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Navigating the Path to Market: an Empirical Analysis of University Inventions

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Evita Milana ist Senior Innovation Managerin und anwendungsorientierte Expertin im Technologietransfer, die wissenschaftliche Erkenntnisse mit praxisnaher Implementierung verbindet. Sie koordiniert mehrere EU-Projekte und strategische Konsortialpartnerschaften, und stärkt so die Zusammenarbeit zwischen Forschung und Industrie. Ihre fachlichen Schwerpunkte liegen in der Entwicklung innovativer Vorhaben in den Bereichen Digitalisierung, Künstliche Intelligenz und Innovationsmanagement.
Dieses Working Paper ist Teil ihrer Dissertation zur Kommerzialisierung universitärer Patente und zu Open Innovation. Ihre Forschungsschwerpunkte als Doktorandin liegen insbesondere in den Bereichen Entrepreneurship, Innovationsmanagement und der Gestaltung von Innovationsökosystemen. Dabei verbindet sie systemtheoretische Ansätze und unternehmerische Perspektiven mit ihrer umfassenden Erfahrung aus der Transferpraxis.

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Navigating the Path to Market: an Empirical Analysis of University Inventions

By Evita Milana

In this Working Paper, the aim is to examine in depth the commercialization processes of university-generated inventions. The explorative analysis draws on primary and secondary data obtained from the internal invention disclosure database of the Technical University of Denmark (DTU) for the period 2000–2015. This dataset is both exceptional and highly exclusive, as most universities do not make comparable information publicly available, often compelling technology transfer researchers to rely on proxies and indirect measures. Access to this privileged dataset enables the use of original, unprocessed information and thereby offers a direct, real-time view of how university inventions progress toward market application. Given the confidential nature of this data, the data analysis remains at an aggregated level, deliberately omitting specific firm names or exact years of invention or patent licensing (that is the precondition under which DTU shared this exclusive data).

1. Introduction

This Working Paper offers an informative and valuable analysis of the primary licensing data and additional secondary data collected about the licensees, which contributes to the cumulative PhD thesis of the author. This data analysis and interpretation lay the groundwork for my PhD thesis and enhances the understanding of the subsequent chapters. I explore the licensing data and reveal the levels of technology readiness of university patents at the moment of licensing and at later stages of their deployment in firms, precisely, at the moment of survey conduction (early 2017) when firms have commercialized these technologies (I analyze inventions and patents that have been documented in the University´s database and licensed in the period from 2000 – 2015). Additionally, I assess the differences in time investment, levels of radical innovation, and the contrasts between innovating university spinouts and established incumbents. This exploratory approach, coupled with the availability of unique data, not only provides us with valuable insights but also enables us to address a gap in the existing literature, particularly, the application of proxies and what is understood with commercialization and innovation. Besides, I fill in the literature gap about deep analytical insights about inventions and patents per se – to my knowledge, there is no deep academic analysis on each of invention´s life cycle, geographical reach or time to market.

2. The Evolution of University Invention Commercialization

The practice of licensing university inventions to private companies for development into innovations represents a relatively recent phenomenon in the historical context of economic development. The evolution of economic systems and theories has been significant in shaping the current landscape of innovation.

A key factor in this paradigm shift is the change in the economic landscape since the 1970s and 1980s. Earlier economic models emphasized large corporations as the primary drivers of scale economy, innovation, and technical change (Arrow, 1962; Chandler, 1977; Williamson, 1975) However, recent decades have seen a transition towards an entrepreneurial economy. In this model, individual entrepreneurs and small firms emerge as the leading forces behind innovation and technological disruption, as evidenced in the works of Ács & Audretsch (2010), Drucker (1993), Link & Siegel (2007), and Colombo et al. (2017). Notably, university spinouts, which constitute a significant portion of our sample, are at the forefront of this technology-driven group.

Another key aspect of understanding commercialization – the process by which university inventions reach the market – is the introduction and adoption of open innovation systems in both academic literature and the practical innovation management of many companies. The open innovation paradigm essentially opens the doors of companies to inventions created outside their premises, particularly those originating from universities (Enkel et al., 2009; Perkmann & Walsh, 2007). Conversely, universities have increasingly oriented their research towards market and societal needs, facilitating a more open exchange of ideas and innovations (Park et al., 2024).

2.1. Commercialization versus transfer

The examination of how university inventions are commercialized is an integral component of research that subsequently informs policy-making (Hoekman et al., 2004; Munari et al., 2016) and formation of regional innovation systems (Brown, 2016). As noted in previous chapters and the introduction, commercialization is often perceived as a facet of the technology transfer process from universities to industry. However, this view is somewhat reductive. True commercialization occurs exclusively within a company, thereby distinguishing it from the transfer process. An invention or patent, in its essence, is merely a document that delineates a technology and grants exclusive rights to it. Without licensing, this 'paper' holds no intrinsic value.

Commercialization of inventions often implies entry into the mass market but also includes moving a product or method from the laboratory or prototype stage into commercial use. The process involves stages such as research and development, ensuring the product is viable for commercial use, and finally, a product launch where advertising, sales promotion, and other marketing efforts are employed to encourage the commercial adoption of the product or method. The transformation of an invention into a tangible product, process, or service, and its subsequent introduction to the market where it is sold to consumers, is what actualizes its commercial value. This process, as delineated by Rogers (2003a), is termed the 'diffusion of innovation'. It is at this juncture that an invention can be considered fully commercialized, achieving its maximum value potential. The explicit goal of commercialization is purposefully to make a profit. Given that universities typically do not pursue profit as their primary objective, the actual commercialization of inventions falls outside their purview.

Conceptually, 'transfer' serves as the critical bridge between a university and a company, facilitating the journey of an invention to the marketplace. This distinction underscores the importance of understanding commercialization as a discrete and company-centric process, which is essential for accurate academic research and effective policy development in the realm of university-driven innovations. Therefore, some authors invite universities also to integrate technology commercialization as part of its technology transfer practices (Meyer et al., 2011; Swamidass, 2013). Yet, uptaking the role of commercializator and market player would probably destabilize the other two mission of the universities: teaching and research.

2.2. Open innovation practice of companies: in-licensing

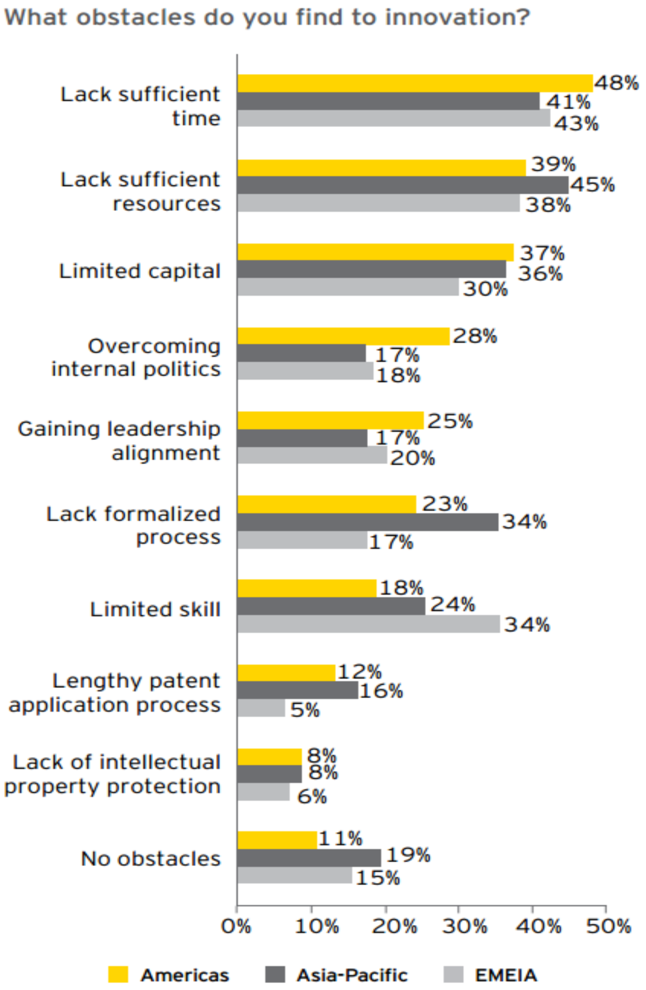
In brief, diffusion of innovations from university to industry can be categorized as a three-step process: research, transfer and commercialization (e.g., García-Aracil et al., 2015; Rahim et al., 2015). The process begins with research at the university level and culminates in the commercialization of these innovations within firms. Therefore, the transformation of an invention into an innovation can be viewed as a progression through various stages of development and advancement.

Despite that some research emphasize the importance of other knowledge and technology transfer channels over licensing (Autio, E. and Laamanen, 1995; Bercovitz & Feldmann, 2006; Bradley et al., 2013), I argue that we need still more sound understanding of licensing – process, patterns and trends - because it is a significant channel for technology commercialization and it creates a value for firms when these develop new technologies.

The significance of licensing in technology transfer and its value creation for firms is evident from various studies in the field. Licensing serves as a crucial method for adopting external technology and facilitating innovation, with its effectiveness often contingent on the technological regime of the industry and firm´s capabilities and previous experience in licensing (Mooi & Wuyts, 2021; Rush et al., 2007). In-licensing does not uniformly enhance innovative performance across all industries. It is more effective in industries characterized by high technological opportunities, low cumulativeness, and high appropriability (Lee et al., 2017).

A global study undertaken by Ernst&Young (Ernst&Young, 2010) indicates that among ten factors, lack of time, resources and capital are the biggest obstacles to innovation for companies all over the world.

Figure 1. Obstacles for firms to drive innovation



Source: Connecting innovation to profit. Five key insights from the world's leading entrepreneurs (Ernst&Young, 2010b).

Following the open innovation logic, engaging in partnerships with academic institutions and securing in-licensing agreements for their patents allows companies to mitigate the significant time and resources typically required for the initial stages of innovation for research and experimentation. Consequently, inventions originating from universities furnish companies with valuable assets in their pursuit of innovation. This dynamic interaction between academic research and industrial application provides a substantive basis to affirmatively address Research Question 1 of the dissertation, demonstrating the positive impact of university inventions on innovation strategies of companies.

And as literature shows, the importance of open innovation is growing and universities are significant partners of this relationship (Pedersen et al., 2022; Remneland Wikhamn & Styhre, 2023; Tucci et al., 2016). Thus, over years the channels of technology transfer might change in some industries, however other industries will stay patent-heavy and we will see this kind of inventions through licensing research-based patents from universities.

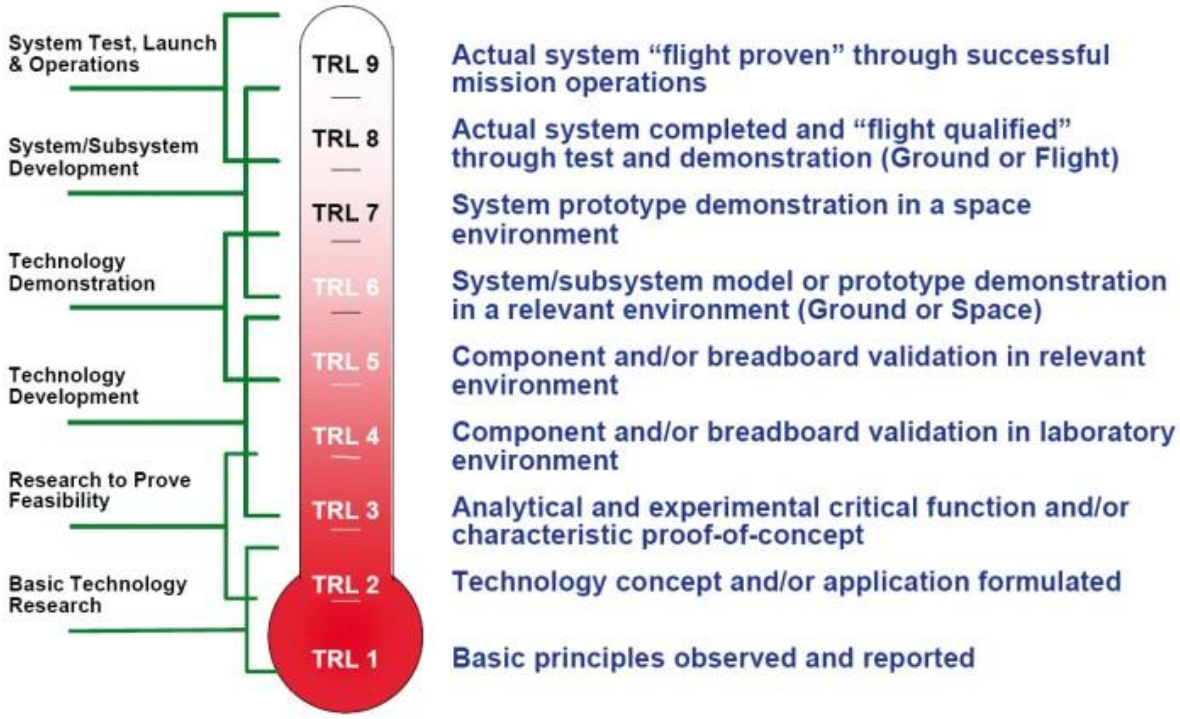
3. Inventions and their technology readiness levels

Technology Readiness Level (TRL) is more than a measurement tool for my research on technology transfer. It is a conceptional tool that in a systemic way describes the development level of a given technology – how ready it is, including its technical parameters as well as market introduction readiness. And besides space agencies, it is often used by firms which develop technological products or services (Héder, 2017; Mankins, 2009), and, thus, is a tool that also accompanies the commercialization pathway of technologies. It allows to asses not only the current status of a technology, but to plan the resources and time needed to invest into the technology for it to reach the market.

3.1. The origins of the TRL concept

Originally, the concept of TRL was developed by NASA and later overtaken by ESA for space system needs, however still later on it was adopted by other organizations outside space industry that developed new technologies and wanted to follow stepwise milestones while innovating the new technological products or services. Recently, it becomes more and more adopted and used for public funding schemes and evaluation of inventions (Bruno et al., 2020; Héder, 2017). Hence, the **technology readiness** scale (see Figure 1. Technology readiness level (TRL) scale is a metric for describing the maturity of a technology and is widely used by practitioners, and recently also by policy makers (European Commission, 2016). It consists of nine levels that represent the stages technological innovation goes through, from the very basic idea (level 1) to the full new product development and introduction in the market (level 9). The meaning of each level is described in Figure 1Figure 1.

Figure 1. Technology readiness level (TRL) scale



Source: Johansson et al. (2010)

This scale begins at level 1 and extends to level 9, comprehensively encapsulating the entire new product development cycle, from the initial conceptualization and basic research to market launch and innovation for subsequent generations.

3.2. Why TRL is an important tool for innovation?

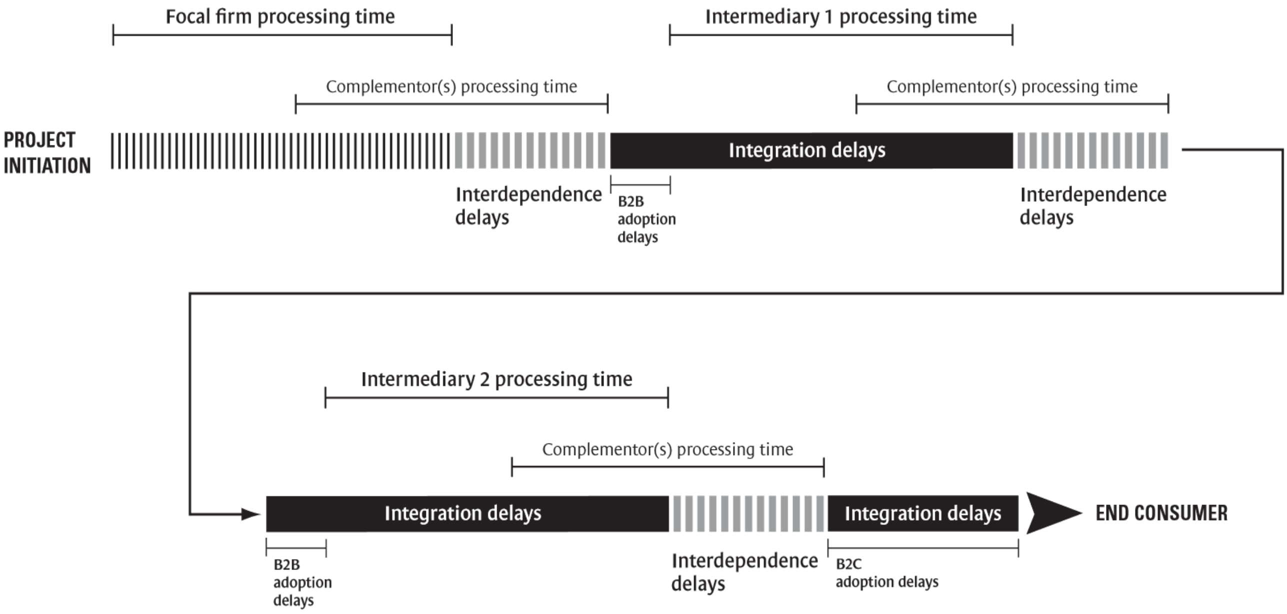
The TRL framework offers a structured scale, where each ascending level builds upon the accomplishments of the preceding ones (Mankins, 2009). The nine progressive stages of the scale effectively indicate the proximity of a technology to its readiness for application in the designated operational context (Héder, 2017). Numerous activities and an extensive amount of time can be dedicated to each phase without specific prerequisites, as the progression of technology development varies significantly across industries and firms, influenced by factors such as internal decisions and the availability of resources.

Therefore, by evaluating the TRL of a technological innovation, insights can also be gleaned regarding the firm's capability to foster innovation. This is particularly relevant as the cost associated with technology development escalates significantly at the higher levels of TRL, with the actual expenditure being highly dependent on the specific technology (Mankins, 2009).

In summary, the TRL framework facilitates the identification of critical stages that technology must undergo to bridge the divide between research and development and actual production or operational deployment as an innovation (Sinquin et al., 2014). Furthermore, academic literature on TRL emphasizes that each stage can be linked to specific financial implications, offering valuable information for both corporations and researchers alike: the cost of developing a technology increases exponentially as it progresses through the higher TRLs.

Technology development expenses escalate dramatically and reach their zenith at TRL 8, marking it as the level that demands the highest financial outlay (Héder, 2017). Mankins (2009b) points out that the specific figures can vary significantly depending on the technology involved. Reflecting on the historical application of TRL in Boeing's research and development activities, a lead scientist from Boeing in 2008 observed that the majority of projects advanced to TRL 6 with less than 10% of the total budget allocated (Whelan, 2008). Yet, it's important to note that while the original TRL framework developed by NASA suggests a substantial cost increase at virtually every stage from TRL 3 to 8, the application of TRL scale within the European Union does not necessarily follow this logic. Instead, the financial implications of advancing through TRL levels in the EU policy context are either not examined or are presumed to follow a linear or moderately increasing trajectory (Héder, 2017). This is the misleading conception that academic literature follows by applying simplistic innovation process, ignoring the fact that before an inventions can reach the market it demands not only high absorptive capacity and dynamic capabilities, but also the strategic inclusion into the challenges of an ecosystem. Adner (2006) invites innovating companies to map an ecosystem into which an innovation has to reach the customer. He illustrates the roadmap of innovation and how many hurdles even at the latest TRL stages innovation face.

Figure 2. Complexity of innovation processes



Source: Adopted from: Adner, Ron. Match Your Innovation Strategy to Your Innovation Ecosystem. Harvard Business Review, April 2006.

Mapping an innovation ecosystem is an effective method for determining if realistic performance expectations have been established for an innovation strategy. Adhering to this process can highlight potential delays that may impede the timely market entry of the innovation and affect its success.

This premise underscores the fundamental source of misconceptions within academic discourse regarding the transition of technology from research phases to market implementation. It also circles back to the driving force behind my thesis: to delineate clearly between the domain of academia and the sphere of commerce within the process of technology transfer.

As the maturation of technology elevates anticipated expenses, particularly during the pilot phase, which may require multiple iterations, it becomes crucial to entrust the commercialization aspect to entities that allocate capital with the expectation of recouping their investment at a later stage.

3.3 Why TRL should be included in academic research on technology transfer between universities and business

In this context, for better understanding of technology development that is the core of innovation process, it is worth looking at I., Bruno et al. (2020) who have proposed graduation of TRLs in the context of product development cycle:

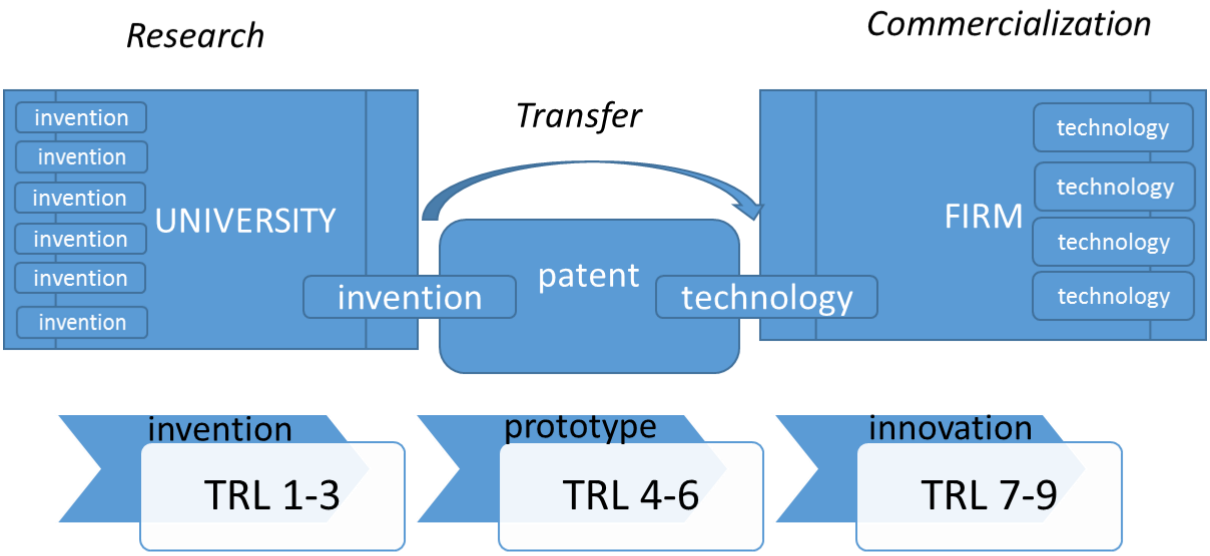
1) TRLs 1-3 pertain to the initial stages of any Research and Development project, where a proof-of-concept is formulated and gradually refined,
2) TRLs 4-6 belong to the validation and demonstration phases, which can and should be realised first in a closed laboratory environment, then in real or near-real world conditions,
3) TRL 7 is the final stage of prototyping,
4) while TRLs 8-9 constitute the usual pre-market and market launch conditions of any new innovation.

Based on this, I delineate the roles of universities and companies at each phase of the TRL scale, addressing a notable gap in the literature on technology transfer regarding the distinct contributions of academic institutions and corporations to the commercialization process. Given that the TRL framework initiates with research activities, I categorize the phase encompassing TRL 1-3 as the invention phase. This phase, from the vantage point of the technology innovation process, predominantly occurs within universities, particularly when firms adopt an open innovation strategy, thereby situating the research component externally to the company. This phase often represents the fundamental research and proof-of-concept stages, where the focus is on validating the scientific principles behind the invention. These stages are primarily academic and exploratory in nature, with significant work needed to demonstrate the feasibility of the technology for practical applications.

The subsequent levels, TRL 4-6, occupy an intermediary position on the scale and present a flexible development landscape. This phase involves further development and validation in a laboratory or simulated environment, moving towards a more defined prototype but not yet a market-ready product. It's during these middle stages that university inventions begin transitioning towards commercial viability, but still require substantial development, testing, and refinement. In certain instances, these stages may continue under the auspices of university research; in others, companies may take the lead in advancing early-stage technologies. This juncture is what I refer to as the transfer stage.

Furthermore, the innovation process from TRL 7 onwards is characterized by pure commercialization, typically unfolding within the corporate domain. While this segmentation is not prescriptive, it mirrors the conventional practices observed in the progression of technology development stages, highlighting the pivotal yet distinct roles played by universities and companies in the journey from concept to commercialization.

Figure 3. Innovation process when licensing university inventions



Source: own illustration

Figure 3 illustrates technology development process and its pathway when a firm, under the practice open innovation, in-licenses an invention from an university and creates innovation. Thus, TRL serves as a pivotal instrument for gauging technological maturity, both within an individual organization and across diverse entities. Owing to its elevated level of abstraction, TRL is instrumental in several key aspects:

- it enables the comparison of various technologies, irrespective of their inherent differences, solely based on their respective positions on the established scale,
- it facilitates the monitoring of a technology's progression through its development stages over time, from inception to completion,
- it aids in the seamless transfer of technologies among different organizations and individuals, ensuring a mutual understanding of the technology’s developmental stage.

Furthermore, TRL emerges as a valuable asset in augmenting academic research focused on technology transfer and open innovation. The discussion in previous section underscores the integration of TRL into research endeavors. This integration aims to heighten the awareness

of academic researchers regarding the necessity of distinctly differentiating between two concepts: technology transfer, which is studied as a transactional process, and technology commercialization, which is frequently, yet erroneously, assumed to be synonymous with technology transfer although is the realm of business (see
Figure 3).

4. Descriptives of invention data

Having access to exclusive data on university inventions and their licensees, which I gathered through a large survey sent to Danish companies (secondary data), in this section I provide brief summary of valuable aspects of this data that in depth describe what is the maturity level when university inventions get licensed to firms.

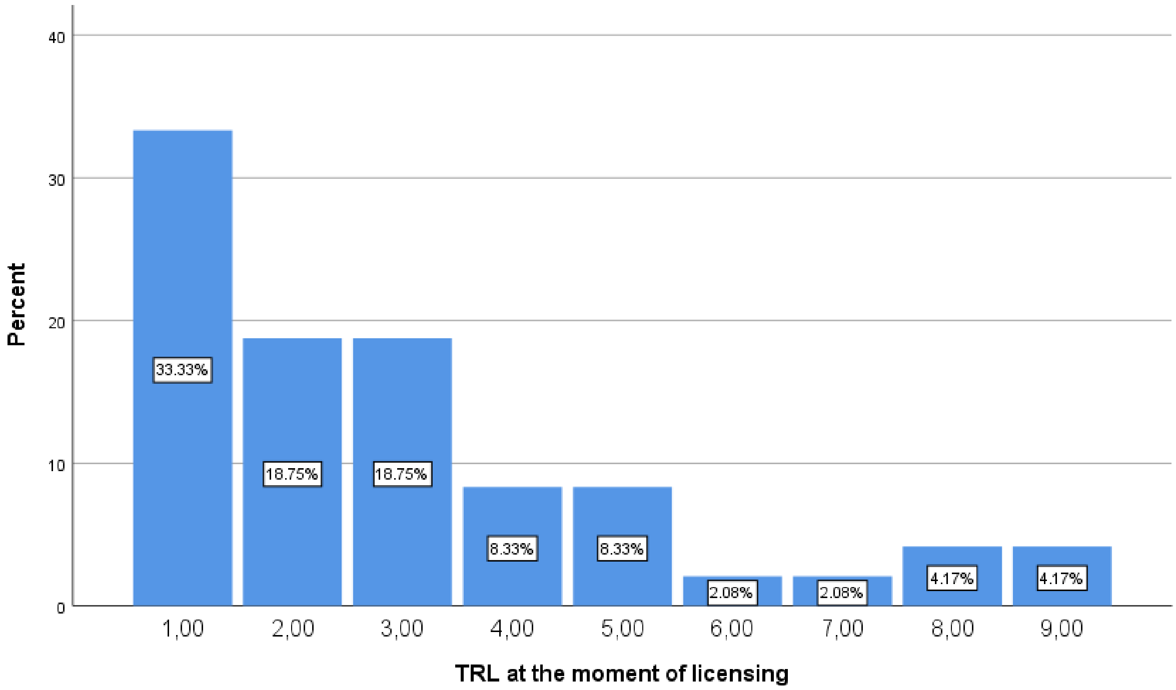
4.1. TRL as maturity indicator

As mentioned above, in my thesis I introduced TRL to assess the maturity of inventions that universities license to firms. University inventions, when licensed to companies, often fall on the lower end of the TRL scale, indicating that they may be considered immature in terms of readiness for commercial application (Maine & Garnsey, 2006; Meyer et al., 2011). Typically, these inventions are at the conceptual or early prototype stages, ranging from TRL 1 to 6.
The maturation process from these early stages to commercial readiness (TRL 7-9) typically necessitates significant investment, time, and specialized expertise to address technical challenges, scale-up production, and navigate regulatory pathways (Mankins, 2009). This development journey underscores the gap between the innovative potential embedded in university inventions and their readiness for commercial exploitation upon licensing.
Therefore, while university inventions hold the promise of novel solutions and technological advancements, they are often immature in the commercial sense at the time of licensing. This necessitates a collaborative effort between academia and industry to undertake the necessary R&D, validation, and commercialization activities to bring these inventions to market.

4.1.1. What is the actual TRL of university inventions?

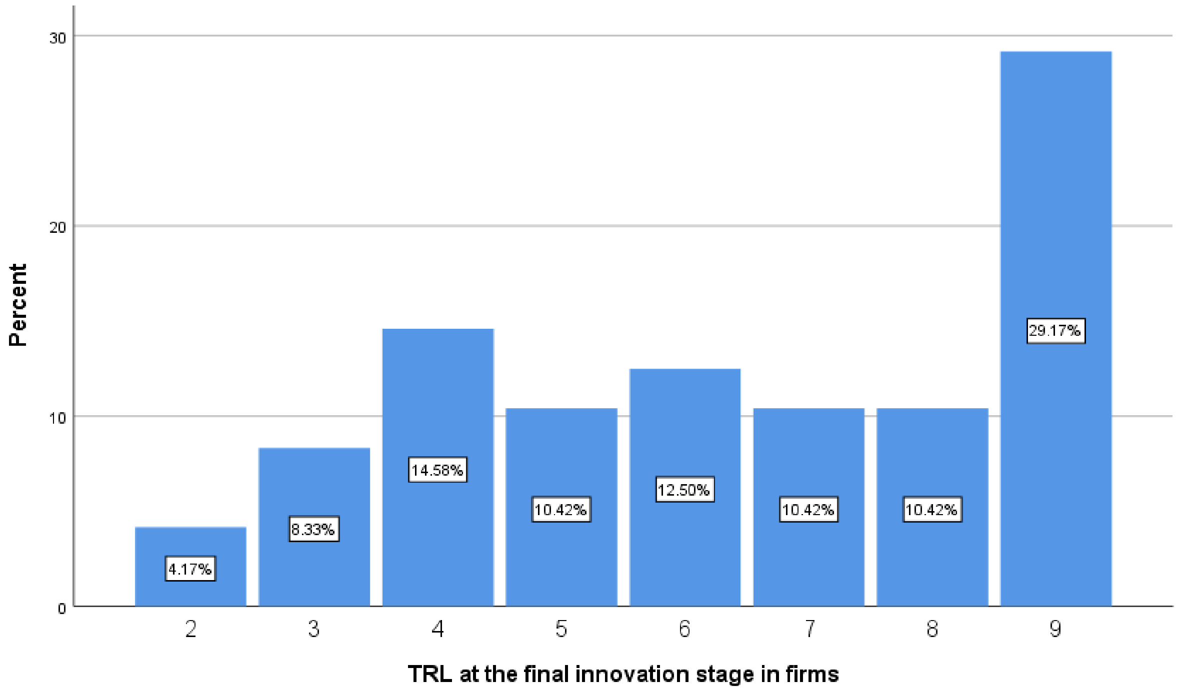
Because university inventions have been criticized of being immature when licensed to companies, empirical evidence was missing in the literature, therefore, I aimed to measure this assumption by assigning TRL to out-licensed technologies. Using TRL as an indicator for technological maturity (see Figure 1), we identify to what extent the technology has been commercialized. We define technology as commercialized if it has reached TRL7 or higher.

Figure 1. TRL of university´s inventions licensed to companies



The analysis of our dataset reveals that a substantial majority, approximately 70%, of university inventions that are licensed out, are, in fact, in the nascent stages of development for commercial exploitation, typically up to TRL 3. This observation aligns prior scholarly work, reinforcing the notion that university-derived inventions often lack the maturity required for immediate commercial application upon licensing (Maine & Garnsey, 2006; Nerkar & Shane, 2007). Intriguingly, our data analysis also indicate the presence of certain inventions that have achieved significantly higher TRLs at the time of licensing, even up to the TRL 9. However, further examination of the underlying data revealed that these particular inventions are associated with licensing to university spinouts, spinning out from the same university. This suggests that researchers with intentions of forming spinout companies may further advance the development of their technology within university laboratories. Such strategic advancement facilitates a smoother transition to commercialization post-licensing, evidencing a deliberate approach to technology development among potential spinout entities. This finding underscores the diversity in maturity levels of university inventions at the point of out-licensing and highlights the role of university environments in supporting advanced development stages, particularly in the context of spinout formation.

Figure 2. Invention commercialization based on TRL scala



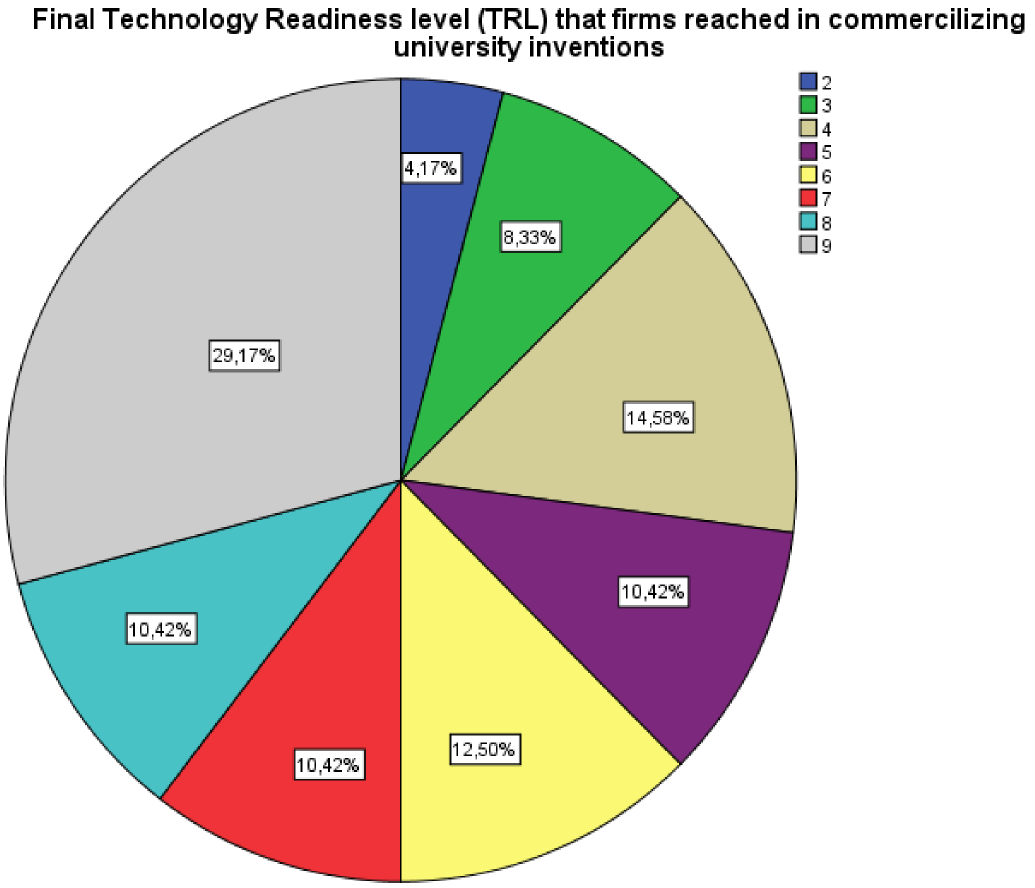
Our evidence on approximate final TRL that a firm had reached after in-licensing the patent through innovation development processes indicates that half of university inventions reach the first early adopter markets or even lead to technology´s further optimization by continuous incremental innovations by reaching TRL 7, 8 or 9 (Figure 6). The other half reached lower TRLs during innovation: 11 technologies placed between TRL 5-6, and 13 technologies - between TRL 2-4. Some of those not yet in the market are still in the process of innovation (at the beginning of 2017 when the survey was conducted) and might reach higher TRL as time passes.

4.1.2. TRL Progress for commercialization

Another interesting aspect from the transfer perspective is to get to know the actual TRL landscape when firms have licensed the patents and developed them into final products or processes. This can give us notion of what is the value of university patents for firms – do firms actually reach the commercialization stage?

Figure 3 visualizes the general distributions of how many university inventions after licensing do get commercialized.

Figure 3. Commercialization landscape of university inventions post-licensing



Furthermore, the crosstabulation results from SPSS software tool present a detailed overview of the progression of technologies from their initial TRL at the time of licensing to their final TRL, as observed in a dataset of 48 licensed university inventions. This analysis allows for a nuanced understanding of how technologies evolve in terms of readiness for commercialization after being licensed.

Crosstabulation analysis (see Table 1) allows to observe the innovation development dynamics per TRL. The higher will be TRL at licensing, the higher TRL is reached at the end of innovation inside firms.

Table 1. Correlations between invention maturity and its commercialization: crosstabulation of TRL at licencing and final TRL reached by firms

Licensing TRL / Final TRL	**TRL 2**	**TRL 3**	**TRL 4**	**TRL 5**	**TRL 6**	**TRL 7**	**TRL 8**	**TRL 9**	**Total**
TRL 1	1	2	2	2	4	2	0	3	16
TRL 2	1	1	1	1	0	1	0	4	9
TRL 3	-	1	4	0	1	1	1	1	9
TRL 4	-	-	0	2	0	1	0	1	4
TRL 5	-	-	-	0	1	0	2	1	4
TRL 6	-	-	-	-	0	0	1	0	1
TRL 7	-	-	-	-	-	0	0	1	1
TRL 8	-	-	-	-	-	-	1	1	2
TRL 9	-	-	-	-	-	-	-	2	2
Total	2	4	7	5	6	5	5	14	48

The table presents the distribution of TRLs across different final TRL stages. The "Total" row and column summarize the number of projects at each licensing TRL and each final TRL, respectively.

At the time of licensing, the distribution of inventions across the TRL spectrum is varied, with the majority being in the early stages (TRL 1 to 3). Specifically, 16 inventions were at TRL 1, indicating a very early stage of development. As these inventions progress, a diverse trajectory is observed in their maturation to higher TRLs. Notably, 3 of the inventions initially at TRL 1 reached the final stage of development (TRL 9), showcasing a significant advancement through the commercialization process.

The data also illustrates a diminishing trend in the number of inventions achieving higher final TRLs as the initial TRL increases. For instance, inventions that were licensed at TRL 2 and TRL 3 show a spread across various final TRLs, but with fewer reaching the highest maturity level (TRL 9) compared to those licensed at TRL 1. This could suggest that inventions licensed at the earliest stages of development have a broader potential for advancement, possibly due to the longer timeframe available for development and the opportunity for more extensive research and development activities post-licensing.

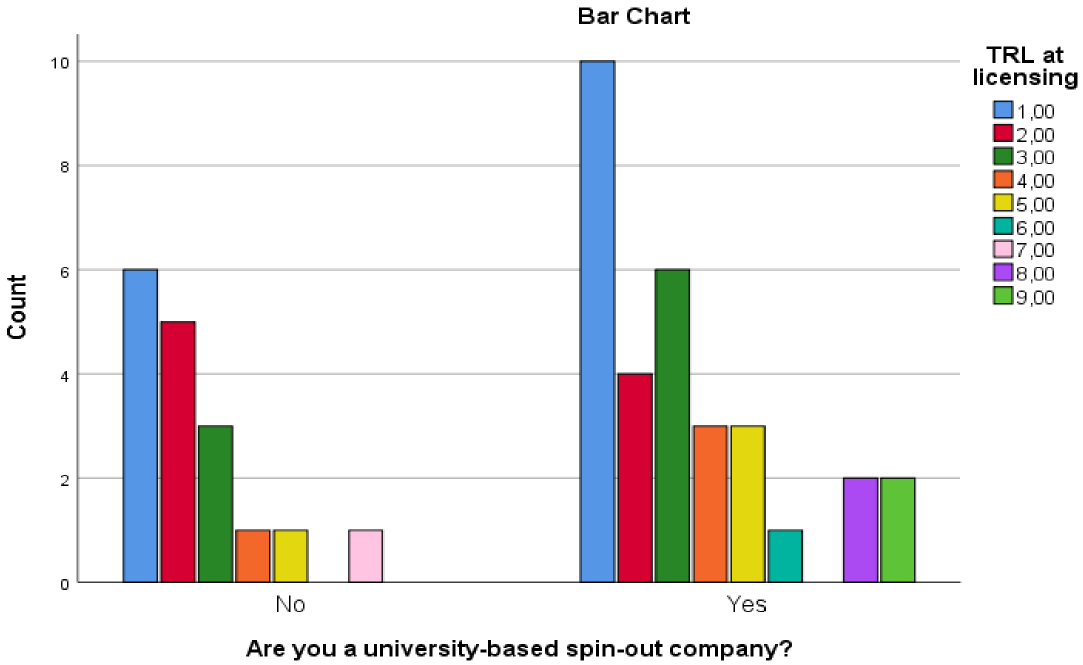
Interestingly, the data reveals that no inventions were licensed at TRLs 4 through 9 that remained at the same level of technological readiness, indicating that all licensed technologies experienced some degree of development progress. The progression from TRL 6 to TRL 7, TRL 8 to TRL 9, and directly from TRL 9 to TRL 9 again (indicating a technology already at market readiness at the time of licensing that maintained its status) highlights specific pathways through which technologies mature to market readiness.

This crosstabulation not only confirms the dynamic nature of technology development post-licensing but also underscores the potential impact of university and industry collaboration in advancing technologies through various stages of readiness for commercialization. It further illustrates the significant role university spinouts may play in the technology transfer process, as inferred from the advanced stages of development at licensing and the subsequent achievement of market readiness.

4.1.3. Highlighting the TRL differences by licensee types

In the next step, I was adding more data to the previous crosstabulation table, namely licensee type wondering what companies in-license university inventions, and found interesting results, which provide new empirical evidence for the literature on technology transfer. Because of data availability we can make detailed descriptive analysis regarding the difference between university spinouts and incumbents when commercializing out-licensed technologies.

Figure 4. Distribution of TRLs at licensing stage for university spinouts vs. incumbents



The bar chart illustrates the distribution of Technology Readiness Levels (TRLs) at the licensing stage for two categories of entities: those that are university-based spinout companies and those that are not (are mainly large corporates):

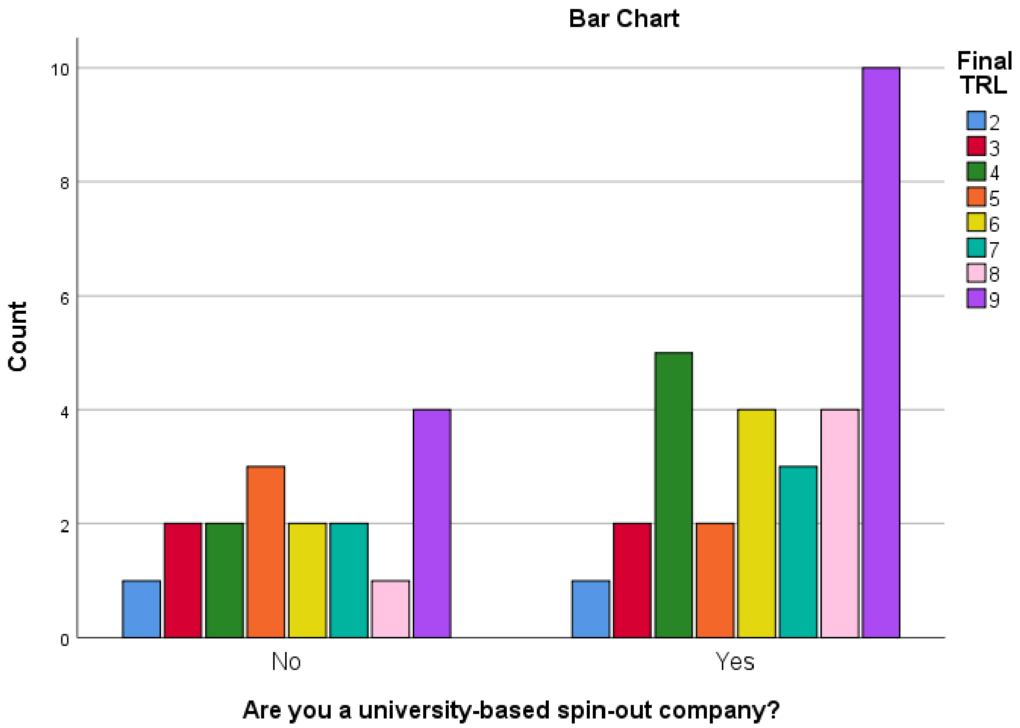
- The horizontal axis (X-axis) represents whether an entity is a university-based spin-out company, with two distinct categories: "No" and "Yes";
- The vertical axis (Y-axis) shows the count of licensed inventions at each TRL stage, which is indicative of how many inventions are at a particular stage of technology development;
- The bars are color-coded to represent different TRLs, ranging from TRL 1 to TRL 9, as indicated in the legend on the right side of the chart.

Drawing from the chart visuals, some conclusions can be made:

1) the majority of licensed inventions to not university spinouts are concentrated at TRL 1, and all of the inventions licensed are placed mainly between TRL 1 and TRL 5, indicating that incumbents have licensed inventions at the earliest stages of technology development;
2) for university-based spinout companies, there is a more even distribution of licensed inventions across TRLs, with the highest count at TRL 6, and exceptionally two technologies even reaching TRL 8 and 9 at the moment of licensing, suggesting a more advanced stage of technology development when licensing to these companies.

The data visualized in this bar chart could be used in future studies to analyze the effectiveness of university-based entrepreneurship programs, the commercial potential of the technologies developed within universities, and the overall landscape of technology development among different types of companies who license university inventions.

Figure 5. Distribution of TRLs reached by companies after licensing: university spinouts vs. incumbents



The bar chart represents the commercialization readiness of university inventions after they were out-licensed to companies for further development, recording the final TRL that companies reached with the particular invention. Practically, this means that if companies buy immature technologies, they have to invest resources, knowledge and time to develop these immature technologies into innovations.

From the chart, we can observe the following:

1) no inventions at TRL 1 are depicted, suggesting that none of the out-licensed technologies are left at the concept stage, and have been introduced into the process of innovation within all kind of companies;
2) for companies that are not university-based spin-outs, there's a relatively uniform distribution across TRLs 2 to 7, with no single TRL dominating;
3) despite the fact that incumbents in-license immature inventions, many of these technologies have reached full commercialization stage, up to TRL 9;
4) for university-based spinouts the distribution of invention development levels is more varied: there are inventions across all TRLs from 2 to 9;

5) differently to incumbents, there is a significant peak at TRL 9, suggesting that spinouts are more likely fully developed technologies and to commercialize these.

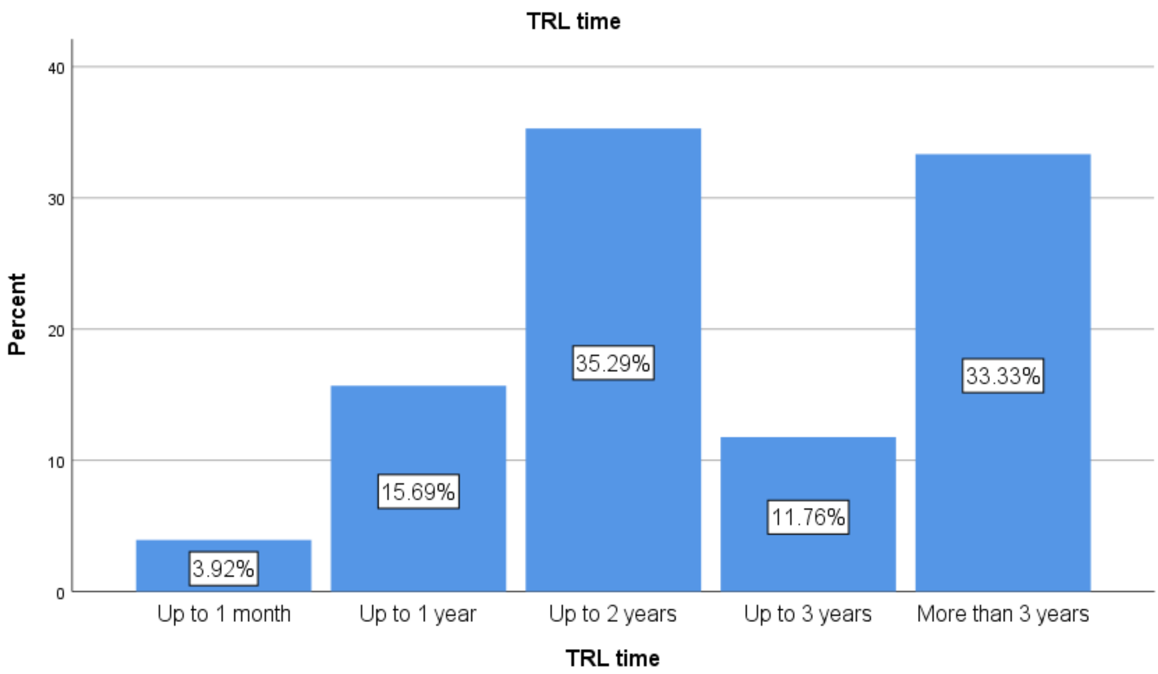
In conclusion, the graph could suggest that spinouts are possibly better equipped or more inclined to bring immature inventions to market than incumbents. Despite this starting disadvantage, university spinouts seem to excel at advancing these early-stage technologies through the development process and bringing them to market effectively. This suggests that university spinouts may possess unique advantages, possibly including a closer connection to the original researchers (or being one of them) and a deeper understanding of the technology's potential, as well as familiarity with the technology's development process, which allow them to nurture and advance the inventions more efficiently than incumbent firms (Zahra et al., 2007). Additionally, this might reflect a strategic choice by researchers to nurture their innovations within the academic environment until they reach commercial viability, thereby hinting at an inherent ambition to oversee the commercialization of their intellectual endeavors by spinning out. In contrast, the lacuna of advanced TRLs among non-spin-out entities could denote a deliberate focus on the developmental aspect of technologies, rather than their immediate market introduction. This development-centric approach may also underscore the ancillary nature of these inventions within their respective portfolios. I also agree with statement of (Mankins, 2009) that final TRL reached by companies might be technology, industry and application dependent.

To further understand the impact and success of these out-licensing efforts, additional data on the market performance of these inventions and the long-term outcomes for both university-based and non-university-based companies would be valuable. This could include metrics like market adoption, revenue generated, and the growth of the companies involved. All in all, the data suggest that university inventions have a great potential to become innovation and it witness a success for technology transfer.

4.2. Innovation time line

Time is the variable that shows how long it takes companies to develop in-licensed inventions into innovations and to bring these to market, in the academic literature on innovation referred as innovation speed. Innovation speed, defined as the ability to move fast from one idea to an actual product (Kessler & Bierly, 2002), has become increasingly important for firm´s ability to innovate by providing 'the most value for the lowest cost in the least amount of time' (Stalk, George Jr.; Hout, 1990, p.31), either as a market leader or through a fast follower strategy. Innovating firms admit that overly long technology development times is the main obstacle to generate returns on innovation and product development (Ringel et al., 2015). Thus, long innovating time might lead to lower value capture, the value firms earn with their innovations. Given this outlook, I can answer on of the research questions from my thesis asking what maximizes the value created by university patents: innovation speed is an innovation component, which maximizes the value creation.

Figure 6. Absolute innovation time within companies after technology in-licensing



The bar chart in Figure 6 provides a distribution of technology development times as measured by TRL final stage time. Each time bar represents a percentage of technologies which needed given time to reach their finalized TRL, not sorted from lowest to highest TRL. Thus, this graphic takes into account only the time in years each firm invested to move forward with the in-licensed technology.

Such a display of time frame chart allows to make following observations:

- a small fraction of technologies, approximately 4%, are developed to the target TRL within one month;
- a larger segment, 15.7%, achieve this within up to one year;
- the most significant proportion, 35.3%, require up to two years for development;

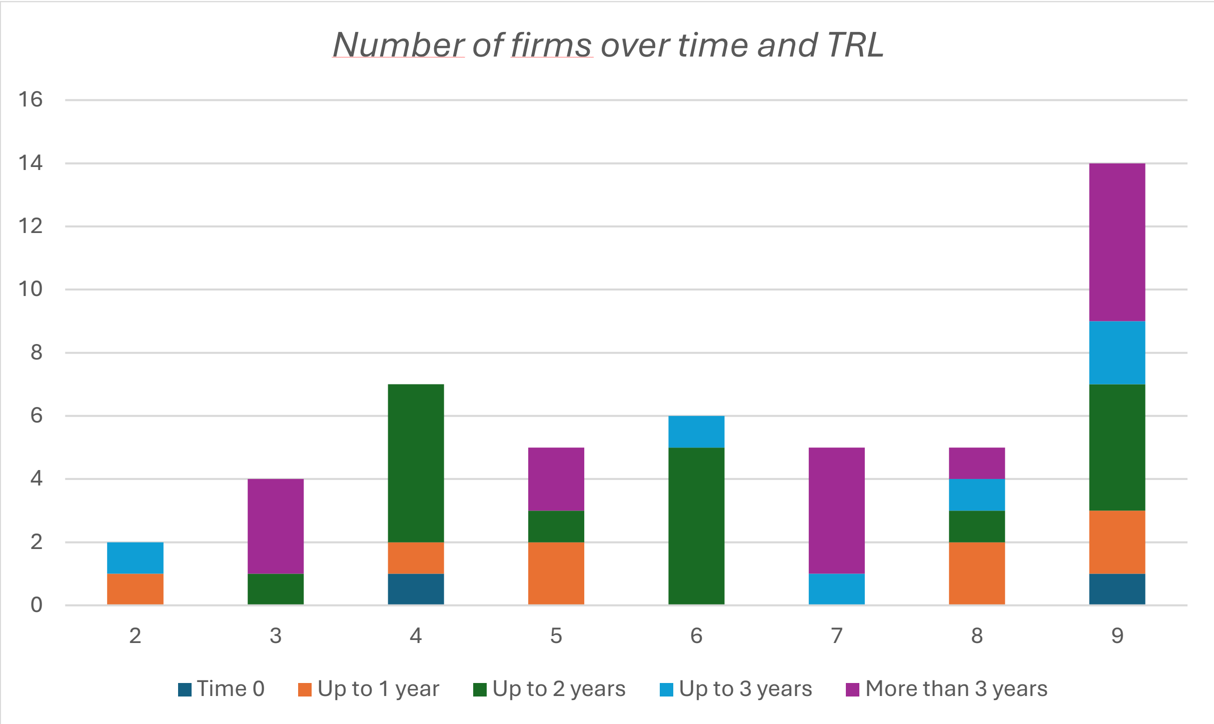
- a smaller percentage, 11.8%, reach the desired TRL in up to three years;

- finally, a substantial portion, 33.3%, necessitate more than three years of development to attain the target TRL.

Further,

Figure 7 illustrates a better understanding of how much time needs to be invested in technology commercialization, especially to reach the TRL 9. The x-axis represents the TRLs, ranging from 2 to 9. The y-axis represents the number of firms. Each bar is divided into five colored segments representing different time durations it takes for firms to reach the respective TRLs.

Figure 7. Time needed to reach particular TRL



From the distribution in Figure 11, we can deduce that:

- slightly more than half of the technologies, when combining the percentages for up to one month, up to one year, and up to two years (which totals approximately 55%), are developed within a two-year period;

- further, almost half, roughly 45%, of all technologies require more than two years for development up to the target TRL. This indicates a significant portion of technologies are associated with longer development cycles;

- consequently, over 30% of all technologies will take more than three years to develop, highlighting that a significant number of technologies are involved in extended development processes.

The graph shows that as the TRL increases, it generally takes a longer time for firms to reach that level of technological development. For example, TRL 9 has the tallest bar, predominantly consisting of the red segment, meaning a larger number of firms took more than 3 years to achieve TRL 9. Conversely, lower TRLs such as TRL 2 and 3 have more firms that reached these levels within a year. The trend suggests that initial technology development stages are achieved more quickly, while advanced stages require significantly more time.

The data reflects the time-intensive nature of technology development, where a considerable number of technologies demand extended periods to progress through the TRL stages to move forward and to reach the market. This can be contingent to many internal and external factors, potentially due to the complexity of development, the need for extensive testing and validation, resources and absorptive capacity of companies, or other factors inherent to the technology maturation process.

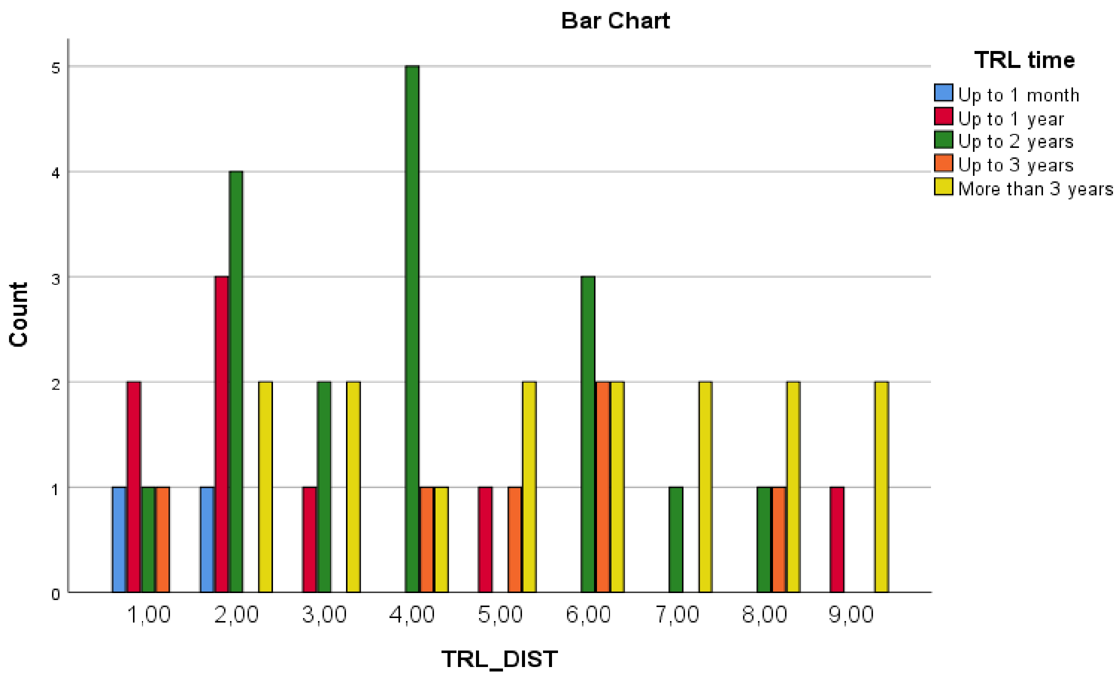
The significance of a firm's age in determining the pace of innovation is a critical observation derived from an analysis comparing firm longevity with their innovation timelines. The empirical evidence suggests that more established firms exhibit a notably slower rate of innovation compared to their younger counterparts. Specifically, companies younger than 10 years demonstrate, on average, a capacity to innovate at a rate twice as fast as that of older firms. Additionally, spinouts generally require more time to develop innovations than non-spinouts, although the temporal discrepancy between these two categories is minimal. The process of licensing technologies from universities at an early stage reveals a uniform duration for innovation development among both spinouts and incumbent firms, averaging slightly over three years to achieve full commercialization.

Consequently, the process of technology commercialization within corporate entities necessitates a protracted temporal investment, with a significant proportion, approximately one-third, extending beyond a three-year period. This elucidates that firms commit not merely financial and material resources but also substantial time towards the commercialization efforts. Such a temporal commitment is frequently underrepresented within the discourse of technology transfer literature.

4.3. Time investment and TRL progress

Our dataset facilitates a more nuanced exploration into whether inventions licensed at low TRL necessitate extended development time, as well as the interplay between the duration of time invested by companies in the further innovation of in-licensed technology and the maturity level of the in-licensed invention. Specifically, drawing upon the figure presented in the preceding section, this analysis delves into the temporal investments made by firms in the advancement of in-licensed technology, juxtaposing it against the quantum of TRL advancements achieved within this timeframe.

Figure 8. Analysis of TRL advancement and associated invested development time



The metric of interest, denoted as TRL distance on the horizontal axis, quantifies the progression of each technology by tracking the TRLs surpassed from the point of in-licensing to the final TRL the technology reached in the innovation process (thus, not necessarily, the highest TRLs). This metric doesn't account neither the starting TRL nor the final TRL, but purely counts how many TRLs one technology jumped over. This measure enables an examination of not only the duration required to attain TRL 9, but also the variance in time that firms require to jump from one TRL to the next advancing through the TRLs. As depicted in Figure 8, there is an absence of a discernible correlation between the time requisite for development and the TRL distance. It is noteworthy that certain technologies fail to reach the commercialization phase (TRL 7-9) yet still demand a considerable development timeframe of approximately 2.3 to 2.5 years. Furthermore, there is no big difference between incumbents and spinouts how fast technologies are developed.

The process of technological advancement is inherently dynamic; thus, it should not be presupposed that less mature inventions will invariably necessitate extended development periods compared to those that are more advanced. The innovation timeline is influenced by a myriad of contingent factors, such as complexity, industry, and firm resources, which are explored comprehensively in Paper 3 of the corresponding dissertation.

4.4. Technology radicalness level

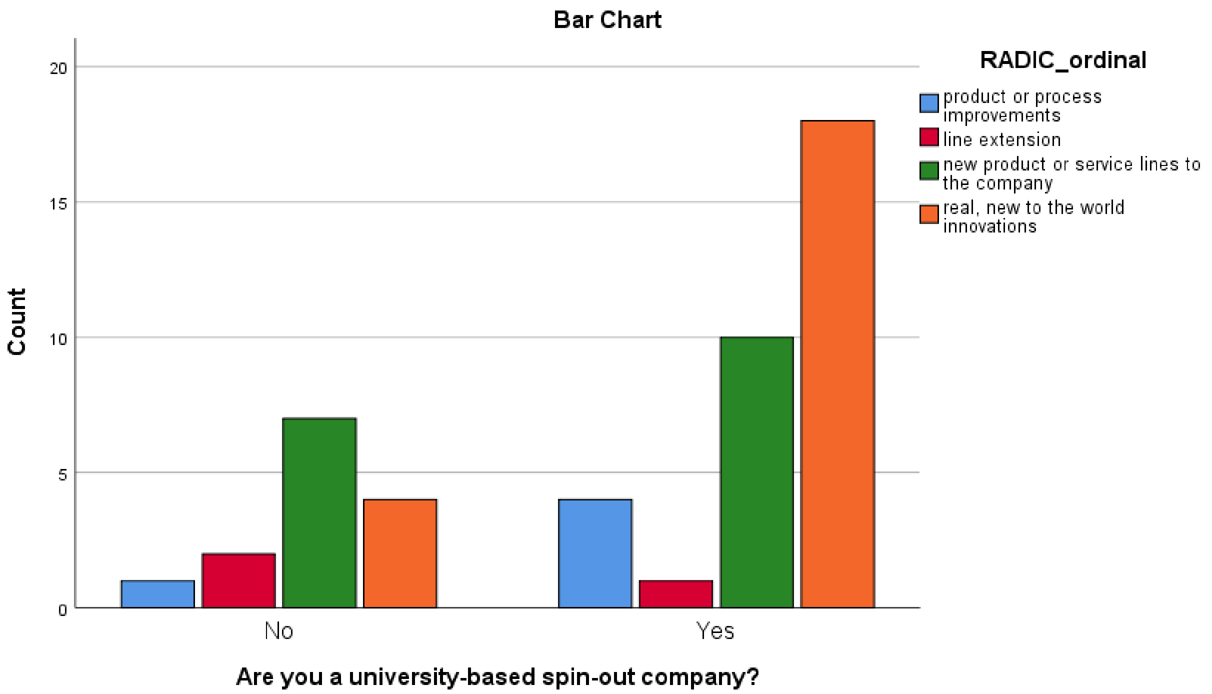
Another variable that I looked at was radicalness of technology due to the ability of radical technologies to solve sustainability challenges and to maximize value by providing market advantages.

Radical innovations generate new-to-the-world outputs and changes the status quo of how business is done at the level of the firm (Chang et al., 2012; Linton, 2009). Therefore, radical innovations bear high risk and uncertainty and significantly *influence the marketplace* (O'Connor & McDermott, 2004). Thus, radical innovations provide competitive advantage for firms in the market and at the product or process level is a ´door opener´ to disruptive innovation that can change the market paradigm (Bergek et al., 2013). In the context of this explorative research, the radicalness is an important factor to look at as it increases the value of technologies (Henkel et al., 2015), thus contributing to my research question 3 of the dissertation what maximizes the value created by university inventions.

To examine if such technologies, which disrupt the market, have been developed from university patents, I retrieved to the survey question on radicalness. And I also added additional category to this chart diagram, namely distinction if the company is a spinout or incumbent to gain more grained results.

Literature recognizes that university-based spinouts are seen as better innovators of radical technologies because of their foundation in high-quality science (Marvel & Lumpkin, 2007). University spinouts are increasingly recognized for their pivotal role in driving radical innovations, leveraging the deep scientific knowledge and research outcomes from their academic origins to disrupt and transform industries. They excel in translating cutting-edge research into innovative products, services, and technologies that challenge the status quo, contributing significantly to economic growth and societal advancement. Yet, at the same time, the commercial success depends a lot from availability of venture capital, underlining the critical role of financing in bringing radical innovations to market (Fukugawa, 2023).

Figure 9. Distribution of four levels of radicalness per spinouts and incumbents



Our data confirms the hypothesis, demonstrating that spinouts predominantly engage in the development of radical technologies, doing so at a significantly greater volume when compared to incumbent firms.

One of explanations is the involvement of inventors in technology commercialization. The radicalness of innovation is significantly influenced by the human capital within technology entrepreneurs, especially those operating within university-affiliated incubators. Marvel & Lumpkin (2007) found that innovation radicalness is positively associated with entrepreneurs' formal education and prior technological knowledge, suggesting that the unique human capital attributes of university spinouts play a crucial role in fostering breakthrough innovations.

Similarly, Zahra et al. (2007) in their research identified that in order to transform inventions into new products, goods and services that create value requires a "knowledge conversion capability" that has three components: conceptualization and visioning of applications of that knowledge; configuration and design of potential products and other applications; and the embodiment and integration of knowledge into products. By comparing university-based spinouts and corporate spinouts, they found that university-based spinouts are better in developing more radical innovations due to their skills of knowledge conversion.

Moreover, Henkel et al. (2015) found that new market entrants have increased likelihood of choosing more radical R&D approaches and, thus, generating higher value innovations. This finding answers the research question of my research about value maximization by defining radicalness as the factor for value maximization.

In conclusion, university spinouts stand out as key innovators of radical technologies, driven by their strong foundation in quality science, the unique human capital they possess, and the strategic collaborations they engage in with industry partners. These factors collectively contribute to their capability to introduce groundbreaking innovations that have the potential to redefine industries and spur economic development.

In this Working Paper, I hypothesize that such paradigm shifts occur through the development of radical technologies, specifically sustainable technologies that are often radical and innovative in the market. This topic is explored further in my PhD thesis.

5. Conclusions

In this Working Paper, the data exploration methodologically advances and deepens the understanding of technology transfer and commercialization processes, thus, contributing to one of the main goals of my PhD thesis and filling the literature gaps. The Paper provides a comprehensive analysis of the maturity levels of university inventions at the time of licensing to firms, utilizing TRL as a metric for assessing technological maturity. It reveals that the majority of university inventions are in the early stages of development, often not exceeding TRL 3, indicating a gap between the innovative potential and commercial readiness. I could observe that university-originated inventions are predominantly licensed at preliminary TRLs, a finding that corroborates existing academic discourse regarding the nascent stage at which university technologies are typically introduced to industrial partners (Maine & Garnsey, 2006; Nerkar & Shane, 2007). Additionally, it discusses the role of university spinouts in achieving higher TRLs, highlighting their strategic advantage in technology development and commercialization.

Moreover, the pathway of innovation is often marked by premature termination, where university patents that hold promise fail to evolve into commercialized products or processes. This discrepancy highlights a critical misunderstanding within the technology transfer literature, which may inaccurately classify such out-licensing as successful commercialization despite the absence of market introduction. This observation underlines the intricate and frequently non-linear process of bringing technological innovations to the market, illustrating that not all research findings transition to commercial success, regardless of their perceived value to firms focused on innovation (Mooi & Wuyts, 2021; Nerkar & Shane, 2007). This delineation clarifies the challenges inherent in the commercialization process, emphasizing the need for a nuanced understanding of what constitutes true commercial success in the realm of technology transfer.

However, the intrinsic value of these embryonic technologies for companies endeavoring to innovate remains indisputable, especially for excellent research (which are the large majority of university inventions) allowing to gain patent rights. This conclusion echoes the findings of (Poege et al., 2019) who articulated that the metrics of "excellence" within the scientific community are predictive of superior outcomes in the technological and commercial domains. Their assertion, “what is considered 'excellent' within the science sector also leads to outstanding outcomes in the technological or commercial realm,” provides a critical lens through which the value of academic research to commercial success can be appreciated.

This empirical evidence substantiates the initial hypothesis posited in my thesis, affirming that university inventions indeed contribute valuable assets for firms' innovation activities.

In sum, this explorative inquiry not only validates the significance of university technologies in the innovation ecosystem but also highlights the multifaceted challenges and opportunities inherent in the journey from invention to commercialization. The findings of this study contribute to a deeper understanding of the mechanisms through which academic research can impact technological advancement and economic growth, thus offering valuable insights for policymakers, researchers, and industry practitioners alike.

These results warrant a cautious interpretation due to the limited scale of the sample. Nonetheless, discernible patterns emerge, warranting attention. It is crucial to note that my analysis is grounded in descriptive methodologies, eschewing statistical manipulations. This approach ensures the integrity of data representation, allowing for the observation of trends without the influence of data manipulation. Such a methodological stance underscores the preliminary yet insightful nature of our findings, highlighting the necessity for further research with larger datasets to validate these emergent trends comprehensively.

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