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**Department of Economics and Management**

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# THE INNOVATION PARADOX: SUCCESS AND EXIT STRATEGIES IN THE LASER INDUSTRY

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# ABSTRACT

This thesis explores the importance of innovation in the laser industry, and its impact on the likelihood of market exit. Innovation is a key element in dynamic industries where there is a constant drive for improvement and advancement of the core product, in this case, lasers. Patents are the measures used to indicate the presence of innovation within a company.

The research questions are divided into two groups. The first group concerns the factors influencing the development of innovation within the laser industry. The second group aims to identify the factors that influence the probability of market exit. In addition, the research seeks to ascertain whether innovation has a tangible impact on the likelihood of companies exiting the market. Furthermore, the study will examine whether innovative companies that exit the market are more likely to do so through failure or mergers and acquisitions.

A quantitative analysis of a sample of companies active in the laser industry is employed to examine the relationship between innovation indicators, such as the number of patents, the number of forward citations, and the number of backward citations, in relation to market exit rates. In order to address the various research questions, a number of econometric models have been employed.

Findings reveal that companies that adopt a broad patents protection strategy, produce higher quality patents, and benefit from accumulated experience tend to file more patents, fostering continuous innovation in the laser industry. Additionally, the research finds that innovators become a desirable target for M&A. This implies that when they exit the market, they are more likely to do so with a positive outcome, as they were selected for acquisition by ither companies.

The study offers practical implications for laser active in the laser industry, suggesting that investment in innovation can mitigate the risk of business failure and enhance industry resilience. In this context, innovation becomes a crucial factor capable of shaping and influencing the dynamics of the industry and the lives of the companies operating in it.

# SOMMARIO

Questa tesi esplora l'importanza dell'innovazione nell'industria del laser e il suo impatto sulla probabilità di uscita dal mercato. L'innovazione è un elemento chiave nelle industrie dinamiche, dove c'è una costante spinta al miglioramento e all'avanzamento del prodotto principale, in questo caso i laser. I brevetti sono le misure utilizzate per indicare la presenza di innovazione all'interno di un'azienda.

Le domande di ricerca si dividono in due gruppi. Il primo gruppo riguarda i fattori che influenzano la produzione dell'innovazione nell'industria del laser. Il secondo gruppo mira a identificare i fattori che influenzano la probabilità di uscita dal mercato. Inoltre, la ricerca cerca di verificare se l'innovazione ha un impatto tangibile sulla probabilità di uscita delle aziende dal mercato. Inoltre, lo studio esaminerà se le aziende innovative che escono dal mercato hanno maggiori probabilità di farlo attraverso il fallimento o le fusioni e acquisizioni.

Un'analisi quantitativa di un campione di aziende attive nell'industria del laser viene impiegata per esaminare la relazione tra indicatori di innovazione, come il numero di brevetti, il numero di citazioni in avanti e il numero di citazioni indietro, in relazione ai tassi di uscita dal mercato. Per rispondere alle diverse domande di ricerca, sono stati utilizzati diversi modelli econometrici.

I risultati rivelano che le aziende che adottano un'ampia strategia di protezione dei brevetti, producono brevetti di qualità superiore e beneficiano dell'esperienza accumulata tendono a depositare un maggior numero di brevetti, favorendo l'innovazione continua nell'industria del laser. Inoltre, questa tesi rileva che gli innovatori diventano un obiettivo appetibile per le fusioni e acquisizioni. Ciò implica che, quando escono dal mercato, è più probabile che lo facciano con un esito positivo, in quanto sono stati ritenuti idonei per l'acquisizione da parte di altre aziende.

Lo studio offre implicazioni pratiche per le imprese attive nel settore dei laser, suggerendo che gli investimenti nell'innovazione possono mitigare il rischio di fallimento dell'impresa e migliorare la resilienza del settore. In questo contesto l'innovazione diventa un fattore cruciale capace di modellare e influenzare le dinamiche dell'industria e la vita delle imprese che vi operano.

# TABLE OF CONTENT

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1: INTRODUCTION

The laser industry from its earliest development has emerged as a vital source of many technologies that have led to the production of several appliances and devices that define the contemporary life worldwide. Although at first glance lasers may appear to be confined to limited uses such as precision cutting, a closer examination of laser history reveals their profound versatility. Far from being limited to industrial uses, lasers have become indispensable in sectors such as manufacturing, healthcare, and telecommunications, highlighting their possibility of being used across different sectors and for different purposes. The versatility of this technology led to a segmentation of the laser industry, which each segment specialized in one or more set of applications.

The laser industry is highly competitive due to its segmented nature and to the widespread interest it attracts from several and various technology firms. An important aspect of the industry is the fact that the industry not only includes companies exclusively focused on laser technology but also encompasses those that produce lasers alongside other goods diversifying in this way their production portfolios. The presence of such diversification reflects the industry's complexity and the strategic importance of laser technology. It is worth noting that in a high-tech environment like this it is normal to see continuous innovations that try to push forward the technological frontier because innovations are not merely common but essential.

These innovations often become the focus of protection under Intellectual Property Rights (IPRs), particularly through patents. Patents not only grant exclusive rights to the firm behind the innovation, but they also provide the firm with the authority to prohibit other firms from replicating the novelty introduced without permission. Furthermore, patents can be used as strategic tools, allowing firms to generate additional profits through licensing opportunities, partnerships, and additional revenue streams.

Starting from these premises, this thesis aims at exploring, within the laser industry, the relationships between patent activity and firm survival.

Moreover, it is crucial to underscore that the analysis is conducted with a focus on the laser market, a significant and diverse sector comprising multiple market segments. Despite this diversity, the market remains clearly delineated with well-defined boundaries that separate different areas of application and specialization.

As previously stated, the laser industry represents an exceptional case of a high-technology sector. This means that this sector is characterised by a rapid sequence of innovations, significant R&D

activities, and substantial capital investment. Since it has existed, the trajectory of the industry has been marked by continuous technological advancements and an expanding number of applications for laser technology in several contexts. These include the scanner used in supermarkets and more recent applications such as 3D printing. In this dynamic industry, patents are an important indicator because they are able to explain the firm's innovative capability and strategic choices to protect their own advancements.

It is therefore essential to gain an understanding of the factors that influence patenting activity in order to gain a deeper insight into the innovative landscape within the laser industry.

The initial phase of the study entails the identification of potential trends and temporal patterns pertaining to firms engaged in operation within the laser industry. The use of graphs and tabular representation derived from the data set allows for the rapid comprehension of the data and the situation. To gain a more detailed view of potential changes over time, timelines are also employed to illustrate, for instance, the fluctuations in the number of market entries and exits. In this phase of descriptive analysis, the geographical distribution of firms, trends of entry, trends of exit and patterns of innovation are analysed in general.

Once an initial view of the business environment of lasers has been obtained, econometric regressions using various models will be carried out to ascertain whether innovative activities are driven by certain factors and, if so, which ones. The objective is then to identify the factors influencing the likelihood of exiting the market.

The first phase of the study investigates the propensity of firms to engage in patenting activities. When a firm develops new product or process, it faces a strategic choice regarding the type of protection of its innovation that best meets its needs. In fact, a firm it is not required to obtain a patent in order to protect its innovations; it may instead opt for another type of protection: secrecy, relying in this way on internal confidentiality measures rather than public legal instruments. This can occur because the process of applying for a patent is costly and complex. The process of obtaining a patent start with the sending of documentation to the patent office desired paying a fee that varies depending on the type of application and the applications' entity size with a cost that range from $10,000 to 40,000. The examination process of the patents starts, and authorized examiners must find if the request meets the standard for patentability. Specifically, the application must demonstrate novelty, meaning that the innovation must be significantly different from previously known invention; non-obviousness, indicating that the innovation must not be a trivial extension of existing technology; and usability of the innovation which implies that the innovation must be useful in some way. Moreover, the outcome of the application is uncertain because it is subject to examination and approval by patent offices, which may decide to reject the application with the allowance to the applicants to revise the summation, now start a process of iteration, in fact the patents application review process often involves multiple rounds.

Given these facts, there are firms that decide to maintain secret their innovations to avoid going through this lengthy process. Nevertheless, the decision to apply for a patent, and utilize it as a means of formally protecting one's intellectual property, remains a practice that occurs with some regularity, particularly within highly technological sectors like the laser industry.

In such industries, patents serve a dual function: following their primary purpose they provide protection, but they also be used as a strategic tool for a firm. Given the importance of patenting in this context, it is important to investigate the frequency with which a firm decide to opt for a patent protection rather than relying on secrecy.

This phase of the study is driven by an analysis based on the number of patents held by each firm listed within the dataset. Patents have been chosen to be a fundamental indicator of their patenting output and thus the innovation that the company brings to the landscape in question. However, it is important to acknowledge that not all companies hold one or more patents, highlighting the differences between companies in terms of innovation and/or the preference for secrecy.

In order to analyse the propensity to engage in patenting activity, the research incorporates a range of variables. These variables were carefully selected based on previous literature to serve as quality proxies of patents as well to reflect other firm-specific characteristics.

For instance, the study includes the average number of claims per patent, the average number of forward citations received by patents, and the average number of backward citations. These metrics are used as proxies of the quality of patents.

In addition to these patent quality proxies; the study also examines firm-specific characteristics to gain a more precise understanding of patenting behaviour. The chosen variables in this case are firm age, which is used, according to the literature, as a proxy for firm size, and fixed effects such as the year of first patenting and the firm's country of origin. It is also important to consider these aspects because they can influence the innovative activity of the firm during its lifetime and thus also the number of patents obtained. In fact, older firms may have more resources to devote to R&D processes and more qualified personnel in the laboratory.

The first analysis is constructed in such a way to highlight the factors that drive firms to engage in patenting activities, and to quantify their impact on this challenging activity.

We predict that qualitatively better innovations lead to the production of new innovations.

Following this initial analysis, the study looks at a further aspect through the implementation of a survival analysis. This analysis is concerned with the examination of the relationship between the probability of exiting the market of a firm and its patent activity. The core objective here is to understand how patenting behaviour influences the likelihood of a firm to remain operational or, conversely, to exit the market. The primary objective at this stage is to provide crucial insights into the strategic implications that the management of intellectual properties have for long-term survival within this context.

The survival analysis is carried out considered fixed effects such as the firm's country of origin and the cohort of entry, to offer a detailed perspective on the contextual factors that affects firm's survival probability. The region of origin considers geographic influences on innovation practices, and their impact on different market conditions based on the registered office of the company, as it is subject to a different set of laws and obligations. Additionally, the context of origin of the firm reveals potential influences also in terms of traditions and cultural differences. The cohort of entry, instead, reflects the temporal context in which a firm decided to enter the market. This variable is essential to distinguish between early entrants, who may have first-mover advantages and face fewer competitors, and laggards, who may have entered a much more competitive and dynamic belt in terms of the innovation required to remain competitive. The timing of entry became a strategic decision and a factor capable of shaping the probability of survival.

This dual-focus research tries to fill a consistent gap in the current available literature on innovation and market exit strategies. Previous studies have often treated market exit as a homogeneous event, failing to distinguish between different types of exits that firms may experience at the end of their lives. Indeed, one of the key strengths of this analysis is its differentiation between exits through failure and those through mergers and acquisitions (M&A). By making this distinction, the study offers a more structured understanding of the underlying dynamics at play when firms decide to exit the market.

Specifically, we predict that more innovative firms with higher quality patents are the most likely to exit the market through mergers and acquisitions.

# CHAPTER 2: A REVIEW OF THE LITERATURE

## 2.1. Innovation and Industrial Dynamics

The study of industrial dynamics plays a pivotal role in the research conducted by numerous economists and offers profound insights into the intricate mechanisms that drive the evolution and transformation of industries. At the core of this exploration are two key concepts: firms' survival and exit. These concepts represent crucial aspects of firm behaviour and industry dynamics that reflect the ongoing processes of firm's existence within competitive landscapes. Both events are essential to reflect the continuous adjustments that firms must make to maintain their presence or decide to exit the market. Studying these dynamics is crucial for understanding how industries adapt to a variety of changing conditions, including technological change, and shift in consumer preferences.

Examining the interplay between survival and exit helps researchers uncover broader industry evolution patterns, which can then guide strategies for sustaining long-term growth and stability.

The survival probability of a firm is widely acknowledged by economists and academics to be related to factors such as age, size, experience, and innovation.

The first stylized fact is the positive relation between the temporal trajectory of a firm and its likelihood of survival. Specifically, the mortality rate of firms tends to be high at the beginning of their life cycle and gradually attenuates over time. This pattern is documented theoretically and through empirical works across several sectors and national contexts. In the literature, this phenomenon is called *liability of newness*, a term coined during the mid-1960s by Arthur Stinchcombe (1965), a distinguished sociologist who has been an important contributor to organizational theory. The formative stages of a firm represent a critical juncture, as they require the interfacing of multiple challenges stemming from organizational, structural, and contextual factors inherent to the market in which it has chosen to operate.

First, when a firm aims to achieve its goals, it must establish a solid network with suppliers, consumers, and distributors to ensure the normal course of operations related to its organisational life. Concerning the acquisition of raw materials from suppliers, the contractual engagement that precedes it represents a crucial aspect with complexities that requires bargaining power, which may be difficult for a new company to possess. Additionally, the lack of reputation makes it hard and often time-consuming to gain the trust of consumers, particularly among those already predisposed to loyalty towards existing competitors. In certain instances, the time required to build this network proves insufficient to achieve desired outcomes within competitive landscape.

Second, unless the new firm has pre-entry experience, the absence of such experience can lead to delays in decision-making and errors that could have been avoided if the entrepreneur had faced similar situations before. In economics ‘learning by doing’ is a fundamental principle, meaning that experiential learning, which involves actively participations in hands-on problem-solving within an authentic context, is deeper and more effective compared to theoretical learning. This concept can be linked both to a production process level, but also to more organisational and decision-making actions as studied by Arrow (1962).

Finally, early-stage firms often face limited financial resources, which act as a constraint as they do not allow for significant investment in R&D, facilities, marketing, and skilled and specialized labor.  Overall, firms that effectively manage these challenges and overcome this threshold in the early stages will be able to mitigate the liability of newness and decrease their risks of exit, thus becoming long-term survivors.

With regard to size, several studies point out that firms that are long term survivals are those that display a higher average size, generally measured in terms of number of employees. Research conducted along these lines, such as Hall (1987) on the manufacturing industry, has led to further insights. Hall (1987) first confirmed that the likelihood of firm survival increases with both age and size. Furthermore, she demonstrated the non-linear nature of this positive relationship, indicating that a 1% change in the size of the firm leads to a greater increase in the probability of survival for smaller firms compared to larger ones. The same results are significant also for with the age-survival relationship.

Klepper and Simons (2000) analysed the importance of pre-entry experience not only in determining market entry but also, notably, in relation to the subsequent survival probability of firms within the U.S. television receiver industry. This industry has undergone a shakeout, a particular event characterized by a concurrent reduction in entry rate and a dramatic increase in the exit rate within the market, leading to a new market structure with a smaller number of active firms. After the shakeout, the market ended up being dominated by firms that came from another industry, specifically home radio producers. In addition to that, they found that there was a positive and statistically significant correlation between being a radio producer and the likelihood of survival in the television receiver market. It is worth noting that not all the types of pre-entry experience turned out to be equally significant. Experience in a related industry, in terms of knowledge, is what matters most given its potential to yield strategic advantages. These advantages stem from the ability to leverage similarities in manufacturing processes, distribution channels, marketing strategies, and technological trends, with respect to the competitors that do not possess any type of experience.

Joseph A. Schumpeter is globally acknowledged as one of the most preeminent figures in the field of economics, renowned for his profound contributions to the discourse on innovation. In the book '*Theory of economic development*' (1912), he made a distinction between invention and innovation. Invention is a sort of exogenous variable related to the emergence of new ideas, while innovation is the commercial translation of invention, which can be identified in the creation of new products or production processes, or more in general it is seen as the result of investment, and it should be treated as an endogenous variable. Thirty years after the publication of the above-mentioned book, he published '*Capitalism, Socialism and Democracy*' (1942), in which he identified competition as a source of innovation:

" […] the competition from the new commodity, the new technology, the new source of supply, the new type of organization (the largest-scale unit of control for instance) competition which commands a decisive cost or quality advantage, and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives".

Innovation-based competition is so powerful that affects firm's survival. Innovation becomes an essential factor both for the creation of the market itself, and, as Schumpeter proposes, for maintaining a competitive level that guarantees the survival of the firm. In the long run, the outcomes are intricately tied to the allocative decision of investments by firms towards innovation.

It is worth noting that innovation is a general term that encompasses a spectrum of multiple meanings. First of all, it is important to make a distinction between radical and incremental innovations. Radical, or drastic, innovation, often characterized as disruptive, can quickly reduce the demand for an old technology to zero, making the technologies used up to that point no longer suitable for the normal conduct of business activities. This type of innovations is intrinsically connected to not only a restructuring of operational processes but also the imperative acquisition of novel knowledge among all employees within the firm. Conversely, an incremental innovation represents a refinement or enhancement of an existing product or process. It is typically developed in response to problems caused by evolving contingent factors, such as shifts in consumer preferences, technological advancements, or regulatory changes. By proactively engaging with emerging challenges within the market landscape, firms can strategically manage these challenges and transform them into opportunities for growth and development.

Two pivotal theories, namely the 'theory of investment behaviour' and the 'theory of research capabilities', posit that new firms are more likely to introduce radical innovation, while incumbents are more inclined toward incremental innovations. The first one was initially demonstrated by Gilbert and Newberry (1982) and Reinganum (1983). This theory, often referred as the "economic theory", tries to explain how economic incentives drive of technological advancements. In particular, the arrival of a new technology opens up new opportunities, and the reactions of firms are mainly driven by changing in economic incentives. Investment decision depends on economic incentives that varies according on whether the innovator is a new entrant or an incumbent. For incumbents' firms, the decision to invest in new technology involves complex economic evaluation. They must try to balance the benefits of investing in a new technology against their losses of revenues with the old technology. This is the so-called "fear of cannibalization", which refers to the loss of sales caused by a company's introduction of a new product that displaces one of its own older products. The losses from cannibalization tend to be higher when new technologies are more radical. The prediction of this theory is that new firms will have higher incentives to introduce radical innovations, whereas incumbents will have higher incentives to introduce incremental innovations. The second theory, known also as Organizational theory was studied by Chandler (1990). This theory makes the same predictions but offers a different explanation. In this case, incumbents dominate incremental innovations because they are better positioned to exploit this type of innovations more effectively than new entrants. The key reason for this lies in the nature of incremental innovation, which is an innovation build upon existing competences of the firms. For incumbents' firms, which have been operating in the market for a significant amount of time, these existing competences include greater economic resources, highly specialized labour, and better knowledge. Incumbents use their knowledge base to develop routines and solve specific problems, which are more suited to incremental than radical innovations.

Another way to analyse innovations is by distinguishing between product and process innovation. In general, product innovation involves the development of new products or the improvement of the quality of existing ones, while process innovation is linked to the reduction of production costs. In a study conducted by Klepper and Simons (1997), they found that the early stages of an industry are characterized by a succession of major product innovations because these play a fundamental and primary role in the creation of a dominant design. When a dominant design emerges, it helps shaping the trajectory that characterizes the development and production of products within that industry. Subsequently, as the industry evolves, process innovations become paramount over product innovations. Once the industry and consumer preferences have been consolidated through the definition of a dominant design, it is reasonable to posit that firms will seek to build competitive advantage in terms of price relative to competitors. This will entail to a reduction in costs and/or production time and a maximization of the use of available resources through process optimisation.

Considering innovation as an endogenous variable means to argue that it stems from the active learning implemented by the firm. Mansfield (1982) conducted extensive research on R&D, focusing on its impact on innovation. The primary driver of this active learning is the investment in R&D, which encompasses all financial resources, specialised personnel, and assets dedicated to the advancement of technological innovation. R&D is a risky, uncertain, and non-linear activity. In addition to incurring a cost in the balance sheet due to the investment, the firm must also bear the risk that the R&D efforts may not lead to the desired results. Furthermore, there is no guarantee that a profitable innovation will be followed by another equally profitable one. There are basically two risks linked to R&D activity: technical and commercial. The technical risk refers to the achievement, or non-achievement, of the technical completion of project of the new technology. On the other hand, the commercial risk concerns the possibility that the introduction of these innovations may not lead to a fair economic success. Furthermore, the technical risk typically presents a more modest magnitude compared to the commercial risk. Once a technical innovation has been developed, its successful commercialization and adoption in the market may pose more significant challenges compared to the initial technological development process.

Unlike other variables that explain the likelihood of survival of a firm, innovation remains the least investigated within the literature. Overall, studies carried out have found a positive relationship between being an innovator and the probability of survival. Cefis and Marsili (2006) have conducted several analyses on this topic, trying to fill the gap. Their research primarily focused on manufacturing firms in the Netherlands in the 1990s. Their investigations of the relationship between innovation and survival can be analysed at three levels: according to the age and size of the manufacturing firm; according to the type of innovation (i.e., process or product); according to the technological characteristics of the environment in which the industry is developed.

Being an innovator increases the survival probabilities across all size and age classes compared to being a non-innovator. More specifically, with regard to the size class, Cefis and Marsili (2005) found that medium-sized firms engaged in innovations are the firms with a higher survival rate in the long run (over a period of more than 4 years), while the large-sized firms that are non-innovators are the ones with the lowest survival rate. Concerning age, young firms are those who benefit most from being an innovator with respect to the ones which are older than 4 years. Another statistically significant determinant that increases the likelihood of survival is the introduction of process innovation rather than product innovation. Product innovators have a probability of survival equal to non-innovators, whereas process innovators show a higher innovation premium, which translates into difference in survival probabilities between innovators and non-innovators.

Although the analysis of Cefis and Marsili (2006) concerns manufacturing firms, they do not all operate in the same environment. One of the main sources of heterogeneity is the technological landscape in which they are active. This differentiation can be delineated into two broad areas based on the level of technological intensity: high-tech manufacturing, and low-tech manufacturing. In the context of SIC (Standard Industrial Classification) codes, high-tech includes all the sectors wherein advanced technologies play a pivotal role in production processes, such as the production of Integrated Circuits, the provision of IT services, and the development of software systems. In contrast, low-tech sectors are those that rely on more traditional and simpler technologies, for example the textile one.

In high-tech sectors, the innovation premium is very close to zero. This is not the case in low-tech manufacturing, where being an innovator significantly increases a firm's likelihood of survival. In addition to that, it is worth noting that the innovation premium is substantial for young firms operating in low-tech environments, and the gap between innovators and non-innovators increases as time passes, making innovation crucial for long-term survival. One possible explanation lies in the nature of low-tech sectors, which are characterised by stable technologies and less frequent and sudden technological shifts. Within these sectors, an innovation can mark a breakthrough for the innovating firm over its competitors. This creates a competitive advantage that lasts longer compared to the effects of innovation within high-tech sectors because, in the latter, innovations unfold at a rapid and continuous pace, with advancements emerging in quick succession, indeed the relentless cycle of innovation makes previous technologies obsolete.

### 2.2. The Role of Patents in Innovation

When discussing patents and intellectual property rights, the discourse typically gravitates towards legal and economic dimensions. However, a deeper exploration into the philosophical underpinnings is crucial. Understanding the moral and theoretical justifications for protecting individual creations enriches the comprehension of this complex issue. John Locke, an English philosopher, and physician, wrote in '*Two Treatises of Government' (1969)*:

" […] every man has a property in his own person. This nobody has any right to but himself. The labour of his body, and the work of his hands, we may say, are properly his. Whatsoever then he removes out of the state that nature hath provided, and left it in, he hath mixed his labour with, and joined to it something that is his own, and thereby makes it his property".

Locke understood the inherent relationship between labour and property. It can be seen as a fundamental tenet of the contemporary discourse on justice, innovation and intellectual property rights.

The foundation of a patent lies in the concept of an idea. An idea, as said by Romer (1990), is a non-rival and a partially excludable good, diverging from the properties typically associated with conventional economic goods (i.e., rivalry and excludability). Rivalry in economics refers to the extent to which a good can be used or consumed by one firm or individual at a time, implying that it is technically impossible to consume the same good in a simultaneous way by multiple parties. In contrast, a good is categorised as 'non-rival' when its consumption by one party does not preclude its consumption by others at the same time. An idea exemplifies non-rivalry due to its ability to be disseminated widely without physical depletion or degradation of its utility to other users. For instance, when one individual acquires a new concept, it does not impede others from comprehending and implementing the same idea, thus allowing it to be utilized without exhaustion. Additionally, an 'excludable' good is defined as a good for which the owner can prevent individuals from consuming or using it. For example, the producer of a good has the possibility to allow its use only by those who make a payment to it. The excludability is an instrument enforced through mechanism such as pricing, licensing, or other access controls.

Rivalry is strict linked to the concept of scarcity. Resources are limited by nature, while the human needs are potentially unlimited. In its purest form an idea is not considered to be scarce, as noted by Williams and Bryan (2021). Ideas, however, serve as foundational elements in the development of inventions and innovations, which are essential for societal advancement.

In the absence of incentives and guarantees, an individual would lack the motivation to develop an idea based on his knowledge if everyone could subsequently implement it without any investment of time and money, simply by appropriating the idea once it enters the public domain. The initiation of a process of R&D requires significant resources from at least one individual or entity. In absence of IPRs, and, consequently, without protection, others could exploit the developed ideas without contributing to their creation, benefiting from the efforts of the original innovator. These individuals act as "free riders".

In addition to that, ideas are uncertain. While a researcher may have a clear understanding of the starting point and the desired outcome of their investigative process, the pathway to achieve this outcome is often unpredictable. This uncertainty extends not only to the methods and processes involved in reaching a particular result but also to the potential applications and uses of the idea itself.

If an innovation, or a general technological change, is considered an endogenous variable within an economic context, and that innovation leads to an increase in social welfare, then the protection of profits associated with such innovation becomes a crucial necessity.

IPRs are a set of policies, decided upon by several authorities around the world, designed to grant special rights to individuals and exclude others from the production, sale, construction, and licensing of the good object of protection. The establishment of this legal framework has a significant impact on industrial dynamics by reducing competition, a departure from the unfettered competition characteristic of a free-market environment (Williams & Bryan, 2021).

In alignment with Schmookler's (1966) assertion that:

"[…] invention is largely and economic activity, which like other economic activities, is pursued for gain"

these rights serve to safeguard the financial interests of innovators by enabling the innovators to capture and retain the profits generated from their innovations, thereby aligning their interest in an environment where the potential for economic gain acts as a primary driven of R&D activities.

The World Intellectual Property Organization (WIPO), established in 1967, it is an agency of the United Nations dedicated to the promotion and protection of the intellectual property rights globally.

Patents are territorial rights. In general, the exclusive rights are only applicable in the country or region in which a patent has been filed and granted, in accordance with the law of that country or region (WIPO Patents).

It is possible to pursue patent protection in multiple countries through several avenues of application. For instance, in the United States the focal point is the United States Patents and Trademark Office (USPTO). Similarly, other developed country such as Japan, South Korea, Russia, and many others maintain their respective national patent offices. Additionally, alongside the European Patent Office (EPO), which provides coverage currently across 44 member countries, individual national patent office's exist within each member country of the European Patent Convention (EPC). Furthermore, numerous developing countries have established their own patent offices.

Each office operates under distinct regulatory frameworks, timelines and procedural guidelines to manage patent application and the intellectual property protection system.

When a patent is granted, the applicant obtains the exclusive right to stop others from commercially exploiting the patented invention for a specified duration, typically 20 years from the filing date of the patent application. During the lifetime of a patent, the market power associated with the IPR allows the patent holder to set prices above the marginal cost, thereby making profits. This period of exclusivity serves as a reward for disclosing the proprietary secrets to the public. Upon the expiry of the patent term, the technical information contained within the patent document becomes fully accessible to all and may be used without permission. The introduction of a temporal framework during which exclusive rights can be asserted is essential to balance the trade-off between ex-ante efficiency and ex-post efficiency. Ex-ante efficiency denotes the government's aim to preserve the firms' incentives to innovate by receiving a fair return on investment in R&D. Conversely, ex-post efficiency, relates to the situation in which the social welfare is maximized when all the firms in the economy have the possibility of use the innovation to foster further technological advances (Arrow, 1962).

From a theoretical perspective, the fundamental role of patents in the creation of innovations is undeniable. Since the second half of the XX century comprehensive studies have been conducted on the impact of patents on the innovation process within firms.

Mansfield in 1986 conducted a seminal study investigating the impact of patent protection on innovation across various manufacturing industries. This study quantified the percentage of innovations that would not have been developed if there would have been no patent protection. The findings were particularly striking within the pharmaceutical industry, where the percentage reached a substantial 60%. This implies that more than one in two pharmaceutical innovations would not have entered the market in the absence of patent laws, underscoring the critical role of such protections in fostering innovation within this sector. Given the paramount importance of pharmaceutical products to public health and wellbeing, this figure is profoundly significant. Additionally, Mansfield provides critical insights into the heterogeneous nature of patent protection's impact across different industries. In the chemical industry the percentage is 38%, still high but less than in the previous sector. In the machinery sector, 17% of innovations depended on patent protection, indicating a moderate influence of patents in promoting new developments. Interestingly, in the office equipment and textiles industries, the study found that patent protection had no discernible impact, with 0% of innovations being dependent on such protection. This phenomenon can be attributed to the standardization in these types of products, and the reliance on alternative forms of IPRs such as trade secrets and copyrights.

For years, the only indicator of patent value used for research purpose was the number of patents held by a firm. However, this gives rise to another critical area of discussion regarding patents pertains to their intrinsic and extrinsic value. It is well-established that not all patents hold equal value. Rather, the distribution of patent value is highly skewed. This skewness indicates that a small proportion of patents capture a disproportionately large share of economic value and importance, while the vast majority of patents hold relatively low value or significance (Harhoff, Narin, Scherer & Vopel, 1999). High-value patents often represent a disruptive innovation that can quickly become the standard on the market and thus dominate it. Conversely, lower value patent may contribute incremental improvements that are unlikely to create significant competitive advantages.

To quantify the value and quality of patents, researchers and economists now rely on various proxies available within the patent documents. Among the most commonly utilized indicators are: the number of claims and the number of backward citations (Hall, Jaffe, & Trajtenberg, 2001) within a patent, and the number of forward citations (Trajtenberg, 1990) it receives. This decision is grounded in their foundational roles and definitions within the context of patent law and practice. Claims define the boundaries of the patent's protection. They specify the novel features of the invention that the patent applicant seeks to protect and determine the scope of the patent rights. Backward citations refer the references that a patent application cites to prior art that existed before the patent application was filed. They are useful to establish the context and background of the patenting invention showing how it builds upon or differs from existing technology. Forward citations refer to the number of times the patent has been cited in subsequent patents, thus indicating the impact on future innovation and its importance in that field (USPTO, 2024).

### 2.3. Heterogeneity in Market Exit and the Role of Patents

When discussing a firm's exit from the market, it is frequently perceived as a singular, uniform event, expression of lack of efficiency that makes unprofitable to stay in business. Within this narrative, the act of exiting is associated to failure, while the ability to survive and generate profits means success. However, it might be simplistic to treat exit as a mere dichotomous variable when considering the actual context in which firms operate. This oversimplification may fail to acknowledge the complexity of the environment and the multitude of commercial and other factors that influence the strategic decision-making process of a firm. Exit should therefore be considered as a heterogeneous event, and one of the most significant decisions in the lifetime of a firm (Cotei & Farhat, 2017).

In more specific terms, the modes of exit may be classified as follows:

- Voluntary Closure: the deliberate decision made by a firm to cease operation within a specific market:
- Liquidation: it is a financial process which involves the winding down through the sale of its tangible and intangible assets, for example intellectual property right, to settle outstanding debts and obligations. It is necessary when a firm becomes insolvent;
- Merger: it involves two or more separate undertakings merging entirely into a new entity (Whish & Bailey, 2012). Merger can be distinguished into vertical and horizontal. Vertical merger occurs when the two (or more) undertakings operate at different stages of the value chain, for example retailer and producer. Conversely, a horizontal merger involves two undertakings operating at the same stage of the production or distribution process;
- Acquisition: it is the corporate transaction whereby one company purchases most or all of another company's stock, typically involving the transfer of control and assets;
- Public Listed: it consists of the transaction from a privately held company into a publicly listed one involving a significant transformation in the ownership structure. The reason it can be considered as a way to exit the market lies in the fact that when a firm decide to undergo an initial public offer (IPO) and lists its shares on a stock exchange, it creates the possibility for the founders to sell their shares and exit the market profitably.

The last three cases are linked to the strategic choice of growth and consolidation in the market, positioning them as a desirable option within the framework of exit strategies (Cotei & Farhat, 2017).

Firms may opt for merger for many different reasons (Whish & Bailey, 2012). The achievement of the economies of scale and scope is one of the major drivers. Realising cost efficiency is often a necessary condition, especially within context marked by an intense price-competition. By sharing resources, expertise, infrastructures, and plants, firms are able to reduce their overall production costs. Moreover, it facilitates the expansion and diversification of the product and service portfolio offered, leading to competitive advantages with respect to the rivals. Another reason is the elimination of competition, or, in a much real sense, a reduction of that. Through a merger, two firms effectively pool their market share and their customer bases, this allows them to increase price, and indeed their market power.

M&A[1] can be seen as a way of absorbing the intellectual property rights of another firm. It is a strategy used to acquire, in a rapid way, advanced technologies, patents, or other proprietary

[1] Merger and Acquisition

knowledge, thereby enhancing their innovation capabilities. IPRs are part of intangible assets that add value to a company. When firm wants to acquire another firm it's crucial to assess the value and validity of the IPRs held by the firm potentially desirable.

Having discussed the various ways of exiting the market, the focus now shifts to examining how patent activity may influence these events.

Wagner and Cockburn (2010) conducted a study to examine the effect of patenting activities on the survival prospect of more than 350 internet-related firms listed on NASDAQ (National Association of Securities Dealers Automated Quotations) stock exchange. They demonstrated that the absence of patent holdings is a significant predictor of a firm's likelihood of exit. Firms possessing at least one patent exhibited a 32% lower probability of exiting the market compared to their non-patenting counterparts. This effect persists across both primary modes of market exit: delisting and M&A, albeit its impact is more pronounced in the case of delisting. Additionally, the study highlights another important outcome of patenting activities: the influence of forward patent citations. Firms with highly cited patents, which are widely recognized in the literature as indicators of higher patent quality, tend to be more attractive targets for M&A.

Cefis and Marsili (2011) studied the relation between firms' innovative capabilities and their exit behaviours, with a particular focus on distinguishing between exits resulting from the closure of activities and those arising from M&A. They found that innovation plays a vital role in ensuring a firm's survival in competitive markets and simultaneously enhances the company's appeal to potential buyers. In particular, young firms engaging in innovation are more attractive target for acquisition, with a 60% higher probability of being acquired compared to other firms in the sample. Despite these significant insights into the role of innovation, the study found that the mere possession of patents does not influence the likelihood of exiting the market by closing activities. Interestingly, the presence of patents appears to have a negative effect on the probability of exiting through M&A. However, it is important to note that the study did not account for patent quality proxies, which could provide a more detailed understanding of how patent characteristics might impact exit behaviours.

Another research conducted by Kato, Onishi, and Honjo (2022), focusing on manufacturing and information sector firms in Japan addressed a similar research question to those examines in the studies referenced earlier. The findings revealed a nuanced relationship between patenting activities and firms' exit behaviours. Specifically, the results indicated that patenting significantly lowers the probability of bankruptcy, suggesting that firms engaged in patenting are better equipped to sustain their operations and avoid business failure. This protective effect of patenting can be attributed to the competitive advantage and market differentiation conferred by proprietary innovations. In addition to that, the study found that patenting activities increase the probability of mergers.

Arora and Nandkumar (2011) studied the role of opportunity cost in relation to two different modes of exit: failure, considered a negative outcome, and acquisition under favourable terms. These two events are conditioned by the quality of the company. In their model, each entrepreneur can make investments that positively affect the probability to be acquired, as acquisition is seen as a more desirable outcome compared to merely surviving in the market. However, pursuing survival while increasing the chances of acquisition also prolongs the period during which a company is vulnerable to failure. Their findings suggest that entrepreneurs with higher opportunity costs are not only more likely to be acquired sooner but also face a higher likelihood of failing faster.

# CHAPTER 3: THE CONTEXT OF ANALYSIS. THE LASER INDUSTRY

## 3.1. The Origins: from Stimulated Emission to the First Laser Patent

The first step in the history of the laser industry dates back to 1916, when physicist Albert Einstein postulated the theoretical foundation for the so-called stimulated emission (Einstein 1972).

The principle of Einstein is applicable to microwave radiation in devices like masers (Microwave Amplification by Stimulated Emission of Radiation). In the late 1940s in the United States, two eminent physicists emerged as the founding fathers of microwave molecular spectroscopy. Charles Hard Townes and Walter Gordy pioneered the field by initiating work in millimeter-wave spectroscopy (Blomberg, 1991).

To fully understand the driving forces behind the development of these technologies, it is essential to first examine the economic and social context of the period.

The golden years of the American economy, spanning approximately from the late 1940s to the early 1970s, positioned the United States as the preeminent driving force of the global economy. This period of economic prosperity was enhanced by the implementation of the Marshall Plan, a substantial monetary aid program aimed at the reconstruction of Europe following the damage incurred during the Second World War. In contrast, the United States experienced relatively minimal physical damage during the war, as the conflict was primarily concentrated in Europe and the Pacific. This lack of domestic destruction allowed the U.S. to emerge from the war with intact infrastructure and a robust industrial base. Furthermore, the wartime economy in the United States was characterized by a prolonged effort on the production of military arms and materials, resulted in a remarkable 50% increase in the country's industrial capacity and potential. After the war the innovations and the production technologies accumulated for military purposes began to be progressively adapted and integrated into the domestic industrial sector. During the Truman administration there was a substantial increase in R&D expenditure for military purpose, largely driven by the Korean War (1950-1953) (Cattini, 2018).  Military spending has triggered progress throughout the economy. However, the field of electronics emerged as one of the primary beneficiaries.

*Figure 3.1: Annual R&D Expenditure (in Billions of USD). Personal elaboration based on information from Bromberg, The Laser in America 1950-1970*

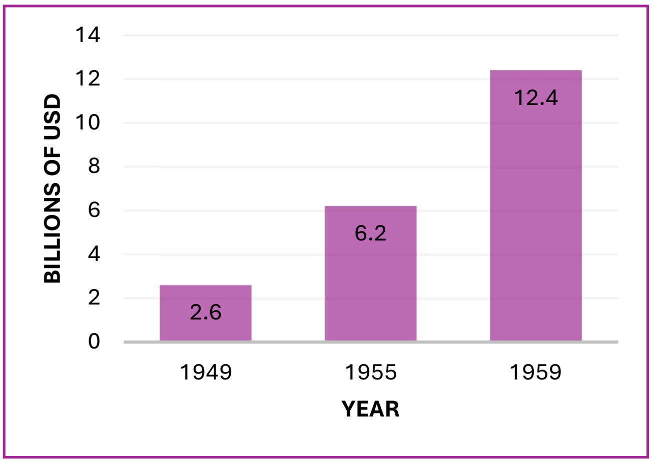
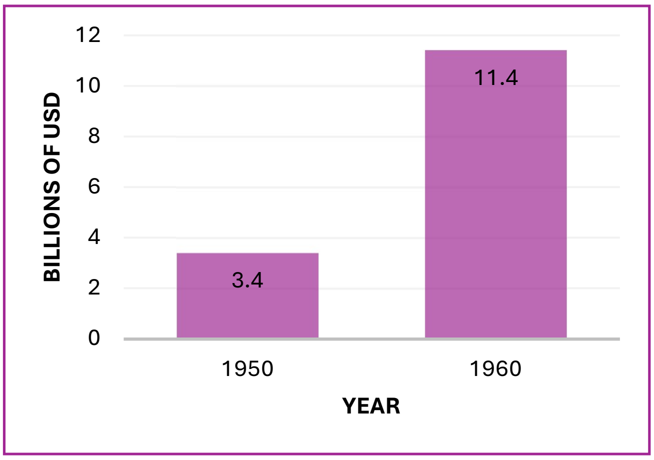



*Figure 3.2: Annual Sales in the Electronics Market (in Billions of USD). Personal elaboration based on information from Bromberg, The Laser in America 1950-1970*




*Figures 3.1* and *3.2* present analysis of data drawn from the book The Laser in America 1950-1970 by Bromberg. These figures highlight significant trends in R&D spending in the United States, beginning the in 1950s. During this period, resources for R&D grew at a remarkable pace. In particular, in 1949 total annual expenditures on R&D were about $2.5 billion, while just a decade later this amount of money reached the $12.4 billion. This trend was driven by the increase in R&D for military purpose. One of the sectors that benefited most was the electronics market, with sales that passed from $3.2 billion in 1950 to $11.4 billion in 1960. The primary driver behind this growth was, once again, military demand, specifically the development and production of guided missiles systems, which required increasingly sophisticated electronics components.

Another significant event that boosted this budgetary trend was the Cold War against the Soviet Union. The investment in R&D and the resultant technological advancements, driven by the geopolitical tensions of this era, were essential for safeguarding national security and ensuring military dominance. Moreover, pre-eminence in scientific and technological domains was instrumental in shaping ideological perceptions, influencing economic development, and driving global geopolitical dynamics in favour of the United States.

The huge increase in research funds led to an expansion of industrial laboratories, with their numbers doubling between 1950 and 1960. Established firms constructed new laboratories, and, in response to the promising economic results associated with the electronics sector, other firms reconfigured their existing facilities to prioritize electronic research. For newly laboratories, the maser, and subsequently the laser, were attractive research area.

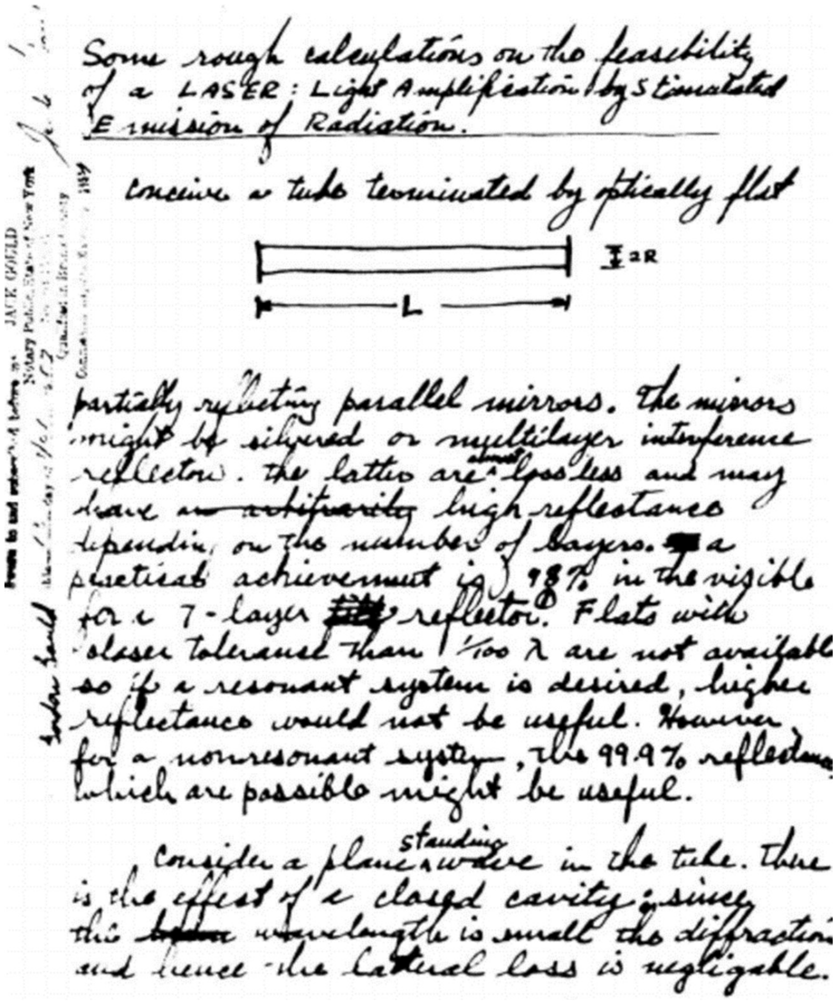
In light of this context, it can be asserted that Townes and Gordy, along with many other inventors, were operating within a highly conducive environment for their work and discoveries.

The millimeter system, mentioned above, captured the military interest due to its utility in reducing the weight of guided missiles and enhancing equipment on tank and submarines. Additionally, millimeter waves offered greater secrecy for short-range communication. The beginning of the 1950s saw important progresses in this field. In 1950, the Electronics Branch of the Office of Naval Research commissioned Townes to organize an Advisory Committee on Millimeter Wave Generation with the aim to promote research efforts and outline a cohesive development strategy within the domain. In the following year he conceived his MASER idea (Bromberg, 1991).

Townes was a consultant of Bell Laboratories when he decided to collaborate with Arthur Schawlow, a member of the technical staff at the same institution. They started to work on an intensive research project focusing on optical masers. This collaboration was particularly opportune given that Bell Laboratories had established active research programs in the field of solid-state masers and their application (Bromberg, 1991).

On November 13, 1957, Gordon Gould, an American physicist, first coined the term “laser” as an acronym for Light Amplification by Stimulated Emission of Radiation. *Figure 3.3* shows the initial page of his notebook, where he wrote the acronym and listed the essential components required for constructing a laser.

*Figure 3.3: Gordon Gould's notebook. From Research Gate*


Some rough calculations on the feasibility
of a LASER: Light Amplification by Stimulated
Emission of Radiation.

Conceive a tube terminated by optically flat

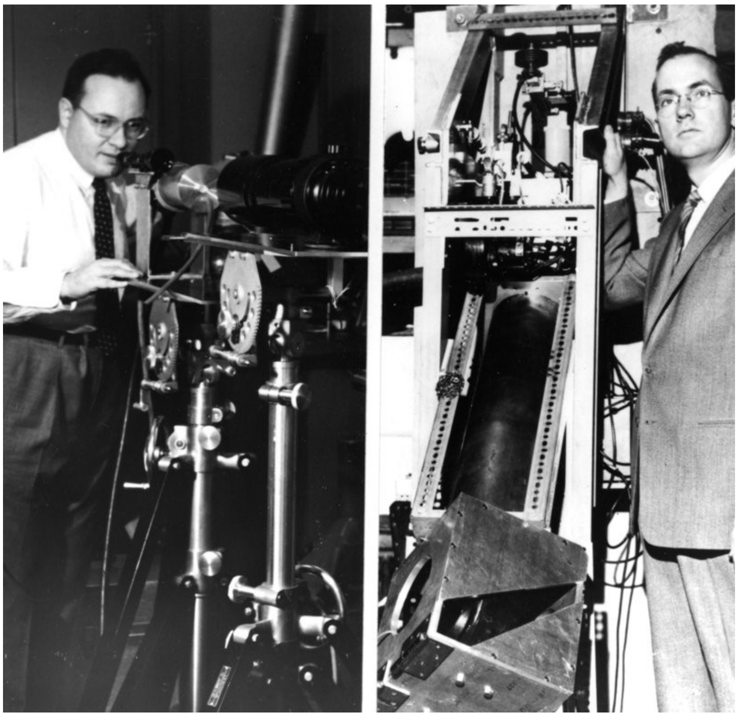


partially reflecting parallel mirrors. the mirrors
might be silvered or multilayer interference
reflectors. the latter are almost lossless and may
have ~~an arbitrarily~~ high reflectance
depending on the number of layers. a
practical achievement is 98% in the visible
for a 7-layer reflector. Flats with
closer tolerance than 1/100 λ are not available
so if a resonant system is desired, higher
reflectance would not be useful. However
for a nonresonant system, the 99.9% reflectance
which are possible might be useful.

Consider a plane standing wave in the tube. there
is the effect of a closed cavity; since
the wavelength is small the diffraction
and hence the lateral loss is negligable.

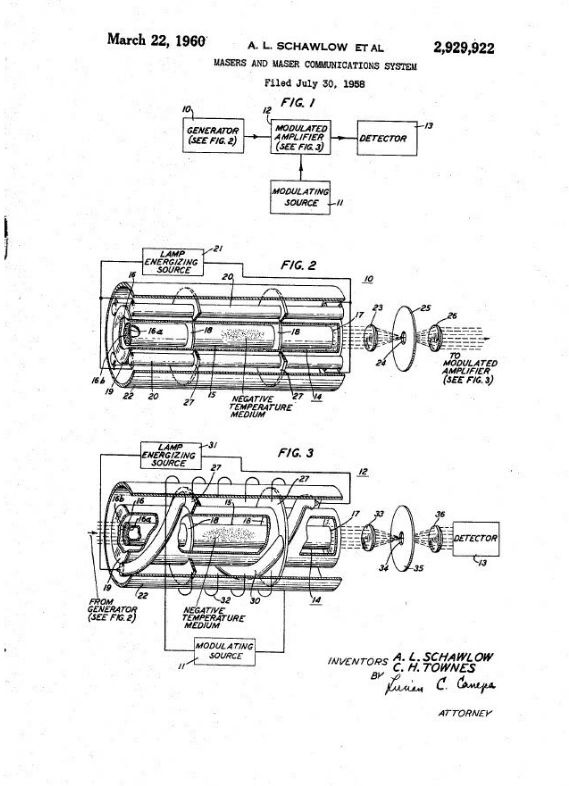
Bell Laboratories submitted a patent application to the USPTO for the invention of the optical maser, an innovative device developed by Townes and Schawlow. This innovative technology would later be known as laser. In the same year the two physicists published their discovery in the prestigious journal *Physical Review* to spread their theoretical advancements and practical applications to the broader scientific community, both domestically and internationally (Bromberg, 1991). *In Figure 3.4*, Arthur Schawlow is on the left and Charles H. Townes is on the right, both pictured in 1958 with their invention.

*Figure 3.4: Arthur Schawlow and Charles Townes with the Laser at Bell Labs, 1958. From Nokia Bell Labs*



The patent, officially granted on March 22, 1960, was assigned number 2,929,922 and was titled "Masers and maser communications system". This first patent in the field of optical masers offers valuable insights into the quality and its impact over time. Notably, the Bell Laboratories' patent contained only one backward citation, referencing a prior patent dated 1958 titled "Atomic or molecular oscillator circuit". This indicates that the basic technology on which this patent was based had limited prior art. It included 11 claims, outlining the fields of application of the invention. The significance of this patent is further highlighted by its substantial number of forward citations. Over 64 years, it has received 145 citations, demonstrating its profound influence and impact on subsequent innovations. The current assignee of the patent is AT&T Corporation, an American telecommunication company that owned Bell Laboratories as a subsidiary. *Figure 3.5* below reports the image included in the official document representing the principles of the invention.

*Figure 3.5: Original patent document image for the first MASER, filed in 1958. From Google Patents* US2929922A




At the end of the 1950s, a competitive and highly dynamic era emerged in the field of laser research, characterized by numerous research teams across various prestigious laboratories striving to develop the first operational laser. Institutions such as Bell Laboratories, IBM, TRG, and Columbia University, were actively engaged in this race. Townes and Schawlow decided to pursue distinct research paths in their quest to realize practical laser systems. Townes opted to focus on the development of potassium laser within the Columbia University. Schawlow directed his efforts towards the development of the ruby laser in the department of Bell Laboratories. Ruby is a crystal primarily composed of aluminium dioxide. However, the development of the first laser entailed technical problems across all the laboratories involved in the research.

### 3.2. The First Five Years of the Laser Market

At the Quantum Electronics Conference held in 1959, it was asserted that lasers represented one of the most promising and transformative new research areas, thus incentivising the research efforts. Three new actors began to emerge in this scenario: Peter Sorokin, Mirek Stevenson, and Theodore Maiman. Each of these individuals made a significant contribution to the advancement of laser technology. Specifically, Maiman focused on developing the ruby laser, while Arthur

Schawlow, on the other hand, critically assessed the project related to ruby lasers because, in his opinion, ruby would not work in lasers. In May 1960, Maiman of Hughes Laboratories successfully assembled an experimental laser, and announced the achievement in July 1960. However, the discovery did not immediately gain widespread acceptance among scientists and researchers. Bell Laboratories, leveraging insights from Maiman's published research, proceeded to construct their own ruby laser. For several years, it was erroneously believed that was Bell Laboratories to win the race. Despite that, subsequent scientific scrutiny Maiman was acknowledged as the pioneer of the first operating prototype of laser.

This seminal development catalysed a series of new discoveries. In 1961, the field saw the introduction of the first four-level solid-state laser, and the first helium-neon (HeNe) laser (Hecht, 2010). The HeNe laser was the first case of laser commercialization, marking a pivotal transition in the trajectory of laser technology from the domain of experimental research to practical application.

These advancements were part of a broader trend of rapid innovation and exploration in laser technology during the 1960s. The trend was reflected in the growing prominence of the annual International Conference on Quantum Electronics, which experienced a substantial increase in attendance. The conferenced counted 475 participants in 1961, and this number surged to 1,100 the following year. Moreover, the interest in laser technology was further evidenced by a marked increase in the number of laser publications during the same period (Blomberg, 1991).

At the beginning of the market for lasers, military sales notably exceeded commercial sales. This was primarily because the earliest users of laser technology were military organizations, which recognized the potential applications of lasers in areas such as: targeting, communications, and defence systems. The military sector, operating with fewer budgetary constraints compared to civilian sectors, provided a major financial flexibility to the firms involved in the industry. This financial support allowed them to produce products with a high level of quality, often operating at the cutting edge of the technological frontier. The military's demand for highly reliable and advanced systems required these firms to maintain a rigorous standard of quality and performance, which, in turn, pushed the boundaries of what was technologically possible at the time. This continuous drive for innovation ensured that military-grade lasers were at the forefront of technological advancements, setting benchmarks for the industry as a whole. The investment and emphasis placed on laser technologies by the military led to a proliferation of firms engaging in research and development within this field. Particularly, firms involved in defence-related applications, like Hughes Aircraft Corporation, were pivotal in advancing laser technology. In fact, contracts from Department of Defense R&D were quite easy to obtain, creating a conducive environment for small firms to enter the market.

In the August 18, 1962, edition of *Business Week*, it was forecasted that the laser industry would evolve into a billion-dollar sector within a decade (Elliott, 1962). The optimism in the financial press encouraged the influx of venture capital, which in turn contributed to the diversification of investment portfolios within the industry. In addition to that, the industry began to target not only its traditional military applications but also a broader spectrum of non-military sectors. Remarkably, the first use of lasers in a medical treatment on a human patient occurred in 1961. This procedure utilized an optical ruby laser to target and destroy a retinal tumor (Rose & Hogan, 2019).

During the early 1960s, several significant advancements in laser technology emerged, including the development of semiconductor diode lasers, gas lasers, dye lasers, and ion lasers. These innovations expanded the range of laser types and applications, reflecting a period of rapid progress and diversification in the field of laser science.

The inaugural Nobel Prize in Physics specifically addressing laser technology was awarded in 1964 to Charles H. Townes, Nikolay Basov, and Aleksandr Prokhorov (see *Figure 3.6*). This prestigious accolade recognized their seminal contributions to the field of quantum electronics, which were instrumental in the development of oscillators and amplifiers founded on the maser-laser principle.

*Figure 3.6: Townes receiving the first Nobel Prize in laser technology, 1964. From The Nobel Prize site*

In 1963, the nascent laser industry was characterized by limited participation, with only twenty to thirty firms actively engaged in the production and commercialization of lasers. The legal landscape concerning patents, particularly as tools for market entry barriers, was uncertain during this period. The initial patent issued covered the maser technology. However, Townes, one of the inventors, argued that the patent also extended to the optical maser (laser). This claim was contested by other companies, which argued that the patent was invalid on the grounds that Townes had published relevant findings prior to filing the patent application with the USPTO, specifically in a publication by the Columbia Radiation Laboratory. Additionally, the patent's validity was challenged on the basis that Gordon Gould had conceptualized the laser as early as 1957, raising questions about the rightful originator of the invention.

The first licensing agreement concerning this patent was not established until 1965 with AT&T, becoming the dominant firm in the market due its control over essential patents. As the assignee of significant patents, AT&T's position was subject of a legal obligation to grant non-exclusive licenses for its patented technologies. This obligation meant that AT&T could not restrict the use of its patents to a single licensee. instead, it had to allow other entities to utilize the patented inventions. Crucially, the terms of these licenses had to be "reasonable," a requirement that was subject to judicial oversight. The courts were tasked with ensuring that AT&T's licensing conditions were equitable and non-discriminatory, preventing the company from imposing unfair or abusive terms. Additionally, the state retained the right to utilize laser systems without the obligation to pay royalties. This provision extended to academic research projects, particularly those funded by government sponsors, allowing these projects to use the technology royalty-free as well. These regulatory provisions were designed to promote competition within the emerging laser market and to prevent monopolistic position by AT&T.

In 1964 was developed an important type of laser: the carbon dioxide ($CO_2$) laser. This laser is now employed globally as a precision cutting tool in both surgical and industrial applications.

By 1965, the laser market had experienced considerable growth, with the number of active participants in the field reaching approximately 115 entities, as reported on the journal Laser Focus 2 in 1966. Despite a remarkable 475% increase in the number of firms participating in the laser market from 1963 to 1965, the applications of laser technology during this period remained confined to a relatively narrow range of sectoral applications.

### 3.3. The Transition from Military to Civilian Applications of Laser Technology

The range of laser applications expanded significantly from the early 1970s. This expansion is well-documented in the *Electrical & Electronics Abstract* index for the years 1969-1970, which highlights the burgeoning interest and research in laser technologies. During this period, a substantial number of studies focused on several key areas of laser application, including:

- Laser communication, which explored the potential of lasers for transmitting information over long distances;
- Machining of materials, where lasers were used for cutting, engraving, and shaping a variety of materials with high precision;
- Measurement of lengths of all sorts, encompassing a wide array of applications from measuring workpiece dimensions in industrial processes to detecting tiny strains such as those observed in diurnal earth tides.

In addition to these primary areas, lasers were increasingly employed in:

"[…] the measurement of the velocities of fluids; the monitoring of constituent of the atmosphere and especially atmospheric pollutants; information storage; the tracking of planes, missiles, and satellites; biomedical applications; and the study of properties of plasmas". (Bromberg, 1991)

In this context, the laser market began to transition from its initial focus on purely military applications to a broader spectrum of civil uses. This shift was influenced by several key economic and social trends. Firstly, there was a notable deceleration in military spending on laser research and development (R&D) compared to the peak levels observed at the end of the 1950s. This reduction in the growth rate of military funding for laser technologies reflected a broader reallocation of defence resources and priorities. Secondly, the financial landscape for university researchers, who had been among the major consumers of laser technology for experimental and exploratory purposes, began to experience constraints. The period saw a relative impoverishment of university research budgets, limiting the ability of academic institutions to invest in cutting-edge, high-cost technologies such as lasers. Additionally, an ideological shift contributed to the changing dynamics of the laser market. During the 1960s, particularly in the United States, there was a growing societal opposition to the Vietnam War, which cultivated a widespread anti-war sentiment. The moral and ethical debates surrounding the use of technology for military purposes led to a re-evaluation of priorities, with an increased emphasis on non-military, civilian applications. Consequently, the advancement of military technology was superseded by the development of products for civilian applications., and lasers began to be sold for industrial use rather than for research laboratories.

One of the pioneering applications of laser technology outside the military domain was in the field of medicine, with early implementations focusing primarily on surgical procedures. The introduction of lasers into the medical field was driven by their exceptional precision and the inherent advantages of non-contact operation. The absence of physical contact between the laser and the patient promotes a higher degree of sterility, reducing the risk of infections and contributing to improved procedural safety. In dermatology, lasers have been employed for a variety of therapeutic and cosmetic purposes. For instance, certain types of skin cancers can be treated with lasers. Additionally, lasers are widely used in dermatology for cosmetic procedures such as tattoo removal with the breakdown of tattoo pigments. Laser have found applications in several other medical specialities like neurosurgery, gastroenterology, and oncology, where laser is used, for example, for the removal of brain tumours.

On 26 June 1974, there was the first installation of supermarket scanner able to read the Uniform Product Code, commonly known as the barcode. The inaugural transaction using this cutting-edge scanner involved a package of Wrigley's chewing gum, which was the first item to be scanned and purchased utilizing this new technology. The scanner employed for this application was based on a red helium-neon (HeNe) laser. This installation represented not only the debut of the UPC scanning system but also the beginning of the era of mass-produced laser-based products. By 1980, scanner technology had become common e widely used.

The second significant mass-produced laser-based product to emerge was the compact disc (CD), a technology that represented a notable advancement in optical storage media. The history of the compact disc can be traced back to the development of the LaserDisc, which was introduced in 1978. Although the LaserDisc was pioneering in its use of laser technology for optical disc playback, its impact on the market was relatively modest. In response to the challenges faced by the LaserDisc, Philips, a leading technology company, initiated a new project aimed at refining and advancing optical disc technology. This project culminated in the development of the compact disc (CD), which was formally introduced to the market in 1982. The CD was essentially a spinoff of the LaserDisc technology. Initially developed in Japan, the first CDs were sold in United States at a high price point of approximately $1,000. Despite the initial high prices, the compact disc quickly gained attention from consumers and industry professionals. As the demand for compact discs increased and advancements in production technology were made, the cost of CDs progressively fell, allowing them to become more affordable for a wider range of consumers. This reduction in price, combined with the growing availability of CD players and a broader selection of music released on CD, facilitated the use of the format in the audio industry (Hecht, 2010). Diode lasers have been instrumental in the detection and retrieval of information encoded in prerecorded digital format on compact discs. During the initial five years following their introduction, compact discs experienced remarkable commercial success. This financial success established the compact disc market as the largest segment for diode lasers during this early period. In fact, by 1987, over 10 million diode lasers were sold specifically for compact disc playback applications.

Another significant domain in which the utilization of diode lasers was solidified was the market for laser printers. The first laser printer was commercialized in 1976 by IBM (International Business Machines Corporation) setting a precedent for future developments in this field. Following IBM's introduction, other major technology companies, notably Xerox and Canon, entered the laser printer market, further advancing the technology and expanding its applications. The period of technological evolution culminated in 1984 with the introduction of the first laser printer designed specifically for mass-market sales by Hewlett-Packard (HP). The advantages of laser printers over their mechanical predecessors were substantial. Laser printers offered superior speed, precision, and print quality compared to traditional mechanical printers. Printers utilizing laser technology rapidly established themselves as the standard for office environments. By 1987, the impact of laser printing technology was evident in the market, with approximately 1.4 million diode lasers used in laser printers.

The use of lasers in the industrial sector is vast and continually expanding, encompassing a wide range of applications. One of the key areas of growth is in additive manufacturing, commonly known as 3D printing. In addition to additive manufacturing, lasers play a crucial role in the cutting of various materials. They are extensively used to cut metals, glass, textiles, and even precious materials such as gemstones and jewellery. The precision offered by laser cutting is unmatched, allowing for intricate designs and exact dimensions that are essential in industries like fashion, electronics, and aerospace.

In summary, the industrial applications of lasers are diverse and rapidly evolving. This ongoing expansion reflects the versatility and efficiency of laser technology in meeting the demands of various industries and different customers.

### 3.4. Empirical Studies on the Laser Industry

Klepper and Sleeper, in their 2005 study, examined the industrial dynamics within the U.S. laser industry from the first commercialization of laser technology in 1961 up to 1994. Their analysis identified nine distinct submarkets, each associated with a specific type of laser technology. These included solid-state, semiconductor, chemical dye lasers, and six categories of gas lasers: helium-neon, carbon dioxide, ion, excimer, helium-cadmium, and an encompassing category for all other gas lasers.

The study highlighted the highly segmented nature of the laser market, where each submarket depended on specialized competencies and catered to distinct customer groups. For instance, the customer base for medical device lasers is significantly different from that for laser printers. This segmentation also means that each submarket is relatively small, characterized by a limited number of customers, despite the overall diversity of the market.

Over the time span of their study, Klepper and Sleeper (2005) noted that firms in the laser industry exhibited varied product portfolios. Specifically, 55% of the firms produced only one type of laser, 20% produced two, 23% developed between three to six different lasers, and a mere 2% produced between seven to nine types. The average number of lasers produced by these firms stood at two. A particularly significant finding from the study was the differentiation in product range between older firms, with more than 20 years of experience, and their less experienced counterparts. The more established firms had an average product range of 4.6 of the nine identified laser types over their lifetime, suggesting that experience and longevity in the industry correlated with a broader product offering. This breadth in product offering, particularly among older firms, could be attributed to the overlap in technology and processes required to produce several types of lasers, such as those within the six categories of gas lasers.

An extensive study conducted by Klepper and Bhaskarabhatla (2014), covering the period from 1961 to 2007, provides additional results. Their research documents a notable trend in the number of laser producers in the United States, which exhibited a consistent and steady increase up until 1996. However, this upward trajectory was followed by a significant period of decline. A critical inflection point identified in the study seems to be the introduction of Diode-Pumped Solid-State (DPSS) lasers around 1988. The advent of DPSS technology appears to have played a key role in altering the dynamics of firm survival and industry structure. The impact of DPSS lasers catalysed a notable period of industry reorganization, characterized by a phenomenon known as a ‘shakeout’. A shakeout is a particular event that can occurred within an industry, manifesting as a dual process involving both am increase in the rate of firm exits and a simultaneous decrease in the rate of new firm entries. In particular, they showed that later entry is associated with a higher hazard of exit following the introduction of DPSS lasers.

In a subsequent study conducted by Buenstorf and Heinisch (2020) a particular attention was given to the German laser industry. The investigation revealed that the first commercial laser application in Germany appeared in 1964, three years following the initial commercialization of laser technology worldwide. In this study, which spanned from 1964 to 2013, a total of 184 firms were identified as being active in the German laser industry. Among these, 110 firms were documented to hold at least one patent, underscoring the industry's engagement in innovation and intellectual property development. A key finding from the study was the trend in patenting activity. The number of patents filed began to increase significantly starting in 1984, though this growth exhibited a discontinuous pattern, characterized by periods of increase followed by declines. Notably, the study observed that patents related to Diode-Pumped Solid-State lasers were relatively scarce. This suggests that the introduction of DPSS laser technology did not act as a major barrier to new firms entering the German laser market, contrasting with the situation observed in the United States. Moreover, the study highlighted the heterogeneity of production within the German laser industry, noting that the industry excels particularly in the domain of industrial materials-processing lasers. Regarding the size distribution of firms within the industry, it is notably skewed, with a preponderance of smaller firms contrasted by a smaller number of large enterprises.

To conclude this subsection, the comparative analysis of Klepper's studies on the U.S. laser industry and the subsequent examination of the German laser industry highlights a crucial difference in their developmental trajectories: the occurrence of a significant industry shakeout in the U.S., contrasted with the absence of a similar phenomenon in Germany. In the U.S., the shakeout reflects the increasing barriers to entry and competitive pressures that led to the dominance of a few major players. Conversely, the German laser industry did not experience such a consolidation; instead, it maintained a diverse and relatively open market structure, with continued entry of new firms even in the face of technological advancements like DPSS lasers. This contrast underscores the influence of differing national contexts and market dynamics on industry evolution.

# CHAPTER 4: DATA CHARACTERISTICS AND VARIABLE OVERVIEW

## 4.1. Data Sources

In order to investigate the dynamics underlying patenting activities of firms and the subsequent survival analysis within the laser industry, it is crucial to carefully select and describe the data sources used in this study. To be able to fully answer the research question, a variety of databases and other sources were used to establish a robust foundation for the subsequent analysis. This chapter outlines all the sources employed in this study, each serving a different and specific purpose in understanding the events that characterize laser manufacturing companies around the world.

The starting point for this research involved the creation of a list of firms operating in the laser industry. For this purpose, the *ORBIS* database was chosen as the sole source of firm-level data. *ORBIS* is rich data resource on both private and listed companies, managed by Bureau van Dijk, a Moody's Analytics company. *ORBIS* is considered a reliable source because it provides information on more than 527 million companies located worldwide, moreover it combines data from over 170 different sources into a standardised and comparable format, providing unparalleled depth and breadth of company information.

An important feature of this database is that it assigns a unique identifier to each firm thus enabling accuracy and consistency of data over time. This unique identifier serves as a stable reference point of each firm, thus avoiding possible loss of companies track due to changes such as name alterations and shifts in legal structure. Another case where the presence of an identifier is useful is in the case of mergers or acquisitions, which allows data to be obtained before and after the event. The possibility of keeping track of each firm during its entire lifetime is crucial to the analysis because it allows the study to limit incomplete information and data as much as possible.

In addition to that, the presence of data collected from firms operating worldwide is particularly valuable for this research, as the context to be examined is not confined to a single geographical area. Key players are located in various areas of the world, most notably in America, Europe and Asia, highlighting the creation of an international market in which firms operate and exchange information. The existence of a network beyond national borders helps to disseminate technological advances faster and more effective, thus intensifying the application and the development of such innovations.

The database offers a wide range of information concerning several sectors, including valuable data on firms active in the laser market. For the purpose of this study it was considered appropriate to include two different categories of firms engaged in laser-related activities: specialized laser companies and diversified companies. To the first category belong all those firms that focused their effort only on laser production, being present exclusively in this area of development. The second category includes instead larger firms whose main line of business is not laser, but with a limited number of segments operating in the laser sector, such as Canon and Hewlett-Packard (HP). These firms are not exclusively focused on lasers but maintain a significant presence in the sector. For instance, Canon and HP, do some business in this area through the production and commercialization of laser printers and 3D printing technology. Additionally, Canon is involved in the production of lasers for analytical purposes and medical diagnostics. However, it is important to note that laser's production represent only a fraction of their overall business activities, and a large part of their effort is concentrated in other sectors of production, maintaining in this way a diversified portfolio.

This selection criterion ensures a true representation of the industry, reflecting the several applications that can occur and the many innovations in the laser sector that have been developed over the last 60 years. The decision to include firms that operate across multiple segments is particularly pertinent.

These diversified companies often exhibit higher economic resilience than their more specialized competitors. The strategy of diversification in production and activities can mitigate the adverse effects of market-specific shocks, thereby enhancing the long-term survival probability of these firms. Moreover, diversification can yield benefits, as technological advancements in one sector of production can be transferred and adopted to others, fostering innovation and bolstering the overall competitiveness of the company.

Diversifying entrants are established firms that decide to expand their production in another market, generally by internal growth or by acquiring existing companies in the target sector. These types of entrants are peculiar because, as incumbent firms in their original markets, they are well-equipped not only in terms of financial resources, but also technical and human resources. Due to their established position and their better financial situation, diversifying firms are more likely to enter in market related in terms of knowledge to the market in that they are already active. This entry strategy allows them to leverage the knowledge and the capabilities that they have already developed in their years of experience. In order to facilitate the process of entry, these firms rely on complementary resources, and they choose the market to enter on the basis of their business scope. This creates the possibility of intensifying their existing distribution channel and use their bargaining power in their favour. Firms with a greater amount of resources have the basis to enter into farther lines of business. It is often the case for larger companies to directly acquire a smaller company specialized in another market rather than specialise a new production line by their own means. Mergers and acquisitions are very common in cases of diversification strategies, as they provide an efficient way for established firms to expand their market presence quickly. This practice of M&A is in line with the objective of this study, and its inclusion thus becomes essential.

The dataset constructed for this research lists a total of 615 companies from around the globe, providing a representative sample of the laser market. By incorporating firms operating in different regions and of varying sizes, the dataset enables a comprehensive examination of patenting activities and market exit strategies within the global laser industry.

It is worth noting that the original list of firms was more extensive, including more than 1,000 firms. However, certain companies were excluded due to incomplete availability of some data. Specifically, firms lacking crucial information, such as missing information on the year of entry or exit from the market were not included. This decision was made to avoid potential biases in the results that could skew the results, and thus ensuring the accuracy and reliability of the analysis. This refinement of the final list of firms ensures the minimization of risk of distortion due to missing or incomplete information.

The sample was carefully constructed with the aim of capturing the actual and broad distribution of corporate characteristics and geographic location, thereby enhancing the generalizability of the findings. This methodical approach contributes to a better understanding of the factors influencing patenting propensity and market exit from the laser sector.

The use of *ORBIS* as a main source brings significant benefits to the research by using high quality information tracked over several years, from the establishment of the company to its eventual termination. The data available are reflective of the latest developments registered in the market for these companies, the findings can be considered both timely and relevant. Additionally, this database is widely used in academic research and policy analysis to examine economic trends, assess the impact of regulation, and develop policy recommendations. It is also a valuable tool for corporate and financial research, supporting the analysis of corporate strategy, financial health, and market dynamics.

In summary, the list of firms extracted from the Orbis database includes 615 firms engaged in the laser market operations on a global scale. The selection and the nature of this dataset provides a solid foundation for the analysis, allowing the previously mentioned relationship to be investigated in an optimal manner.

The second step in the construction of the dataset included a systematic collection of information regarding different moments in the life of the firms listed. This includes a wide range of data, such as:

- the year of entry into the market,
- the year of exit from the market,
- the mode of exit (if the event had occurred).

This step is not merely procedural, it is crucial for understanding the temporal dynamics and exit strategies of firms within the laser industry and creating in this way a pool of information pertaining to the company lifecycle.

This information is vital to understand when and how a firm decides to enter and exit the market, offering the possibility to develop a study on longevity patterns and related exit strategies.

To ensure an accurate data collection, several sources were used. The primary sources to retrieve this information include a combination of official websites of each firm and several open-access databases that collect corporate data.

On the official websites of the companies, usually in the "*History*" or "*About us*" sections, the various timelines of the company's development are recounted in detail, including the date of market entry and whether they have experienced a M&A. By directly consulting this source, it is possible to manually extract the most accurate data available on the Internet.

In addition to official websites were used open-access database to complete the collection of these critical information. The database employed are: *Crunchbase, OpenCorporates*, and *PitchBook*.

*Crunchbase* and *PitchBook* offer data on the year of entry, exit and the mode of exit distinguishing between M&A and failure. *Crunchbase* focuses more on startups and venture capital, while *Pitchbook* on venture capital and private equity.

Another valuable source is *OpenCorporate*, it provides a wide range of business data, such as company registration details and historical data about corporate events.

The completeness of the dataset is ensured by the simultaneous use of these different sources for data collection. When one source has gaps in some information, another is used, which addresses the potential information gaps that may result from relying on a single source. Furthermore, the comparison of information collected on different websites makes the dataset much more accurate. By verifying the same data across multiple sources, any discrepancies can be easily identified and resolved, avoiding the inclusion of untrue data in the final dataset.

In addition to that, where possible, further research and efforts were conducted by gathering data from secondary sources such as corporate reports and publications. These statements often provide deeper information and insights into the decision of M&A, or other modes of exit linked to a negative outcome, such as liquidation or bankruptcy.

In summary, this second step involved the enhancement of the dataset with a robust temporal and exit-related information set, achieved through the combination of data from multiple sources.

The subsequent phase of the process entails the acquisition of a register of patents pertaining to each of the companies included in the final list. This is crucial to concentrate the study on patent-related information, which is key to understand the pattern of innovative activities and the importance of intellectual property rights on the survival probability of firms within the laser industry.

The search engine employed for this purpose remains *ORBIS*. This part of the dataset contains a list of patents registered in various countries. Specifically, *ORBIS-IP* provides the official document number for each patent, which is a useful identifier for collecting additional information about the patents themselves. This list of patents includes those registered in multiple jurisdictions, such as the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the Taiwan Intellectual Property Office (TIPO), the European Patent Office (EPO), and many others.

Not limiting the analysis to a single jurisdiction adds an extra element of accuracy and versatility to the results. Companies often use patent strategies that extend beyond their home country's borders to better protect their efforts and discoveries.

The total number of patents included in the dataset is 3,157, all of which have been registered with one of the previously mentioned patent offices. This considerable number of patents serves as a notable indicator of the advanced technological status of the sector. It is worth noting that only patents belonging to a specific technology class are included in this study. Specifically, patents with the International Patent Classification (IPC): H1S3/00. This includes innovations related to the development of "*devices using stimulated emission or electromagnetic radiation in the infrared, visible or ultraviolet wave range*". Collecting only this subset of patents is essential for the significance of the results because some companies, particularly diversifiers, may patent in other areas of technology that are not relevant to lasers. Including patents that are not laser-relevant would lead to result that are not able to capture the effect of patenting in the laser field.

Once the patent numbers have been obtained from *ORBIS* it is possible to complete the final dataset by adding the information that captures the quality of all the patents in question. First, the patent numbers are taken and systematically searched in *Google Patents*, which is a search engine specialised in collecting patents and others vast related information.

In this search engine it is possible to consult the complete document of each patent, within which there is the information useful for this research. The information provided is of high quality, since it comes directly from the original patent document and has not been subject to revisions or comments by third parties, ensuring the accuracy and reliability of information.

Specifically, the information that have been kept among the many presents in the document are:

- The number of claims associated with each patent;
- The number of (backward) patent citations;
- The number of non-patent citations;
- The number of (forward) citations;
- The name of the inventor(s);
- The current assignee, which coincides with the current firm that owns the rights attached to the patent;
- Data on the worldwide application, highlighting the geographical reach and market aspirations of the patent holders.

With this extensive information in hand, new quality proxies for patent activity can be meticulously constructed in order to meet the primary aim of the study. The inclusion of quality proxies is important to avoid the mere use of total number of patents and thus trying to bring the analysis to a non-superficial level.

Among the indicators considered there are the average citations per patent and the average number of claims per patent. In addition to computing the averages, the total number of citations and claims per firm was also computed. This approach ensures that both the intensity and extent of a firm's patenting activities are captured in the analysis, providing a more holistic view of its innovation portfolio.

It was decided to compute and consider both the total number and the average of these key indicators to ensure a broader and more detailed view of the data. The decision was made to reflect different strategies that firms may adopt in their use of IPRs.

For instance, it is possible for a company to hold a relatively small number of patents, yet have those few patents be very impactful. Therefore, these patents might receive a large number of citations from other patents or span over a wide number of fields of interest, and so a large number of claims. As argued above, it is acknowledged that a higher number of citations is linked to a higher impact of subsequent technological advancements and innovations. In such cases, the average citation number would be high, reflecting the focus on developing groundbreaking innovations, rather than on simply basic research. On the other hand, some companies may be the assignee of a larger number of patents, but many of these might have a marginal impact on future innovations. While it is generally true that owning more patents will naturally increase the total number of claims or citations, it is not necessarily true that a higher number of patents it is related to an increase in the average number of these proxies of quality. Employing both these metrics is essential to ensure a more detailed understanding of how firms decide to leverage their intellectual property, whether through disruptive innovations or through the accumulation of a broader but potentially less impactful patent portfolio.

Additionally, while Google Patents offers a wealth of information beyond what has been incorporated into the final dataset, certain data points were deliberately not collected and utilized for this study. One such data point is the status of the patent, which indicates whether a patent is still active, has expired, or has been otherwise discontinued. The status of a patent is a critical element in understanding the current relevance and enforceability of intellectual property rights. In fact, active patents continue to offer protection and can influence a firm's competitive positioning, while expired patents no longer hold such protective power.

Furthermore, the classifications of patents, which categorize patents based on their technical subject matter, were also not included in the dataset. Patent classifications can indicate the technological focus of a firm's innovation efforts, highlight emerging technological trends, and provide insights into the distribution of inventive activity across different fields.

However, despite the valuable insights that patent classifications and patent status could potentially offer, the dataset remains purposefully structured to emphasize and offer results focused on the core aspects of patent quality and firm-level innovation behaviour.

In conclusion, the final dataset represents a comprehensive compilation of critical information pertaining to firms operating within the laser industry, making it possible to analyse both their corporate existence and lifecycle as well as detailed data on their patent portfolios. It is a useful instrument for learning about the competitive dynamics and innovation processes that define the laser business, which will help us comprehend this important sector on a deeper and more complex level.

### 4.2. Variable Description

In this section, it is provided an in-depth examination of the 23 variables utilized in this study, categorizing them according to their roles providing in descriptive statistics, econometric analyses, or both. This detailed description helps to in understand how each variable contributes to the analysis and the interpretation of results.

*Table 4.1: Description of variables*

| Variable Name | Description of the variable |
|---|---|
| **firm** | Name of the firm |
| **n_patents** | Total number of patents held by the firm |
| **innovation** | It is a binary variable that is equal to 0 if the firm has never filed for a patent, and 1 if the firm has at least one patent. |
| **entry_year** | The year in which the firm enters the market |
| **exit_year** | The year in which the firm exits the market |
| **survival_time** | It measures the duration, in years, that the firm remains in the market until it exits or is censored |
| **exit** | It is a binary variable equal to 0 if the firm is still in the market at the end of the observation period, and 1 if the firm exited the market, regardless of the exit modalities |
| **acquisition** | It is a binary variable that is equal to 0 if the firm was neither acquired, nor merged, during the observation period, 1 if it experienced M&A |
| **failure** | It is a binary variable that is equal to 1 if the firm exited the market due to bankruptcy, failure, voluntary dissolution, or liquidation, and 0 if the firm has not experienced these types of exits |
| **entrants_** | This variable categorizes firms into one of three cohorts based on the year they entered the market |
| **region** | It indicates the geographic location of the registered office of the firm. It is categorized as USA, Europe or rest of the world |
| **tot_claims** | It denotes the number of claims included across all patents held by the firm |
| **backward_cit** | It represents the cumulative number of backward citations across all patents held by the firm |
| **forward_cit** | It denotes the total number of forward citations that the firm's patents have received |

| | |
|---|---|
| **mean_bc** | This variable represents the average number of backward citations per patent held by the firm. It is calculated as the ratio of the total number of backward citations to the total number of patents |
| **mean_fc** | This variable represents the average number of forward citations per patent held by the firm. It is calculated as the ratio of the total number of forward citations to the total number of patents |
| **mean_claims** | This variable represents the average number of claims per patent held by the firm. It is calculated as the ratio of the total number of claims to the total number of patents |
| **mean_y_fc** | The weighted average number of forward citations per year |
| **y_first_pat** | The year in which the firm has published its first patent |
| **fam_pat** | The total number of patents held by the firm that are part of a patent family. |
| **nofam_pat** | The total number of patents held by the firm that aren't part of a patent family. |
| **logt** | Log of survival time |
| **lnpat** | Log of n_patents |

The analysis begins with the company's name. This is a nominal variable that serves as a unique identifier for each firm within the dataset. While this foundational variable does not contribute directly to the analytical measures, it is essential for distinguishing between different entities. Beyond its primary and simple role as an identifier, it was also used as unique variable in the process of merging the two datasets: the one on company data taken from *ORBIS*, and the one on patent activity data built from *Google Patents*. Moreover, the presence of the company name facilitates the comparison across firms during the analysis process.

A significant number of variables in the dataset is dedicated to capturing the lifecycle of each company. This includes the year of market entry, which specifies the year a firm began its operations in the market. It is important to clarify that this variable reflects the firm's initial market presence and is not restricted to its entry into the laser market or the starting of its laser-related operational segment. The year of exit, similarly, denotes the year in which a firm ceased its market activities altogether. This variable is important in understanding the duration of a firm's market presence.

Survival time is another critical variable, measuring the time span, in years, that a firm remains active in the market before its exit, or until the end of the observation period, which is set at 2024. It is calculated as the difference between the year of exit (or 2024) and the year of entry. This metric provides a measure of firm's longevity. In cases where a firm is active in 2024, its survival time is considered censored, meaning that while the firm's market presence is ongoing, there is no recorded exit event within the dataset. Censoring is a crucial concept in survival analysis because it allows to maintain a complete dataset containing information about firms that have not yet exited the market, without treating them as incomplete or introducing gaps into the data. By applying this censored approach to firms still in business, the analysis can reflect the ongoing nature of the market, rather than artificially truncating their survival time. This avoids the presence of missing value that would have certainly influenced the results.

The dataset includes several dummy variables that capture various types of exit events. In particular there are:

- The acquisition variable, which is coded as 1 if the firm has undergone a merger or acquisition, and 0 otherwise. Although mergers and acquisitions are technically two distinct events, they are treated as synonyms in this analysis. This is due to the challenges of obtaining precise information about these events. Often in the open databases mentioned above, *CrunchBase*, *PitchBook* and *OpenCorporate* no distinction is made but they are recorded under the same category, with no differentiation between the two. Thus M&A are grouped together under this single dummy variable. For the purposes of the analysis, M&As are treated as favourable events, representing successful exit strategies for the firm involved.
- The failure variable, which is assigned a value of 1 if the firm exits the market due to reasons other than a merger or acquisition, encompassing scenarios such as bankruptcy, voluntary closure, failure, or liquidation. This variable provides a measure of non-M&A-related exits. More specifically, these modes of exit are interpretated as a negative outcome, although this may not always be the case in reality. For instance, a voluntary closure could occur for strategic reasons, such as the owners of the firm may decide to retire, rather than as a result of financial distress.
- The exit variable, which is a composite measure, coded as 1 if either the failure or acquisition variable is 1, indicating that the firm has experienced some form of exit from the market. This variable is constructed in such a way it synthesizes the two distinct types of firms' exits, favourable and not, into one more general variable. This allows to make a broader analysis, examining overall exit trends.

In order to facilitate comparative analysis, firms in the dataset are grouped into three distinct cohorts based on their respective year of market entry. The cohorts are defined as follows:

- Entrants Before 1970: Firms that began operations prior to 1970, indicating the early participants. As said before, the year of entry indicates the year of entry into any market, it is not indicative of the year of entry into the laser market. However, since the laser market developed in the 1960s, the year 1970 was chosen as a reference point to define this subgroup. This choice was made to ensure a relatively even distribution of firms across the three cohorts while reflecting the historical context in which these firms operated. The firms listed in this category are treated as early entrants.

- Entrants 1971-1992: Firms that entered the market between 1971 and 1992, a period characterized by significant disruptive innovations and advancement in the technological frontier.
- Entrants 1993-2024: Firms that began operations from 1993 onwards, reflecting the most recent market entrants.

These cohorts are structured to prevent disproportionate representation across groups and to align with the historical development of the laser market. The analysis can highlight the trends and patterns that might vary depending on the era in which entered the market, crucial to assess the more important industrial dynamics.

Additionally, firms are categorized by their geographical location. This classification divides firms into three regions: the USA, Europe, and the Rest of the World. This geographic classification enables the analysis of regional market dynamics and enables comparative studies across different global contexts. This geographic classification is used as a fixed effect in the analysis.

The dataset also includes several variables related to patenting activities. Patenting is a key indicator of firm's effort on research and development, as well as its ability to produce innovation. Two primary variables are included in the dataset:

- The number of patents is a numerical variable representing the total count of patents held by each firm, reflecting its innovative output. A higher number of patents typically indicates a greater level of firms' innovativeness (as a consequences of R&D activity). This variable reflects the overall innovation strategy of each firm.
- The innovation variable is binary, indicating whether a firm is involved in patenting activities as a whole. It is coded as 1 if the firm holds at least one patent, thus capturing the presence of patenting activity, and 0 if it does not. This variable is important because it allows to generalize the involvement in the development of innovations or not.

These two variables are used in two different analyses, they are therefore substitutes for each other, both equally important and beneficial for the interpretation of the results.

To assess the quality of patenting activities, several proxies were collected from the official patent document and then utilized. These include:

- Claims: The total number of claims across all patents held by the firm, which outlines the scope of legal protection granted to each patent. The greater the number of claims, the wider the scope of the patent.
- Backward citations: The total number of prior patents cited by the firm's patents, indicating the foundational knowledge and prior art on which the firm's innovations are based.
- Forward citations: The total number of subsequent patents referencing the firm's patents, reflecting the impact and influence of the firm's innovations. A patent with many forward citations suggests that it has been inspirational and fundamental for subsequent technological advancements and innovations.

By analysing these three proxies it is possible to conduct a more precise study on patenting activities and their potential impact on industrial dynamics.

To further increase the accuracy of the analysis and the assessment of patent quality, it was considered essential to calculate and include not just aggregate numbers of claims and citations but also their average values per patent. The mean of these proxies is calculated as the ratio of the total number of citations (both backward and forward) and claims to the total number of patents, providing a further measure of patent quality. This process allows to obtain variables that reflect the average characteristics of the firm's patent.

In addition to the previously mentioned proxies, other variables related to patent families are also considered. These variables provide insight into the geographic dimensions of a firm's patent portfolio. In particular, the two variables are:

- Patent Family Count, it is a numerical variable representing the number of patents that are part of a patent family. Patent families consist of patents filed in multiple jurisdictions linked by a common priority claim, indicating the breadth of international protection. This means that the same invention is protected in different countries. The firm can opt to provide protection on a global scale.
- Non-Family Patents, it is a numerical variable denoting patents not included in any patent family. These are standalone patents that have been filed in only one jurisdiction, without any corresponding protection in other countries.

A fixed effect variable, first patent year, records the year in which the firm filed its first patent. This variable serves as a proxy for the firm's seniority and experience in patenting activities.

To improve the performance and accuracy of econometric analysis, it is often necessary to transform certain variables to solve problems such as skewed distributions and make the result more interpretable. Two variables are transformed in this context:

- Logarithm of Number of Patents. The natural logarithm of the total number of patents is used to normalize the distribution and facilitate the interpretation of results on a relative scale. It is frequently observed that a small number of firms hold a disproportionately large number of patents, leading to a fat-tailed distributions where the majority of firms hold zero or relatively few patents. The natural logarithm allows to compress extreme values reducing the impact of outliers.
- Logarithm of Survival Time. The natural logarithm of survival time is employed to handle skewed distributions and to model time-related effects more accurately.

This thorough explanation of the variables offers a solid foundation for comprehending their functions and measures, guaranteeing a methodical and transparent approach to the analysis and interpretation of the study's findings.

# CHAPTER 5: DESCRIPTIVE ANALYSIS

This chapter presents the descriptive analysis of the collected data. The aim is to provide a detailed overview of the key characteristics, distributions, and trends observed in the dataset. Specifically, in line with the research question, it is important to understand potential patterns linking patent activity, the survival probability and the modes of exit from the laser industry.

## 5.1. Geographic Distribution of Businesses

As a first analysis, we look at the geographical location of firms operating in the laser industry. Using precise latitude and longitude coordinates for each firm, it is possible to map the locations of these firms to better understand their spatial distribution. This exercise allows us to visually observe possible regions with high concentration of active firms, and others with no active enterprises. This geographic perspective highlights potential geographical trends and clusters that would not be as obvious through tabular data alone.

In order to avoid omitting potentially useful information, several analyses have been carried out on this subject:

- Global representation;
- Focus on the United States;
- Focus on Europe;
- Focus on innovator firms.

This multifaceted approach provides a richer picture of the geographical distribution of firms and innovations across the world.

MATLAB was used to create this visual representation. Specifically, the internal function *geobubble* was employed to plot weighted nodes, and to visualize the presence of companies in a specific region. In this context, each bubble on the map represents a different location where firms are active. The size of each bubble is proportional to the number of firms operating at that specific coordinate, meaning that larger bubbles indicate a higher concentration of business activity in that region.

### 5.1.1 Global Representation

The first map provides a representation of firm activity on a global scale. To improve the clarity and focus of the image, some simplifications were made, allowing a particular cluster to be emphasised.

One of the key adjustments made involved grouping all the firms active across the various states of United States into a single pair of latitude and longitude. All the firms that have the value 1 in the dummy variable USA are represented into a single geographic point. By doing this, the map emphasises the overall presence of firms in USA, allowing the country to be understood as a unified entity in the global context.

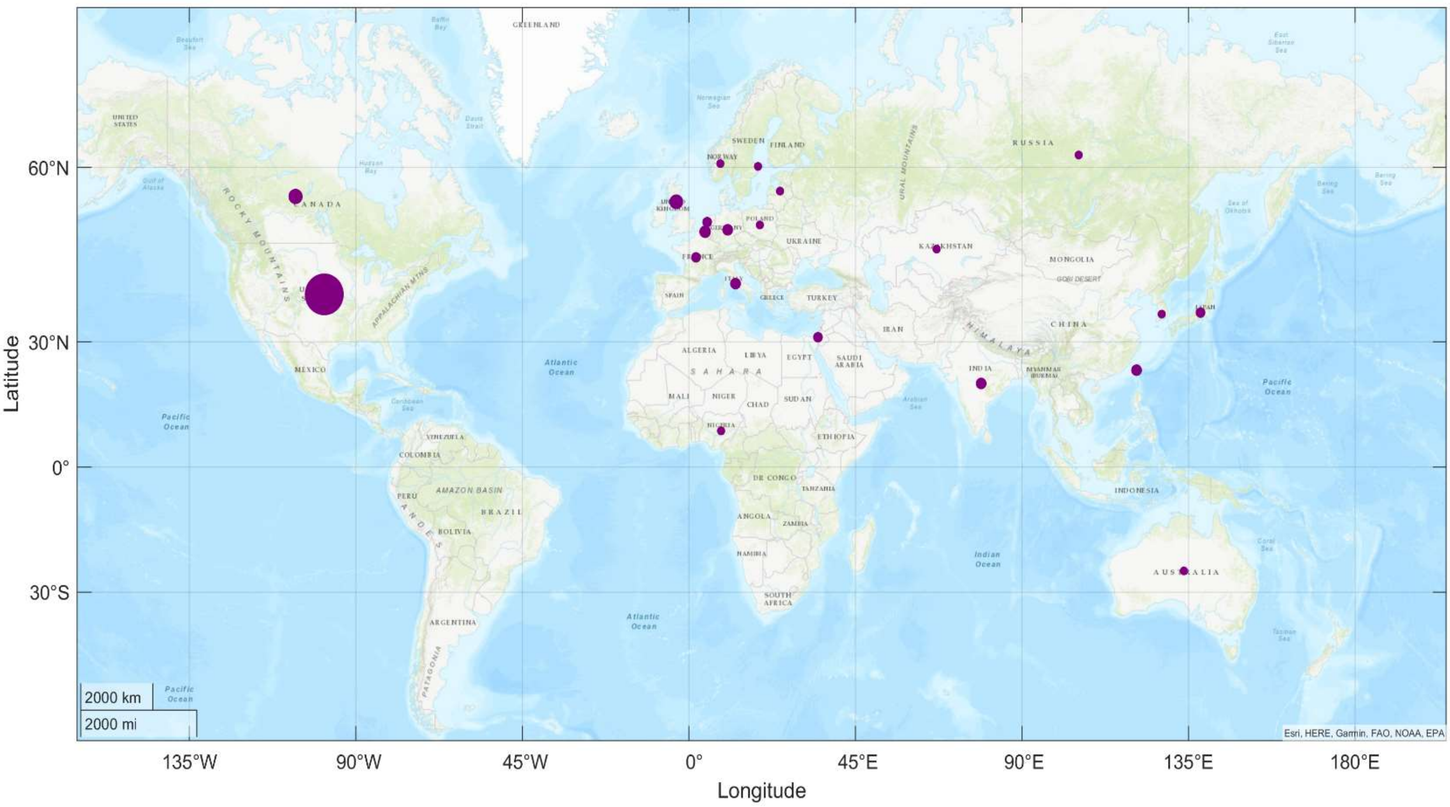
Similarly, regarding the Europe, one geographic coordinate was selected to represent each country.

These deliberate choices in data simplification in this first analysis help to focus the attention on specific patterns and concentration of firms at a global scale.

*Table 5.1: Geographical distribution*

| Region | Active firms |
|---|---:|
| USA | 501 |
| Europe | 26 |
| Rest of the World | 24 |

*Figure 5.1: Global representation of concentration of firms*



It is worth noting that it was not possible to find the exact position for all the companies listed in the dataset, and therefore for this descriptive analysis it was chose to exclude them.

The first thing that it is possible to see is the dominance of USA as the main centre for the firms that decide to operate in the laser industry, as a segment of their production or as their only production strategy. The massive bubble located in the USA includes 501 firms over the 551. This undoubtedly makes the USA the dominant player globally, with the largest concentration of firms by a significant margin representing the 91% of the total.

The availability of R&D funding, combined with a concentration of laboratories at university dedicated to advancing these technologies, has created a fertile environment for laser market growth and concentration in the USA.

Historically, the laser and its subsequent market developed primarily in this region, allowing a limited number of firms to initially operate in this area. As argued above, initially, the market was created to meet specific needs in a military field. As time passed, the market started to fragment and led to the creation of other submarket focused on medical applications, industrial use, and more.

Klepper and Sleeper (2005) studied the pattern of entry into the laser market. This study has highlighted the presence and the importance of the entrepreneurial spinouts. This type of entrant can be seen as a crucial explanation for the concentration of companies operating in the laser market in the United States. An entrepreneurial spinout is a firm that is founded by a former well-educated and experienced employees of incumbent's firm in the industry setting up its firm in the parent industry. The new created firm is completely independent from the parent's company.

Klepper and Sleeper, looking at a period from 1961 to 1994, found that out of 486 market entries, 79 were spinouts. This significant presence of spinouts highlights a dynamic in the market: these firms emerged from established companies, bringing with them experience and innovation.

Spinouts can enter the market through several pathways. One common approach is for these new companies to produce the same products as their parent company. This entry strategy allows them to use their knowledge accumulated over the years. By using their familiarity with the technology, production processes, and customer preferences, spinouts can effectively compete in the market with an older company.

Alternatively, some spinouts can decide to diversify with respect to their parents by developing a novel variant of the original laser. In this case the previous knowledge is crucial. This approach also encourages further advancements in the technological frontier, as well as allowing them to differentiate themselves from competitors.

In this context, the geographical proximity of spinouts to their parent companies is another strategic advantage. Employees who decide to create their own firms often do so in locations close to their previous workplaces. This proximity allows them to fully exploit their knowledge. In particular, this choice of settlement facilitates the access to the same suppliers and customers, making possible to construct in an easier way a solid network within the market. Additionally, operating in a familiar regulatory environment can reduce the number of managements changes, saving time and money.

In the study mentioned above, revealed an important finding: there is a positive relationship between the years of activity in the laser industry and the likelihood to spawn a spinout. In other words, the longer a company operates in the laser market, the greater the probability that some of its employees will eventually leave to form their own independent companies.

In the context of the United States, this finding takes a particular significance. As the birthplace of the laser market, the United States was home of the pioneering companies in this field. These early entrants, being active for several decades, allowed workers to accumulate knowledge and valuable experience. This dynamic has contributed to the high concentration of laser firms in the United States. The early development of the laser market in this area means that there are more firms with long histories of activities, which in turn increases the probability of spinout creation. Each spinout adds to the growing pool of companies within the industry, further concentrating the market in this region.

As a result, the USA become the dominant player in the laser industry, partly due to this self-sustaining cycle of spinouts and new market entrants.

This first result is consistent with the history of the United States. The USA has positioned itself as a global leader in technological innovation and productions across a wide range of industries. From the industrial revolution to the digital era, the United States has created an environment highly technological and highly competitive. It is not surprising that in a highly technological field like laser technology, the United States seems to be one step ahead of others.

There are some examples of this leadership over the years. In Europe and Japan, a decade after the end of the Second World War, as the society became more prosperous, there was an enormous increase in the consumption of durable industrial goods, such as radios, televisions, motorcycles, cars, and other small domestic appliances, while in the United States, this type of market had already been fully developed in the first half of the twentieth century. Additionally, in the development of the personal computer industry this region played the main role. In the 1970s and 1980s, American companies such as IBM and Microsoft revolutionized the way the world worked and communicated. Similarly, in the internet era, Google, Amazon, and Facebook redefined business models.

In the laser industry, a similar pattern can be observed. The United States in the 1950s quickly became the centre of laser research within institutions such as Bell Labs or the Hughes Laboratories.

Moving the focus to Europe, the map shows several smaller bubbled across different regions, but more specific in Western and Central Europe. In Europe there are 26 firms. The number of active companies in the United States and Europe is very different.

The rest of the world, also in this case, is represented by smaller bubbles scattered across various regions, including parts of Asia, Australia, and selected countries from other continents. In total, 24 firms are located across these regions.

With regard to Europe and the rest of the world, the analysis will be detailed later in the dedicated section.

### 5.1.2 USA

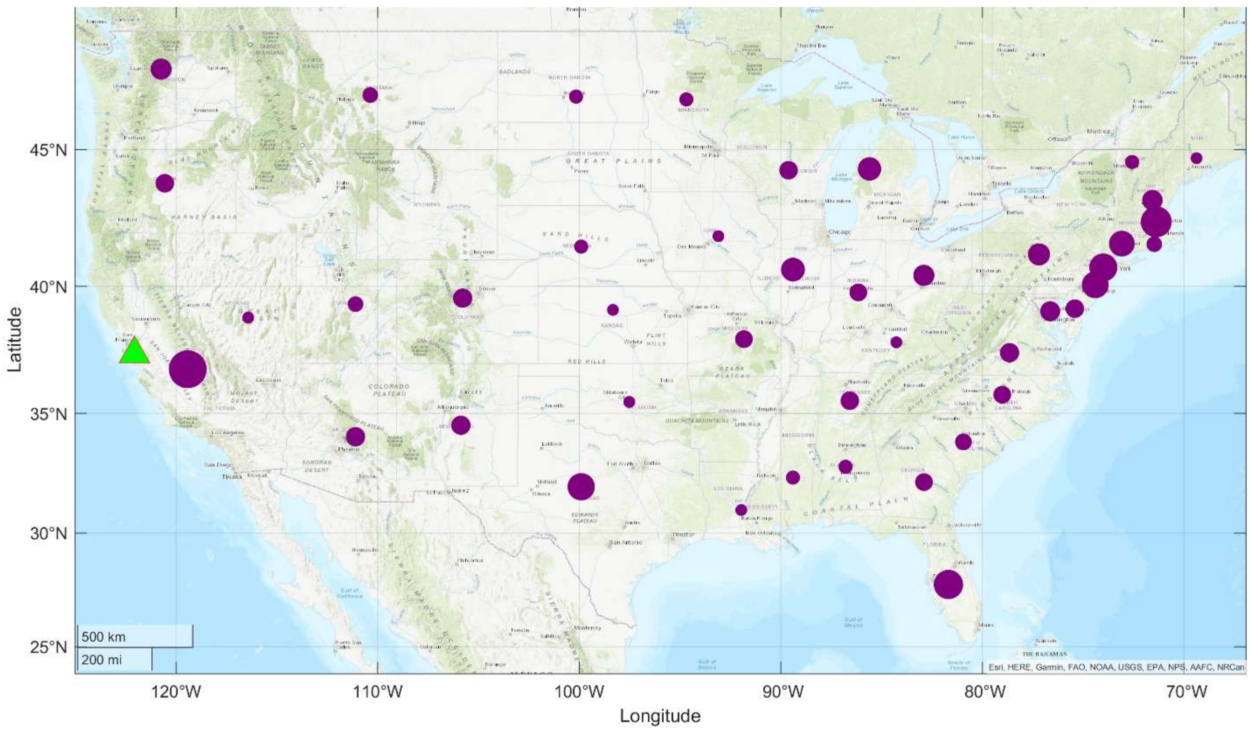
Now, we delve deeper into the analysis specifically focused on the United States. In the earlier sections, all companies active in this region were grouped and represented as a single coordinate. In this more detailed examination, the companies are categorised according to the specific state in which they are based. On a global level, it is interesting to see the size of the United States as a whole, but for an in-depth analysis it is better to divide by state. This allows for a clear view of how the industry is developed across different parts of the country.

In Figure 5.2, the approach follows the same principles used in Figure 5.1, where each bubble's size is proportional to the number of firms active in each state. However, in this image there is an additional element: a green triangle that represents the location of Silicon Valley.

*Table 5.2: Geographical Distribution in the United States*

| USA | Active firms | USA | Active firms |
|---|---|---|---|
| California | 120 | Georgia | 5 |
| Massachusetts | 46 | Indiana | 5 |
| Florida | 37 | Missouri | 5 |
| New York | 31 | North Carolina | 5 |
| Texas | 28 | South Carolina | 4 |
| New Jersey | 26 | Montana | 3 |
| Connecticut | 22 | Rhode Island | 3 |
| Illinois | 16 | Utah | 3 |
| Michigan | 15 | Alabama | 2 |
| Pennsylvania | 12 | Minnesota | 2 |
| Ohio | 10 | Mississippi | 2 |
| Washington | 10 | Nebraska | 2 |
| New Hampshire | 9 | North Dakota | 2 |
| Maryland | 8 | Vermont | 2 |
| Arizona | 7 | Hawaii | 1 |
| Colorado | 7 | Iowa | 1 |
| New Mexico | 7 | Kansas | 1 |
| Virginia | 7 | Kentucky | 1 |
| Delaware | 6 | Louisiana | 1 |
| Oregon | 6 | Maine | 1 |
| Tennessee | 6 | Nevada | 1 |
| Wisconsin | 6 | Oklahoma | 1 |

*Figure 5.2: Geographical representation of firms active in the United States*



Silicon Valley, located in California, is one of the richer regions in terms of advanced technology and represents the main centre for technological innovation. It was chosen to add this visual tool to see a possible relationship between the geographical distribution of these companies and Silicon Valley.

To fully understand why the inclusion of Silicon Valley was deemed worthy of focus, it is appropriate to explain the importance and influence this area has played in the past and continues to play today for technology companies. For decades, Silicon Valley has been synonymous with innovation and spirit of entrepreneurship.

Marshall (1890) elucidated the existence and the importance of economies of scale external to the firm. While internal economies of scale relate to the reduction of costs as a firm increases its level of output, external economies of scale occur when the increase in the output at a regional level caused input cost to decline for companies located there. This external factor creates the incentive for companies to cluster together in the same location to benefit from these cost advantages.

The combination of proximity in space of firms and the linked reduction in costs is a phenomenon that it is called "agglomeration economy". In this scenario, a small company, which may not be able to achieve the large-scale efficiency on its own, can still take advantage reducing its cost simply by being located in the same geographical area of the other firms. The choice of company location thus represents one of the most pivotal strategic decisions. The presence of an industrial district in turn attracts other companies involved in that industry or related industries.

The advantages of industrial agglomeration go beyond the mere presence of competitors or companies in the same industry. These benefits include:

- the availability of specialised suppliers and service providers. When firms operating in the same sector cluster in the same region, create a profit opportunity for their supplier, as they see this agglomeration of companies as a large pool of possible costumers for their tools, machinery, or services. This situation often leads to the emergence of specialized suppliers near the industrial district. The suppliers provide their products or services at a lower cost due to economies of scale. For instance, firms that rely on these suppliers can acquire these complementary goods more easily and cheaply than elsewhere;
- the availability of specialised labor. The creation of a region comprising a significant number of companies engaged in high-tech production inevitably attracts a cohort of workers who possess the requisite knowledge and expertise to meet the demands of that

particular sector. This enables a reduction in the costs associated with the recruitment and hiring of employees.

- knowledge spillovers. The proximity of firms facilitates the exchange of tacit knowledge, ideas and other information when a worker from one firm moves to another, or when informal connections between companies are established. The dissemination of this knowledge confers benefits on all the companies involved, as it contributed to accelerate technological advancement and the implementation of more efficient production processes.

One example of industry that exhibits characteristics of powerful external economies is the semiconductor industry concentrated in Silicon Valley. Semiconductor, such as silicon, is a substance that serve as a fundamental component for computers and other electronic devices due to its electrical conductivity. The semiconductor industry is therefore the group of firms engaged in the production of semiconductor devices such as transistor, diodes and ICs[2]. This industry was formed in the 60s, coinciding with the launch of first operating prototype of laser and with the subsequent rise of the laser industry. It is interesting to note that the transistor was developed by several researchers including a Bell Labs researcher: William Shockley. As mentioned above, Bell Labs was an important laboratory in the field of lasers in the very embryonic stages of the product.

The semiconductor industry is highly dependent on laser technology across various stages of its long manufacturing process. This reliance is due to the extreme precision and control that lasers offer, making them indispensable for the production of micro-components included in all semiconductor devices. Lasers are particularly used in precision process such as cutting, welding, coating removal and marking.

One of the primary applications of laser technology in the semiconductor industry is in precision cutting, The availability of lasers for this process is essential to avoid material loss around the cut of wafers and chips. Moreover, lasers allow to reduce the risk of damage during the operation. This characteristic is important due to the fragility and the reduced thickness of materials.

The semiconductor must be clean and clear of defects to be used effectively in subsequent stages of production. For this purpose, a particular type of laser (Nd:YAG[3]) is employed to remove any superfluous material that may have been overlooked during the previous processing stages. The

[2] Integrated Circuits, also called chips, microchips, are semiconductor wafers.

[3] Neodymium-doped yttrium aluminium garnet, it’s a crystal used for solid-state lasers

removal of resins, coppers, and other unwanted materials is a necessary process made possible thanks to lasers.

In addition to cutting and cleaning, lasers are used also in the process of marking chips. The minute dimension and sophisticated electronic circuitry of semiconductor chips necessitate the implementation of effective traceability and identification procedures through marking. Laser marking is used to imprint serial numbers, logos and other barcodes in this small surface without any damage. This process ensures that even the smallest components can be kept track during its industrial lifecycle.

It is possible to state that the semiconductor industry needs laser for its development and correct functioning. In this context, lasers and semiconductors are complements in production because the use of the ormer is essential for the production of the latter. Laser technology has been employed in collaboration with the semiconductor industry for a considerable period of time, due to the unique capabilities of lasers to cut and perform functions, which are unparalleled by other manufacturing systems.

Furthermore, it is important to examine the existence of another type of interconnection between the two markets, namely the complementary in production. Lasers and semiconductors are frequently employed together in end products, many of these rely on semiconductor components to emit laser light, such as laser diodes. In this context, it can be highlighted that among the numerous submarkets pertaining to lasers, there is a specific submarket dedicated to Semiconductor Diode Lasers, which is more commonly referred to as the 'laser diode'. The global semiconductor laser market was valued at approximately $8.08 billion in 2023, and it is also projected to continue growing in the following years.

*Figure 5.3: Semiconductor Laser Market size divided by type, 2020-2030 in USD Billion. Source: https://www.grandviewresearch.com/industry-analysis/semiconductor-laser-market*

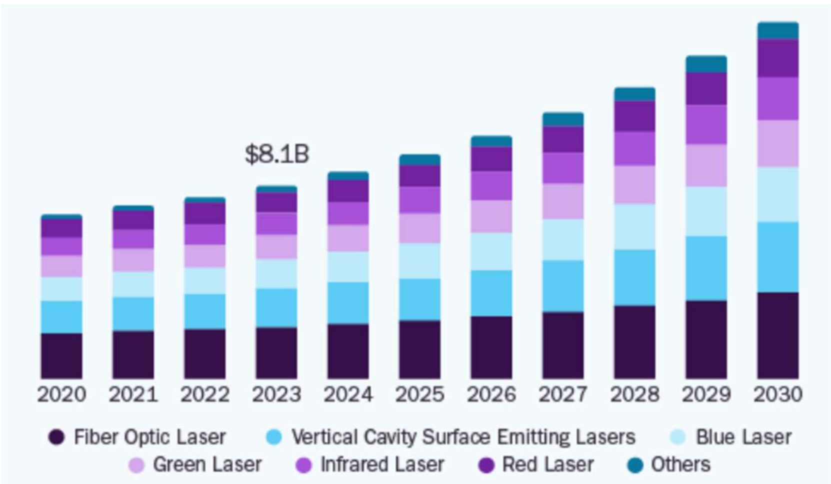


Figure 5.3 illustrates the projected trajectory of the value of this submarket until 2030, disaggregated by type of semiconductor laser.

The submarket is expected to grow due to the advent of 5G network, which will stimulate the demand for fiber optic components within the communication system. In fact, the fiber optic laser is expected to be the most profitable even in 2030. Furthermore, semiconductor lasers are employed in a multitude of consumer devices, including laser printers and optical disk drives. Additionally, they are used in a multitude of sectors, such as: aerospace, defence and military, medical, and other material processing.

The relationship between lasers and semiconductors is not only evident but also essential to understand the nature of these two technologies. Silicon Valley it is a region famous for the establishment of companies specialising in the production of semiconductors, and the laser industry plays a crucial role in enabling the precision manufacturing required by the development of semiconductor devices.

The fact that more than one-fifth of American laser companies are located in Silicon Valley is not a mere coincidence; rather, it is a consequence of the synergy between these two disparate yet not distant industrial sectors.

One of the most pronounced benefits of an industrial district, particularly in this scenario, is the availability of specialised supplier, as emphasized by Marshall (1890). Precision cutting machinery using laser technology can be produced by laser firms and sold directly to companies involved in the semiconductor industry or can be produced to be used by these specialised companies providing subsequent specific services for the production of semiconductor devices. The proximity of semiconductor firms and specialised supplier of laser technology enables faster communication, closer collaboration, and innovation. Semiconductor manufacturers can work closely with laser firms to develop tailored technologies that improves efficiency, reduce waste, and meet their exact needs.

The geographical closeness of these two industries allows for the rapid prototyping and testing of new technologies, thereby promoting innovation. Furthermore, the proximity of laser and semiconductor companies in Silicon Valley presents opportunities for venture capital investments. The substantial inflow of capital that characterises this region is beneficial to all firms located there.

The advantages derived from the proximity of laser companies to Silicon Valley is a clear phenomenon that explains the power of industrial clustering. The impact this region has had on the laser industry is considerable, evidenced by the 120 companies that have decided to locate in California.

### 5.1.3 Europe and Rest of the World

The following tables focus on the distribution of companies in Europe and the rest of the world, with the exception of the United States.

*Table 5.3: Geographical distribution in Europe*

| Europe | Active firms |
|---|---|
| United Kingdom | 8 |
| Belgium | 4 |
| Germany | 3 |
| Italy | 3 |
| France | 2 |
| Netherlands | 2 |
| Sweden | 1 |
| Poland | 1 |
| Norway | 1 |
| Latvia | 1 |

*Table 5.4: Geographical distribution in the rest of the world*

| Rest of the World | Active firms |
|---|---|
| Canada | 9 |
| India | 3 |
| Taiwan | 3 |
| Israel | 2 |
| Japan | 2 |
| Australia | 1 |
| Kazakhstan | 1 |
| Nigeria | 1 |
| Russia | 1 |
| South Korea | 1 |

*Figure 5.4: Geographical representation of firms active in Europe*

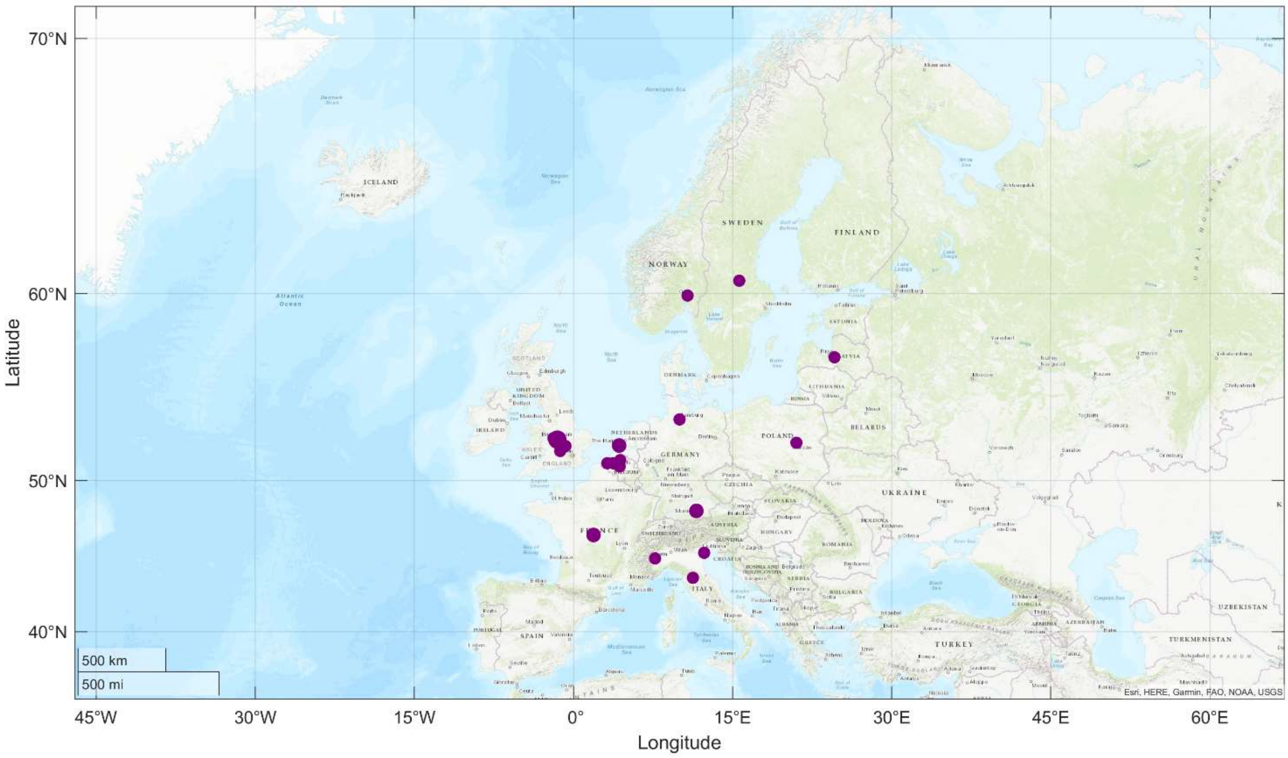



Figure 5.4 shows the exact location of the laser companies in Europe. Focusing on this region, it is clear that some of the major economies also host the largest number of companies. The United Kingdom leads with 8 firms, followed by Belgium with 4, Germany and Italy with 3 each, France and Netherlands with 2.

However, what stands out is that none of these countries seems to dominate the others in terms of the number of laser firms. Despite the presence of economies such as Germany or the United Kingdom, there is not a clear concentration of activity in any one country. This underscores a key characteristic of the European laser market: its fragmentation. The industry's activities are spread across multiple countries rather than being concentrated in a single location. Unlike in the United States, where there are regions, such as Silicon Valley, that are able to attract a high number of high-tech firms, in Europe the distribution of laser firms is more uniform. The decentralization could be due to several factors, including the regulations of the European Union and its creation of the single market and the free movement of people and goods, as well as the desire to encourage innovation and technological development across its member states. Moreover, the difference in national research programs, and the presence of historical industrial clusters contribute to the spread of firms across the region.

While the total number of firms in Europe is much smaller than in the United States, the region still represents a significant hub for innovation and development in the laser field.

Looking beyond Europe and the United States, the distribution of laser firms highlights other important players in the market. In Asia, Taiwan and India each host 3 firms, while Japan is home to 2, and South Korea and Russia each have 1. As in Europe, the total number of firms active in this area is relatively small despite the technological importance of countries such as Japan and Taiwan. This is probably due to their chosen direction. Their technological and highly innovative progress is focused on other segments and markets.

An interesting observation from the data is the presence of Canada, which hosts 9 laser firms, highlighting the importance of this country as the most significant non-US players in the laser industry. Canada's neighbourhood to the United States may have influenced its magnitude. Many Canadian firms benefit from their close ties to American research institutions and companies.

Additionally, there are another possible explanation for that phenomenon. The existence and functioning of treaties such as NAFTA, and now USMCA, may have accentuated this proximity effect. NAFTA (the North American Free Trade Agreement), which was in effect from 1994 until 2020 was replaced by USMCA (United States-Mexico-Canada Agreement), both helped promote close economic ties between these countries. NAFTA provided benefits in terms of elimination of tariffs and reduction in trade barriers, enabling the Canadian firms to have access to a large and more lucrative market in the United States. Then, NAFTA promoted a strict R&D collaboration. Canadian laser firms likely benefited from partnership with the universities and other research institutions located in US, especially in field like photonics and optical technologies where the United States has been a leader since the early 1960s. This cross-border exchange of knowledge and innovation would have been facilitated by NAFTA. Another way in which this treaty may have helped is the creation of investment opportunities. NAFTA made it easier for US firms to invest in Canadian companies (and vice versa). This increased flow of investment could have been beneficial because it provides the availability of capital needed to grow and innovate. Moreover, the reduction of restrictions for worker to move has positively influenced the mobility of specialised workers, required in high-tech sectors such as lasers.

While the United States remain the dominant player in the laser market at a global level, Europe and other regions like Canada and Asia are important contributors to the industry.

### 5.1.4 Location of Innovative Firms

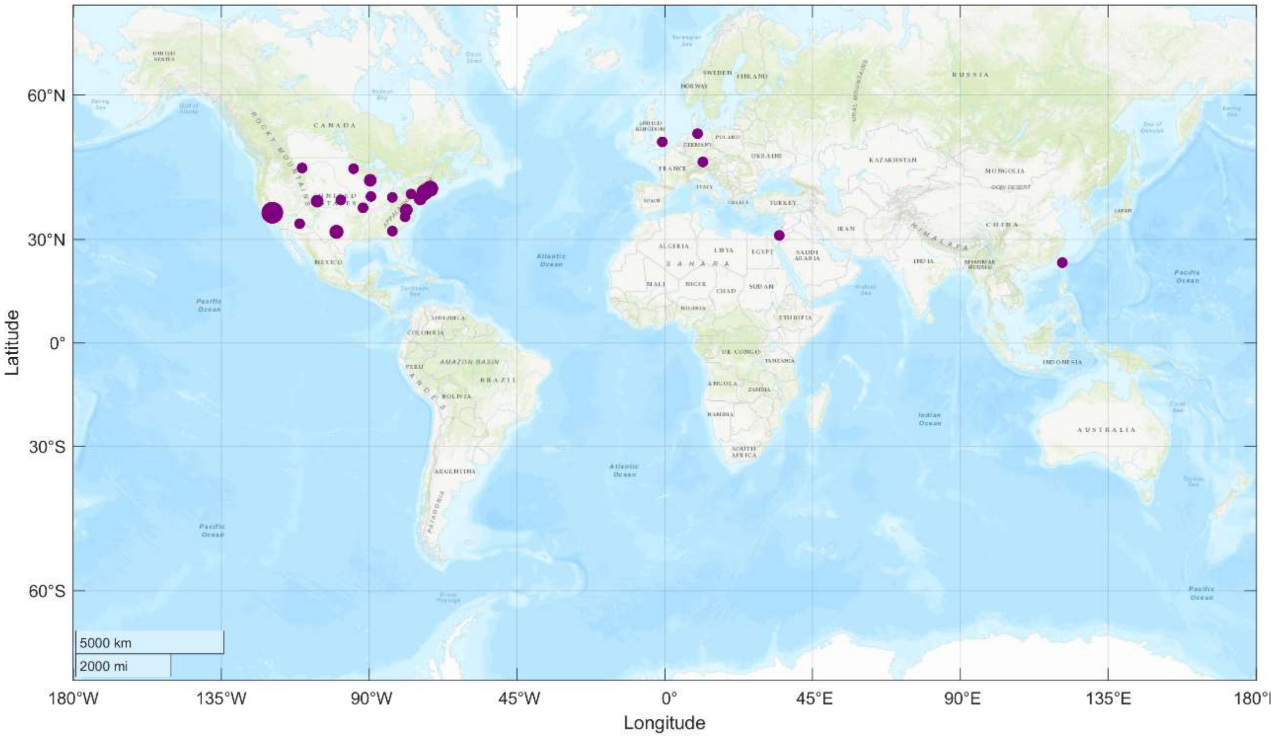
In this section, we discuss the geographical distribution of firms active in laser market that hold at least one patent, identifying them as "innovators". Patents, as previously mentioned, are crucial indicators of innovative activity within a company, especially for firms active in high-tech industry like lasers. Understanding where these innovators are located it is important to have a complete vision of the industry landscape. This insight is essential for a multi-faced analysis that touches on all aspects of this research: lasers, innovation, survival and exit modes.

Identifying the location of innovators provides valuable evidence to assess how the market is shaped at a global level, and how the technological advancements in distributed. It is worth noting that, in this first analysis of innovation, only the binary distinction of being innovative or not is it taken into account, the number of patents is irrelevant. Although the number of patents could offer additional insights into the depth of innovative capability of firms, in this preliminary phase the existence of innovation is considered sufficient to evaluate the industry landscape as a whole.

*Table 5.5: Geographical distribution firms that are innovators (at least one patent)*

| Region | Innovator firms |
|---|---|
| USA: | 51 |
| California | 19 |
| Connecticut | 5 |
| Massachusetts | 5 |
| Texas | 3 |
| New Jersey | 2 |
| New York | 2 |
| Colorado | 2 |
| Virginia | 2 |
| Wisconsin | 2 |
| Arizona | 1 |
| Georgia | 1 |
| Illinois | 1 |
| Minnesota | 1 |
| Missouri | 1 |
| Montana | 1 |
| North Carolina | 1 |
| Ohio | 1 |
| Pennsylvania | 1 |
| Germany | 2 |
| Taiwan | 1 |
| UK | 1 |
| Israel | 1 |

*Figure 5.5: Geographical of firms that are innovators at a global level*




As reported in Table 5.5, the United States maintain a leadership in terms of innovators, abysmally distancing the second region on the list, by a margin of 51 to 2. This result aligns and reinforce the previous ones. Previously it was observed that 91% of companies involved in the production of lasers in the dataset were based in the United States, and now we see that this trend extends to innovative firms, with 91% of all firms holding at least on patent located in this country.

Another crucial aspect is that among the 51 innovators located in United States, 19 are based in California, near Silicon Valley. The majority of American's firm are in California, as well as the majority of innovators. This evidence reinforces the idea that the emergence of Silicon Valley as an industrial cluster exerts a significant influence on the innovative attitude of companies that are in close connection with those involved in semiconductor production.

A difference is observed in the distribution of firms outside the United States. In fact, the remaining 9% of innovative firms is located between a smaller number of countries: Germany, Taiwan, United Kingdom, and Israel. This distribution, on the one hand emphasizes the fundamental role of the United States in matter of innovators in the field of laser, and on the other hand it underscores the presence of other important actors.

The United States began its massive investment in science and technology on the eve of Cold War, driven by the fear of falling behind its global rivals, particularly the Soviet Union. This period led to a wave of investment from both private and public sector. Investing in research and development allowed to build industries and develop innovations, making the United States the leader in a number of different fields. Investments quickly began to touch several sectors, from the military to the technological sector, to industry.

As a result, this region emerged as a global leader in science and technology in the second half of the twentieth century. The growth in expenditures in R&D was the main reason why the United States became a powerhouse of innovation.

In a document produced by the U.S. Department of Commerce, Office of Technology Policy (1997) it can be seen that by 1960, the United States accounted for approximately 69% of the world's R&D funding. R&D plays a foundational role in the innovation process, building the basis for new inventions and subsequent patent applications.

In 1960, the laser industry was at its incubation phase. However, the presence of R&D laboratories involved in laser technology were rich and widespread. These laboratories, which proliferated across the country, were among the first beneficiaries of the boost in R&D expenditures made by the government.

More than half of the total R&D expenditure registered at a global level came from the United States, demonstrating the country's dominance in the field. This significant investment facilitated the development of groundbreaking technologies that helped to create a fertile environment for those companies that had an innovative spirit. Those who have been able to ride the wave of increased R&D investment and manage the innovation environment were the best placed to succeed.

For all these reasons, it is not surprising that the United States has such a large number of innovative companies compared to the rest of the world.

The evaluability of R&D not only increased the number of innovation and innovators, but also attracted global talent. Brainpower people are one key determinants, this favourable climate certainly helped the arrival of this workforce.

*Table 5.6: Top 20 of the countries with the highest expenditure on R&D in 2020. Source: https://sgp.fas.org/crs/misc/R44283.pdf*

| Rank | Country | Amount | Rank | Country | Amount |
|---|---|---|---|---|---|
| 1 | United States | 720.9 | 11 | Canada | 30.1 |
| 2 | China | 582.8 | 12 | Spain | 25.1 |
| 3 | Japan | 174.1 | 13 | Turkey | 25.0 |
| 4 | Germany | 143.4 | 14 | Australia | 24.0 |
| 5 | South Korea | 112.9 | 15 | Netherlands | 23.7 |
| 6 | France | 74.6 | 16 | Belgium | 21.3 |
| 7 | United Kingdom | 56.0 | 17 | Sweden | 20.1 |
| 8 | Russia | 48.0 | 18 | Israel | 19.8 |
| 9 | Taiwan | 47.9 | 19 | Switzerland | 19.4 |
| 10 | Italy | 38.2 | 20 | Poland | 18.1 |

Table 5.6 reports the countries that, in 2020, showed the largest amount of R&D expenditures (in billions of dollars) based on data collected from the Organisation for Economic Cooperation and Development (OECD). After six decades since the pivotal year of 1960, the United States maintains its leadership in the field of R&D. Although its share of global expenditure has decreased over the years, the magnitude of investments remains significant. The United States was able to maintain a leading position, reflecting in this way the robustness of its system of valuable universities, consistent private sector investment, and governmental support.

Another important aspect to highlight from the data is the fact that almost all the countries that host innovators are listed in the top 10 R&D spenders. The correlation between R&D investment and companies able to develop an innovation is crucial.

Interestingly, Israel, a small nation known for its startups culture, while it does not appear in the top ten, it is among the top 20 countries for R&D expenditures. Israel's focus on high-tech industries and research is a clear example of how smaller nations can play an important role in global innovation dynamics.

The presence of a relatively small number of innovators in regions such as Europe does not diminish the value and the impact of the companies that are located there. Particularly, in Europe there is one of the oldest companies listed in the dataset, Siemens. Siemens was founded in Germany in the middle of nineteenth century. This business, from its inception, has been focused on innovation and technological progress.

As can be read on its official website, when it was created, Siemens was focussed on the production and sale of an improved version of the electric telegraph, which was a groundbreaking communication technology of the time. As Siemens grew, its business strategy encompassed a wide range of production, later concentrating on electrical installations and making significant contributions to the development of infrastructure and energy systems in Europe and beyond. After the Second World War, Siemens demonstrated resilience and adaptability by diversifying its offer. The company started the production of semiconductors, televisions and other household appliances.

Siemens has always been actively engaged in innovations, registering a robust portfolio of patents, marking its strength and presence in the global market, even in the face of the American giants. In its history it has been subject of mergers and acquisitions that allowed to further increases the lines of production and the segment in which operated. Siemens is a perfect example of a company that is not only concentrated on the production of lasers, but it is diversified into several markets, some of which have segments where lasers are the main focus.

Siemens employs lasers for the additive manufacturing, also called 3D printing, one of the biggest applications of lasers in recent years. Siemens has developed advanced solutions which improved a technology already in the market by speeding up a moulding process known as laser metal deposition. This improvement has real effects all over the world as it has increased the possible applications of 3D printing across various industries. For example, a division of Siemens created by a merger, leverages this technology to create custom-made shoe sole, demonstrating the breath of the laser application power. Additionally, Siemens employs diode laser for several applications in the process industries. These applications range from precision cutting and welding to advanced material processing.

The company, one of the only two innovative companies in Germany, demonstrates how innovation can be managed and that it is possible to be highly competitive, even in a geographical area that is not as clustered as Silicon Valley. Siemens is not only able to maintain its relevance in a competitive global market, but it also plays a decisive role in shaping innovation and pushing the technological frontier.

In conclusion, it can be stated that the laser market is dominated by companies based in the United States, with a particular concentration in California. However, this does not diminish the significance of other major players in other regions, such as Europe and Asia. Additionally, with regard to innovation and the presence of companies with at least one patent, the United States appears to be the primary location.

### 5.2 Patterns of Market Entry and Exit

This section explores the dynamics of market entry and exit, which are among the most impactful forces shaping the industrial landscape.

The dynamics of entry in the market is captured by identifying three distinct cohorts. The first group consists of the early entrants, those who make their entrance before 1970. These pioneers laid the foundation for the laser industry. The second cohort includes entrants who joined the market between 1971 and 1992. Finally, there are those who entered the market between 1993 and 2023, this group represents the later entrants.

Before delving into the analysis, it is essential to clarify the criterion used for selecting the year of entry. As stated in the previous chapter, the approach taken was to include all companies that have at least one segment of their production involved in the development of laser technologies, regardless of the specific type of laser products they produce. This means that, in addition to lasers, these companies are also diversified into other products.

This choice has significant implications. Notably, it allows to account for a diverse array of companies, some of which were established prior to the start of the laser market, whose origins date back to the 1960s. These companies initially operated in other industrial sectors. However, they subsequently capitalised on the emergence of laser technology to expand their business activities.

It is worth noting that if the aim had been to include only companies for which it was possible to ascertain the exact year in which they commenced production of lasers, it would have been necessary to reduce the sample size considerably, due to the challenge of obtaining this information. Employing a reduced dataset of 'specialized laser firms' would have inevitably constrained the ability to analyse the full landscape of participants in the laser market. Consequently, it was decided to use a larger sample comprising information about the company's foundation date instead of strictly adhering to their entry into the laser market.

The inclusion of diversifiers it is considered important because these companies bring with them age of experience from other industries, relayed to lasers in terms of similar production process or knowledge bases. A diversifier is a company that was not originally established with the objective of operating within the laser market but has subsequently chosen to expand its production through internal growth or acquisition. These companies may have started operations in sectors such as electronics, manufacturing, telecommunications, or even healthcare, where there are similar resource requirements to fully exploit its production capability. These companies entered the laser industry though the establishment of divisions or subsidiaries that maintain the same legal entity of their parent company.

In conclusion, the approach employed reflects the decision to prioritise a broader sample of companies with at least one segment engaged in one of the submarkets of the laser industry, thereby underscoring the interplay between established firms and emerging technologies.

*Table 5.7: Market entries divided by cohorts*

| Cohort of entry | Frequency |
|---|---|
| Entrants before 1970 | 180 |
| Entrants 1971-1992 | 209 |
| Entrants 1993-2023 | 226 |

Table 5.7 reports the distribution of companies based on the year they entered any market, divided into three cohorts. The first cohort consists of 180 companies that likely were responsible for setting initial industry standards, initiating the development of new products and creating new market demands. These early entrants operated in a market where laser technology was still in its infancy, and their efforts helped shape the foundational aspects of the laser industry.

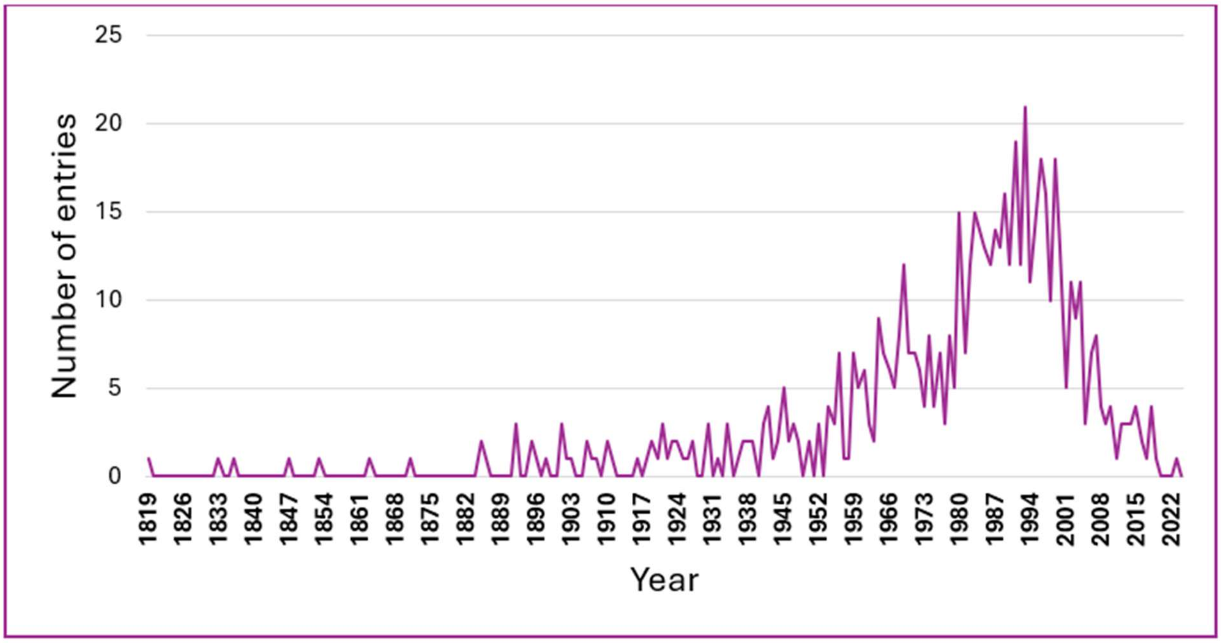
During this initial phase of its life cycle, the industry was characterised by high technological uncertainty, as the potential applications and future directions of laser technology were unknown. At the same time there is low barriers to entry due to the absence of economies of scale and new firms are key innovators, as well as key contributors to the definition of the technological trajectory. In general, these pioneers have the first mover advantage.

The second cohort, "Entrants 1971-1992" consists of 209 companies. Over these 20 years, there has been a notable increase in the number of companies engaged in this field. This growth can be largely attributed to the rapid advancement of laser technology and the proliferation of potential application fields, spanning from military to manufacturing, and beyond. Consequently, an increasing number of companies active in various industries have chosen to expand their production line by adding lasers to it.

The final cohort, "Entrants 1993-2003", includes 226 companies. Similarly, the rise in the number of participants can be attributed to the increase in the number of applications for the laser technology.

Figure 5.6 reports the pattern of entry, highlighting possible peaks and throughs. It spans from the early nineteenth century through 2023.

*Figure 5.6: A graphical representation of the genesis of business enterprises over the specified period.*




From the 1800s until the mid-20th century, the graph shows few entries. The fact that there are a limited number of companies in this age group is expected as laser technology had not yet been developed. Nevertheless, it remains a noteworthy phenomenon to consider, as it illustrates the involvement of corporations that existed for decades, and in some cases more than a century prior to entering the laser industry.

Over the course of their extensive operational history, these companies may have expanded their technical expertise and increase their financial resources. The availability of capital enables these companies to invest in R&D, recruit highly skilled personnel, or purchase existing businesses that already have a market presence in the laser industry.

Over time, as lasers became more relevant on a global scale, in particular within their respective fields of expertise, it made sense for them to leverage their existing infrastructure and capabilities to explore this promising new area. The first notable increase occurs around the 1960, which coincides with the first commercialization of lasers. Around this year there is the first cluster of entrants. The early entrants were those who recognized in advance the potential of the laser technology at an early stage.

From the late 1970s to the late 1980s, the laser industry experienced a steady increase in the number of entries. During this transformative period for the industry, laser became increasingly commercialised across various sectors. Lasers became an essential tool for industries that required high precision and efficiency. In industrial processes, lasers were rapidly adopted for cutting and welding, providing a high level of accuracy.

This function became indispensable in a number of sectors, including automotive, aerospace, electronics, as well as jewellery, and health sectors, where it is used in surgical procedures, such as eye surgery. As the demand for these technologies grew, more companies saw the value in investing in laser-based solutions, driving a surge in market entries during this period.

One of the most significant applications during this time was the advent of compact discs (CDs) and CD-ROM, which became highly popular due to their ability for digital data storage. This innovation revolutionised not only data storages but also opened up more opportunities for lasers.

In this decade the number of new firms peaked in 1989. This peak reflects on one hand the technological maturity reached by lasers, and on the other hand the growing recognition that these technologies were no longer just an optional innovation but a necessity in many industrial and commercial applications.

After 1995, the number of entrants declines, although there is still a significant number of new firms continue to enter the market. The observed decline suggests that the laser industry had begun to consolidate, with fewer companies able to enter the industry, due to the rising barriers to entry.

As of the new millennium, the number of entries sees a new and more pronounced decline, with almost no entries from 2010 onwards. This decline is likely attributable to market saturation, which makes it increasingly challenging for new entrants to establish themselves without significant innovation or resources. The minimum level of skilled required in this phase is the highest possible, and therefore the number of entries become almost zero.

In summary, both the table and the picture reveal that laser industry experienced several waves of growth, with the largest peak in entries at the turn of the 1980s and the 1990s. After this fertile period, a gradual decline started. This trend suggests that the market has gone through a period of experimentation with low barrier to entry and consolidation of standards governed by radical innovations, followed by period of consolidation and maturation, making it harder for new companies to enter.

Following this analysis of market entries, the focus is now shifted to an investigation of market exits, with a particular emphasis on the mode of exit.

*Figure 5.7: A graphical representation of market exits over the specified period.*

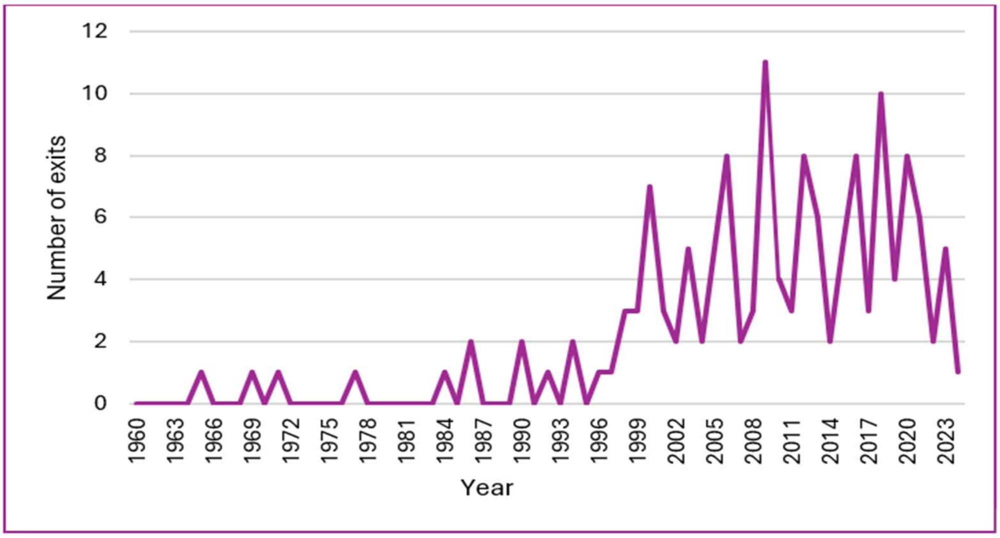



Figure 5.7 reports the temporal distributions of firms that exited the market. In this case we focus on two primary modes of exit that firms experienced: exits due to mergers or acquisitions and exits due to failure.

The first mode of exit encompasses case where a company either merged with another firms or was acquired, typically, by a larger entity. This means that the legal structure of the company changes and its operations and assets are absorbed into the acquiring or merging organization. The other mode of exit includes all other cases of voluntary or involuntary exit, i.e. bankruptcy, liquidation, failure.

In the early period the number of exits remained quite low, this trend reflects the infancy of the laser market, where the technology was still developed, and fewer firms were competing within this environment.

In the early 1990s, the number of exits began to increase at a steady rate, coinciding with the growing commercialisation and competitive pressure within the laser industry. The rise during this period may be indicative of the fact that, while more firms enter the market, not all are able to maintain their position in the face of intensifying competition.

The figure illustrates a notable surge in the number of exits from the late 1990s through the early 2000s, with the highest number of market exits occurring around 2010. As with entries, the market appears to be undergoing a period of consolidation during this decade, a hypothesis that is supported by the new data. The pronounced surge may be attributed to the increase of mergers and acquisitions, as the consolidation of dominant industry players elevates the likelihood of acquisitions.

After 2012, exits continued at a relatively high but fluctuating level. Notably, the number of exits has exhibited a slight decline in the most recent years, particularly from 2018 onwards. This trend could be attributed to the consolidation of key actors within the laser industry.

In summary, the figure highlights a preliminary phase during which the number of exits is relatively low, followed by an increase in the number of exits, which reached its highest point in the early 2000s. The number of exits is currently in a phase of decline.

*Table 5.8: State of firm's activities at the end of the period under examination*

| State of activity | Frequency |
|---|---|
| Dead: | 152 |
| M&A | 127 |
| Failure | 25 |
| Still active | 463 |

Table 5.8 presents a summary of the status of the companies listed in the dataset at the end of the period under examination (2024). Out of the total companies listed in the dataset, 463 are still active. Of the firms that have undergone exit, 152 are classified as "dead", meaning they have ceased operations entirely. Within these, 127 exited through M&A, while the other 25 firms experienced failure.

It should be noted, however, that this data may be subject to certain limitations, given that information pertaining to bankruptcy or failure proceedings is not always publicly available.

## 5.3 Analysing Patents: Trends in Innovation

This section examines the trend in patent activities of the firms in the sample, with a particular focus on the quality of the intellectual property rights in question.

*Table 5.9: Division between companies that are innovators and those that are not*

| Innovator firms | Frequency |
|---|---|
| Yes | 57 |
| No | 558 |

Table 5.9 provides a breakdown of companies into two distinct categories: those classified as innovators and those that are not. In this context, a company is defined as innovator if it holds at least one patent.

According to the data presented, 9.27% of the firms listed in the dataset have filed at least one patent. This means that just one-tenth of the companies are innovators. Not all firms need to innovate to remain active in the market. Many companies opt for an imitation strategy, adopting existing technologies developed by the innovators. This strategy allows them to reduce costs associated to the risky activity of R&D. These companies tend to favour a rational approach, understanding that being too innovative does not always lead to profitable results. Semadeni and Anderson (2010) captured this idea well when they described the need for firms “to be new, but not too new”. The introduction of a new product (or process) to the market may not be met with an immediate acceptance by consumers, the innovators are those who take this risk.

This analysis incorporates a crucial element that is frequently overlooked in studies examining innovation. Patents are initially granted and valid only in the country in which they were first filed. However, in order to ensure a broader application and protection across multiple countries, companies may file the same patent in different jurisdictions. In the absence of this additional phase, the patent will only provide protection in its country of origin, leaving the innovation vulnerable to imitation of appropriation in other markets.

In this context, patents can be part of a family of patents or not. A patent family refers to a collection of related patents that are filed in different countries or jurisdictions to protect the same invention. It includes all the patents that are originated from a single original priority patent application. All the patents within a family share the same inventors or are owned by the same company. While all patents in a family stem from the same invention, the scope of protection may vary from country to country due to the differences in patent law in different jurisdictions. Applying for multi-country patent applicability is the result of a company’s global strategy.

In light of this factor, patents were classified according to whether they belonged to a patent family. In the context of this research, only the priority patent was considered for analysis, particularly for those patents that are part of a family. This choice was made to ensure the integrity of the econometric results. Since a patent family includes more than one patent, counting each individual patent within the family would artificially inflate the dataset and skew the results. The decision to include only the priority patent ensures that the focus of the analysis on innovation, without over representing its scope just because it was filed in multiple jurisdictions.

In addition to that, the use of a variable that categorise patents on the basis of this characteristic facilitates an understanding impact of broader applicability on market survival.

*Table 5.10: Classification of patents based on whether they are part of a family*

| Patent family | Frequency |
|---|---|
| Yes | 455 |
| No | 692 |

Table 5.10 breaks down the number of patents. Out of 1,147 priority patents, 455 belong to a patent family, while the remaining 692 patents do not. This result suggests that about 40% of the innovator firms has recognized the global potential of the invention.

However, the decision to pursue a broader protection through a patent family is not solely determined by the perceived commercialisation and strength of the invention, it is also significantly influenced by the amount of financial resources owned by the assignee. As previously stated, the filing of patents requires a considerable financial investment, and the process of patent application is uncertain. Larger firms are more likely to pursue a global patent strategy. The number of patents that form part of family can be used as an indicator of size of the company and its financial well-being, and of course, its propensity and ability to innovate.

In order to provide a comprehensive view of the process of patent application across different countries, the following table reports the number of patents that have been accepted and granted by each patent office worldwide. This detailed breakdown gives insight into the global reach of patent protection, highlighting how different regions contributes to the landscape of IPRs.

For this descriptive analysis, all 3,157 patents were considered, as the purpose here is to see the extent of patent filings globally.

*Table 5.11: Distributions of patents according to the jurisdiction of interest*

| Patent office | Frequency |
|---|---|
| United States Patent and Trademark Office (USPTO) | 736 |
| Japan Patent Office (JPO) | 488 |
| European Patent Office (EPO) | 480 |
| German Patent and Trademark Office (DPMA) | 359 |
| World Intellectual Property Organization (WIPO) | 312 |
| United Kingdom Intellectual Property Office (UKIPO) | 189 |
| Canadian Intellectual Property Office (CIPO) | 101 |
| Taiwan Intellectual Property Office (TIPO) | 100 |
| IP Australia (Australian Patent Office) | 79 |
| French National Institute of Industrial Property (INPI) | 33 |
| Korean Intellectual Property Office (KIPO) | 27 |
| Israel Patent Office (ILPO) | 16 |
| Italian Patent and Trademark Office (UIBM) | 11 |
| Danish Patent and Trademark Office (DKPTO) | 9 |
| Spanish Patent and Trademark Office (OEPM) | 8 |
| Russian Federal Service for Intellectual Property (ROSPATENT) | 8 |
| Hong Kong Intellectual Property Department (IPD) | 5 |
| Mexican Institute of Industrial Property (IMPI) | 5 |
| Netherlands Patent Office (Octrooicentrum Nederland) | 4 |
| Austrian Patent Office (ÖPA) | 3 |
| Norwegian Industrial Property Office (Patentstyret) | 3 |
| Intellectual Property Corporation of Malaysia (MyIPO) | 2 |
| Polish Patent Office (Uprp) | 2 |
| Finnish Patent and Registration Office (PRH) | 1 |

The United States Patent and Trademark Office (USPTO) leads the rank with 736 applications, almost a quarter of all patents granted related to laser technologies. This figure underscores the magnitude of the United States in matter of innovation.

However, upon closer examination, the geographic distribution of the innovator companies within the dataset reveals a more nuanced story than the initial impression might suggest. A total of 91% of the identified innovator companies are geolocated in the United States. This finding suggests that U.S. companies place a significant emphasis on maximizing the international reach of their parents, seeking to ensure that their innovations are protected in more than one jurisdiction. Conversely, if emphasis on global patent protection were less pronounced among U.S. companies, were not the case, the relevance of the USPTO would be even more substantial. This suggests that American companies are focused not only on their home country but are also strategically oriented in foreign markets, identifying them as dominant players in the global landscape. Additionally, this trend highlights the competitive nature of the laser industry.

Japan received a large amount of applications. This is in line with the relevance of this country in sectors were the technology is a crucial element, despite the limited number of active laser companies in this country. The European market is a significant economic entity, and it is therefore vital for companies to have legal protection in place to avoid potential economic damages.

The European Patent Office (EPO) also received a significant volume of applications. This highlights the strategic importance of this region, even in the absence of a very large number of operating companies.

A particularly interesting case is that of the German Patent and Trademark Office (DPMA), which received 359 applications for laser patents. This figure is probably due to the presence of large enterprises in Germany, such as Siemens. Germany is the European jurisdiction where the most patents have come in, far outnumbering the other major European economies. For instance, France only received 33 applications, while Italy recorded a mere 11. The only other one European country with a significant number is UK, receiving 189 patent applications.

Taiwan stands out as well, contributing a substantial 100 applications to the overall count. This reflects the growing importance of this country in the global technology supply chain, particularly in manufacturing and electronics, two pivotal sectors where the use and production of lasers are crucial.

An important patent office to analyse is the World Intellectual Property Organization (WIPO). WIPO is the base of the PCT[4] system, which provides a unified and streamlined process for seeking patents on an international scale.

In accordance with the PCT system, following the submission of the priority patent in a selected jurisdiction, it is possible to submit a further application via the PCT in a single language at a single patent office. This application is significant in that it has the same legal effect as filing separate patent applications in more than 150 PCT member countries. In our analysis there are 312 applications at WIPO which ranks fifth.

In conclusion, these results emphasise the necessity of acquiring comprehensive patent protection, particularly in an era characterised by rapid technological advancement and intense competition. A large and diversified portfolio of patents can facilitate a company's ability to remain competitive in the market. Patents have increasingly become a strategic asset.

[4] Patent Cooperation Treaty. The treaty entered into force in 1978.

*Figure 5.8: Distribution of patent granting over time*

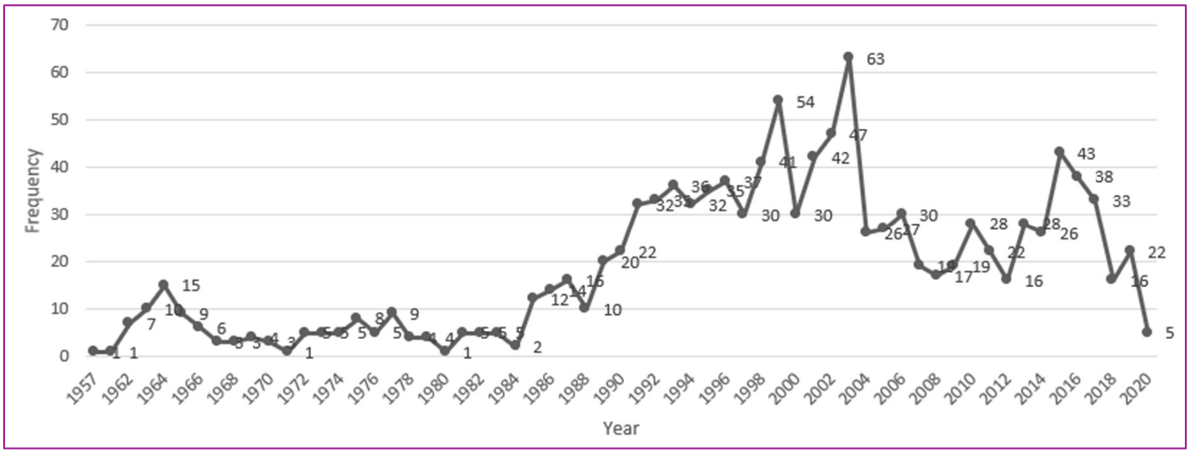



Figure 5.8 reports the trend in patent granted within the laser industry from 1958 to 2020. Over this period, compared to the frequency of entries and exits in the laser industry previously analysed, there seems to be a less homogenous trend, with more ups and downs.

The first recorded patent is dated 1958, marking the official starting point of this technological innovation. At the beginning of the laser industry, the number of patents granted was relatively low, probably due to the presence of a small number of market participants.

The first notable peak occurred in 1965, with 15 granted patents. This spike can be interpreted as the first significant wave of commercialization and importance in the market for lasers. However, this growth was short-lived, as the number of patents declined over the following decade.

The late 1990s and the early 2000s marked the industry's peak period of innovation, with 63 in 2003. New technologies emerged and the number of participants increased significantly. After this peak the number of granted patent started to decline, following by years of fluctuations. During this period, companies may have prioritised the improvement of existing technologies over the developments of new ones.

Interestingly, between 2014 and 2017, the industry saw a periodic revival in patent activity. Then, after 2017, the number of patents declined sharply, reaching just 5 applications by 2020. This could be attributed to the saturation of the market and the reduction in R&D spending.

The innovation cycle in this field has undergone significant shifts, deviating from a linear process. The existence of multiple peaks and troughs indicates that this industry is characterised by the necessity for new, potentially radical innovations on a regular basis. Following a period of low innovation, the industry requires new innovation peaks in order to maintain its viability and to meet the ever-changing demands of the market.

The distribution of patents by firms can highlight some relevant patterns.

*Figure 5.9: Distribution of patent by firms*

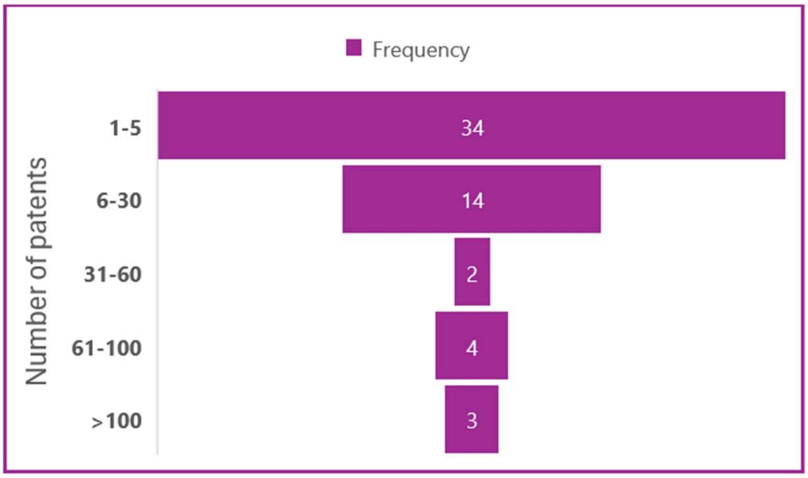



Figure 5.9 reports this distribution, with the bar indicating the number of companies within each group. The first strong result is the high concentration of companies in the group that contains the lowest number of patents, between 1 to 5. In particular, 34 companies are grouped within this category. This suggests that among the innovators, the most populated group is represented by many smaller players who have only generated social benefits for the community through a few innovations.

The number of companies drops significantly as the patent range increases. Only 14 companies have between 6 and 30 patents. This mid-tier group may be more established with respect the previous one but still less dominant in terms of innovative output. In contrast, only 2 companies have patents ranging from 31 to 60, indicating a further significant sharp decline in firms with larger patent portfolios.

Regarding the two last groups, which are groups with a significant number of patents, the number of companies becomes almost constant. 4 companies hold between 61 and 100 patents, while 3 companies count more than 100 patents. They represent the top tier in terms of innovations within the laser industry.

This small elite dominates the patent landscape, thereby exerting a significant impact on technological advancements. They have been instrumental in driving innovation during the existence of the lasers, shifting the technological frontier forward on numerous occasions. It seems reasonable to posit that these companies invest a considerable amount of resources, both financial and otherwise, in research and development activities. Such an outcome is feasible when a company has substantial financial resources at its disposal, which is often indicative of a large company.

This distribution serves to illustrate the skewness that exist in the industry with regard to innovation. These skewness point to disparities not only between firms that are innovators and those that are not, but also within the innovators themselves. The majority of firms identified as innovators hold relatively few patents, while only a small number possess extensive patent portfolios, which positions them as leaders in innovation and market influence.

The focus of the analysis now shifts to patent quality, rather than the mere possession of the intellectual property right in question. The quality proxies used are the following:

- number of claims;
- number of forward citations;
- number of backward citations.

Each of these indicates a distinct characteristic of the patent document, from the scope of the patent to the capability of influencing subsequent innovations.

Table 5.12 shows the average of each quality proxies. The mean is calculated from the 1,147 patents, which include only one patent per patent families. This is done because patent within the same family typically encompass the same claims and citations, or at most exhibit minor numerical discrepancies due to the difference in patent law across different countries.

*Table 5.12: the average quality proxies of patents*

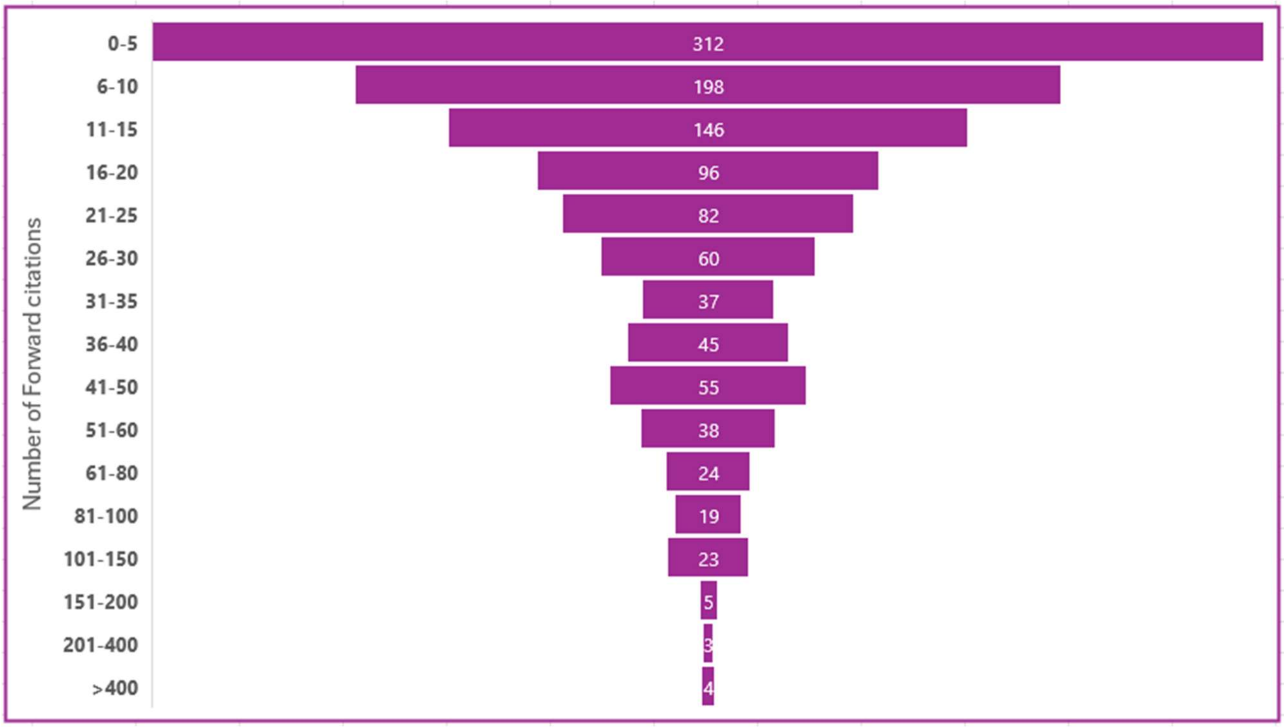
| Type of indicator | Mean |
|---|---|
| Number of Claims | 16 |
| Number of Forward citations | 24.9 |
| Number of Backward citations | 17.4 |

The number of claims indicates the breadth of application of the innovation. Its mean is 16, indicating a moderate level of complexity in the patents within the dataset. The forward citations, indicator of the degree of influence a patent has subsequent patents, shows a mean of 24.9, however this figure it is analysed in depth in the following graph. The mean of backward citations is 17.4, indicating the number of patents cited in each document.

The combination of these information suggests the existence of a robust patent landscape where innovations are both influential and complex.

In order to conclude the analysis of innovation, the distribution of forward citations is examined below.

*Figure 5.10: Distribution of patents according to their forward citations*




The starting point is a well-established tenet within the literature, namely that not all inventions turn out to have the same value once they are developed and patented. The value in question can be measured using different information sources, including the quality proxies mentioned above or, in some cases, the commercial value of the patented innovation. However, given the difficulty in directly measuring the commercial value of individual patents, the number of forward citations was identified as the optimal indicator of quality for analysis, given its representation of influence on future innovations. Consequently, patents with a greater number of forward citations are seen as more impactful and valuable to the related industry.

The most striking observation when examining the graph is again the skewness of its distribution. Out of the 1,147 patents considered, 312 patents fall into the group that has been cited between 1 and 5 times. This group represents the most crowded group, suggesting that the majority of the patents in the laser industry have minimal influence on the following innovations. It is likely that very recent patents also fall within this category, given the fact that they have had less opportunities to be cited.

Each subsequent group represents patents with an increasing number of forward citations. As the citation count rises, the number of patents listed in each group decreases, creating a narrowing pattern that is reminiscent of a funnel. This visual representation demonstrates that as the influence of a patent increases, the frequency of high-impact patents declines.

For example, in one of middle groups, ranging from 51 to 60 there are only 38 patents, a notable reduction in comparison to the earlier groups. This pattern reinforced the idea that highly citated patents are a relatively uncommon phenomenon.

At the upper end of the distribution, the last three groups are the patents that have received more than 150 citations. Collectively, there are only 12 patents in this high-impact range. Specifically, 5 patents fall into the group 151-200 citations, 3 patents have been cited 201-400 times, and 4 patents have received more than 400 forward citations, marking how few patents achieve the profound influence and importance in the innovative landscape. All these 12 patents are, without doubt, patents with a very high significance in the laser industry.

It seems reasonable to posit that these highly cited patents have constituted and will continue to constitute a solid foundation for this technology. Without these patents, the laser industry would probably have developed in a different way. The fact that some of these have been referenced time and again implicates that they introduced a radical advancement that other innovations have built upon.

In summary, the distribution of forward citations highlights a clear disparity in the impact of innovations within the laser industry. The majority of patents show a small or modest impact on the development of other innovations. Conversely, there is an elite sub-group of patents that appear to shape the introduction of subsequent innovations in a strong way, underscoring their exceptional impact.

To resume consideration of the table above, the mean on 24.9 for the number of forward citations is also attributable to these highly significant, albeit limited, cases.

### 5.4 Firm Exit and Innovation: A Kaplan-Meier Approach

Kaplan-Meier[5] curves, also referred to as the limit product estimator, represent a statistical tool employed for the purpose of estimating the survival function. In particular, it allows the comparison of two or more groups of subjects in terms of their survival probability over the course of the observation period.

In order to undertake the requisite analysis, three elements must first be defined:

[5] The estimator is named after two famous statisticians: Edward L. Kaplan and Paul Meier.

- the first is the definition of an observable characteristic that enables the dataset to be partitioned into distinct groups. The goal is to create groups that can be compared to determine how they differ in terms of the event to be studied (i.e., survival);
- the second is the definition of the observation period, and thus defining how long the subjects are followed to monitor whether or not the event of interest occurs. The survival time for subjects who experience the event is defines as the time elapsed between their initial observation and the occurrence of the event. In contrast, the survival time for subjects who do not experience the event is the time span between their entry in the study and the conclusion of the observation period. These subjects are classified as censored;
- finally, the event of interest must be clearly defined.

Depending on the context of study, the survival event can be understood in different ways. It can be defined as true survival, for example, in the case of two groups of patients, one undergoing medical treatment and one not. Alternatively, as in our analysis, survival can be defined as permanence in the market by companies, and thus the event is whether or not a company exits the market during the observation period.

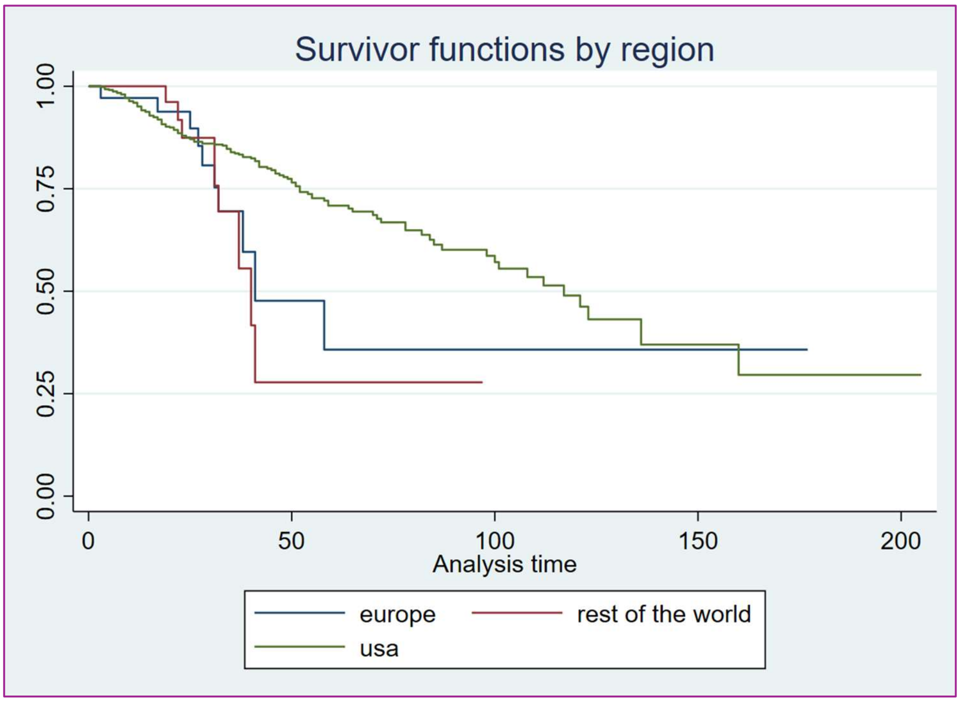
In this research the exit event can assume two different modes: exit by failure or exit by M&A. Since this categorisation includes on the one hand a positive outcome, exit due merger or acquisition, and on the other hand a negative outcome, exit due failure, the use of exit as a singular event may not reflect this bivalence of outcomes.

In order to obtain results that are insightful for our analysis, two separate Kaplan-Meier estimations were carried out. The first estimation treats all exits as a singular event, regardless of whether the exit occurred though failure or M&A. The second estimation considers the exit event only in the case that a company experiences a merger or acquisition, exits due to failure are excluded. By isolating M&A events from failures, this analysis allows for a more precise understanding of which group of enterprises is most likely to end up being acquired by other companies. In this second type of analysis, the term ‘survival’ indicate that firms were not acquired.

The observable characteristics employed to break the dataset into distinct subgroups are as follows:

- geographical location of the company.
- year of market entry divided by cohorts;
- whether the company is an innovator.

*Figure 5.11: Survival function depending on the region of origin of the companies. Exit includes both failure and M&A*




This Kaplan-Meier survival curve in Figure 5.11 provides a comparative view of the survival functions of firms in the laser industry across three regions: Europe, the USA, and the rest of the world. The analysis tracks the time of exit, where exits are defined either by failure or M&A.

To better understand the implications of these curves, it is helpful to remind that the horizontal axis represents time, namely the observation period, the vertical axis depicts the percentage of companies that are still in the market at any given point in time. This is essentially the survival probability, where a value of 1 indicates that 100% of the companies are still in operation.

Firms located in the United States, represented by the green line, show the highest overall survival rates over time. The curve shows a more gradual decline, indicating that firms in this region tend to survive longer before experiencing an exit event.

However, it is interesting to note that during the initial stages of a company's life, those based in Europe and elsewhere are more likely to survive than their US counterparts. This suggests that while American firms may face more challenges early on, those that successfully survive the initial phases of activity tend to be more resilient in the long run.

Once a company reaches around 30 to 40 years of operation, a much higher probability of survival is shown in the US than in the other two categories. This suggests a more robust industry environment, in which firms are able to benefit from economies of scale, well-developed infrastructure, or more favourable market condition. Additionally, the data implies the presence of more consolidated market participants, which may register greater longevity and resilience.

European firms, i.e. blue line, exhibit lower survival rates compared to the United States but still perform better than those in the rest of the world. The decline is relatively steady in the first decades of life, but there is a clear decline drop after the first 25 years of operation. This may suggest the presence of more challenges in maintaining competitive advantages in the laser sector. Older firms may face difficulties in adapting to technological changes with respect the American companies, this statement may also be supported by the relative scarcity of innovative companies outside the United States.

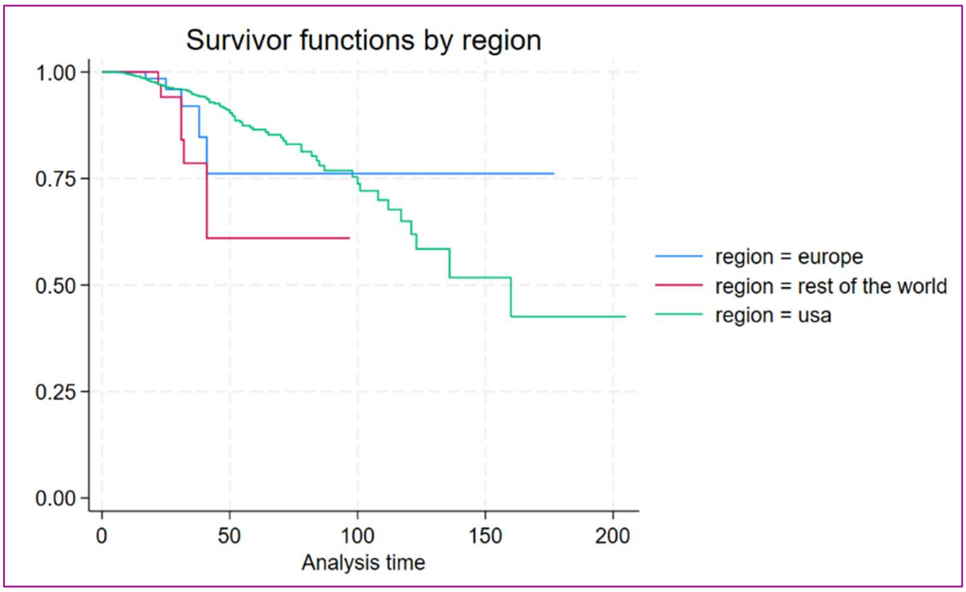
Finally, firms in the "rest of the world" category, represented by the red line, show the lowest survival rates overall. In the first decades, it shows some overlapping with the curve for European firms, indicating that there is no difference between the two-survival rate in that period. However, as time goes on, the survival rates for these firms diverge, with companies outside of Europe and the US showing a more pronounced decline. Also in this case, firms may face greater challenges over time, potentially due to a more intense competition from global leaders.

The survival rate declines differently depending on the country in which they are located. This pattern likely reflects regional differences in market dynamics, and competitive pressures in the laser industry.

The null hypothesis is rejected, indicating that there is a significant difference between firms in different regions. Overall, this first Kaplan-Meier survival analysis underscores the significant impact that geographic location has on the longevity of firms within the laser industry. In particular, firms located in United States are more likely to survive.

Now, in Figure 5.11, only exits through M&A are considered. Consequently, firms that exited the market through failure are excluded. The focus is on whether a firm exited the market through M&A during the observation period.

*Figure 5.12: Survival function depending on the region of origin of the companies. Exit only includes cases of M&A*




Unites States exhibit a steeper decline in the long term when exit is only due to merger or acquisition cases, particularly after 100-time units. This indicates that while US firms are resilient against failure, as shown in the first graph, they eventually face exits through acquisitions. The more pronounced decline in this graph illustrates the dynamic nature of the environment, in which mergers and acquisitions play a pivotal role in influencing the ultimate stages of a firm's life cycle. This trend may indicate the presence of an industry culture that favours consolidation or strategic acquisitions as a preferred exit strategy for companies that have reached a certain level of maturity.

European companies, on the other hand, maintain similar survival behaviour in both graphs, but the M&A-focused graph suggests that many firms either survive long-term or get acquired relatively early.

The same occurs for firms located in the rest of the world, however this last graph shows that these firms are more likely to be acquired than to fail outright.

Given the stark difference in survival functions across the regions. Particularly between the United States and the other categories, we would likely reject H0, indicating that there is indeed a significant difference in survival probability across regions.

*Figure 5.13: Survival function depending on the cohort of entry. Exit includes both failure and M&A cases.*

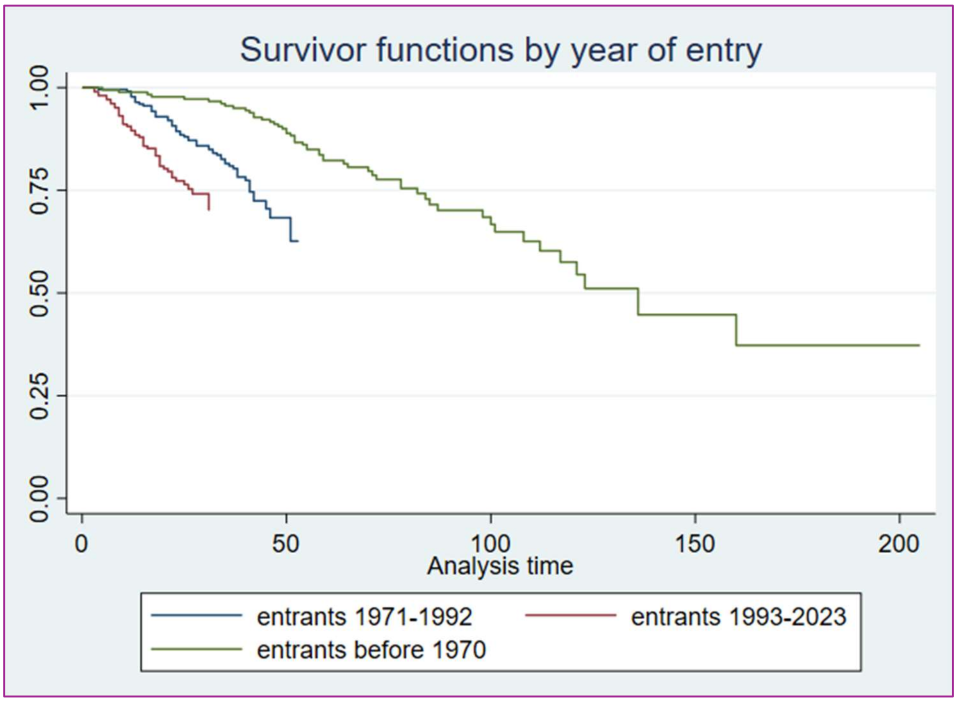



Figure 5.13 compares the survival probability of firms categorized by cohort of entry, where the exit event is defined as either failure or a M&A. There are three distinct cohorts: those entering before 1970 (green line), those entering between 1971-1992 (blue line), and those entering from 1993 to 2023 (red line).

The early entrants exhibit the highest survival rates over time. The survival curve shows a less steep decline, indicating that firms entering the market before 1970 tend to remain the market longer than more recent entrants. These firms are more resilient and are more able to withstand market pressures.

Firms entering between 1971-1992 have a steeper decline in survival probability than the early entrants, particularly in the first 50 years of their existence. However, the decline in the survival rate is less sharp than the later entrants (1993-2023), indicating that this second cohort performs better than the later entrants. Second cohort is more resilient than third cohort.

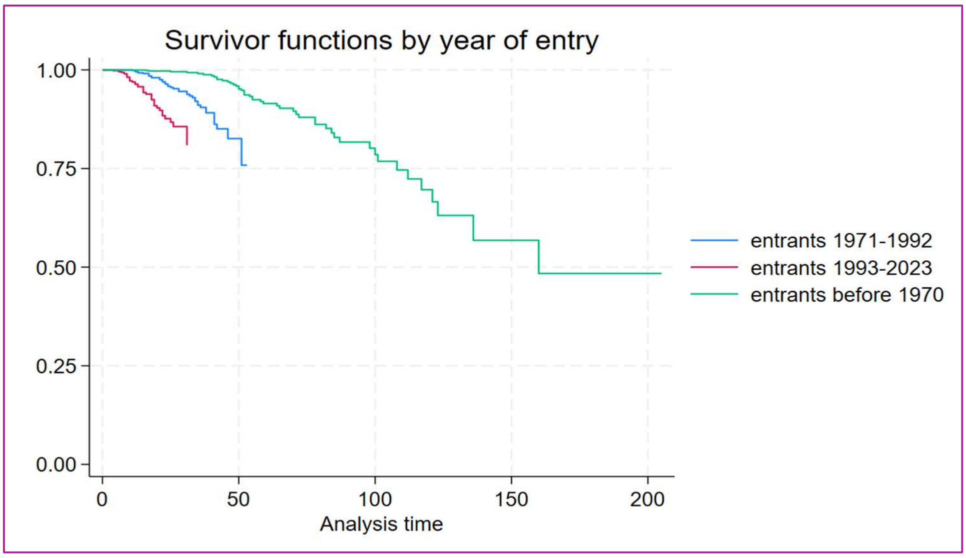
The red line shows a rapid drop in survival rates in the early stages, suggesting that these firms are more likely to exit the market quickly. The firms included in this group are entered the market in a period in which the industry had already become well-established and consolidated. By this time, many of the key market participants had already accumulated more than 50 years of experience.

Additionally, this group of firms also represent the most crowded of the three. This means that the later entrants not only entered a market that is saturated with long-established competitors but also experienced increasing competition from other mew firms. These conditions indicate that there is simply not enough room for everyone in the market, especially for new entrants. In these last decades, the barrier to entry have likely become too high, making it challenging for new entrants to gain competitive footing. Factors such as increased capital requirements, advanced technological knowledge, and the need to differentiate products in an already competitive environment contribute to the challenges met by later entrants.

A visual inspection of the survival curves reveals a clear and net divergence in the survival probabilities across the three cohorts. In light of the discernible discrepancy, we would similarly conclude that the null hypothesis of survival equality across the cohorts should be rejected.

Overall, these results suggest that there a clear first mover advantage in the laser industry. Entering earlier enhances the probability to survive, likely because firms have more time to grow, establish a customer base, and adapt to technological and competitive changes. Furthermore, this group encompasses the diversifiers, that is to say, those companies that existed and operated even before the advent of laser industry. This factor is also likely to have positively influenced their survival, as they entered the laser market already having accumulated experience, knowledge, and resources beforehand.

*Figure 5.14: Survival function depending on the cohort of entry. Exit only includes cases of M&A.*



Focusing only on merger and acquisition cases, as illustrated in Figure 5.14, we can see that there is not a big difference comparing the two graphs.

The data illustrated in both graphs indicates that companies that entered the market prior to 1970 demonstrate the highest survival rates over time. In the second graph, in particular, which depicts M&A only, the decline is less precipitous, suggesting that a considerable number of these older firms possess greater resilience to failure.

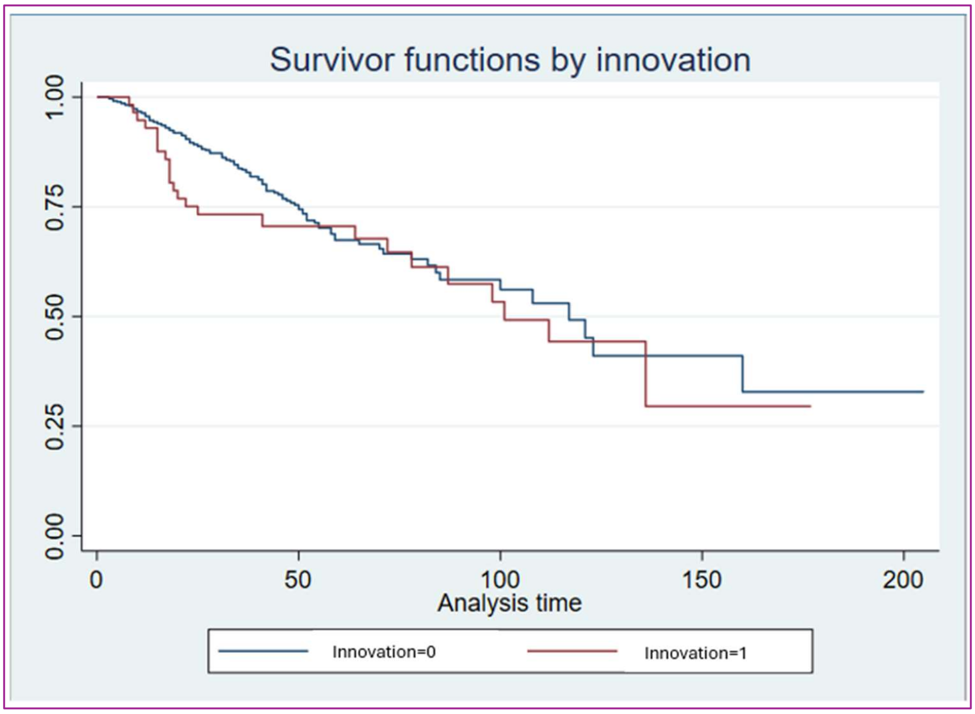
The firms that entered between 1971 and 1992 demonstrate a comparable pattern in both graph; however, the decline is more pronounced in the former, indicating that failure contributes significantly to their overall exit. These firms are less likely to be acquires early but may fail more frequently.

The later entrants show a most rapid decline in both graphs during the initial period. In the second graph, the decline remains strong but is less pronounced than in the first, suggesting, as in the case of entrants between 1971 to 1992, that failure is a significant factor in the exit of these firms.

Overall, in can be argued that the early entrants are more likely to exit through M&A than failure, in contrast to what happens in the other two cohorts.

Moreover, also in this case the null hypothesis would be rejected.

*Figure 5.15: Survival function of being or not an innovative company. Exit includes both failure and M&A cases.*



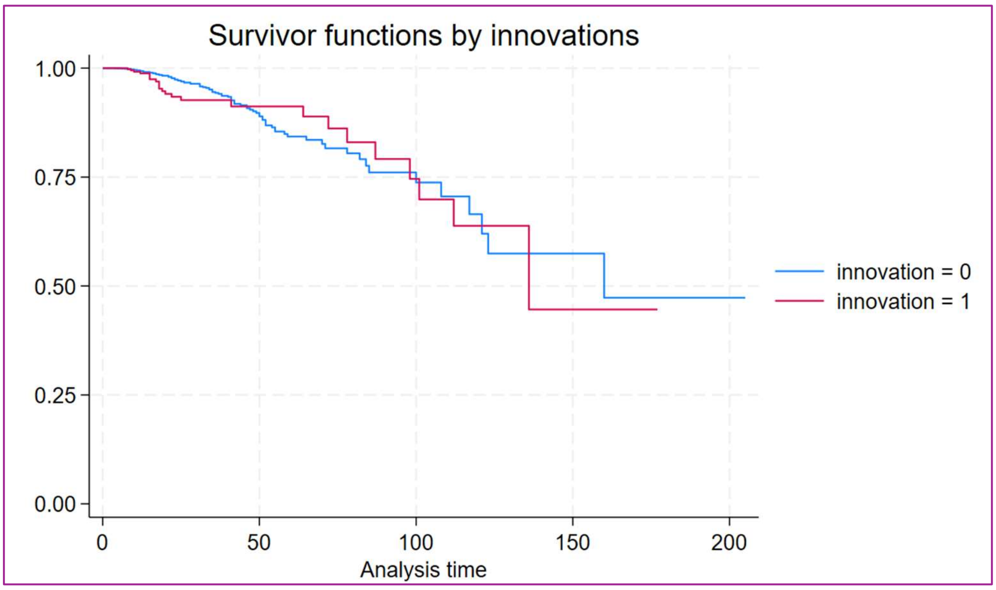
In this last case, the observable characteristic that we focus upon is whether or not the company owns at least one patent, and thus to be defined as an innovator or non-innovator.

In the first 50 years the innovators seem to have experienced a lower survival probability compared to non-innovators. As time passed, the likelihood of survival overlapped between these two categories, and then when a firm reaches a certain amount of year of experience exits the market with a probability that does not seem to depend on whether or not it owns a patent.

Being an innovator is becoming significant in the probability of exit only in the stabilisation phases of the company and impacts negatively on it. This is because innovating enterprises are exposed to greater risks than non-innovating ones. Research and development activities are inherently uncertain and expensive. The introduction of a new and patented product to the market does not always yield the desired result, and it may not be accepted by consumers. A negative entry linked to a significant cash outflow may increase the probability of the company exiting the market.

Nevertheless, the term "exit" in this context encompasses both failure and mergers and acquisitions. In order to gain a deeper insight into the actual impact of innovation on exit, it is instructive to examine the following graph.

*Figure 5.16: Survival function of being or not an innovative company. Exit only includes M&A cases.*




As it can be observed in the figure, the probability of innovators exiting the market is higher during the initial decades. However, in this case, where only mergers and acquisitions represent a means of exiting the market, it can be seen that innovators represent a preferable target for acquisition, particularly during the first 40 years of business.

A notable distinction between the preceding estimate and the current one is the reduced degree of overlap between the two categories, as illustrated by the curves. Indeed, following approximately 50 years, non-innovators are more likely to be acquired than those with at least one patent.

In conclusion, during the initial 40-year period, innovators are the preferred target for acquisition, whereas after this period, non-innovators are the preferred choice. This finding is of significant interest and merits further, more detailed analysis.

One potential explanation for this shift in the curves is as follows. A small innovative company, in the sense of a few years of experience, may be a preferable target for a large company for two reasons. Firstly, being an innovator is a pro as it implies the presence of a strong R&D department. Secondly, being young increases the possibility of acquiring it at a lower cost because it is less established in the market.

As the innovating company matures, the cost of acquisition increases. Consequently, it may be more advantageous to pursue the acquisition of an established company that has not engaged in significant innovative activities, as the latter may offer a more robust customer base and a greater depth of experience.

# CHAPTER 6: ECONOMETRIC ANALYSIS OF INNOVATION AND FIRM SURVIVAL

This chapter presents an in-depth econometric analysis of two key aspects in the evolution of the laser industry: innovation and firm survival. Innovation plays a crucial role in driving competitiveness and progress in technological landscape, especially in technologically advanced sectors like laser industry. However, firms operating in such dynamic environments face significant challenges in maintaining long-term survival.

In this analysis, the first aim is to examine the determinants of innovative activities within firms, using two indicators: the total number of patents owned by each firm and the binary measure of whether a firm possess at least one patent.

Following this investigation, the second aim of the analysis is to explore the determinants of firm survival. This analysis tackles aspects such as the presence of innovation within the firm and its associated indicators, the geographical location at which the firms is situated and the cohort of entry, which pertains to the year in which the firm first entered the market.

By examining the interplay between innovation and a firm's survival capabilities, it is possible to assess the extent to which innovation influences a firm's longevity and, consequently, to gain a more robust understanding of the dynamics of the laser industry.

## 6.1 Determinants of Innovation and Patent Activities

In order to investigate the factors that influence innovation within a firm, particularly in terms of the number of patents, four distinct econometric models were employed: Linear regression, Poisson regression, Negative Binomial regression, and the Heckman model. These models were selected due to their ability to capture different aspects of the data.

In this first set of regressions, the dependent variable is the count of the patents held by each firm, which is used as an indicator of the degree of innovativeness of the firm. The count of patents provides valuable insights into the firm's research and development efforts and its ability to translate these efforts in tangible outcomes, representing a new process or a new product.

*Table 6.1: Linear regression, Poisson Model, and Negative Binomial Model*[6]

| Variables | Linear Regression | Poisson Model | Negative Binomial Model |
|---|---|---|---|
| survival_time | 0.001(0.001) | 0.017(0.003) *** | -0.008(0.007) |
| fam_pat | 0.051(0.009) *** | 0.032(0.003) *** | -0.058(0.032) * |
| nofam_pat | - | - | 0.278(0.092) ** |
| mean_fc | 0.025(0.009) ** | 0.03(0.17) * | 0.127(0.029) *** |
| mean_bc | 0.044(0.013) ** | 0.057(0.009) *** | 0.229(0.03) *** |
| region | no statistically significant effects | - | statistically significant effects |
| constant | 0.101(0.093) | -1.884(0.38) *** | -2.01(0.49) *** |
| | | | |
| N | 615 | 615 | 615 |
| R-squared | 0.82 | 0.7759 | 0.3613 |

The linear regression model was chosen for its simplicity and ability to capture baseline relationship between the dependent and independent variables. Only in this case, the dependent variable is not the simple count of patents but is a transformation of natural logarithm of number of patents, in order to address several potential issues commonly encountered with count data. In particular, the transformation used is $log(1 + n\_patents)$.

In this dataset the distribution of the variable n_patents is highly skewed, meaning that the great majority of firms listed have few or no patents. As analysed before, only 57 firms out of a total of 615 possess at least one patent, and many of these firms hold just 1 or 2 patents. Introducing the logarithmic transformation of the dependent variable compresses its scale, reducing the impact of large values and making the distribution closer to normal, which is an underlying assumption of linear regression model. Large patent counts could disproportionately influence the model, leading to biased estimates. Using the natural logarithm these outliers have less influence on the results.

Additionally, adding 1 to the number of patents allowed to include zero counts, since the simple logarithm of zero is undefined. If this step was not made, the natural logarithm would exclude firms with no patents, representing in this sample a very large subgroup of observations.

Regarding the linear regression model, the time, measured in years, over which the company remained active is not statistically significant (p-value > 0.10). This suggests that, when predicting the log of patents, the duration of the firm's operation does not play a significant role.

[6] *Significant at 10%; **significant at 5%; ***significant at 1%

The variable fam_pat, which represents the number of distinct patent families a company holds, instead is highly statistically significant and positive correlated. The interpretation is the following: ceteris paribus, for each additional set of patent families, the expected number of patents increases by 5.1%. It is worth noting that, in these econometric analyses the patents belonging to the same family, meaning patents for the same invention but filed in different jurisdiction, are counted only once, so this variable indicates the number of different patent families there are in the company's portfolio. For instance, whether a firm holds 2 or 20 patents within the same patent family they are counted as one patent family.

The fact that this variable is statistically significant indicates that the decision to obtain patents covering the same innovation in multiple jurisdictions increases the likelihood of obtaining additional patents. This suggests that firms that are active in developing new ideas and innovations are likely to continue innovating and filing new patents. Interestingly, this finding also highlights the strategic aspect of international patenting. Firms with a greater number of 'international' patents show a greater tendency to develop a wider range of innovations over time.

As mentioned above, applying for a patent is expensive. Therefore, firms who decide to make multiple applications are companies with good financial resources, which can not only support patenting activities but also a continuous focus on R&D activities to develop new technologies and innovations.

**Mean_fc** and **mean_bc** are variables that indicate the average number of forward and backward citation respectively at a company level. Both are statistically significant at 5%, and both variables have a positive effect on the number of patents. Specifically, for each additional forward citation, the expected number of patents increases by 2.5%, and for each additional backward citation, the expected number of patents increases by 4.4%. This finding highlights the role of citation dynamics in innovation.

These two variables are two quality proxies of a patent. The fact that both have positive effects on patent numbers underscore that patents of higher quality are linked to increased activities related to innovations. Patents that receive more citations in this analysis not only contribute to technological progress but also increase the firm's propensity to continue innovating.

An important aspect is that backward citations have a greater effect than forward citations. Backward citations are references to prior patents presented within the patent document, while the forward citations are citations that this patent receives in subsequent patents. This suggests that the depth of firm's engagement with existing technology, as represented by the mean of backward citations, is more influential in driving future patent production than the recognition the innovation receives in future patents. In this context, the role of knowledge accumulation is of great significance. Firms that build upon a broad base of existing innovations are more likely to continue to innovate.

The region fixed effect does not appear to have a statistically significant effect on the number of patents in the linear regression model. The findings indicate that there is no systematic difference in the innovation outcomes of firms situated in distinct geographical location. Essentially, being based in one region versus another does not appear to confer a substantial advantage or disadvantages in terms on filing patents.

The number of patents is a count variable. Despite the log transformation allowed to obtain truthful results, it did not perfectly account for the count nature of the data. In order to gain more reliable conclusion about the factors that drive patent filings, in addition to the linear regression model, two other econometric models are used.

In order to double-check the results obtained, it is necessary to proceed with the Poisson and the Negative Binomial models, enabling to refine the findings obtained from a basic model with a more sophisticated treatment of these data.

The Poisson regression it is designed to model count data. In this model, the variable **survival_time** becomes highly statistically significant and is positively related to the number of patents filed. For each additional year of operation, the expected number of patent increases by 1.70%. This effect is not so high but shows that a firm with more year of experience has a higher likelihood to file for additional patents over time, suggesting a gradual accumulation of knowledge and innovation capacity as firms becomes older.

Additionally, the variable **fam_pat** is still statistically significant and positively related to patent counts, as observed in the linear regression model. However, the effect is slightly smaller here, for each additional patent family, the expected number of patents increases by 3.25%. Also in this case there is a relationship between the strategic decision to increase the coverage of a patent and the decision to pursue future innovations, with subsequent patents.

The average effect of forward citation passes from significant at 5% level to 1% level. However, the effect is practically the same with the expected number of patents increased by 3.05% every additional unit in the average of this quality proxy.

In contrast, the average effect of backward citations increases its level of significance, shifting from 5% to 10% level. The effect has a value of 5.86%, showing a higher value than the previous model, further highlighting its importance as an indicator of the firm's engagement with existing knowledge, which contributes actively to more innovation.

The results across the linear and Poisson models show a degree of consistency, thus increasing the reliability of these findings. However, to fully address potential issue like overdispersion, the Negative Binomial model is used. It is an extension of Poisson regression able to provide more robust estimates.

In this regression, the variable that measures the duration of firm's operation within the industry is not statistically significant, mirroring the results of the linear regression model. This variable is not a determinants of patent activities.

The variable **fam_pat** is inversely related to the number of patents but is weakly significant at the 10% level. Additionally, in this regression there is the introduction of a new variable that accounts for the patents that are not part of a family. This variable has a significance level of 5%. For each additional patent that is not part of a family, the expected number of patents filed by the firm increase by approximately 32.05%. It could reflect a different patent strategy where firms put more efforts in different R&D activities, creating a wide range of distinct innovation, rather than spend money and time to fil the same patents in multiple jurisdictions.

Regarding the quality proxies, also in this case they are positively related to the dependent variable ad are both highly statistically significant. Another important aspect is that they have intensified their effect. Specifically, for each additional point in the mean of forward citations, the expected number of patents increases by 13.55%, while for the backward citation the effect has reached the 25.77%. This underscores the critical role of both forward and backward citation as patent quality. Patents that are cited by future innovations and those that build upon a broad base of prior knowledge are crucial indicator in the ability of a firm to file for a great number of patents.

Finally, the region fixed effects are statistically significant, indicating that geographic location plays a role in the likelihood of filing patents. This could reflect the different regional environments in which the firms operate that may advantage some of these.

In order to conclude the estimation of patent activity, it is employed a two-step estimates: Heckman selection model. This model accounts for the fact that the patenting activity is actually comprised of two steps: the first step accounts for the decision to patent or not (i.e., the selection equation), the second step accounts for the number of patents (i.e., the estimation equation).

The first stage has the aim to select a subset of firms in the dataset, particularly those firms holding at least one patent, so those that are called innovators. In fact in this first stage the dependent variable is a dummy variable – innovation – that assumes value equal to 1 if the firm has one or more patents, 0 otherwise.

The second stage, conditional on having at least one patent, explains the number of patents a firm holds. This model ensures that estimates of how firm characteristics and patent's quality proxies affect patents counts are not biased by the fact that some firms never innovate. The observations at this stage are 57 because only 57 firms are involved in innovative activities. In other words, this stage models the intensity of innovation for firms that are already identified as innovators.

The first stage identifies firms that are likely to engage in patenting activity, while the second stage estimates how several factors, such as the region of origin or characteristics of previously filed patents, influence the number of patents produced by those firms.

*Table 6.2: Heckman selection model*

| Variables | Estimation equation (Dep. var. = n_patent) | Selection equation (Dep. var. = innovation) |
|---|---|---|
| survival_time | - | 0.007(0.002) *** |
| y_first_pat | statistically significant effects | - |
| mean_y_fc | 3.753(1.6) ** | - |
| mean_fc | -0.164(0.07) ** | - |
| mean_bc | 0.032(0.33) | - |
| fam_pat | 1.278(0.14) *** | - |
| region | statistically significant effects | - |
| constant | 60.36(2.99) *** | -1.672(0.12) *** |
| | | |
| N | 615 | |
| Selected | 57 | |
| Non-Selected | 558 | |
| Wald chi2 | 35575.75 | |
| Prob > chi2 | 0.00 | |

Table 6.2 reports the results of the Heckman selection model. In the selection equation, the variable **survival_time** is highly statistically significant, indicating that the number of years a firm survives in the market positively affects the probability of innovating. Older firms are those that are more likely to be involved in innovative activities, and subsequently to apply for any patents.

In this model, it was decided to include only one explanatory variable in the selection estimation and not to include it in the second stage. This was done in order to distinguish the selection process (being an innovator or not) from the outcome process (the number of patents).

With regard to the estimation equation, this part explains the variation in the number of patents a firm has, conditional on having at least one patent.

The variable **y_first_pat** is a categorical variable that indicates the first year in which the firms has obtained a patent. Essentially, this marks the moment when a firm first succeeded in obtaining intellectual property protection for its technological advancements. The table indicates that this variable has statistically significant effects on the number of patents. In particular, firms that started patenting earlier tend to have accumulated more patents compared to those that entered the patenting landscape later.

Firms that were pioneers in obtaining patents could have established themselves as key players in innovation within the laser industry, enjoying a first-mover advantage. This advantage can lead to a reinforcing cycle, with early patent applications leading to more investment in R&D, which in turn results in additional patents. These firms have had more time to gain experience in the process of innovation development and in the process of patent application.

**Mean_y_fc** indicates the mean number of forward citations received per year by each firm. This variable is positive and significant at the 5% level, implying that firms whose patents receive more forward citations per year tend to have a higher number of patents filed over time. On the other hand, **mean_fc**, which indicates the mean number of forward citations received by each firm, not weighted per year, is always statistically significant at 5%, but negatively related to the number of patents. This result, at first glance, may seem counterintuitive, yet it may conceal an important relationship between these two variables and the propensity to patent.

First, these two variables capture distinct dynamics:

- the average forward citation per years measures the yearly intensity of citations a firm receives. The positive coefficient indicates that a constant flow of attention and recognition of a previous innovation by other firms when they develop an innovation, leads to a higher production of new patents per year;
- the average total forward citations, reflects the overall average citations received by the firms, independently of the time unit. This means that the average total citation may be influenced by older patents or a few high-impact inventions. Firms may have focused on a small number of impactful patents in the past but may not be as prolific in producing new patents.

Firms with a high average forward citations per year are likely focused on high-impact patent that consistently attract attention from the laser community, thus encouraging the creation of new high-quality patents. This explains the positive coefficient for citation per year. Additionally, it can be asserted that firms with high yearly citation average are likely active innovators, regularly generating new technologies and patents.

On the other hand, those firms with a high average total number of forward citations may be seen as leaders who have made important innovations in the past but have been less active in recent years in terms of patents, which could explain the negative coefficient of the variable.

Concerning backward citations, in this model their average is not statistically significant, suggesting that the number of references a patent makes to earlier patents doe not have an effect on the number of patents a firm produces.

The variable that measures the number of patents families is highly statistically significant and positively related to the number of patents. This result is consistent with the other findings obtained from the Linear regression and Poisson model.

The region fixed effects are statistically significant, implying that the geographical location of a firm is a factor able to influence the patenting activity.

In summary, considering all four econometric models presented in this section, it can be stated that firms surviving longer are more likely to innovate. Additionally the number of citations, forward and backward, in general both positively affect the number of patents. Another factor that is positively related with the dependent variable is the number of patents families present in the patent portfolio of firms.

### 6.2 Determinants of Firm Survival

This section delves into the analysis of factors influencing the survival of firms operating in the laser industry. Exit is an event that marks the end of the business activities of the company in its current form and is categorised into two possible distinct outcomes: M&A and failure, with failure defined as the discontinuation of business due to insolvency or other kind of underperformance.

The laser industry, characterized by disruptive technological advances that have changed structure of the industry and the laser itself, provides an ideal setting to examine how different factors, especially those related to firm innovativeness and firm characteristics, affect the likelihood of a firm exiting the market.

The analysis proceeds in different stages, progressively refining the understanding of exit strategies. The initial regression is a survival analysis, where exit is considered as a binary outcome, exit versus survival, helps to identify the general factors that affect the survival time of firms. Subsequently, the analysis is refined by focussing on the M&A exit strategy. Finally, the analysis goes further to distinguish between the two exit modes, M&A and failure, providing a more nuanced view of the dynamics behind each type of exit.

In order to conduct these analyses, it is necessary to employ a survival time analysis method. The time between the start time, considered the birth of the company, and the event, considered the exit from the market, is the survival time, measured in years. In the case of firms that have not experienced exit at the conclusion of the study dated 2023, the assigned end date is the year in which the study ends. These firms are categorised as censored firms. This is necessary because the survival time analysis requires a starting point and an end point. However, in order to differentiate firms that have exited the market and those that have been censored, the latter will be assigned a value of zero in the variable indicating the occurrence of the exit event, in contrast to those that have left the market.

To detect the factors that influence survival time and to gain insights into the way they exert their effects, the Cox regression is employed.

*Table 6.3: Cox regression*

| Variables | Cox Regression |
|---|---|
| innovation | 0.96(0.251) *** |
| region | no statistically significant effects |
| n_patents | 0.024(0.056) |
| entrants_ | statistically significant effects |
| tot_claims | -0.007(0.004) * |
| backward_cit | 0.003(0.002) |
| forward_cit | -0.001(0.001) |
| | |
| N | 615 |
| LR chi2 | 77.84 |
| Prob > chi2 | 0 |
| Log likelihood | -820.45 |

The dependent variable is the time until firms exit the market or the conclusion of the study. In this context, exit is defined as the cessation of operations, encompassing both M&A and failure.

The coefficient for **innovation**, indicating whether the company holds patents, is highly statistically significant. The positive coefficient suggests that firms with at least one patents have a higher hazard rate, meaning that innovators are more likely to exit the market compared to firms without patents. This result may be a symptom of the bivalence of the term "exit", two additional models are employed to dissect the true nature of exit and how it interacts with innovation.

**Total claims** refer to the number of claims made by the patents a firm owns, serving as a proxy of quality of the intellectual property. The negative coefficient is statistically significant at 10% level, meaning that as the number of claims increases, the hazard rate decreases, albeit slightly. Firms with broader patents are less likely to exit the market. This result suggests that firms with patents that cover a larger scope are better protected from competition and imitation from rivals, reducing the likelihood of exit the market.

A critical observation is that the number of patents held by a firm is not statistically significant. This outcome underscores an important distinction: it is not the quantity of patents that determines a firm's chances of survival, but rather the quality of these patents, captured by the total claims.

In addition to total claims, the analysis also examines other quality proxies related to patents, namely total backward citations and forward citations. However, these variables do not exhibit any statistically significant effect on the survival of firms in the laser industry.

The variable **entrants_** represents the entry time fixed effect when firms are divided into three group: those that entered before 1970, those that entered from 1971 to 1992, and those that entered from 1993 to 2023. This categorical variable is highly statistically significant at 1%, indicating that the differences in entry strategies are statistically meaningful and warrant further examination.

In the context of this analysis, the reference category is represented by the firms that entered the market earlier, thus before 1970. The coefficients for the other two cohorts are compared to the performance of the early entrants. The coefficient for the middle cohort is 1.35, while the coefficient for later entrants is equal to 2.12.

The positive coefficient for entrants from 1971 to 1992 indicates that this group has a higher likelihood of exiting the market compared to the reference group. This effect suggests that firms entering during different time period faced a different market landscape.

Early entrants might have built competitive advantages being first movers that firms entering the market later could not easily replicate. These advantages could include establishing a strong customer base and enjoying a larger market share in a period with a low number of competitors. This consequently results in a reduction in the potential market for those who enter a later stage. Middle entrants, on the other hand, might have entered the market during a period of growing competition. By this time, early entrants had already established themselves. Mid entrants may have faced higher competitive pressure from both established incumbents and newer firms.

Later entrants show a positive coefficient larger than the previous group. This indicates that later entrants face an even higher hazard rate than middle entrants and are much more likely to exit the market compared to early entrants. Who entered the market in this last phase have a substantially higher risk of exiting than both early entrants and middle entrants.

The higher risk could be linked to several factors. By the time these firms entered the market, the laser industry may have reached a point of market saturation. When a market becomes saturated, it can become much more difficult for a company to increases its market share, and deciding to enter in this period is critical to survival probability. Additionally, later entrants may face high technological barriers that make it challenging for new entrants with underdeveloped structures to compete effectively. As time passes, the concept known as the liability of newness becomes stronger. Newer firms may encounter greater challenges in surviving in a market that is already well-developed and highly competitive than its initial phase.

The laser industry could have reached a point where new entrants struggle to differentiate themselves, or build competitive advantages, making them more vulnerable to failure or acquisition.

The p-value for the likelihood-ratio test of the overall model fit is equal to zero (prob > chi2 = 0), meaning that the independent variables included in the Cox regression have a statistically significant impact on explaining the variation in survival time.

In order to gain a more detailed understanding of the exit dynamics, two additional regressions are conducted. The first one examines exit in a general sense, combining the two modes of exit highlighted in this study: M&A and failure. The second regression focuses specifically on the positive outcome of M&A, isolating this from the cases of exit due to failure. This allows for a clearer picture of the dynamics at play for firms that are acquired versus those that fail. It is essential to differentiate between these two modes of exit in regression analyses, as the act of exiting alone can be perceived as a negative outcome. However, this does not fully capture the nuances of the situation, as it encompasses both positive and negative events.

To model this regression analysis, the method chosen is the Complementary Log-Log Regression (Cloglog) rather than a more traditional logistic regression. Cloglog, as logistic regressions, are a statistical modelling technique used to analyse binary variables, making them suitable to exit and acquisition dummy variables. However, it was chosen to not employ a simple logistic regression because it assumes that there is a sort of symmetry in the distribution of the probability of the occurrence of the event. This assumption holds true when there is constant hazard rate, meaning that there are equal odds of a firm exiting the market across the time period. In contrast, the complementary log-log regression is more performative with survival analysis, assuming that the event rate increase or decreases unevenly over time, often with rare events during the period under examination. The probability of observe the event, exit in the first case, and M&A in the second one, is asymmetric, either more likely in certain periods than others, or more likely for specific types of firms based on characteristics like being an innovator or not.

*Table 6.4: Complementary log-log regression*

| Complementary log-log Regression | | |
|---|---|---|
| **Variables** | **Exit** | **M&A** |
| innovation | 1.001(0.25) *** | 1.193(0.26) *** |
| region | no statistically significant effects | no statistically significant effects |
| entrants_ | statistically significant effects | statistically significant effects |
| n_patents | 0.026(0.06) | 0.03(0.06) |
| tot_claims | -0.007(0.004) * | -0.007(0.004) * |
| backward_cit | 0.003(0.002) | 0.003(0.002) |
| forward_cit | -0.001(0.001) | -0.001(0.001) |
| logt | 0.776(0.13) *** | 0.87(0.15) *** |
| constant | -8.12(0.13) *** | -8.87(0.74) *** |
| | | |
| N | 26,463 | 26,463 |
| LR chi2 | 88.78 | 84.03 |
| Prob > chi2 | 0 | 0 |
| Log likelihood | -891.4 | -762.7 |

The table above displays the results of two complementary log-log regressions. The dependent variable in the first column is the exit of firms, including both M&A and failure, while the second column represents M&A only.

The variable **innovation** is positive and statistically significant at the 1% level in both models. Specifically, for exit the coefficient is 1, while for M&A is approximately 1.2. This result adds robustness to the previous findings in which being an innovator is a factor that shapes the survival of firms.

In general, a positive coefficient suggests that firms with at least one patent are more likely to exit the market compared to those without patents. However, the stronger effect in the M&A model implies that innovative firms are more likely to be acquired than to exit the market due to failure.

Innovators firms are approximately 3.3 times more likely to exit via M&A than that of a firm operating in the laser industry with imitation strategies, avoiding producing innovations themselves and thus patents.

The high hazard rate for innovators could reflect the desirability of firms involved in innovative activities as acquisition targets. This finding highlights the strategic value that of a firm acquire if it is engaged in the development on innovation, especially when innovations are legally protected through patents. For acquiring companies, the prospect of gaining access to new technologies, intellectual property, and strong R&D laboratories can be a significant motivation to pursue an acquisition. Competitors may see significant value in acquiring innovative firms to gain access to intellectual property that could otherwise act as a competitive threat. In this scenario, innovation does not serve as a mean of achieving profitability in the traditional market sense but also enhances the attractiveness of a firm to potential acquirers.

This finding indicates a potential shift in business strategy, whereby some firms are increasingly considering alternative measures of success beyond the traditional focus on market profitability. It is possible that firms may elect to operate within the laser industry, and subsequently, they may decide to exit the market for several reasons, rather than simply aiming to survive. In order to achieve a successful exit, through M&A, being an innovator is a critical factor.

The number of patents is not yet statistically significant, indicating that the characteristic associated with innovations that affect the likelihood of exit from market due to M&A is simply involvement in innovation, regardless of the number of such innovations.

The cohort of entry is statistically significant at 1% level. Specifically, the entrants from 1971 to 1992, and entrants from 1993 to 2023 show a positive coefficient, meaning that they face higher risk of both exit and M&A compared to the early entrants. It is worth noting that the middle entrants show a higher coefficient in the exit model, rather than M&A. This means that this group of firms may be more inclined to exit through failure than through M&A. Later entrants show a higher hazard rate of exit overall and an even greater hazard of being acquired compared to the other two groups. In this case, later entrants exhibit higher likelihood of exit the market due to M&A, rather than in the model in which exit encompasses both modes.

In order to confirm the above findings, a final regression was carried out: the Multinomial logistic Regression. This type of method is used when the dependent variable is a nominal variable, and it has more than two categories that do not have a given rank or order but are randomly given. In this case the dependent variable is the status of firms at the end of the period under observation. The reference category is the case = 0, when the firms are censored, i.e., they are still alive at the end of 2023. Then there is the case = 1, when the firms have exited the market during their lifetime due to M&A cases. Finally, the case = 2 represents the cases where the firm exited the market due to failure.

*Table 6.5: Multinomial Logistic regression*

| Multinomial Logistic Regression | | |
|---|---|---|
| **Variables** | **M&A** | **Failure** |
| innovation | 1.195(0.27) *** | -14.353(1084) |
| region | no statistically significant effects | no statistically significant effects |
| entrants_ | statistically significant effects | statistically significant effects |
| n_patents | 0.030(0.06) | -0.023(120) |
| tot_claims | -0.007(0.004) * | 0.009(7.63) |
| backward_cit | 0.003(0.002) | 0.001(3.73) |
| forward_cit | -0.001(0.001) | 0.001(3.01) |
| logt | 0.874(0.15) *** | 0.373(0.27) |
| constant | -8.88(0.74) *** | -8.152(1.26) *** |
| | | |
| N | | 26,463 |
| LR chi2 | | 115 |
| Prob > chi2 | | 0 |
| Log likelihood | | -946.2 |

The results must be interpreted in relation to the case where companies in the laser industry are still operating.

It is interesting to note that with regard to failure, the only variable that is statistically significant is the cohort of entry. Specifically, firms that have entered the market in the second cohort are those that present the higher likelihood to fail. Conversely, firms that entered the market in the third cohort (later entrants) show a higher probability to exit due to failure compared to the early entrants, but a lower probability compared to the firms in the second cohort.

The other variables pertaining to innovation are not statistically significant, suggesting that, while patents and their quality proxies may have an effect on the probability of exit due to M&A compared to maintaining a presence in the market, these variables do not have the same level of explanatory power when it come to failure.

Regrading the cases of M&A, the coefficients and the level of statistical significance confirmed the results obtained from the Complementary Log-Log regression.

Holding at least one patent positively affects the likelihood to exit through a M&A transaction, compared to remain active in the market. The high coefficient reflects the attractiveness of patent-holding firms as acquisition target. Companies that innovate hold valuable assets that make them desirable to larger firms looking to expand their own technological capabilities. Additionally, the number of patents does not seem to have an effect on the likelihood to exit the market.

The cohorts of entry remain statistically significant, and specifically as the cohort of entry is more recent the likelihood of exit from market due to M&A increases. The risk of being acquired is higher for firms that entered the market more recently than for those that did so earlier.

The negative coefficient of total claims indicates that firms with patents covering a broader scope are less likely to exit via M&A. Consequently, these firms are more likely to remain active in the market. However, the effect is relatively small.

In summary, it can be argued that innovative firms are more likely to exit the market. However, this outcome is driven by the positive effect that these innovations have on their desirability as acquisition targets. The key characteristic, therefore, is owning at least one patent, as the specific number of patents does not significantly predict the occurrence of the "market exit" event.

# CHAPTER 7: CONCLUSION

### 7.1 Summary of Findings

This section summarizes the key findings from the analysis of trends among companies operating in the laser industry, along with the results of the econometric exercises conducted. The results provide valuable insight into how innovation has influenced firm survival, and market dynamics in the laser industry.

The laser industry is an industry born from the arrival of exogenous innovation and has experienced a very long incubation period. Its lifecycle has been characterised by the involvement of several R&D laboratories and the advent of continuous innovation that has pushed the technological frontier many times over.

Our study has revealed several important trends and temporal patterns in the lifecycle of the laser industry.

The first notable trend relates to the geographical distribution of firms in the laser industry. The vast majority of firms, approximately 91%, are located in the United States, highlighting the dominance of the country in this sector. Non-US companies, fewer in number, are dispersed across various region of the globe. Although there are no clear clusters, the companies are mainly located in Europe, Canada, and Asia. In Europe, the United Kingdom and Belgium emerge as key players in the laser industry.

Focusing on the United States, California stands out as the primary hub for laser technology companies. California is known for its innovation ecosystem, particularly in Silicon Valley for its role in advancing cutting-edge technology. This geographical concentration reflects the trend in the high-tech sectors, where proximity to innovation ecosystem often accelerates development and growth.

Interestingly, the geographical distribution of *innovative firms* specifically in the laser industry follows a similar pattern to the general distribution. The United States continue to lead, with California again taking the top spot, accounting for 37% of all innovators in the laser industry. In Europe, Germany takes the lead when it comes to firms driving innovation.

The start of the laser industry is dated 1960. The critical elements of market dynamics have been the patterns of firm entry and exit. With regard to entry, the first significant wave occurred around 1960, the second around 1989, reflecting the maturity of the technology and the growing recognition of the usability of lasers in a range of sectors, from manufacturing to healthcare. Following the mid-1990s there was a gradual decline in the number of new entrants, suggesting a consolidation of the market around established dominant players. In general, the laser industry experienced multiple periods of growth and a subsequent gradual decline as it matured.

Regarding exits, in the early 1990s the number of firms leaving the market began to increase at a steady rate, reaching a peak in the 2010s. This may indicate a period of consolidation and maturation of the market, as previously suggested in relation to the pattern of entries.

By the end of the observation period, a majority of the firms in our sample, around 75%, remain active in the market. Among the 152 firms that exited the market during this time, 127 did so through M&As, this type of exit can be seen as a strategic exit linked to a positive outcome. On the other hand, the remaining 25 firms exit through other means, including bankruptcies, liquidation, or voluntary closure, typically signal less favourable outcomes.

The second focus of this study has been innovation, as measured by involvement in patent activity. A patent is a particular legal right that confers the ability to exclude others from making, using, and selling the invention in object without the patent holder's permission. In this context, the term "innovator" is used to refer to a firm that owns at least one patent. A mere 9% of the firms listed in the dataset are classified as innovators.

Starting from this data, further insight into the characteristics of these innovations and their quality have been gained. A patent is only legally protected within the jurisdiction in which it is granted. In order to obtain a broader protection, often international, it is necessary to apply for the same patent in several jurisdictions. This concept is known as patent family system, patents belonging to the same family are linked to the same invention.

A significant portion of innovations in the laser industry, approximately 40%, applied for and received applications in more than one jurisdiction. This trend has suggested the considerable presence of inventions that are of significant global importance within the field of lasers. The jurisdiction that received more filing patents has been the United States Patent and Trademark Office, followed by Japan Patent Office, European Patent Office, and German Patent and Trademark Office, representing as a group the 68.95% of all patents filed in the laser industry. This grouping demonstrates the concentration of innovation leadership in just a few major economies and the relevance of these regions for companies producing innovation even if they are located in the other parts of the world.

Regarding the distribution of patent granting over time, the trend was non-homogenous. The period from 1958 to 2020 has experienced multiple peaks and multiple troughs. At the beginning of the laser industry, the number of patents filed was relatively low. The first peak was reached in 1965, indicating an increasing importance of lasers. The number increased since 1990s, and it reached the highest peak in 2000s. Although the number of market entries began to decline from the 2000s onwards, and exits increased in those years, the number of patent applications reached its peak in those years. This may indicate that the companies that remained operational during the maturity period of the laser industry began to exert their dominance through the development of new innovations.

Categorising firms according to the number of patents they hold shows that the vast majority of firms own a small number of patents (less than 3). As the number of patents increases, the number of companies decreases. The patent landscape is characterised by an elite of companies that invest heavily in R&D activities, represented by the tiny fraction, 3 out of 57, that own more than 100 patents. The disparity between the innovators may be indicative of the different relevance of innovations between companies, as well as the disparate innovative capabilities. This underscore the fact that only a modest percentage of firms is capable of making a significant impact in this context of technological advancement in the field of lasers.

The number of patents alone, however, is not sufficient as an indicator of company quality. The presence of quality proxies for these patents is crucial to gain a deeper understanding of the influence of innovation on the operational activities of companies. One of the most widely recognised indicators is the number of forward citations, which indicates the number of citations received in subsequent innovations. In general, patents with a higher number of forward citations are considered to be more impactful and valuable with respect to the others. The trend in the distribution of patents according to the number of forward citations follows the same path as the distribution of companies according to the number of patents held. Specifically, as the number of forward citations rises, the number of patents in that category declines. These findings reinforce those of previous studies which have indicated that only a small portion of patents are highly valuable, while the majority exhibits a modest impact.

Now that the descriptive statistics have been summarised, showing trends and patterns, a summary of the results of the econometric models will now be presented.

The first analysis aimed at studying the factors influencing the number of patents held by each company. One of the significant findings has been the positive influence of patent families on the number of patents filed by companies. The results suggest that reliance on broader protection strategies has been a driving force behind the development of new inventions.

Additionally, averages of forward and backward citations per company were found to have a positive impact on the number of patents. A patent that has a greater impact on future technological developments and has a strong foundation in prior inventions is classified as being of higher quality. High quality patents often inspire additional inventions, further fuelling the cycle of innovation within a company.

Furthermore, the analysis has shown that the age of a company seems to have a positive effect on the dependent variable, although to a lesser extent than the other statistically significant variables. Older companies may benefit from accumulated knowledge and experience, which can contribute to improve their ability to innovate.

In summary, companies that adopt broad patent protection strategies, produce higher quality patents, and benefit from accumulated experience tend to file more patents, fostering continuous innovation in the laser industry.

The second analysis has focused on survival time of firms and their potential exit from the market. One of the most significant results has been the strong influence that innovation has on firm's likelihood of exiting the market. In particular, firms that are classified as innovators are those that show the highest hazard of exit from the market through merger or acquisition cases. Acquiring companies see great value in gaining access to functioning, forward-looking R&D department, which accelerates their technological advancements. Additionally, acquiring an innovative firm provides access to valuable property, helping the acquiring company stay competitive in this market. Therefore, innovation, regardless the number of patents held, increases the likelihood of a strategic acquisition rather than failure.

Another important result from the analysis is the statistically significant impact that the cohort of entry has on the probability of not surviving in the market. In general, the early entrants are those that exhibit a lower probability of exiting the market, whether through failure or M&A.

In contrast, the middle group, represented by firms that entered the market between 1971 and 1992, it is the group that shows a higher probability of exiting the market due to failure. This group entered the industry during a period of significant technological shifts and increasing competition. Many of these firms may have faced challenges in adapting to rapid technological changes, which led to a higher rate of market exits through failure.

The last group, consisting of firms that entered the market after 1993, demonstrates a higher likelihood of exiting the market via M&A. These later entrants, although often smaller and less established, enter at a time when the market is reaching its maturity. At this stage, the minimum level of skills required, frequently in the domain of technology, to penetrate the market is exceptionally high. Consequently, these companies introduce novel technologies and innovative approaches to the industry. For larger, more established companies, the acquisition of these new entrants represents an opportunity to integrate new innovations and maintain a competitive advantage in the race for technological dominance. A considerable number of these later entrants are exiting the market not as a result of any inherent failure, but rather because they are perceived as potential acquisition targets by larger entities.

In conclusion, it is important to recognize that market exit is not a homogeneous event. Innovation plays a crucial role in shaping the dynamics of industries like the laser market. The laser industry, in particular, is marked by significant trends, with innovation playing a central role.

### 7.2 Limitations of the Study and Implications for Future Research and Theory

While this study offers valuable insights into the importance and relevance of innovation within the laser industry, particularly in the context of exit through M&A, it is essential to acknowledge the presence of limitations. Identifying these limitations allows for a more nuanced understanding of the research and provides a foundation for future investigations to build upon and address gaps in knowledge.

The first limitation of this study concerns the collection of data related to exit through failure. In many cases, detailed information on companies that exit the market through failure is not always publicly available. This lack of transparency can limit the ability to analyse patterns of failure with the same depth as M&A exit. The possibility that this data are not complete may be a reason why many variables in the case of failure are not statistically significant. Despite this limitation, the findings still offer meaningful contributions to the existing literature. Future studies should aim to collect of more detailed failure data, which could enhance the understanding of why some companies fail and how their innovation strategies may play a role in this process.

Additionally, future research could enrich this analysis by adding several variables, especially those that characterise companies. While this study used age as a proxy of size, future research could extend this by including additional metrics, such as the number of employees. Incorporating these variables could provide a deeper understanding of how the size of the company influences the production of innovation. Moreover, the amount of money invested in R&D activities is another crucial variable that could be considered in future analyses. In particular, for studies examining the number of patents held by firms R&D expenditures could offer a link between financial investment and the resulting intellectual property outputs. This is especially pertinent in the laser industry, where the environment is highly technological.

In general, the study adopts a comprehensive approach based on a well heterogeneous and amalgamates set of variables, including both firm-specific and innovation-related variables. The set of variables captures both the fixed characteristics of firms, such as age and geographical location, and the dynamic aspect of innovation, not only in terms of the number of patents, but also in terms of the quality of patents.

In conclusion, addressing the limitations of data availability, and refining the variables used to measure firm characteristics, will contribute to a deeper and more practical understanding of innovation dynamics in the laser industry.

# BIBLIOGRAPHY


Arora, A., & Nandkumar, A. (2011). Cash-Out or Flameout! Opportunity Cost and Entrepreneurial Strategy: Theory, and Evidence from the Information Security Industry. *Management Science, 57*(10), 1844-1860.

Arrow, K. (1962). *Economic Welfare and the Allocation of Resources for Invention.* Princeton: Princeton University Press.

Arrow, K. (1962). The Economic Implications of Learning by Doing. *Review of Economic Studies, 29*(3), 155-173.

Bhaskarabhatla, A., & Klepper, S. (2014). Latent submarket dynamics and industry evolution: lessons from the US laser industry. *Industrial and Corporate Change, 23*, 1381–1415.

Bromberg, J. L. (1991). *The Laser in America: 1950-1970.* Cambridge: The MIT Press.

Buenstorf, G., & Heinisch, D. (2020). Science and industry evolution: evidence from the first 50 years of the German laser industry. *Small Business Economics, 54*(2), 523-538.

Cattini, M. (2018). *The Making of Europe - A Global Economic and Social History* . Bocconi University Press.

Cefis, E., & Marsili, O. (2005). *A Matter of Life and Death: Innovation and Firm Survival.* Retrieved from LEM: https://www.lem.sssup.it/WPLem/files/2005-01.pdf

Cefis, E., & Marsili, O. (2006). Innovation Premium and the Survival of Entrepreneurial Firms in the Netherlands. In *Entrepreneurship, Growth, and Innovation* (pp. 183-198).

Cefis, E., & Marsili, O. (2006). Survivor: The role of innovation in firm's survival. *Research Policy, 35*, 626-641.

Cefis, E., & Marsili, O. (2011). Born to flip. Exit decisions of entrepreneurial firms in high-tech and low-tech industries. *Journal of Evolutionary Economics*, 473-496.

Chandler, A. (1990). *Scale and Scope.* Cambridge: Harvard University Press.

Cockburn, I., & MacGarvie, M. (2011). Entry and Patenting in the Software Industry. *Management Science, 57*(5), 915-933.

Cotei, C., & Farhat, J. (2017). The M&Aexit outcomes of new, young firms. *Small Business Economics*, 545.

Einstein, A. (1972). *Laser Theory* . (F. A. Barnes, Ed.) New York : IEEE Press.

Elliott. (1962, August 18). Spotlight. *Business Week.*

Gilbert, & Newberry. (1982). Preemptive Patenting and the Persistence of Monopoly. *American Economic Review, 72*, 514-526.

Hall, B. (n.d.). The relationship between firm size and firm growth in the US manufacturing sector. *The Journal of Industrial Economics, 35*, 583-606.

Hall, B., Jaffe, A., & Trajtenberg, M. (2001). *The NBER patent citations data file: lessons, insights and methodological tools.* National Bureau of Economic Research.

Harhoff, D., Narin, F., Scherer, F., & Vopel, K. (1999). Citation frequency and the value of patented innovation. *Review of Economics and Statistics, 81*(3), 511-515.

Hecht, J. (2010, August). Short History of Laser development. *Applied Optics, 49*(25).

Kato, M., Onishi, K., & Honjo, Y. (2022). Does patenting always help new firm survival? Understanding heterogeneity among exit routes. *Small Business Economics*, 449-472.

Klepper, S., & Simons, K. (1997). Technological extinctions of industrial firms: an iniquiry into their nature and causes. *Industrial and Corporate Change, 6*, 379-460.

Klepper, S., & Simons, K. (2000). Dominance by Birthright: Entry of Prior Radio Producers and Competitive Ramifications in the U.S. Television Receiver Industry. *Strategic Management Journal, 21*(10/11), 997-1016.

Klepper, S., & Sleeper, S. (2005). Entry by Spinoffs. *Management Science, 51*(8), 1291-1306.

Locke, J. (1689). *Two Treatises of Government* (1988 ed.). (P. Laslett, Ed.) Cambridge: Cambridge University Press.

Mansfield, E. (1982). How Economists see R&D. *Research Management, 25*(4), 23-29.

Mansfield, E. (1986). Patents and Innovation: An Empirical Study. *Management Science, 32*(2), 173-181.

Marketers' and Buyers' Guide. (1966). *Laser Focus 2*.

Marshall, A. (1890). *Principles of Economics.* London: Palgrave Macmillan London.

Office, U. G. (1997). *The Global Context for U.S. Technology Policy.* Washington, D.C: CRS Analysis.

Reinganum. (1983). Uncertain Innovation and the Persistence of Monopoly. *American Economic Review, 73*, 741-748.

Romer , P. (1990). Endogenous Technological Change. *Journal of Political Economy, 98*(5), 71-102.

Schmookler, J. (1966). *Invention and Economic Growth.* Cambridge: Harvard University Press.

Schumpeter, J. A. (1912). *The Theory of Economic Development* . Berlin: Duncker & Humblot.

Schumpeter, J. A. (1942). *Capitalism, Socialism & Democracy.* New Yord: Harper & Row.

Stinchcombe, A. (1965). *Social Structure and Organizations.* Chicago.

Trajtenberg, M. (1990). A Penny for Your Quotes: Patent Citations and the Value of Innovations. *The RAND Journal of Economic, 21*(5), 172-187.

Wagner, S., & Cockburn, I. (2010). Patents and the survival of Internet-related IPOs. *Research Policy*, 214-228.

Whish, R., & Bailey, D. (2012). *Competition Law.* Oxford: Oxford University Press.

Williams, H., & Bryan, K. (2021, August). Innovation: market failures and public policies. *National Bureau of Economic Research*.

## SITOGRAPHY

(n.d.). Retrieved from Research Gate: https://www.researchgate.net/figure/First-page-of-Gordon-Goulds-November-1957-notebook-shows-his-sketch-of-a-Fabry-Perot_fig1_46158628

(n.d.). Retrieved from The Nobel Prize: https://www.nobelprize.org/prizes/physics/1964/townes/photo-gallery

*Google Patents US2929922A*. (n.d.). Retrieved from Google Patents: https://patents.google.com/patent/US2929922A/en

*History*. (n.d.). Retrieved from Nokia Bell Labs: https://www.bell-labs.com/about/history/

Hobbins, K. (2023, July 13). *Looking at the Role of Lasers in Semiconductor Manufacturing*. Retrieved from Medical Device and Diagnostic Industry: https://www.mddionline.com/manufacturing/looking-at-the-role-of-lasers-in-semiconductor-manufacturing

Mustafa, A. (2023, October 2). *A Gentle Introduction to Complementary Log-Log Regression*. Retrieved from Towards Data Science: https://towardsdatascience.com/a-gentle-introduction-to-complementary-log-log-regression-8ac3c5c1cd83

*PCT, Summary for New Users*. (n.d.). Retrieved from WIPO: https://www.wipo.int/pct/en/users/summary.html

Rose , M., & Hogan, H. (2019, June). *A History of the Laser: 1960 - 2019*. Retrieved from Photonics Spectra: https://www.photonics.com/Articles/A_History_of_the_Laser_1960_-_2019/a42279

*Semiconductor Laser Market Size & Trends*. (n.d.). Retrieved from Grand View Reserach : https://www.grandviewresearch.com/industry-analysis/semiconductor-laser-market

Service, C. R. (2022, September 14). *Global Research and Development* . Retrieved from Congressional Research Service : https://sgp.fas.org/crs/misc/R44283.pdf

*Siemenes History*. (n.d.). Retrieved from Siemens: https://www.siemens.com/global/en/company/about/history.html

*Statistics Resources - Multinomial Logistic Regression*. (2024, October 3). Retrieved from Academic Success Center: https://resources.nu.edu/statsresources/Multinomiallogistic

*Supermarket Scanner*. (n.d.). Retrieved from National Museum of American History: https://americanhistory.si.edu/collections/nmah_892778

USPTO. (2024). *Manual of Patent Examining Procedure (MPEP)*. Retrieved from uspto.gov: https://www.uspto.gov/web/offices/pac/mpep/index.html

*What Laser Systems Are Used in Semiconductor Manufacturing?* (n.d.). Retrieved from A-Laser: https://a-laser.com/semiconductors-laser-types-manufacturing/

*WIPO Patents*. (n.d.). Retrieved from WIPO: https://www.wipo.int/en/web/patents/