absence of collaboration, the optimal decision would be to abandon the patent. Among the collaborative options, selling the patent offers the highest payoffs. However, the profitability of this strategy is heavily influenced by the transactional costs associated with the sale process.

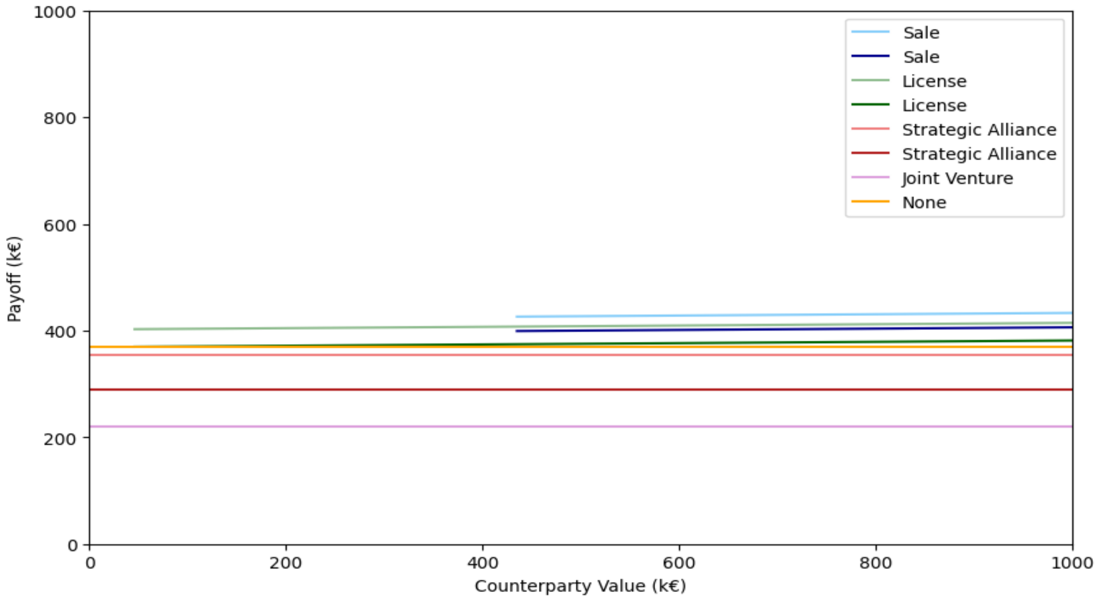
Figure 6.8: ACE patent: Low value, default scenario



Source: Own elaboration. (2024)

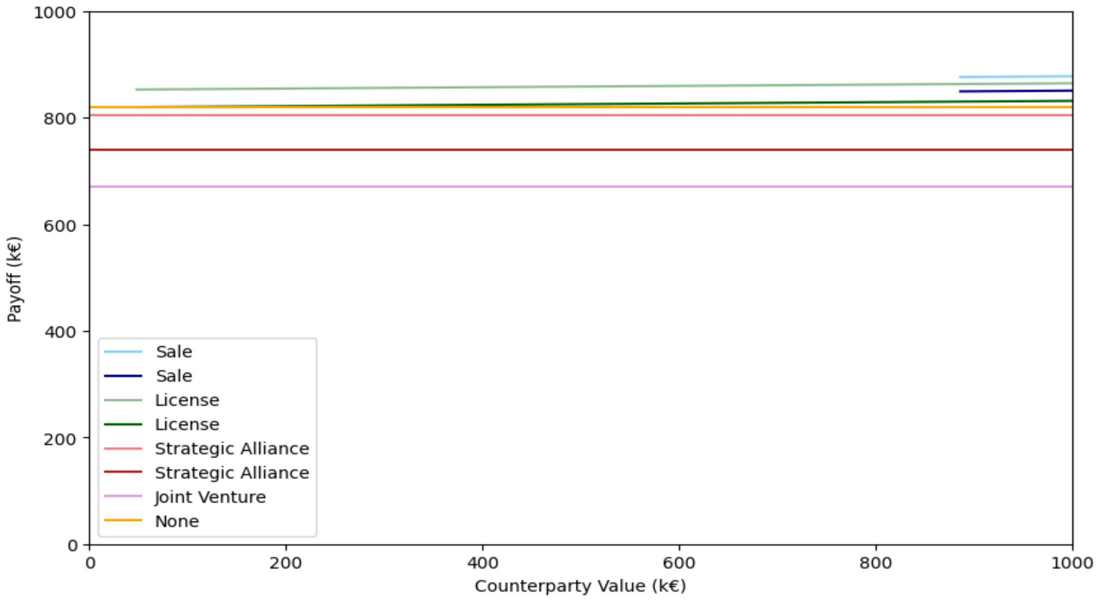
As in Siemens' case, higher patent values make the licensing alternative more attractive, as depicted in Figures 6.9 and 6.10. Nevertheless, in this case, the optimal decision remains highly dependent on the final transaction costs. Due to the company's lower bargaining power, the potential license fees or sale values are more constrained. As a result, the sale option, with typically lower transaction costs, can emerge as the optimal strategy in a greater number of scenarios compared to the major player.

Figure 6.9: ACE patent: Moderate value, default scenario



Source: Own elaboration. (2024)

Figure 6.10: ACE patent: High value, default scenario

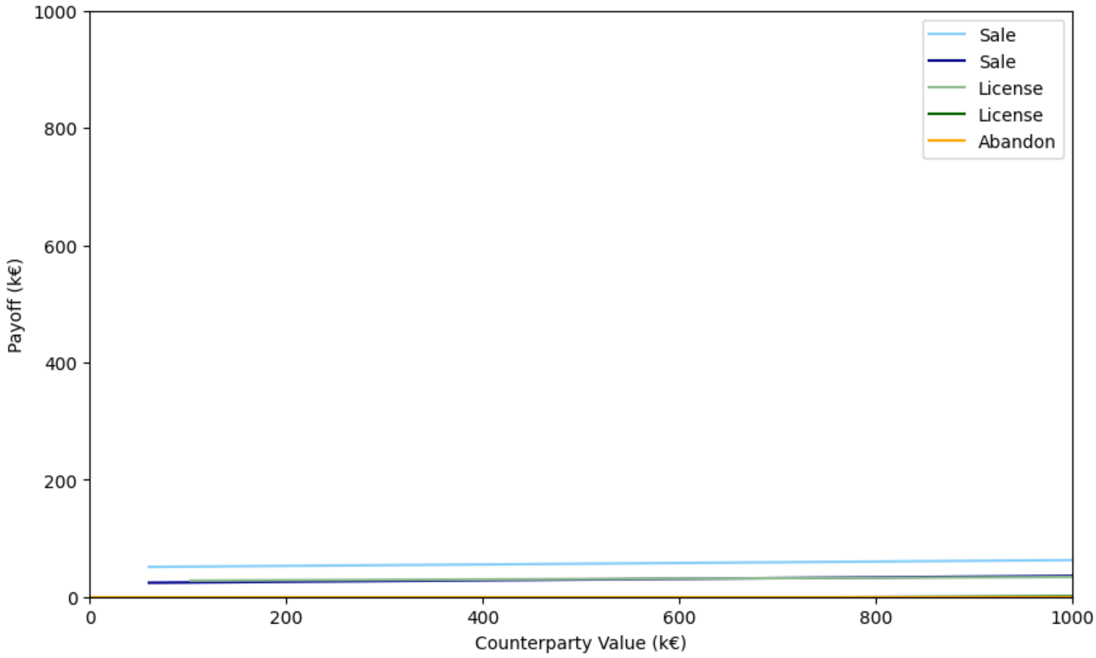


Source: Own elaboration. (2024)

In the scenario with a high exclusivity factor, the results are presented in Figures 6.11, 6.12, and 6.13. The dynamics observed are similar to those of the default scenario, with the optimal strategy remaining highly dependent on transactional costs. In this case, however, the sale option has a greater likelihood of providing higher payoffs, driven by the buyer's increased willingness to pay in order to secure the exclusivity benefits associated with the patent.

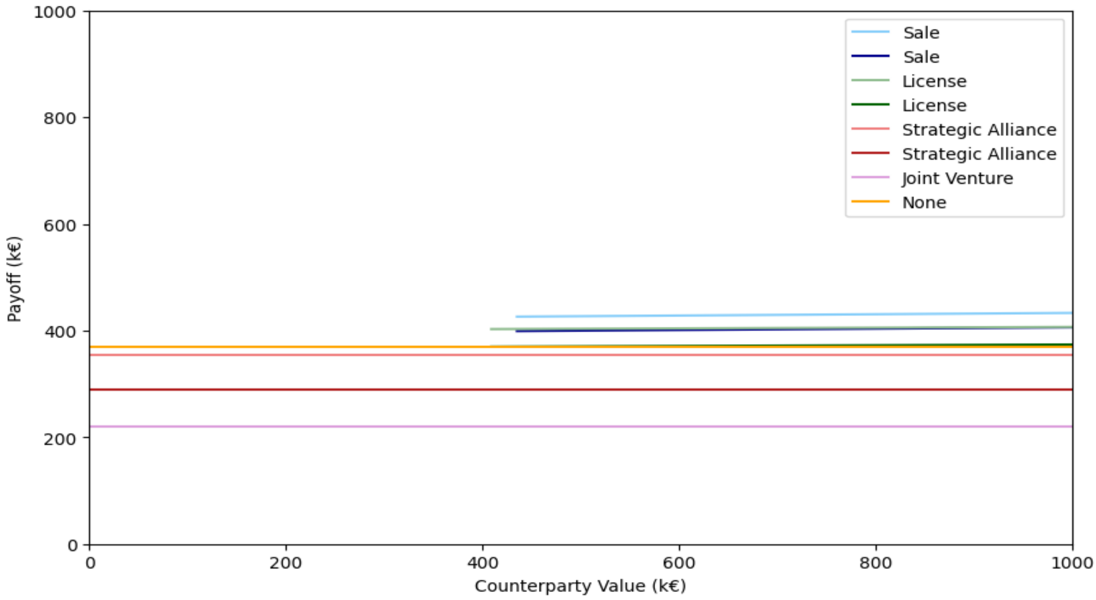
For a minor player with lower market power, the optimal decision is less influenced by exclusivity and more dictated by transactional costs. Furthermore, the reduced bargaining power of the company means that selling the patent tends to be the dominant strategy across a range of scenarios. This observation is consistent throughout the analysis of the minor player and reinforces the critical role that bargaining power plays in determining outcomes, particularly in cases where there is a significant disparity in market power between the two players, as seen in this study's chosen scenarios.

Figure 6.11: ACE patent: Low value, higher exclusivity



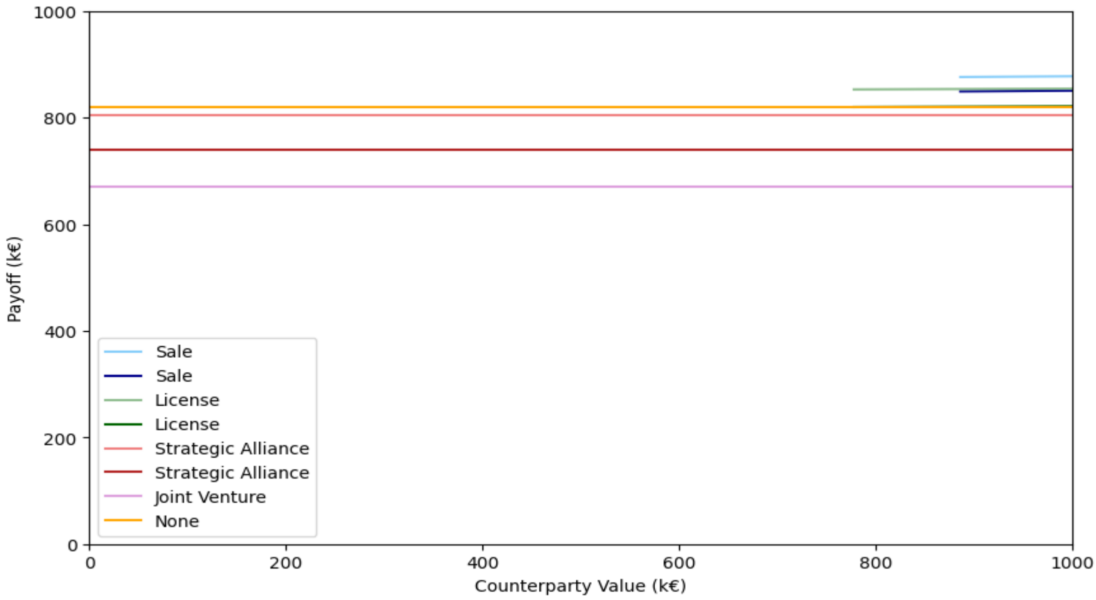
Source: Own elaboration. (2024)

Figure 6.12: ACE patent: Moderate value, higher exclusivity



Source: Own elaboration. (2024)

Figure 6.13: ACE patent: High value, higher exclusivity



Source: Own elaboration. (2024)

The small slope observed in the payoff curves for the minor player highlights the limited leverage available in negotiations. This further supports the conclusion from the analysis of the major player, where bargaining power was shown to be a decisive factor. In this case, the minor player effectively acts as a price taker in the transaction, unable to exert significant influence over the terms of the deal and instead relying on the conditions set by the counterpart. This dynamic underscores the importance of market power in shaping strategic decisions, particularly when negotiating with a significantly stronger counterpart.

These findings are consistent with observed industry behaviors, as larger companies often choose to acquire patents, or even entire businesses, from significantly smaller players when exclusivity is a critical factor. This ensures exclusive access to the intellectual property while simplifying future operational or strategic decisions.

In conclusion, the analysis highlights that for smaller players, exclusivity plays a secondary role compared to the impact of transaction costs and bargaining dynamics. The model effectively captures these variations, reflecting realistic outcomes in line with industry practices

6.2.3 Comparison and Conclusions

The analyses of the major and minor players provide valuable insights into how the model reflects the effects of different factors, such as bargaining power, patent value, exclusivity, and transactional costs, on strategic decision-making within the same sector.

For the major player, Siemens, the results highlight the company's ability to capitalize on its significant bargaining power and dominant market position. In the default scenario, the exclusivity factor has a relatively small impact on strategic decisions, as the benefits of collaboration, through licensing or selling, outweigh the potential losses in exclusivity given the fragmented nature of the sector. However, when exclusivity becomes more critical, non-collaboration emerges as an appealing alternative in high-value scenarios, especially when expected counterparty values are insufficient to compensate for the exclusivity loss.

For the minor player, ACE, the results demonstrate how lower bargaining power and limited market presence shift strategic priorities. In these cases, transactional costs become a decisive factor in determining the optimal strategy. The sale option, with its typically lower transaction costs, emerges as the dominant strategy across a wider range of scenarios, even in cases where exclusivity plays a significant role. This is consistent with observed industry trends, where larger players often acquire patents (or entire companies) from smaller players to secure exclusivity and streamline operations.

The model is able to effectively capture the nuanced interplay of factors influencing decision-making:

- **Bargaiging Power:** A key determinant of the potential license fees or sale values, directly affecting the profitability of collaborative strategies.
- **Exclusivity Impact:** More significant for major players, particularly in high-value patents, where exclusivity loss can result in substantial value reductions.
- **Transactional Costs:** A critical factor for minor players, whose lower bargaining power makes them more sensitive to cost variations when adopting collaborative strategies.
- **Patent Value:** The higher the patent value, the more likely licensing becomes the preferred strategy for major players, while minor players may lean toward selling, depending on the counterparty value.

In conclusion, the model robustly reflects the effects of these factors, providing a flexible and adaptable framework for analyzing patent strategies across players with differing market positions and characteristics under imperfect information. It offers a comprehensive tool for understanding how key variables shape optimal decision-making and collaboration strategies in the context of industrial property management.

6.3 Analysis Under Perfect Information

This section tests the model under the assumption of perfect information, meaning that all variables in the game are known to the players. The game involves the same two players analyzed in the imperfect information scenarios: Siemens and ACE. As in the previous analysis, Siemens has significantly more power and influence in the sector compared to ACE.

6.3.1 Base Collaboration Game

In this first analysis, the dynamics of collaboration will be evaluated for a total of six patents, with four owned by Siemens, and two owned by ACE. The results of Pre-Phase 1, as outlined in section 6.1.2 of this chapter, provide the contextual market information (fragmentation, bargaining power of each player...), and the details of the patents themselves are presented in Table 6.5.

For this initial scenario, it is assumed that none of the patents will be used for R&D, and, based on the type of technology, the model has categorized all six patents as revenue-generating patents.

Table 6.5: Game Data: 1st scenario

Patent	**Owner**	**Publication No.**	**Type**	**R&D**
EP23768144	Siemens	WO2024046795	Benefit	0
EP24710638	Siemens	WO2024199844	Benefit	0
EP23169561	Siemens	EP4456363	Benefit	0
EP23465507	Siemens	EP4459815	Benefit	0
EP23902350	ACE	WO2024125150	Benefit	0
EP23915567	ACE	WO2024148806	Benefit	0

Source: European Patent Office (EPO)

Since real income-based valuations for the patents are not available, randomized valuations have been assigned to enable the analysis of various scenarios. These values were selected to reflect a diverse set of outcomes. For Siemens' four patents, the company assigns low value to one patent, moderate value to two patents, and high value to one patent. On the other hand, for ACE's two patents, the company considers one patent as low value and the other as moderate value.

The valuations used to test the model are presented in Tables 6.6 and 6.7. By simulating this game under perfect information, the goal is to verify the consistency of the results with the observations from the imperfect information analysis and explore the dynamics of collaboration between players with distinct characteristics.

Table 6.6: Siemens Data

Patent	Ownership	Type	Value (€)
EP23768144	1	Benefit	799469.88
EP24710638	1	Benefit	232885.82
EP23169561	1	Benefit	598468.21
EP23465507	1	Benefit	23796.03
EP23902350	0	Benefit	510867.37
EP23915567	0	Benefit	976457.70

Source: Own elaboration (2025)

Table 6.7: ACE Data

Patent	Ownership	Type	Value (€)
EP23768144	0	Benefit	603009.87
EP24710638	0	Benefit	977824.97
EP23169561	0	Benefit	714493.97
EP23465507	0	Benefit	785006.22
EP23902350	1	Benefit	501880.85
EP23915567	1	Benefit	23860.47

Source: Own elaboration (2025)

The data described above will serve as the results from Pre-Phase 2 and, combined with the sectoral information obtained in Pre-Phase 1, will act as inputs for the model defined in Section 5.3.4. In this scenario, since no patents are designated for R&D, the possible strategies for each patent are no collaboration, sale, or license. This results in a 9 x 81 payoff matrix, where ACE can adopt 9 different strategies for its patents, and Siemens has 81 possible combinations of strategies.

Payoffs for each player and combination of strategies are calculated using the formula [20], alongside transaction costs randomly assigned within the predefined limits outlined in Table 5.1. In this case, the Nash equilibrium is achieved with the following strategies:

- ACE will:
  - License EP23902350
  - Sell EP23915567

- Siemens will:
  - License EP23768144
  - License EP24710638
  - License EP23169561
  - License EP23465507

These results are consistent with the observations from the previous section on imperfect information. For Siemens, the findings once again demonstrate that, regardless of the valuation of the patents, licensing is generally the optimal strategy in a highly fragmented sector when exclusivity has no significant impact on a specific patent's value. This aligns with the sectoral dynamics, where the large number of players ensures that the inclusion of an additional participant does not substantially alter the competitive landscape of the sector, making licensing the most advantageous option in most scenarios.

However, if Siemens were to indicate that the value of any of these patents relies more heavily on exclusivity, the results would likely differ, as observed in Figures 6.5, 6.6, and 6.7. In such cases, licensing may cease to be the optimal strategy, with Siemens instead prioritizing maintaining exclusive control over the patent to maximize its strategic value.

For ACE, the optimal strategies highlight important nuances. The first patent, EP23902350, is licensed because the valuations for both parties are too close to justify a sale that would cover the transactional costs and still benefit both sides. In contrast, the second patent, EP23915567, which holds a low value for ACE but a high value for Siemens, is optimally sold. This result is also consistent with the imperfect information analysis, where selling was identified as the most typical optimal strategy for ACE, particularly for patents with higher value to the counterparty. However, the decision remains highly sensitive to the transaction costs, as demonstrated in both scenarios.

In summary, these outcomes reinforce the conclusions driven from the imperfect information analysis, demonstrating the model's consistency and ability to capture the dynamics of patent transactions under varying strategic and informational conditions.

6.3.2 R&D Collaboration Game

Additionally, the model will be tested to analyze a game involving the same patents but with a different allocation: this time, four of the patents (two from Siemens and two from ACE) are intended for R&D purposes. The updated game information is presented in Table 6.8. In this scenario, the model incorporates the probabilities of success in R&D and subsequent commercialization, as determined in Pre-Phase 1 and based on Assumption 13 from Section 5.2. The valuations of the patents remain as shown in Tables 6.6 and 6.7, ensuring consistency with the previous analysis.

Table 6.8: Game Data: 2nd scenario

Patent	Owner	Publication No.	Type	R&D
EP23768144	Siemens	WO2024046795	Benefit	1
EP24710638	Siemens	WO2024199844	Benefit	1
EP23169561	Siemens	EP4456363	Benefit	0
EP23465507	Siemens	EP4459815	Benefit	0
EP23902350	ACE.	WO2024125150	Benefit	1
EP23915567	ACE	WO2024148806	Benefit	1

Source: European Patent Office (EPO)

The analysis produces three distinct payoff matrices:

1. A non-cooperation matrix of the same size as the previous one (9 x 81), but with payoffs adjusted according to the success probabilities.

2. A strategic alliance matrix based on the four patents designated for R&D, with Siemens' remaining patents evaluated under the three non-cooperation strategies: no collaboration, sell, or license. This results in a 1-row x 9-column matrix.

3. A joint venture matrix similar in structure to the strategic alliance matrix but representing a full joint venture framework for the R&D patents.

In this case, the optimal outcome identified by the model is non-cooperation. This result reflects the high level of competition in the sector, where the likelihood of securing a patent and winning a patent race is relatively low. Consequently, unless otherwise specified, the success probabilities for the R&D process and subsequent commercialization are significantly reduced. Under these conditions, the expected revenues generated from such efforts are not projected to be sufficient to offset the substantial costs associated with forming a strategic alliance or a joint venture.

The choice of non-cooperation as the optimal strategy also emphasizes that high transactional costs of complex collaborative processes, such as forming a joint venture or strategic alliance, play a critical role in determining outcomes. These processes only become economically viable when the scale of shared patents is sufficiently large, enabling the potential benefits to outweigh the associated costs despite low success probabilities.

Consistent with the results observed in the base collaboration game and the analysis under imperfect information, Siemens would license the patents that are not designated for R&D, as this strategy provides mutual benefits for both parties. Licensing allows Siemens to secure additional income while ACE benefits from access to valuable industrial property, leveraging Siemens' significant bargaining power. For the remaining patents intended for R&D, however, no collaboration strategy emerges as the optimal strategy. As explained earlier, the probabilities of success are too low to justify the high transactional costs of strategies such as licensing or sale.

It must be noted that his outcome is highly sensitive to transactional costs and the success and commercialization probabilities of R&D projects. Adjusting these parameters could significantly alter the results. For instance, if one or both companies had greater confidence in their likelihood of success in the R&D proccess or commercialization, collaborative strategies such as strategic alliances or joint ventures could become optimal. Increased certainty in these probabilities would enhance the expected revenues, making these costlier strategies more justifiable.

In conclusion, the model highlights non-collaboration as the optimal strategy in this case, given the current assumptions about low success and commercialization chances and high transactional costs. However, this result also underscores the importance of context-specific factors in determining optimal strategies. By varying key parameters, such as transactional costs or success probabilities, the model demonstrates its flexibility and capacity to reflect dynamic scenarios, offering valuable insights into how firms can evaluate collaboration strategies under diverse market conditions.

6.4 Conclusions

The model verification process demonstrates the robustness and adaptability of the proposed framework in analyzing patent transactions and collaboration strategies. The model's ability to perform a detailed sectoral analysis, as illustrated in the results from Pre-Phase 1 analyzed in sections 6.1.1 and 6.1.2, allows it to capture key characteristics of the competitive landscape and patent ownership distribution. This contextual understanding provides a solid foundation for the evaluation of strategic decisions, highlighting how sector-level dynamics, such as fragmentation or concentration, influence outcomes.

The model has proven effective in evaluating optimization strategies under both perfect and imperfect information scenarios. In imperfect information cases, the framework captures the uncertainties faced by players, providing insights into how bargaining power, exclusivity, and counterparty valuations shape decision-making. Under perfect information, the model demonstrates consistency, faithfully reflecting the same dynamics while offering deeper clarity into optimal strategies when all variables are known.

Moreover, the model is adept at accurately representing the characteristics of the sector, companies, and patents involved, and how these factors impact the optimization of knowledge-sharing processes. The results consistently align with theoretical expectations, showcasing the model's ability to:

- Reflect the influence of bargaining power, with larger players like Siemens leveraging their position to secure better outcomes in fragmented markets.
- Capture the role of transactional costs, particularly for smaller players like ACE, where these costs heavily dictate the choice of collaboration strategies.
- Accurately model the impact of exclusivity, illustrating how sectors with low concentration diminish the value of exclusivity and favor licensing, while highly exclusive assets shift preferences toward non-collaboration or sales.
- Incorporate R&D success probabilities and their influence on collaboration strategies, demonstrating how alternatives like joint ventures or strategic alliances can significantly improve outcomes in high-risk R&D scenarios.

The factors integrated into the model, including patent valuations, exclusivity, transactional costs, sectoral fragmentation, and R&D probabilities, have all been shown to be faithfully represented in the model. These elements directly influence the optimization of patent strategies, providing a comprehensive framework that adapts to various scenarios and player characteristics.

In conclusion, the model stands as a reliable tool for analyzing and optimizing intellectual property decision-making. It captures the interplay between market dynamics, company characteristics, and patent-specific factors, offering a nuanced understanding of optimizing knowledge-sharing processes across diverse strategic contexts. This validation reinforces its applicability and potential for real-world use in managing intellectual property effectively.

Chapter 7

Economic Analysis and Impact Assessment

This chapter focuses on analyzing how companies can leverage the results obtained in chapter 6 to estimate potential benefits and optimize their strategies in the most advantageous manner. By examining both imperfect and perfect information scenarios, the analysis explores the financial implications of the model's recommendations and evaluates how these outputs can guide firms in making economically sound decisions. The goal is to demonstrate how the model provides a valuable framework for maximizing profitability, enhancing resource allocation, and aligning strategic collaboration efforts with business objectives.

7.1 Economic Analysis Under Imperfect Information

This section analyzes the economic implications of the model under imperfect information scenarios. The focus is on understanding how companies can estimate potential economic benefits and refine their strategies when faced with uncertainties about counterparty valuations and other critical variables. By using the outputs provided by the model, firms can identify optimal collaboration strategies and assess their associated payoffs and earnings under various assumptions.

The economic analysis focuses on evaluating the outcomes provided by the model in section6 in both absolute and incremental terms. In absolute terms, the analysis examines the economic benefits (in k€) that a company can achieve by engaging in various collaboration strategies. From an incremental perspective, it evaluates the percentage increase in a patent's economic performance when adopting the optimal strategy proposed by the model.

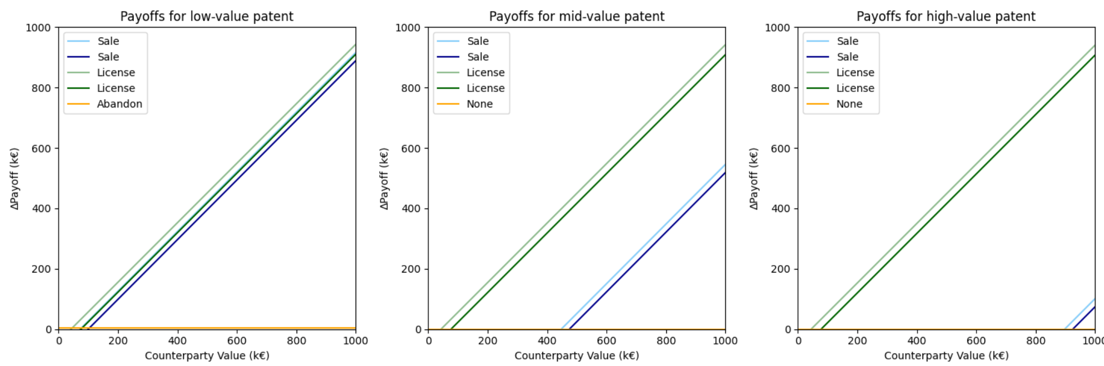
To avoid reiterating the conclusions drawn in chapter 6 and considering that the graphs presented in that chapter (Figures 6.2-6.13) accurately illustrate the influence of factors such as exclusivity and bargaining power, this analysis narrows its focus to a smaller set of cases. By doing so, the chapter aims to provide deeper insights into specific scenarios without duplicating earlier findings.

The economic analysis will primarily center on a scenario involving Siemens and a single patent where exclusivity has an effect aligned with the characteristics of the sector. This approach allows for a detailed examination of the full range of economic assessments enabled by the model, including absolute and incremental gains.

Additionally, this section will explore the potential impact of adopting different strategies, as outlined by the model, on the company's final financial outcomes. By focusing on this representative case, the chapter demonstrates how the model can serve as a tool for firms to comprehensively assess the economic implications of their collaboration strategies.

To analyze the potential economic benefits for Siemens, this section first focuses on evaluating the incremental gains (in k€) that the company could expect from applying the three most appealing strategies identified in chapter 6: abandonment, sale, or licensing. By comparing these different strategies to the baseline scenario of non-collaboration, the analysis reveals several key insights as can be seen in Figure 7.1.

Figure 7.1: Siemens patent economical analysis: ΔPayoff (k€)



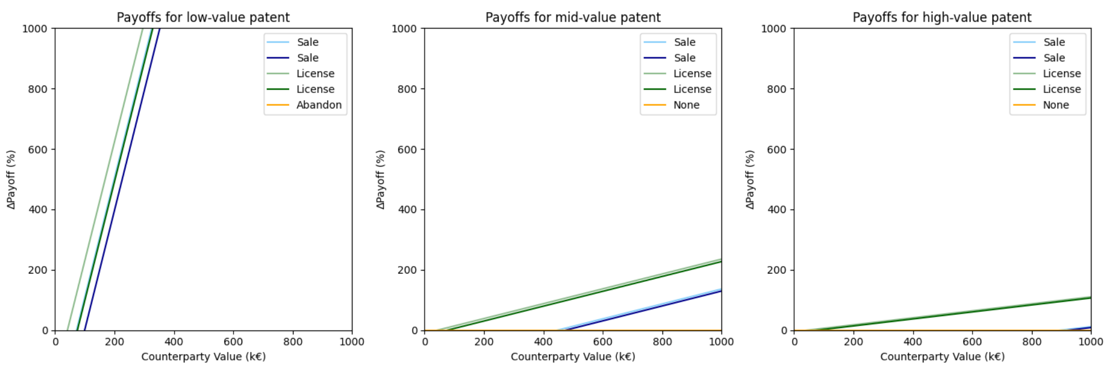
Source: Own elaboration. (2025)

For a low-value patent valued at 25k€, the model suggests that if the counterparty also assigns a very low valuation to the patent (even lower than Siemens), the most beneficial option is abandonment. In this case, the economic benefit arises from saving on maintenance costs, as the expected revenues are insufficient to cover these expenses. Specifically, the model estimated maintenance costs of approximately 30k€ for the patent over its useful life, resulting in a net benefit of ∼5k€ from abandonment. This conclusion holds as long as the counterparty also finds the patent unprofitable to retain in its portfolio.

As shown in Figure 7.1, licensing the patent offers similar income streams regardless of Siemens' internal valuation of the patent. The additional revenues from licensing depend primarily on the counterparty value. This is because, as discussed in chapter 5, Siemens' substantial market power in the sector positions the company as a price-maker, enabling it to negotiate favorable license fees. This highlights the impact of Siemens' significant bargaining power and elevated market position.

Licensing becomes particularly advantageous in scenarios where the counterparty value is high, potentially allowing Siemens to generate more income from licensing than from exploiting the patent itself. This is evident in the mid-value scenario, where Siemens anticipates deriving ∼400k€ from patent exploitation. By opting for a licensing strategy, these earnings could increase to as much as ∼1000k€ if the counterparty value is significantly high. This trend is also clearly illustrated in Figure 7.2, which highlights the impact of adopting different strategies on the final economic benefit derived from the patent. Specifically, in the mid-value case, Siemens could achieve up to a 200% increase in profitability if the counterparty value is high, underscoring the substantial economic potential of collaborative strategies like licensing.

Figure 7.2: Siemens patent economical analysis: ΔPayoff (%)



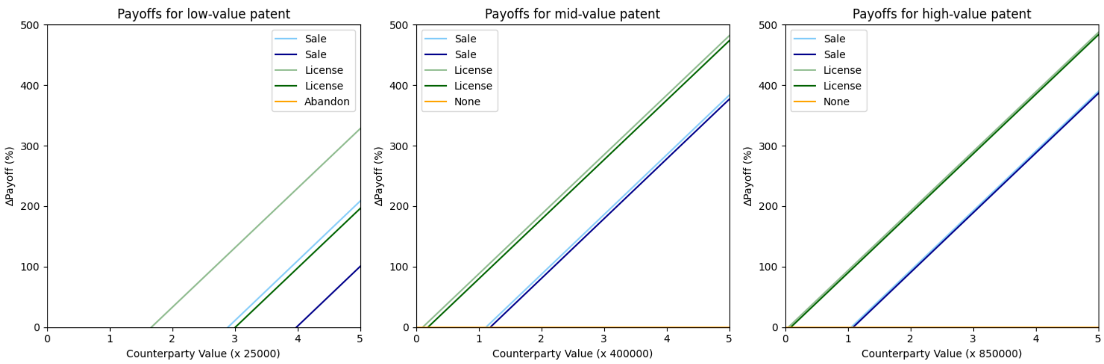
Source: Own elaboration. (2025)

Another interesting observation Siemens can draw from the previous graph (Figure 7.2) is that while the absolute economic benefits in € might be similar for a patent regardless of its value, the impact of adopting a licensing strategy varies significantly in terms of percentage profitability depending on the patent's initial valuation. This is primarily because, with a much lower baseline expected value, an absolute increase in € results in a greater percentage impact on profitability when the initial estimation is smaller.

Although this is feasible, Siemens could conduct a parallel analysis to account for the fact that finding a company that values a low-value patent as a high-value one might be challenging. Figure 7.2 illustrates this point by showing that for a low-value patent (valued at 25k€ by Siemens), payoffs are calculated assuming counterparty valuations of up to 1M€—a staggering 40 times higher than Siemens' valuation.

To refine this analysis, Figure 7.3 presents an alternative perspective where expected counterparty values are expressed relative to Siemens' valuation of the patent rather than in absolute terms. For example, the counterparty value ranges from 0 to 5 times the value Siemens attributes to the patent. Observing this updated graph reveals that, for a low-value patent, achieving similar profitability impacts as those seen for mid- or high-value patents requires a proportionally much higher counterparty value relative to Siemens' own valuation.

Figure 7.3: Siemens patent economical analysis: ΔPayoff (%) adjusted



Source: Own elaboration. (2025)

Additionally, the overall profitability of the process depends more heavily on transactional costs in the case of low-value patents. Conversely, for patents with higher valuations, the relative impact of transactional costs diminishes, further reinforcing the advantages of holding high-value patents in collaboration scenarios.

Another valuable economic insight the model provides is identifying the minimum counterparty value necessary for a collaboration strategy to become profitable compared to non-collaboration or abandonment. Specifically, Siemens could expect sufficient revenues from licensing to offset transactional costs and the loss of exclusivity if the counterparty value exceeds ∼50k€–100k€, depending on the anticipated transactional costs, as can be observed in both Figure 7.1 and 7.2.

Finally, the analysis indicates that selling the patent generates lower economic gains than licensing in most cases. Moreover, profits from selling would only materialize if the counterparty value is sufficiently high to justify a sale price exceeding the expected benefits from exploitation and covering the associated transactional costs.

In conclusion, the analysis demonstrates that collaboration, particularly through licensing, could significantly enhance Siemens' economic outcomes. In this case, the magnitude of these incremental benefits is closely tied to the counterparty value, reinforcing the importance of considering bargaining power when optimizing collaboration strategies.

This analysis demonstrates that the proposed model not only optimizes knowledge exchange through effective collaboration strategies but also serves as a powerful tool for companies to evaluate the potential benefits of their patents. By leveraging the insights provided by the model, firms can assess the economic impact of adopting various strategies on their overall patent portfolio, enabling them to make informed decisions that maximize profitability and strategic value. This dual functionality underscores the model's practical applicability and its potential to drive more efficient and beneficial collaboration in the industrial property landscape.

7.2 Economic Analysis Under Perfect Information

This section focuses on analyzing the two scenarios presented in Section 6.3, using the data provided in Tables 6.5 through 6.8. For each scenario, an in-depth economic analysis will be conducted based on the results derived from the respective games, with the corresponding payoff matrices included in Appendix B. The objective is to assess the economic implications of the strategies identified by the model under perfect information, examining how collaboration strategies impact profitability.

7.2.1 Base Collaboration Report

In the base case analysis, where no patents are allocated for R&D (Table 6.5), the initial incomes for both parties, Siemens and ACE, are outlined in Table 7.1. These incomes are derived from their respective patent valuations, as detailed in Tables 6.6 and 6.7. This analysis sheds light on the economic outcomes for each player in the absence of collaborative strategies, highlighting how they initially value their patent portfolio.

Table 7.1: No Collaboration Profits: Base Case

Company	**Profit (k€)**
Siemens	1,614.6
ACE	505.7

Source: Own elaboration (2025)

As outlined in Section 6.3.1, the optimal strategy identified by the model specifies that ACE will license patent EP23902350 and sell patent EP23915567, while Siemens will license all their patents involved in the game (EP23768144, EP2471063, EP23169561, and EP23465507). Based on this strategy, the expected final payoffs are summarized in Table 7.2.

Table 7.2: Collaboration Profits: Base Case

Company	**Profit (k€)**
Siemens	5,736.0
ACE	660.9

Source: Own elaboration (2025)

The results reveal that Siemens would achieve a significant increase in profits of approximately 250%, a finding that aligns with expectations based on the data presented in Tables 6.6 and 6.7. Several patents that Siemens values as mid-value are considered high-value by ACE, and as shown in Figure 7.2, licensing mid-value patents can lead to substantial profitability increases for Siemens when the counterparty value is high. This highlights the strategic advantage Siemens gains by leveraging its patents in a collaborative framework. Moreover, Siemens secures access to two new patents from ACE, one of which the company values as mid-value and another they classify as a high-value patent, acquired with exclusive rights.

Additionally, Siemens' status as a significantly larger entity than ACE positions it as a price-maker in these negotiations, enabling it to secure more favorable licensing and sale terms, further amplifying its economic gains.

Conversely, ACE sees a more modest profit increase of approximately 30%. This disparity can be attributed to ACE's smaller market power and lower bargaining capacity, which limit its ability to negotiate equally advantageous terms. As a result, the improvements in its patent portfolio yield less pronounced profitability gains, regardless of the counterparty valuation.

In scenarios where the negotiation occurs between companies of more comparable size, the resulting profit increases would likely be more evenly distributed. This underscores the critical influence of market power and bargaining dynamics in shaping the economic outcomes of collaboration strategies.

7.2.2 R&D Collaboration Report

The economic analysis for this case uses Table 6.8 as the primary reference, indicating that two of Siemens' patents and both patents owned by ACE are designated for R&D purposes. The valuation of these patents by each company remains consistent with the data presented in Tables 6.6 and 6.7.

In this scenario, and based on the success chances outlined in Assumption 13 from section 5.2, the initial profits expected by each company from their patent portfolios are summarized in Table 7.3. These initial profits reflect the anticipated revenues from exploiting the patents under non-collaborative conditions, adjusted for the probabilities of success in R&D and subsequent commercialization. The values serve as a baseline for assessing the economic impact of adopting alternative collaboration strategies.

Table 7.3: No Collaboration Profits: R&D Case

Company	**Profit (k€)**
Siemens	618.7
ACE	0.1

Source: Own elaboration (2025)

A significant loss in the value of the patent portfolio is observed when the value of certain patents becomes contingent on the success probabilities of R&D

processes. Specifically, compared to the initial results from the base case shown in Table 7.1, Siemens' portfolio in this scenario would lose more than 60% of its value if two of its four patents are designated for R&D. Similarly, ACE's portfolio would experience a nearly total loss of value if all its patents were part of the hypothetical patent race in the sector. This highlights the substantial economic risks associated with R&D-driven strategies in highly competitive environments.

In this case, as outlined in section 6.3.2 and confirmed by the corresponding payoff matrix in Appendix B, the Nash equilibrium is reached when Siemens licenses its two patents not designated for R&D to ACE. The final results for this strategy are summarized in Table 7.4, reflecting the economic outcomes for both parties under the optimal strategy identified by the model.

Table 7.4: Collaboration Profits: R&D Case

Company	**Profit (k€)**
Siemens	1,967.2
ACE	70.3

Source: Own elaboration (2025)

The results demonstrate how both Siemens and ACE significantly enhance their profits through the licensing transaction involving the patents not designated for R&D. Despite the lack of collaboration on the patents allocated for R&D, this strategy enables both companies to maximize the economic potential of their remaining assets.

To further explore the significant impact of success probabilities in the analysis of a game involving R&D, an additional scenario will be evaluated. In this scenario, Siemens, as a major player, expresses interest in the patents held by a smaller company, ACE. Unlike the previous case where the entire sector was assumed to be engaged in a highly competitive patent race, this scenario considers a situation with considerably less competition. As a result, ACE, with a significantly advanced research process, is assumed to have a 60% probability of success and commercialization. Siemens, while less advanced in its R&D process, benefits from its substantial market power, granting it a 20% chance of success due to its superior commercialization capabilities. The remaining 20% success probability is attributed to other players in the market.

Under these revised conditions, the updated valuation of the patent portfolio for each company, incorporating these adjusted success probabilities, is presented in Table 7.6. This last analysis aims to highlight how changes in competitive dynamics and individual company capabilities can dramatically influence strategic decision-making and the perceived value of industrial property.

Table 7.5: No Collaboration Profits: R&D Case with less competition

Company	**Profit (k€)**
Siemens	828.7
ACE	303.4

Source: Own elaboration (2025)

In this scenario, the initial value of the patent portfolio for both companies increases significantly compared to the values presented in Table 7.3, particularly for ACE. The substantial improvement in ACE's success probability in the R&D process contributes to this rise, although the portfolio's value does not fully recover to the levels observed in the base scenario where no patents were allocated for R&D.

Given the notably high success probability brought by ACE's advanced R&D efforts, combined with Siemens' superior commercialization capabilities, the optimal strategy in this case would be to form a joint venture, provided that transactional costs remain within reasonable limits. The joint venture leverages ACE's R&D strength and Siemens' market power, creating a synergistic collaboration that significantly enhances the likelihood of successful commercialization.

Furthermore, due to the increased success probabilities, cooperative strategies gain considerable value. Unlike in prior scenarios, the expected value and success probabilities in this case are sufficient to offset the transactional costs associated with collaboration. As such, strategies such as strategic alliances or joint ventures now present viable and beneficial alternatives for both parties.

As in previous analyses, patents not allocated for R&D would be licensed, ensuring additional revenue streams for both companies. The new results reflecting these strategies and their economic impact are presented in Table Z.

Table 7.6: No Collaboration Profits: R&D Case with less competition

Company	**Profit (k€)**
Siemens	3729,6
ACE	1513,1

Source: Own elaboration (2025)

7.3 Conclusions

The economic analysis conducted in this chapter highlights the significant value that the proposed model provides to companies by offering detailed insights into the potential economic performance of various collaboration strategies. Whether under conditions of imperfect or perfect information, the model demonstrates its utility in helping firms evaluate the financial impact of their decisions, optimize their strategic approaches, and better understand the dynamics influencing their industrial property portfolios.

In the context of imperfect information, the model captures the complexities of decision-making when firms lack full knowledge of the counterparty's patent valuations. It faithfully reflects how factors such as bargaining power, exclusivity, and transactional costs shape the economic outcomes of collaboration strategies. For instance, the analysis revealed that major players like Siemens tend to benefit significantly from licensing strategies due to their ability to act as price-makers, leveraging their market power to secure advantageous license fees. Similarly, the results highlight how smaller players like ACE, with lower bargaining power, achieve smaller yet meaningful economic gains, emphasizing the importance of context and relative market power.

The model also proves invaluable in identifying key thresholds, such as the minimum counterparty value required for a specific strategy to become profitable. This level of granularity provides companies with actionable data to guide their decisions and tailor their strategies to maximize returns.

The perfect information analysis further reinforces the model's robustness and its ability to evaluate collaboration strategies under different scenarios. In the base collaboration game, Siemens and ACE achieved significant profit increases through optimized strategies, such as licensing non-R&D patents. These findings demonstrate the model's effectiveness in identifying mutually beneficial outcomes, even when firms have asymmetric market power. Importantly, the analysis confirms that collaboration strategies like licensing are consistent across both imperfect and perfect information scenarios when the sector has high fragmentation, reinforcing the model's predictive validity.

In the R&D patent scenarios, the model captures the nuanced trade-offs that arise when patents are allocated for research and development. The significant reduction in the initial portfolio value observed in the standard R&D scenario underscores the impact of low success probabilities on patent valuation. However, the analysis also shows that as success probabilities increase, so too does the appeal of cooperative strategies like joint ventures or strategic alliances. By accounting for variables such as success chances, commercialization probabilities, and transactional costs, the model enables firms to evaluate the economic viability of these high-cost strategies under specific conditions.

Across all scenarios analyzed, the model proves to be a powerful tool for companies seeking to optimize their collaboration strategies. It not only helps firms assess the direct financial benefits of engaging in specific strategies but also offers a broader understanding of how key factors, such as exclusivity, bargaining power, transactional costs, and success probabilities, impact the outcomes.

The model's ability to adapt to different contexts and provide actionable insights is particularly valuable for firms operating in fragmented and competitive sectors, where strategic decisions must be carefully calibrated in order to maximize returns. Moreover, by allowing companies to simulate various scenarios, the model equips them with the foresight needed to navigate complex industrial property landscapes and align their strategies with their broader innovation and market goals.

In conclusion, this chapter's economic analysis reaffirms the utility and adaptability of the model presented in chapter 5. By faithfully reflecting the complex dynamics of knowledge-sharing processes and providing detailed financial projections, it empowers companies to make informed decisions, optimize their knowledge-sharing strategies, and unlock new opportunities for growth and collaboration.

Chapter 8

Conclusions & Future Developments

This master's thesis has achieved its central objective of developing a robust and comprehensive framework to optimize collaboration strategies for industrial property management. By addressing the intricate dynamics of knowledge-sharing processes, the model provides a nuanced tool capable of evaluating various strategic decisions within the context of patent transactions. This final proposed model integrates theoretical foundations, contextual variables, and real-world applicability, ensuring that the proposed solutions are both practical and adaptable to diverse scenarios.

At its core, the thesis tackles the challenges presented by the current industrial property landscape, characterized by restrictive competition practices, overlapping patents, and a rising volume of disputes. These issues hinder innovation and complicate market entry for smaller firms, necessitating the development of robust frameworks that promote effective collaboration while preserving the economic potential of industrial property. The detailed exploration of industrial property concepts and game theory principles provided a solid basis for constructing a model capable of capturing these complexities.

A key accomplishment of this work is the model's ability to represent the essential factors influencing collaboration strategies faithfully. Elements such as exclusivity, bargaining power, sectoral fragmentation, patent valuations, and transactional costs are integrated into the framework, enabling a detailed analysis of their effects on decision-making. For example, the model captures how exclusivity impacts patent value in both competitive and concentrated markets, highlighting the scenarios in which licensing, sale, or non-collaboration are optimal. It also reflects how transaction costs can disproportionately influence the strategies of smaller players, such as ACE, compared to larger firms like Siemens.

Another significant contribution is the model's dual focus on perfect and imperfect information scenarios. In cases of imperfect information, the framework accounts for uncertainties surrounding counterparty valuations, proving how bargaining power and exclusivity shape decisions under these conditions. On the other hand, for perfect information scenarios, the model provides clarity into optimal strategies, consistently aligning with theoretical expectations. The inclusion of R&D-specific scenarios further validates the model's flexibility, showcasing its ability to assess how success probabilities and cooperative strategies, such as joint ventures, affect outcomes in competitive environments.

The verification process, grounded in real-world-inspired patent data, demonstrated the model's reliability and effectiveness. By simulating scenarios involving firms with varying market positions and patent portfolios, the model highlighted the importance of sectoral dynamics, such as fragmentation, and company-specific factors, such as resource allocation and strategic priorities. The results consistently demonstrated the developed model's ability to adapt to diverse contexts, reflecting the trade-offs and complexities inherent in industrial property transactions.

This thesis also underscores the importance of flexibility in the valuation of patents and the adaptability of the model to incorporate player-specific inputs. By allowing external valuation data to be seamlessly integrated, the model ensures that it can accommodate varying perspectives and strategic considerations. This adaptability is critical in representing the contextual nature of industrial property, where patent value and strategy are deeply influenced by the competitive landscape, market conditions, and individual company goals.

In broader terms, this project contributes to fostering a more interconnected and innovative industrial environment. By providing actionable insights and optimizing collaboration strategies, the framework developed supports firms in navigating the complexities of intellectual property management. It reduces barriers to innovation, enhances the economic potential of industrial property assets, and also facilitates mutually beneficial cooperation among industry players.

In conclusion, this master's thesis aims to help in understanding and optimizing the dynamics of industrial property transactions. It combines theoretical rigor with practical relevance, offering a tool that is not only robust and versatile but also capable of adapting to the evolving needs of a competitive and innovation-driven marketplace. By addressing the key challenges of knowledge-sharing and industrial collaboration, the framework defines a way for more effective and equitable management of industrial property, ultimately supporting economic growth and technological advancement.

8.1 Future Developments

The model developed in this master's thesis provides a robust foundation for optimizing collaboration strategies for industrial property management. However, there is still potential for future developments to enhance its comprehensiveness, scalability, and applicability. These extensions would allow the model to address more complex scenarios and refine its ability to reflect the nuanced realities of industrial property transactions.

One interesting direction for future work is the inclusion of additional factors that influence decision-making in patent transactions. For example, the interrelation between patents could be explicitly modeled, considering whether patents are complementary, substitutive, or independent. On the one hand, complementary patents may incentivize collaboration, as their combined use can create value beyond their individual contributions. Conversely, substitutive patents could lead to more competitive dynamics, as firms may aim to consolidate control over overlapping technologies. Incorporating such interrelations would provide a deeper understanding of the strategic considerations driving knowledge-sharing decisions.

Another area for improvement lies in enhancing the valuation process for patents. Currently, the model treats patent value as an external input, relying on data provided by each player and income-based estimations. Future developments could aim to internalize Pre-Phase 2 by creating a sub-model capable of estimating patent value using a market-based approach. This could involve leveraging existing benchmarking techniques or analyzing comparable transactions to estimate fair market values. Additionally, the model could incorporate multi-factor valuation methods that account for industry trends, patent interrelations, and economic projections. These advancements would reduce reliance on external inputs and provide a more integrated framework for decision-making.

Scalability is another critical aspect for future consideration. While the current model is designed for two-player scenarios, expanding its capabilities to include multiple players would allow for analyzing more complex and refined collaborative arrangements, such as patent pooling. Patent pools, where multiple firms agree to share patents under a unified licensing structure, are particularly relevant in industries with high interdependence and overlapping intellectual property. Adapting the model to include these multi-player dynamics would enhance its versatility and applicability across a broader range of industries.

Furthermore, the incorporation of dynamic game structures could provide valuable insights into evolving strategic interactions. While the current model is designed as a static framework, extending it to account for sequential decision-making and time-based strategies could better capture the iterative nature of collaboration agreements. For instance, firms might adjust their strategies based on the outcomes of earlier interactions, changes in market conditions, or advancements in R&D efforts. Dynamic modeling could also evaluate how long-term commitments, such as joint ventures or alliances, influence decision-making and outcomes over time.

In conclusion, while the current model offers a robust foundation for optimizing collaboration strategies, future developments could significantly enhance its scope and applicability. By incorporating additional factors, considering some alternative valuation methodologies, enabling multi-player scenarios, and introducing dynamic structures, the framework could evolve into an even more powerful and flexible tool for managing industrial property in a competitive and innovation-driven landscape. Such advancements would ensure that the model continues to provide actionable insights that drive collaboration, foster innovation, and optimize the economic potential of industrial property assets.

Appendix A

Python Code

A.1 Pre-Phase 1

This Pre-Phase centers on calculating the Fragmentation Index, a measure that assesses how patent ownership is distributed across the industry. This index offers valuable insights into the market structure by revealing whether the sector is controlled by a few key players with substantial patent holdings or is more evenly divided among numerous participants with smaller shares. Such an analysis is crucial for understanding the competitive dynamics and their impact on strategic decisions related to patent management and collaboration opportunities.

Alongside the Fragmentation Index, the process also determines the proportion of patent ownership attributed to each company within the sector. This measure provides a clear view of the influence and negotiating power of individual firms based on their share of patents.

A.1.1 Inputs

The code used to calculate this information requires a data frame named *patent_data*, which must contain essential details from a representative sample of patents in the sector. This data frame should have the following structure:

Table A.1: *patent_data* structure

Application No.	**Title**	**Publication No.**	**Applicant**	**Representative**	**IPC**

A.1.2 Code

```
import numpy as np
import pandas as pd

def calculate_concentration_index(patent_data):
    applicants = pd.DataFrame()
    patents_split_applicants =
    ↪  patent_data["Applicant"].str.split("\n").explode()
    patents_split_applicants = patents_split_applicants.str.upper()
    split_applicants =
    ↪  (patents_split_applicants).reset_index().rename(columns={"Patent"
    ↪  : "Application No.", "Applicant" : "Applicant"})
    split_applicants["Ownership"] = (split_applicants["Application
    ↪  No."].map(split_applicants["Application
    ↪  No."].value_counts()).rdiv(1))
    applicants["N patents"] =
    ↪  split_applicants.groupby("Applicant")["Ownership"].sum()
    applicants = applicants.sort_values(by="N patents", ascending=False)
    applicants["% patents"] = applicants["N
    ↪  patents"]/len(patent_data.index)*100
    concentration_index = (applicants["% patents"]**2).sum()
    if(concentration_index>2500):
        print("Highly concentrated market")
    elif(concentration_index>1500):
        print("Moderately concentrated market")
    else:
        print("Low concentration")

    return(applicants, concentration_index)
```

A.2 Analysis Under Imperfect Information

This code evaluates collaboration strategies for a specific patent by varying the counterparty's valuation. This enables companies to assess the potential outcomes of their strategic decisions while accounting for uncertainties in the counterparty's valuation.

In such contexts, where companies must manage patents without fully knowing counterparties' preferences or valuations, the proposed model provides a framework to analyze strategies like selling, licensing, forming alliances, or pursuing joint ventures by simulating different counterparty value scenarios.

A.2.1 Inputs

The required inputs for this code include the following: *patent_data*, which contains sector-specific information as detailed in Table A.1, to carry out Pre-phase 1; an array with the *players* involved in the game; data on the *patent* being analyzed with the information shown in Table A.2; the *value* estimated by the owning company using an income-based approach (serving as input for Pre-phase 2); and, if applicable, an adjusted $exclusivity_factor$ to account for cases where the patent's value is affected by exclusivity in a way that deviates from the sector's standard measure.

Table A.2: *patent_data* structure

Owner	
Publication No.	
Type	
R&D	

A.2.2 Code

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

def plot_patent_strategy_payoffs(patents_data, players, patent, value,
↪ exclusivity_factor = None):

    applicants, concentration_index =
    ↪ calculate_concentration_index(patents_data)

    bargaining_power = pd.DataFrame(columns=["% patents"])
    for player in players:
        try:
            patents_ownership = applicants.loc[player, "% patents"]
        except:
            patents_ownership = 0
        patents_ownership = pd.DataFrame({"% patents" :
        ↪ patents_ownership}, index = [player])
        bargaining_power = pd.concat([bargaining_power,
        ↪ patents_ownership])
```

```
bargaining_power["Power"] = bargaining_power["% patents"]/bargaining_power["% patents"].sum()
if not exclusivity_factor:
    exclusivity_factor = concentration_index/10000

player_test = patent["Owner"]
power = bargaining_power.loc[player_test]["Power"]
patent_rd = patent["R&D"]
if patent_rd == 1:
    success_chance_player = bargaining_power.loc[player_test]["% patents"]/100
    success_chance_players = applicants.loc[players, "% patents"].sum()/100
else:
    success_chance_player = 1
    success_chance_players = 1
counterparty_value = np.linspace(0,1000000,500)

sale_value = (value+35000)*(1-power) + (counterparty_value-70000)*power
print(sale_value)
counterparty_sale_payoff = counterparty_value - sale_value
negatives = counterparty_sale_payoff < 1
sale_payoff_min = sale_value - 8000
sale_payoff_min[negatives] = np.nan
sale_payoff_max = sale_value - 35000
sale_payoff_max[negatives] = np.nan

license_value = ((value)*exclusivity_factor+45000)*(1-power) + (counterparty_value-30000)*(1-exclusivity_factor)*power
print(license_value)
counterparty_license_payoff = -license_value + counterparty_value*(1-exclusivity_factor)*success_chance_player
negatives = counterparty_license_payoff < 1
license_payoff_min = license_value + value*(1-exclusivity_factor)*success_chance_player - 12000 - 30000
license_payoff_min[negatives] = np.nan
license_payoff_max = license_value + value*(1-exclusivity_factor)*success_chance_player - 45000 - 30000
license_payoff_max[negatives] = np.nan
```

```
alliance_min = value*success_chance_player - 15000 - 30000
alliance_max = value*success_chance_player - 80000 - 30000

jv_min = value*success_chance_players - 150000 - 30000
jv_max = value*success_chance_players - 1000000 - 30000

plt.figure(figsize=(10,6))

counterparty_value = counterparty_value/1000
base_case = "None"
base_case_payoff = (value*success_chance_player-30000)
no_action_payoff = (value*success_chance_player-30000)
if base_case_payoff<0:
    base_case = "Abandon"
    no_action_payoff = 0

plt.plot(counterparty_value, sale_payoff_min/1000, label = "Sale",
↪   color = "lightskyblue")
plt.plot(counterparty_value, sale_payoff_max/1000, label = "Sale",
↪   color = "darkblue")
plt.plot(counterparty_value, license_payoff_min/1000, label =
↪   "License", color = "darkseagreen")
plt.plot(counterparty_value, license_payoff_max/1000, label =
↪   "License", color = "darkgreen")
if alliance_min >= 0:
    plt.axhline(y=alliance_min/1000, label = "Strategic Alliance",
    ↪   color = "lightcoral")
if alliance_max >= 0:
    plt.axhline(y=alliance_max/1000, label = "Strategic Alliance",
    ↪   color = "firebrick")
if jv_min >= 0:
    plt.axhline(y=jv_min/1000, label = "Joint Venture", color =
    ↪   "plum")
if jv_max >= 0:
    plt.axhline(y=jv_max/1000, label = "Joint Venture", color =
    ↪   "purple")
plt.axhline(y=no_action_payoff/1000, label = base_case, color =
↪   "orange")
plt.legend(fontsize=10)

plt.xlabel("Counterparty Value (k€)")
plt.ylabel("Payoff (k€)")
```

```
plt.xlim(0,1000000/1000)
plt.ylim(0,1000)
```

A.3 Analysis Under Perfect Information

This section introduces the optimization model designed to evaluate strategic decisions in patent exchange and management. The primary goal of the optimization model is to find the Nash Equilibrium, where no player has an incentive to deviate unilaterally from their chosen strategy. This ensures that the resulting strategies are both stable and mutually advantageous within the competitive environment

A.3.1 Inputs

The required inputs for this code include the following: $patent\_info$, a data frame listing the patents involved in the optimization model (those included in the game) following the structure outlined in Table A.3; *industry_patent_data*, equivalent to the *patent_data* data frame described in previous section, providing sector-specific information as detailed in Table A.1; an array with the *players* participating in the game; and the $players\_info$, a data frame with detailed information for each player including whether a player is the owner of a specific patent, their valuation of the patent derived from Pre-phase 2, and other relevant data outlined in Table A.4.

Table A.3: $patent\_info$ structure

Application No.	**Owner**	**Publication No.**	**Type**	**R&D**

Table A.4: $players\_info$ structure

Application No.	**Ownership**	**Type**	**Value**

A.3.2 Code

```
import pandas as pd
import numpy as np
import itertools
import re
import random

def randomize_transactional_costs():

    transactional_costs_limits = {
        "sale_seller"           :   (8000,35000),
        "sale_buyer"            :   (16000,70000),
        "license_licensor"      :   (12000,45000),
        "license_licensee"      :   (7000,30000),
        "strategic_alliance"    :   (15000,80000),
        "joint_venture"         :   (150000,1000000),
    }

    transactional_costs = {
        var : np.random.uniform(low,high) for var, (low,high) in
        ↪  transactional_costs_limits.items()
    }

    return(transactional_costs)

def sale_licensing_matrix(patents, patent_info, industry_patent_data,
↪   players, players_info, rd_strategy, transactional_costs):

    players_ownership = pd.DataFrame()
    players_value = pd.DataFrame()
    for player in players:
        player_info = players_info[player]
        players_ownership[player] = player_info["Ownership"]
        players_value[player] = player_info["Value"]

    patent_owner = patent_info["Owner"]

    patent_type = pd.get_dummies(patent_info["Type"], prefix='',
    ↪  prefix_sep='')
    patent_type = patent_type.astype(int)

    patent_rd = patent_info["R&D"]
```

```
for col in ['Benefit', 'Cost']:
    if col not in patent_type.columns:
        patent_type[col] = 0

applicants, concentration_index =
↪   calculate_concentration_index(industry_patent_data)
exclusivity_factor = concentration_index/10000

players_profit_var =
↪   ((-players_ownership+(1-exclusivity_factor))*players_value).abs()
↪   + players_ownership*30000 - (1-players_ownership)*45000

bargaining_power = pd.DataFrame(columns=["% patents"])
for player in players:
    try:
        patents_ownership = applicants.loc[player, "% patents"]
    except:
        patents_ownership = 0
    patents_ownership = pd.DataFrame({"% patents" :
    ↪   patents_ownership}, index = [player])
    bargaining_power = pd.concat([bargaining_power,
    ↪   patents_ownership])
bargaining_power["Power"] = bargaining_power["%
↪   patents"]/bargaining_power["% patents"].sum()

if rd_strategy == "Nocop":
    player_patents = {player: patent_info[patent_info["Owner"] ==
    ↪   player].index.tolist() for player in players}
    player_combinations = {player: generate_strategies(patents) for
    ↪   player, patents in player_patents.items()}
else:
    non_rd_patents = patent_info[patent_info["R&D"]==0]
    non_rd_player_patents = {player:
    ↪   non_rd_patents[non_rd_patents["Owner"] ==
    ↪   player].index.tolist() for player in players}
    player_combinations = {player: generate_strategies(patents) for
    ↪   player, patents in non_rd_player_patents.items()}

player1 = players[0]
player2 = players[1]
strategies_player1 = player_combinations[player1]
strategies_player2 = player_combinations[player2]
```

```
payoffs = pd.DataFrame(index=strategies_player2,
↪ columns=strategies_player1)

for row in payoffs.index:
    for col in payoffs.columns:
        payoffs_array = []
        strategy_info = {patent: 1 for patent in patents}

        for patent in patent_info.index:
            search_info = rf"(Sell|License){patent}"

            match_row = re.search(search_info, row)
            if match_row:
                action_row = match_row.group(1)
                strategy_info[patent] = action_row

            match_col = re.search(search_info, col)
            if match_col:
                action_col = match_col.group(1)
                strategy_info[patent] = action_col

        sale_value = pd.DataFrame(index=["Sale Value"],
        ↪ columns=patent_info.index)
        for patent in patent_info.index:
            if strategy_info[patent]==1:
                sale_value[patent] = 0
            else:
                sale_value[patent] = sum(v*(1-p) for v,p in
                ↪ zip((players_value.loc[patent]+players_ownership.loc[patent]*35000-p
                ↪ bargaining_power["Power"]))

        license_fee = pd.DataFrame(index=["license_fee"],
        ↪ columns=patent_info.index)
        for patent in patent_info.index:
            if strategy_info[patent]==1:
                license_fee[patent] = 0
            else:
                license_fee[patent] = sum(v*(1-p) for v,p in
                ↪ zip(players_profit_var.loc[patent],
                ↪ bargaining_power["Power"]))

        for player in players:
            ownership = players_ownership[player]
```

```
                value = players_value[player]
                if rd_strategy == "JointVenture":
                    success_chance_player = applicants.loc[players, "%
                    ↪ patents"].sum()
                else:
                    success_chance_player = applicants.loc[player, "%
                    ↪ patents"]
                payoff = calculate_payoff(patents, ownership, value,
                ↪ strategy_info, patent_type, patent_rd, sale_value,
                ↪ license_fee, exclusivity_factor,
                ↪ success_chance_player, rd_strategy,
                ↪ transactional_costs)
                payoffs_array.append(payoff)
            payoffs.at[row,col] = payoffs_array

    return payoffs

def generate_strategies(player_patents):
    actions = ["Keep", "Sell", "License"]
    strategies = ["None"]
    for r in range(1, len(player_patents)+1):
        for combo in itertools.combinations(player_patents, r):
            for action_cobination in itertools.product(actions[1:],
            ↪ repeat=len(combo)):
                strategy = "".join(f"{action}{patent}" for patent,
                ↪ action in zip(combo, action_cobination))
                strategies.append(strategy)
    return strategies


    benefit_patents = patent_type["Benefit"]
    Benefits_extra_patents = 0
    cost_patents = patent_type["Cost"]
    Cost_reduction_patents = 0
    Sale = 0
    License = 0
    Maintenance_cost = 0
    Total_transaction_expenses = 0

    for patent in patents:
        if ownership.loc[patent] == 1:
            transaction = 1
            if strategy_info[patent] == "Sell":
```

```
            operator = 0
            exclusivity = 1
            is_license = False
            Transaction_costs = transactional_costs["sale_seller"]
        elif strategy_info[patent] == "License":
            operator = 1
            exclusivity = 1 - exclusivity_factor
            is_license = True
            Transaction_costs =
             ↪  transactional_costs["license_licensor"]
        else:
            operator = 1
            exclusivity = 1
            is_license = False
            Transaction_costs = 0
    else:
        transaction = -1
        if strategy_info[patent] == "Sell":
            operator = 1
            exclusivity = 1
            is_license = False
            Transaction_costs = transactional_costs["sale_buyer"]
        elif strategy_info[patent] == "License":
            operator = 1
            exclusivity = 1 - exclusivity_factor
            is_license = True
            Transaction_costs =
             ↪  transactional_costs["license_licensee"]
        else:
            operator = 0
            exclusivity = 1
            is_license = False
            Transaction_costs = 0
    maintenance_fee = 10000
    if patent_rd.loc[patent] == 1:
        success_chance = success_chance_player/100
        maintenance_fee = 0
        if rd_strategy != "Nocop":
            operator = 1
    else:
        success_chance = 1

    Benefits_extra_patents += (
```

```
            ↪  value.loc[patent]*operator*benefit_patents[patent]*exclusivity*success
        )
        Cost_reduction_patents +=(

            ↪  value.loc[patent]*operator*cost_patents[patent]*success_chance
        )
        Maintenance_cost = Maintenance_cost - maintenance_fee*operator
        Total_transaction_expenses = Total_transaction_expenses +
        ↪  Transaction_costs
        if not is_license:
            Sale += sale_value[patent].values.astype(float)*transaction
        else:
            License +=
            ↪  license_fee[patent].values.astype(float)*transaction

    if rd_strategy == "Alliance":
        Total_transaction_expenses = Total_transaction_expenses +
        ↪  transactional_costs["strategic_alliance"]
    elif rd_strategy == "JointVenture":
        Total_transaction_expenses = Total_transaction_expenses +
        ↪  transactional_costs["joint_venture"]

    payoff = Sale + License + Benefits_extra_patents - (0 -
    ↪  Cost_reduction_patents) + Maintenance_cost -
    ↪  Total_transaction_expenses
    return payoff


def optimal_strategy(patent_info, industry_patent_data, players,
↪  players_info):

    print("Calculating...")

    patents = patent_info.index

    best_rd_strategy = None
    best_total_payoff_row = float("-inf")
    best_total_payoff_col = float("-inf")
    best_nash_equilibria = []

    transactional_costs = randomize_transactional_costs()
    print(transactional_costs)
```

```
for rd_strategy in ["Nocop", "Alliance", "JointVenture"]:

    payoffs = sale_licensing_matrix(patents, patent_info,
    ↪   industry_patent_data, players, players_info, rd_strategy,
    ↪   transactional_costs)
    num_rows = len(payoffs)
    num_cols = len(payoffs.iloc[0])

    best_payoff_row = float("-inf")
    best_payoff_col = float("-inf")
    nash_equilibria = []

    for row in range(num_rows):
        for col in range(num_cols):

            payoff_row = payoffs.iloc[row, col][0]
            payoff_col = payoffs.iloc[row, col][1]

            if payoff_row > best_payoff_row:
                if payoff_col > best_payoff_col:
                    best_payoff_row = payoff_row
                    best_payoff_col = payoff_col

            best_row_payoff = max([payoffs.iloc[r, col][0] for r in
            ↪   range(num_rows)])
            best_col_payoff = max([payoffs.iloc[row, c][1] for c in
            ↪   range(num_cols)])

            if payoff_row == best_row_payoff and payoff_col ==
            ↪   best_col_payoff:
                nash_equilibria.append((row,col))

    if best_payoff_row > best_total_payoff_row:
        if best_payoff_col > best_total_payoff_col:
            best_total_payoff_row = best_payoff_row
            best_total_payoff_col = best_payoff_col
            best_rd_strategy = rd_strategy
            best_nash_equilibria = nash_equilibria

cooperation = {
    "Nocop"         :   "not cooperate",
    "Alliance"      :   "form a strategic alliance",
```

```
    "JointVenture"   :   "form a joint venture"
}

print(f"The companies will {cooperation[best_rd_strategy]}")

payoffs = sale_licensing_matrix(patents, patent_info,
↪   industry_patent_data, players, players_info, best_rd_strategy,
↪   transactional_costs)

for row, col in best_nash_equilibria:

    payoff_row = payoffs.iloc[row, col][0]
    payoff_col = payoffs.iloc[row, col][1]
    print(f"\nNash Equilibrium in ({row}, {col})")

    if payoffs.index[row] != "None":
        row_patents = payoffs.index[row]
        row_patents = re.findall(r'(Sell|License)(EP\d+)',
        ↪   row_patents)
        print(f'{players[1]} will:')
        for action, patent in row_patents:
            print(f"{action} {patent}")
    if payoffs.columns[col] != "None":
        col_patents = payoffs.columns[col]
        col_patents = re.findall(r'(Sell|License)(EP\d+)',
        ↪   col_patents)
        print(f'{players[0]} will:')
        for action, patent in col_patents:
            print(f"{action} {patent}")

return(payoffs)
```

Appendix B

Payoff Matrices

B.1 Base Collaboration

Table B.1: Base Collaboration Case: Payoff Matrix

	None	SellEP23768144	...	LicenseEP23768144 LicenseEP24710638 LicenseEP23169561 LicenseEP23465507
None	[([1614619.94]), ([505741.32])]	[([1400949.32056269]), ([456809.59260048])]	...	[([4355406.92903846]), ([639459.64790322])]
SellEP23902350	[([1611129.5126624]), ([452075.93050077])]	[([1397458.89322509]), ([403144.20310125])]	...	[([4351916.50170086]), ([585794.258404])]
LicenseEP23902350	[([2066732.02919334]), ([513590.770788])]	[([1853061.40975603]), ([464659.04338848])]	...	[([4807519.0182318]), ([647309.09869122])]
SellEP23915567	[([2543054.64111441]), ([463761.51204876])]	[([2329384.02167711]), ([414829.78464924])]	...	[([5283841.63015287]), ([597479.83995198])]
LicenseEP23915567	[([2526596.13619485]), ([519357.09187893])]	[([2312925.51675754]), ([470425.36447941])]	...	[([5267383.1252333]), ([653075.41978215])]
SellEP23902350 SellEP23915567	[([2539564.21377681]), ([410096.12254954])]	[([2325893.59433951]), ([361164.39515002])]	...	[([5280351.20281527]), ([543814.45045276])]
SellEP23902350 LicenseEP23915567	[([2523105.70885725]), ([465691.7023797])]	[([2309435.08941994]), ([416759.97498018])]	...	[([5263892.6978957]), ([599410.03028293])]
LicenseEP23902350 SellEP23915567	[([2995166.73030775]), ([471610.96283676])]	[([2781496.11087045]), ([422679.23543724])]	...	[([5735953.71934621]), ([660924.87057015])]
LicenseEP23902350 LicenseEP23915567	[([2978708.22538819]), ([527206.54266693])]	[([2765037.60595088]), ([478274.81526741])]	...	[([5719495.21442664]), ([605329.2907399])]

B.2 R&D Collaboration

Table B.2: R&D Collaboration 1st Case: Payoff Matrix

	None	...	LicenseEP23169561 LicenseEP23465507	...	LicenseEP23768144 LicenseEP24710638 LicenseEP23169561 LicenseEP23465507
None	[([618730.313415]), ([105.148264])]	...	[([1967152.89235938]), ([70323.31622925])]	...	[([3397614.37975685]), ([-1413890.98623745])]
SellEP23902350	[([127014.746319]), ([436682.60815888])]	...	[([1475437.32526338]), ([506900.77612413])]	...	[([2905898.81266084]), ([-977313.52634257])]
LicenseEP23902350	[([581671.49230557]), ([18278.27230495])]	...	[([1930094.07124995]), ([88496.44027021])]	...	[([3360555.55864742]), ([-1395717.86219649])]
SellEP23915567	[([600775.71053451]), ([-29556.58621713])]	...	[([1949198.28947889]), ([40661.58174812])]	...	[([3379659.77687636]), ([-1443552.72071858])]
LicenseEP23915567	[([584849.426632]), ([22502.85608654])]	...	[([1933272.00557638]), ([92721.02405179])]	...	[([3363733.49297385]), ([-1391493.27841491])]
SellEP23902350 SellEP23915567	[([109060.14343851]), ([407020.87367774])]	...	[([1457482.72238289]), ([477239.041643])]	...	[([2887944.20978036]), ([-1006975.2608237])]
SellEP23902350 LicenseEP23915567	[([93133.859536]), ([459080.31598141])]	...	[([1441556.43848038]), ([529298.48394667])]	...	[([2872017.92587784]), ([-954915.81852003])]
LicenseEP23902350 SellEP23915567	[([654643.95107679]), ([-178246.78375401])]	...	[([1912139.46836946]), ([58834.70578907])]	...	[([3342600.95576693]), ([-1425379.59667763])]
LicenseEP23902350 LicenseEP23915567	[([547790.60552257]), ([40675.98012749])]	...	[([1896213.18446695]), ([110894.14809274])]	...	[([3326674.67186442]), ([-1373320.15437396])]

Table B.3: R&D Collaboration 2nd Case: Payoff Matrix

	None	SellEP23169561	...	LicenseEP23169561 LicenseEP23465507
None	[([2382678.38690464]), ([1449930.45890464])]	[[([2491154.29401142]), ([1378539.64405185])]	...	[([3729638.78925119]), ([1513105.86669091])]

Bibliography

[1] Draft Comittee. "Universal Declaration of Human Rights (UDHR)". In: United Nations General Assembly. Dec. 1948.

[2] Spanish Institute for Foreign Trade (ICEX). *Industrial and intellectual property*. https://www.investinspain.org/en/doing-business/industrial-intellectual-property. Accessed: 15 October 2024.

[3] C.M. Kalanje. *Role of Intellectual Property in Innovation and New Product Development*. Tech. rep. Wordl Intellectual Property Organization, 2006.

[4] A. Moore and K. Himma. "Intellectual Property". In: *The Stanford Encyclopedia of Philosophy*. Ed. by Edward N. Zalta and Uri Nodelman. Fall 2022. Metaphysics Research Lab, Stanford University, 2022.

[5] B. Bugbee. *The Genesis of American Patent and Copyright Law*. Public Affairs Press, 1967.

[6] Metida. *Toblerone: The Fusion of Intellectual Property and Uniqueness*. https://metida.com/toblerone-the-fusion-of-intellectual-property-and-uniqueness. 2023.

[7] Tiffany & Co. *Tiffany Blue*. https://press.tiffany.com/our-story/tiffany-blue. Accessed: 14 October 2024.

[8] L. Daniel. "Distinctive sounds like the MGM lion's roar protected by law". In: *The Gazette* (2012).

[9] Wilson Gunn. *The History of Patents*. https://www.wilsongunn.com/history/history_patents.html. 2014.

[10] C. May. "The Venetian Moment: New Technologies, Legal Innovation and the Institutional Origins of Intellectual Property". In: *Prometheus* 20.2 (2010), pp. 159–179.

[11] M. Brown and A. Evans. *The Statute of Monopolies – still relevant 400 years on*. Tech. rep. AJPark, 2024.

[12] Intellectual Property Rights Office (IPRO). *Copyright history*. https://intellectualpropertyrightsoffice.org/copyright_history. Accessed: 14 October 2024.

[13] S. Mehmood. “Intellectual property”. In: *The News International* (2016).

[14] World Intellectual Property Organization (WIPO). *Paris Convention for the Protection of Industrial Property*. https://www.wipo.int/treaties/en/ip/paris/. Accessed: 14 October 2024.

[15] World Intellectual Property Organization (WIPO). *Berne Convention for the Protection of Literary and Artistic Works*. https://www.wipo.int/treaties/en/ip/berne/. Accessed: 14 October 2024.

[16] The Editors of Encyclopedia Britannica. “World Intellectual Property Organization”. In: *Encyclopedia Britannica* (2024).

[17] World Intellectual Property Organization (WIPO). *Convention Establishing the World Intellectual Property Organization*. https://www.wipo.int/treaties/en/convention/. Accessed: 14 October 2024.

[18] World Intellectual Property Organization (WIPO). *About WIPO*. https://www.wipo.int/about-wipo/en/. Accessed: 15 October 2024.

[19] World Intellectual Property Organization (WIPO). *PCT – The International Patent System*. https://www.wipo.int/pct/en/. Accessed: 15 October 2024.

[20] World Trade Organization (WTO). *TRIPS — Trade-Related Aspects of Intellectual Property Rights*. https://www.wto.org/english/tratop_e/trips_e/trips_e.htm. Accessed: 15 October 2024.

[21] A. George. “The Importance of Defining ’Intellectual Property’”. In: *Constructing intellectual property*. Cambridge University, 2012.

[22] *Oxford University Press (OUP). Intellectual property. In Oxford English Dictionary*. https://www.oed.com/dictionary/intellectual-property_n?tab=meaning_and_use. Accessed: 15 October 2024.

[23] University of Oxford. *Intellectual Property*. https://researchsupport.admin.ox.ac.uk/innovation/intellectual-property. Accessed: 15 October 2024.

[24] World Intellectual Property Organization (WIPO). *What is Intellectual Property?* World Intellectual Property Organization (WIPO), 2004.

[25] W.C. Holmes. “Intellectual Property and Human Rights”. In: *A Panel Discussion to Commemorate the 50th Anniversary of the Universal Declaration of Human Rights*. World Intellectual Property Organization (WIPO). Nov. 1998.

[26] H. Chang. "Intellectual Property Rights and Economic Development: Historical lessons and emerging issues". In: *Journal of Human Development* (2001).

[27] M. Boldrin and D. Levine. "The Case Against Intellectual Property". In: *The American Economic Review* (2002).

[28] M. Boldrin and D. Levine. *Against Intellectual Monopoly.* Cambridge University Press, 2008.

[29] J. Hughes. *The Philosophy of Intellectual Property.* Georgetown University Law Center, 1988.

[30] J. Locke. *Two Treatises of Government.* Awnsham Churchill, 1689.

[31] G.W. Hegel. *Elements of the Philosophy of Right.* Cambridge University Press, 1820.

[32] R. Paul. "Intellectual Property Rights: A Utilitarian Perspective". In: *University School of Law and Legal Studies, Guru Gobind Singh Indraprastha University* (2021).

[33] P.C. Neves et al. "The link between intellectual property rights, innovation, and growth: A meta-analysis". In: *Economic Modelling* (2021).

[34] D.K. Sharma. "Intellectual Property and the Need to Protect It". In: *Indial Journal of Science and Research* (2014).

[35] European Union (EU). *Treaty on the Functioning of the European Union - Article 118.* Jan. 1957. URL: `https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX%3A12008E118%3AEN%3AHTML`.

[36] European Parliament. *Intellectual, industrial, and commercial property.* `https://www.europarl.europa.eu/factsheets/en/sheet/36/intellectual-industrial-and-commercial-property`. Accessed: 16 October 2024.

[37] World Trade Organization (WTO). *Overview: the TRIPS Agreement.* `https://www.wto.org/english/tratop_e/trips_e/intel2_e.htm`. Accessed: 17 October 2024.

[38] *Paris Convention for the protection of industrial property of March 20, 1883, as revised at Brussels on December 14, 1900, at Washington on June 2, 1911, at The Hague on November 6, 1925, at London on June 2, 1934, at Lisbon on October 31, 1958, and at Stockholm on July 14 1967.* World Intellectual Property Organization, 1967.

[39] World Intellectual Property Organization (WIPO). *Types of intellectual property.* `https://www.wipo.int/about-ip/en/`. Accessed: 17 October 2024.

[40] World Intellectual Property Organization (WIPO). *Patents.* https://www.wipo.int/en/web/patents/. Accessed: 17 October 2024.

[41] World Intellectual Property Organization (WIPO). *Trademarks.* https://www.wipo.int/en/web/trademarks. Accessed: 17 October 2024.

[42] World Intellectual Property Organization (WIPO). *Industrial Design.* https://www.wipo.int/en/web/trademarks. Accessed: 17 October 2024.

[43] World Intellectual Property Organization (WIPO). *Geographical Indications.* https://www.wipo.int/geo_indications/en/. Accessed: 17 October 2024.

[44] World Intellectual Property Organization (WIPO). *Trade Secrets.* https://www.wipo.int/en/web/trade-secrets. Accessed: 17 October 2024.

[45] World Intellectual Property Organization (WIPO). "Understanding Industrial Property". In: *World Intellectual Property Organization (WIPO)* (2016).

[46] Christensen Fonder Dardi. *What are the five requirements for patentability?* https://www.cfd-ip.com/blog/2021/04/what-are-the-five-requirements-for-patentability. Accessed: 20 October 2024.

[47] World Intellectual Property Organization (WIPO). *Innovation and Intellectual Property.* https://www.wipo.int/web/ipday/2017/innovation_and_intellectual_property. Accessed: 21 October 2024.

[48] S. Wagner. "Are 'Patent Thickets' Smothering Innovation?" In: *Yale Insights* (Apr. 2015).

[49] C. Shapiro. "Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard Setting". In: *Innovation Policy and the Economy.* National Bureau of Economic Research, 2000, pp. 119–150.

[50] B.H. Hall et al. *A Study of Patent Thickets.* Tech. rep. Intellectual Property Office, 2013.

[51] M. Entezarkheir. "Patent thickets, defensive patenting, and induced R&D: an empirical analysis of the costs and potential benefits of fragmentation in patent ownership". In: *Empirical Economics* (2016).

[52] J. Bessen. "Patent Thickets: Strategic Patenting of Complex Technologies". In: *Boston University* (2003).

[53] G. von Graevenitz, S. Wagner, and D. Harhoff. "Incidence and Growth of Patent Thickets: The Impact of Technological Opportunities and Complexity". In: *The Journal of Industrial Economics* (2013).

[54] S. Roosa. *Annual Litigation Trends Survey.* Tech. rep. Norton Rose Fulbright, 2024.

[55] A. Galetovic and S.H. Ross Levine. "An Empirical Examination of Patent Holdup". In: *Journal of Competition Law & Economics* (2015).

[56] M.A. Lemley and C. Shapiro. "Patent Holdup and Royalty Stacking". In: *Stanford Law and Economics Olin Working Paper* (1991).

[57] Y.N. Elizabeth et al. "Unfair Competition in the Field of Intellectual Property Rights: Analyzing Concepts, Acts of Unfair Competition and Laws". In: *Journals of Politics and Law* (2021).

[58] M.A. Lemley and C. Shapiro. "The Role of Antitrust Preventing Patent Holdup". In: *Stanford Law and Economics Olin Working Paper* (2019).

[59] T.F. Cotter. *Patent Holdup, Patent Remedies, and Antitrust Responses.* Tech. rep. University of Minnesota Law School, 2009.

[60] H. Chesbrough. "The Market for Innovation: Implications for Corporate Strategy". In: *California Management Review* (2007).

[61] F. Caviggioli et al. "Patenting strategies and characteristics of declared inventions in the long term evolution standard". In: *R&D Management* (2016).

[62] W.W. Fisher and F. Oberholzer-Gee. "Strategic Management of Intellectual Property: An integrated approach". In: *California Management Review* (2013).

[63] T. Grzegorczyk and R. Glowinski. "External Patent Exploitation Strategies: Mtives and Forms". In: *Zeszyty Naukowe* (2019).

[64] M. Reitzig. "Strategic Management of Intellectual Property". In: *MIT Sloan Management Review* (2004).

[65] D. Somaya. "Patent strategy and management: An integrative review and research agenda". In: *Journal of Management* (2012).

[66] A. Arora and M. Ceccagnoli. "Patent protection, complementary assets, and firms' incentives for technology licensing". In: *Mangement Science* (2006).

[67] B. Carlsson et al. "Intellectual property (IP) management: Organizational processes and structures, and the role of IP donations". In: *Journal of Technology Transfer* (2008).

[68] P. Belingheri and M.I. Leone. "Walking into the room with IP: Exploring starts-Ups' IP licensing strategy". In: *Management Decision* (2017).

[69] A. Al-laham, T.L. Amburgey, and C. Baden-fuller. "Who is my partner and how do we dance? Technological Collaboration and Pattenting Speed in US Biotechnology". In: *British Journal of Management* (2010).

[70] N. Ziegler et al. “Creating value through external intellectual property commercialization: A desorptive capacity view”. In: *Journal of Technology Transfer* (2013).

[71] M. Grimaldi, L. Cricelli, and F. Rogo. “Auditing patent portfolio for strategic exploitation: A decision support framework for intellectual property management”. In: *Journal of Intellectual Capital* (2018).

[72] P. Grindley and D.J. Teece. “Managin intellectual capital: Licensing and cross-licensing in semiconductors and electronic”. In: *California Management Review* (1997).

[73] F. Kohler. “Patent cross-licensing, the influence of IP interdependency and the moderating effect of firm size”. In: *Journal of Technology Transfer* (2011).

[74] U. Lichtenthaler. “External commercialization of knowledge: Review and research agenda”. In: *Internal Journal of Management Reviews* (2005).

[75] H. Delerue. “Shadow of joint patents: Intellectual property rights sharing by SMEs in contractual R&D alliances”. In: *Journal of Business Research* (2018).

[76] C. Kim and J. Song. “Creating new technology through alliances: An empirical investigation of joint patents”. In: *Technovation* (2007).

[77] A. Di Minin and D. Faems. “Building Appropriation Advantage: An Introduction to the Special Issue on Intellectual Property Management”. In: *California Management Review* (2013).

[78] S. den Uijl, R. Bekkers, and H.J. de Vries. “Managing Intellectual Property Using Patent Pools: Lessons from Three Generations of Pools in the Optical Disc Industry”. In: *California Management Review* (2013).

[79] A. Leiponen. “The Oxford Handbook of Innovation Management”. In: Oxford Academic, 2013. Chap. Intellectual Property Rights, Standards, and the Management of Innovation.

[80] A. Gambardella. *Innovative S&T indicators combining patent data and surveys: Empirical models and policy analyses.* Tech. rep. European Comission, 2012.

[81] S. Torrisi et al. “Used, blocking and sleeping patents: Empirical evidence from a large-scale inventor survey”. In: *Research Policy* (2016).

[82] A. Hayes. *Game Theory: A Comprehensive Guide - What is Game Theory?* `https://www.investopedia.com/terms/g/gametheory.asp#toc-what-is-game-theory`. 2024.

[83] O. Morgenstern and J. von Neumann. *Theory of Games and Economic Behavior*. Princeton University Press, 1944.

[84] A. Hayes. *Game Theory: A Comprehensive Guide - How it works?* `https://www.investopedia.com/terms/g/gametheory.asp#toc-how-game-theory-works`. 2024.

[85] J. Nash. "Non-Cooperative Games". In: *Annals of Mathematics* (1950).

[86] L. Flokas et al. "No-regret learning and mixed Nash equilibria: They do not mix". In: *Neural Information Processing Systems* (2020).

[87] R.E. Kranton. "Reciprocal Exchange: A Self-Sustaining System". In: *The American Economic Review* (1996).

[88] P.J. Reny. "On the Existence of Pure and Mixed Strategy Nash Equilibria in Discontinuous Games". In: *Econometrica: Journal of the Econometric Society* (2003).

[89] K. Catterjee. "Complexity of Strategies and Multiplicity of Nash Equilibria". In: *Group Decision and Negotiation* (2002).

[90] O. Chatain. "Cooperative and Non-cooperative Game Theory". In: *The Palgrave Encyclopedia of Strategic Management*. palgrave macmillan, 2016.

[91] E.N. Barron. *Game Theory: An Introduction*. Wiley, 2008.

[92] H. Bencherkroun and N. van Long. "Game Theory: Static and Dynamic Games". In: *Research Tools in Natural Resource and Environmental Economics*. World Scientific, 2011.

[93] S. Kuhn. "Prisoner's Dilemma". In: *The Stanford Encyclopedia of Philosophy*. Ed. by E.N. Zalta and U. Nodelman. Metaphysics Research Lab, Stanford University, 2019.

[94] T. Scheve. "How Game Theory Works". In: *How Stuff Works* (2024).

[95] F.C. Zagare. *Game Theory: Concepts and Applications*. Sage University Paper, 1984.

[96] I. Mehmet. "Maximin equilibrium". In: *Munich Personal RePEc Archive* (2014).

[97] A. Hayes. *Game Theory: A Comprehensive Guide - strategies*. `https://www.investopedia.com/terms/g/gametheory.asp#toc-types-of-game-theory-strategies`. 2024.

[98] L. Pavel. "Basics of Game Theory". In: *Static & Dynamic Game Theory: Foundations & Applications*. Birkhäuser, 2011.

[99] S.M. Limaei. "Mixed strategy game theory, application in forest industry". In: *Forest Policy and Economics* (2010).

[100] J.E. Suris et al. "Cooperative Game Theory for Distributed Spectrum Sharing". In: *IEEE* (2007).

[101] C. Shapiro. *Innovation Policy and the Economy*. National Bureau of Economic Research, 2000.

[102] E.J. Egan & D.J. Teece. "Untangling the Patent Thicket Literature". In: *Tusher Center for Management of Intellectual Capital* (2015).

[103] R.H. Ziedonis. "Don't Fence Me In: Fragmented Markets for Technology and the Patent Acquisition Strategies of Firms". In: *Management Science* (2004).

[104] I.M. Cockburn, M.J. MacGarvie, and E. Müller. "Patent thickets, licensing and innovative performance". In: *Industrial and Corporate Change* (2010).

[105] G. Clarkson. "Patent informatics for patent thicket detection: a network analytic approach for measuring the density of patent space". In: *Academic Management* (2005).

[106] S. Wasserman and K. Faust. *Social network analysis: Methods and applications*. Cambridge University Press, 1994.

[107] G. von Graevenitz, S. Wagner, and D. Harhoff. "How to measure patent thickets—A novel approach". In: *Economic Letters* (2011).

[108] T. Fischer and P. Ringler. "The coincidence of patent thickets—A comparative analysis". In: *Technovation* (2015).

[109] J. Farre-Mensa & D. Hegde & A. Ljungqvist. "What Is a Patent Worth? Evidence from the U.S.Patent "Lottery"". In: *The Journal of Finance* (2020).

[110] D. Martin & D. Drews. *Intelelctual Property Valuation Techniques*. Tech. rep. IPmetrics, 2010.

[111] R. Pitkethly. "The Valuation of Patents". In: *Oxford: The Said Business School* (1997).

[112] J. Tobin and W.C. Brainard. "Asset Markets and the Cost of Capital". In: *EliScholar* (1976).

[113] R. Razgaitis. "Pricing the intellectual property of early-stage technologies: a primer of basic valuation tools and considerations". In: *Intellectual property management in health and agricultural innovation: a handbook of best practices*. CABI, 2008.

[114] J.H. Matsuure. "An Overview of Intellectual Property and Intangible Asset Valuation Models". In: *Research Management Review* (2004).

[115] V. Ignat. "Modern evaluation of patents". In: *IOP Publishing* (2016).

[116] I.T. Lopes. “The Boundaries of Intellectual Property Valuation: Cost, Market, Income, Based Approaches and Innovation Turnover”. In: *Mykolas Romeris University* (2011).

[117] U. Michel-Schneider. “16th Economics & Finance Conference”. In: *Patenting - A Cost Management Perspective*. Czech Technical University. June 2022.

[118] M.C. Hübscher and S. Ehrhart. “Relief from Royalty”. In: *Intangubles in the World of Transfer Pricing*. Springer, 2021.

[119] Y. Todoroki and N. Watanabe. “Pricing strategy for resealable intellectual properties: a game theoric approach”. In: (2018).

[120] S. Kishimoto. “Stable bargaining outcomes in patent licensing: A cooperative game approach without side payments”. In: *Mathematical Social Sciences* (2013).

[121] A. Mallios. “Licensing Games”. PhD thesis. Göteborgs universitet. Handelshögskolan, 2018.

[122] D. Zhao. “Choices and impacts of cross-licensing contracts”. In: *International Review of Economics & Finance* (2017).

[123] J.P. Choi. “Patent Pools and Cross-Licensing in the Shadow of Patent Litigation”. In: *International Economic Review* (2010).

[124] W. Zheng. “Patent abandonment and subsequent cumulative inventions”. PhD thesis. University of Illinois Urbana, 2019.

[125] L. Mingxing et al. “Evolutionary game theory in patent alliance dynamics: strategy and policy implications”. In: *Technology Analysis & Strategic Management* (2024).

[126] S.V. Ramani. “Game Theory and the Logic of R&D Alliances”. In: *IIM Bangalore Research Paper* (1995).

[127] M. Xu et al. “Stochastic evolutionary game analysis of tacit knowledge sharing in patent commercialization”. In: *Wiley* (2024).

[128] European Patent Office (EPO). *European Patent Register*. `https://www.epo.org/en/searching-for-patents/legal/register`. Accessed: 02 January 2025.

[129] United States Patent and Trademark Office (USPTO). *Search for patents*. `https://www.uspto.gov/patents/search`. Accessed: 02 January 2025.

[130] L. Almeida and I. Dierickx. “The Strategic Deployment of Quality-Improving Innovations”. In: *The Journal of Business* (2005).

[131] S. van Triest and W. Vis. “Valuing patents on cost-reducing technology: A case study”. In: *International Journal of Production Economics* (2007).

[132] R.P. Merges. “Commercial Success and Patent Standards: Economic Perspectives on Innovation”. In: *California Law Review* (1988).

[133] J. Hodge and C. Hakkio. “The probability of technical success and RD appraisal”. In: *Resources and Energy* (1990).

[134] V. Denicolò. “Patent Races and Optimal Patent Breadth and Length”. In: *The Journal of Industrial Economics* (1996).

[135] R. Sevensson. “Commercialization of patents and external financing during the R&D phase”. In: *Research Policy* (2007).

[136] M. Entezarkheir. “Patent Ownership Fragmentation and Market Value: An Empirical Analysis”. In: *International Journal of Innovation Management* (2019).

[137] A. Gambardella and M.S. Giarratana. “General technological capabilities, product market fragmentation, and markets for technology”. In: *Research Policy* (2013).

[138] M. Noel and M. Schankerman. “Strategic Patenting and Software Innovation”. In: *The Journal of Industrial Economics* (2013).

[139] M. Entezarkheir. “Patent thickets, defensive patenting, and induced RD: an empirical analysis of the costs and potential benefits of fragmentation in patent ownership”. In: *Empirical Economics* (2016).

[140] F. Jell, J. Henkel, and M.W. Wallin. “Offensive Patent Portfolio Races”. In: *Long Range Planning* (2017).

[141] J.W. Oh and H.W. Park. “Income approach to technology valuation for innovations”. In: *Technology Management* (2022).

[142] G. da Cruz, D. Jabur, and F.M. Junior. “How Much Am I Selling It for? Approaches and Methods of Patents Valuation in Technology Transfer Processes”. In: *International Business Research* (2017).

[143] European Patent Office (EPO). *European Patent Register*. `https://www.epo.org/en/applying/fees`. Accessed: 04 January 2025.

[144] Y.M. Chen et al. “A preemptive power to offensive patent litigation strategy: Value creation, transaction costs and organizational slack”. In: *Journal of Business Research* (2016).

[145] F. Caviggioli et al. “Corporate strategies for technology acquisition: evidence from patent transactions”. In: *Management Decision* (2017).

[146] European Patent Office (EPO). *Cooperative Patent Classification (CPC)*. `https://www.epo.org/en/searching-for-patents/helpful-resources/first-time-here/classification/cpc`. Accessed: 07 January 2025.

[147] European Patent Office (EPO). *Cooperative Patent Classification (CPC)*. https://worldwide.espacenet.com/patent/cpc-browser#. Accessed: 07 January 2025.

[148] European Patent Office (EPO). *Cooperative Patent Classification (CPC)*. https://worldwide.espacenet.com/patent/cpc-browser#!/CPC=H. Accessed: 07 January 2025.

[149] European Patent Office (EPO). *Cooperative Patent Classification (CPC)*. https://worldwide.espacenet.com/patent/cpc-browser#!/CPC=H02. Accessed: 07 January 2025.