Universidade de Aveiro Departamento de Economia, Gestão e Engenharia Industrial e Turismo
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Modelos de comercialização de tecnologias

Technology commercialization models

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Gestão Industrial, realizada sob a orientação científica do Prof. Doutor Pedro Manuel Moreira da Rocha Vilarinho, Professor Auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro

Para o Xavier.

“Doutoramento, um trabalho que demora muito tempo.”
(Xavier, 4 anos)

o júri

presidente

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palavras-chave

Inovação, competitividade, economias do conhecimento, empreendedorismo de base tecnológica, valorização do conhecimento, valorização da tecnologia, processo de transferência de tecnologia, modelos de comercialização da tecnologia, risco, valor, avaliação do processo.

resumo

O desenvolvimento económico sustentado das empresas é um fator chave para a competitividade. Num ambiente competitivo global, intenso e dinâmico, a eficiência e rapidez do desenvolvimento de novos produtos e serviços pode permitir obter a diferenciação que sustenta uma vantagem competitiva. De forma a tornar a inovação numa competência sustentada, é necessária a criação de um eficiente processo de transferência de conhecimento dos centros de investigação e desenvolvimento (I&D) para as empresas. A criação de valor económico e social requer que o este conhecimento seja incorporado numa tecnologia. A eficiência dos processos de comercialização de tecnologias tem impacto na criação de novas empresas de base tecnológica e consequentemente no desenvolvimento económico do país. No entanto, as elevadas taxas de insucesso destes processos são um forte sinal da necessidade de investigar novos modelos de comercialização.

Neste contexto, a definição de novos modelos de comercialização de tecnologia é de destacada importância para aumentar a eficiência do processo, para a criação de valor a partir do conhecimento gerado pela investigação e desenvolvimento e consequentemente para aumentar a competitividade.

A principal contribuição deste trabalho de investigação reside na proposta de um novo modelo de comercialização de tecnologia, resultante da análise de diferentes modelos de comercialização de tecnologia, na identificação dos seus fatores críticos de sucesso, bem como dos elementos facilitadores. De forma a atingir estes objetivos, o trabalho incidirá sobre a:

i. Descrição teórica do processo e dos conceitos inter-relacionados;
ii. Análise de processos, atividades e dos diversos atores envolvidos;
iii. Análise do valor e do risco da tecnologia, bem como da assimetria de informação entre os atores;
iv. Definição e a avaliação de um novo modelo valorização da tecnologia e na redução do risco.

keywords

Innovation, competitiveness, knowledge based economies, technology-based entrepreneurship, knowledge valorisation, technology valorisation, technology transfer process, commercialisation models, risk, value, process assessment.

abstract

Sustainable economic development is a key factor for competitiveness. In a global, intense and dynamic competitive environment, efficiency and development lead time of new products and services enablers' differentiation and competitive advantage. In order to make innovation a sustained competence, an efficient knowledge transfer process from Research and Development (R&D) organizations to other parties is required. The deployment of this knowledge to create social and economic value requires it to be embedded in a technology. The efficiency of technology commercialization processes impacts the creation of new technological-based companies and consequently countries economic development. However these processes have high failure rates which point toward the need to investigate new technology commercialization models.

In this context, the definition of a new technology commercialization model is particularly important to increase process efficiency, to create value from knowledge generated by research and development and therefore to increase competitiveness.

This research work main contribution, towards different technology commercialization models analysis, their critical success factors, and enablers´ identification, is to propose a new technology commercialization model. In order to achieve these objectives, the work will focus on:

i. Process theoretical description and inter-related underpinnings;
ii. Process, activities and involved actors analysis;
iii. Technology risk, value and informational asymmetry analysis;
iv. Proposal of a value approach and risk reduction technology commercialization model and assessment model.

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ACRONYMS

AUTM – Association of University Technology Managers

BA – Business Angels

BDA – Bayh-Dole Act

BRL – Business Readiness Levels

EIF – European Investment Found

EVCA – European Private Equity & Venture Capital Association

GCI – Global Competitiveness Index

GDP – Gross Domestic Product

IUS – Innovation Union Scoreboard

IP – Intellectual Property

IPR – Intellectual Property Rights

KEI – Knowledge Economy Index

KVU – Knowledge Valorization Unit

NPD – New Product Development

POC – Proof of Concept

POCC – Proof of Concept Centre

R&D – Research and Development

TLO – Technology Licensing Office

TPM – Technology-to-Product-to-Market linkages

TRLs – Technology Readiness Levels

TTO – Technology Transfer Office

VC – Venture Capital

WB – World Bank

WEF – World Economic Forum

1 OVERALL INTRODUCTION

1.1 Introduction

There is a recognized need for industrial economies to change their development paradigm from one based on the exploitation of resources to a new one based on knowledge and innovation. As Thurow observes [1], “The world is moving from an industrial era based on natural resources into a knowledge-based era based on skill, education, and research and development”. So, knowledge as a base for innovation has emerged as a crucial source for economic development and job creation. Schumpeter in his seminal book “Capitalism, Socialism and Democracy” conceptualised a process, coined creative destruction, where the old is ~~being~~ constantly replaced by the new, thus identifying innovation as the critical dimension of economic change [2].

The European Union recognised this need to change the economic development paradigm, by defining in the Lisbon Strategy [3], “a new strategic goal for the next decade: to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion”. This statement is reaffirmed in the Europe 2020 Strategy [4] for smart growth through more effective investments in education, research and innovation. Thus, the Union recognizes in both strategies that strengthening knowledge and innovation are drivers of future growth and, to achieve this, there is a need to improve the quality of education, enhance research performance and promote innovation and knowledge transfer, so that innovative ideas can be turned into new products and services that generate growth, quality jobs and help address European and global societal challenges.

Research and Development (R&D), a crucial source of knowledge, fosters social and economic value by converting the knowledge generated into innovation. R&D, as defined in the Frascati Manual [5], is “the creative work undertaken on a systematic basis in order to increase the stock of knowledge and the use of this stock of knowledge to devise new applications”. The Oslo Manual [6] defines two main types of innovation: (i) marketing and organizational innovation, and (ii) technological product and process innovation. For the purpose of this work, we henceforth use the term innovation to refer to the latter type of innovation that, according to the Oslo Manual, comprises implemented[1] technologically new products and processes and significant technological improvements in products and processes.

Dewar & Dutton [7] distinguished two types of innovation based on the degree of technological knowledge embedded into it: (i) radical innovations, containing a high degree of new knowledge, and (ii) incremental innovations, having a low degree of new knowledge. In the literature on innovation (e.g.[8]), radical and incremental innovations are related to two different innovation strategies: technology pull and market push. Innovation based upon market pull is developed by the R&D

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[1] A technological product or process innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation).

function in response to an identified market need [8], [9]. In contrast, technology push strategy implies that a new invention is pushed through the R&D function to the market in order to fulfil an unmet (or ill met) market need.

According to the Association of University Technology Managers (AUTM), technology transfer is defined as the process of transferring scientific findings from one organization to another for the purpose of further development and commercialization. Thus, this process is a key enabler for amassing knowledge that is generated through R&D, to foster the referred radical innovations.

Following this perspective, technology transfer has taken a lead role in creating new businesses, sustaining the development of existing businesses and creating new jobs, therefore it needs to be assumed as a strategic area for a nation’s economic growth. As a result, multiple technology commercialization models have been implemented in order to maximize transfer efficacy, i.e., the increase of social and economic value for each money unit spent in R&D. Technology commercialization involves a formal transfer of Intellectual Property rights to the market [10]. The commercial mechanisms of technology transfer are diverse and can vary from licensing agreements to technology-based start-ups. Traditionally, patenting and licensing technologies has been the preferred path for commercialization, however, recent attention has also been put on the creation of spin-offs with the researcher’s involvement.

The literature review (e.g.,[11]–[15]) shows that, around the world, similar approaches of technology commercialization have been adopted that encompass a set of crucial steps, namely: (i) invention disclosure, (ii) technology intellectual property protection (e.g., patenting) and (iii) commercialization through licensing or spin-off/start-up creation. The stages and main activities of the technology commercialization process may vary according to the sequence and implementation strategy, often occurring simultaneously.

The perceived value and risk of technology plays a major role in assessing the preferred path for technology commercialization and differs according to the process stakeholders involved in the technology development process. In order to diminish this valuation mismatch, the technology commercialization process should be designed to reduce this information asymmetry and to reach a tipping point in which a ‘fair value’ is perceived by the relevant stakeholders.

Technology commercialization returns have also been in debate for quite a long time, due to the difficulty in measuring its direct and indirect impacts. Direct impacts, such as return on investment, are rarely measured due to [16]: (i) the long-time lags between technology transfer events and the successful commercialization of new products, (ii) the multiple difficulties, and significant costs, of assessing economic impacts resulting from technology transfer, and (iii) the fact that, after technologies are transferred from the public to the private sector, subsequent commercialization activities and economic impacts are generally beyond the public institution’s direct purview and control.

In the technology commercialization process, as in any other process, there is a cause and effect chain between the process aims and outcomes. Process outcomes need to be measured and any selected measure should be an element of this chain. As such, there is a need to establish a mix of lag indicators (outcome measures) and lead indicators (performance drivers) which, in the case of technology transfer, are not always easy to derive due to the reasons pointed above.

The development of a technology commercialization model that addresses these critical issues, namely information asymmetry between stakeholders, value and risk perception and the development of a knowledge valorization strategy map, will contribute to the process efficacy.

1.2 Objective

Innovation drives competitiveness and public funded research is crucial for generating the knowledge that nurtures innovation [17]–[19]. Knowledge valorization, i.e. the formal transfer of knowledge resulting from basic and applied research in research organisations to other parties to create social and economic benefit [20], requires a set of structured mechanisms, to transform inventions into commercial products or services, that are critical elements of effective technology transfer. Some countries have established processes for identifying promising discoveries generated by research carried out in public funded institutions and aid the development of these inventions up to a point where private funding picks them up to engender successful commercial products or services [21].

Therefore, technology commercialization is about transforming the output of research into social and economic value. In order for the technology transfer to be successful, the invention (fostered by R&D) needs to be converted into a commercially viable innovation, thus requiring technology and business development [22].

Being the technology in the discovery stage, in an early stage of development, carries a high level of associated risk. The public sector can contribute significantly to the reduction of technical risks through promoting investments in the early stages of technology development, and when technology successfully achieves proof-of-concept, private investment becomes available, highlighting the technology value. In countries where private funding and public funding reinforce each other, there is less effort wasted in bridging the financing gap, compared with those that, although having those type of mechanisms, are more focus in investments closer to the market, with less risk [23].

The main objective of this work is to provide a better understanding of the mechanisms that can improve the technology commercialization process and, thus, technology valorization, and from there derive a new model for technology valorization that seeks to fulfil the gaps found in current models.

1.3 Structure

This thesis is organized as follows. In Chapter 2, the relevant theoretical framework will be analysed through a literature review on competitiveness, innovation, and knowledge-based economies. From the starting point that, even though it is not consensual, investments made in innovation have a crucial role in knowledge-based economies performance, we will use publicly available data to assess the existence of a correlation between the innovation and education performance of nations, and their Gross Domestic Product (GDP). Afterwards, data from the Innovation Union Scoreboard [24] for Portugal will be used to illustrate the actuality of the European Paradox and the need for policies to reinforce the downstream activities in the knowledge valorization chain.

Chapter 3 reviews and synthesizes technology commercialization push models, from a critical point of view. For this purpose, we will review the theoretical technology commercialization models, focusing on their stages, activities and core enablers, identifying those involved in each process step, the process stakeholders. In summary, inputs, main activities and process outputs will be described and defined in an empirical way. The chapter ends with a study of the proof of concept centres and technology accelerators as technology commercialization process enablers.

As in any process, the technology commercialization process can face multiple decision nodes that decrease the probability of success, acting as barriers. What can be done to decrease the technology risk and increase its value? Chapter 4 aims to answer these questions. To that end, the surrounding concepts of innovation strategy, namely the technology push and the market pull, market gap and the identification of an unmet market need, will be reviewed and the informational gap between technology licensors and potential licensees, technology valuing, financing, and technology risk, will be analysed.

“Efficiency is concerned with doing the existing things right, effectiveness, the foundation of success, is concerned with doing the right things [25]”. Peter Drucker words clearly state that process value is generated by process effectiveness. In Chapter 5 a model to support technology commercialization, a value creation process focused on risk reduction and value creation, will be proposed.

Effective management decisions are based on performance metrics, a significant topic among technology commercialization. Selecting success metrics is a subjective process that is highly individualized for each organization. The aim of Chapter 6 is to propose a strategy map for a Knowledge Valorization Unit (KVU), based on Balanced Scorecard, to support metrics selection.

The final Chapter presents the main conclusions and proposals for future research.

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2 THEORETICAL UNDERPINNINGS ON KNOWLEDGE, COMPETITIVENESS AND INNOVATION

2.1 Introduction

In spite not being consensual that entrepreneurship and innovation are key elements in leveraging a country's economic growth through competitiveness, political leaders have recognized that, to increase competitiveness, economies need to change their development paradigm from one based on the exploitation of resources to a new one based on knowledge, innovation and entrepreneurship *(*Global Competitiveness Report 2012-2013 [1]). The importance of fostering a knowledge-based economy, was recognized by the European Union in the 2000 Lisbon strategy [2], where the European Council made a commitment for the European Union to become not only the most dynamic and competitive knowledge-based economy in the world but also the global entrepreneurial leader, in order to ensure prosperity. This statement was reaffirmed in the Europe 2020 strategy [3] of smart growth through more effective investments in education, research and innovation.

The transition to a knowledge-based economy occurs when a substantial part of country's GDP comes from the science, technology and educational sectors [4]. These economies, once based on resource exploitation, are moving towards a knowledge-based economy, leading to a paradigm shift that will create new opportunities, higher standards of living and the expansion of its economic activity [5]. The knowledge-based economy concept was popularized by Peter Drucker, as the title of Chapter 12 in his book *The Age of Discontinuity* [6] where he suggests that "knowledge is becoming the one factor of production, sidelining both capital and labour". Nowadays, knowledge-based economy is an expression coined to describe "trends in advanced economies towards greater dependence on knowledge, information and high skill levels, and the increasing need for ready access to all of these by the business and public sectors" [4]. In this line of thought, the literature reviewed points to a link between knowledge and economic growth, establishing knowledge as a driver of productivity [7]–[9], and assumes that return rates from the investment in R&D are consistent with the view that knowledge, an innovation input, is related to economic growth [5], [10], [11].

The recognition that economic growth, in today's knowledge-based economy, is not based on accumulation, but in the innovative capacity stimulated by appropriable knowledge and technological externalities, is not consensual in the established economic doctrines, namely the ones referred to as Neoclassical, Keynesian, and Schumpeterian economics. These doctrines have formed the thinking about economics, and the relative importance of entrepreneurship and innovation in promoting economic growth. The main differences among these economic frameworks are related to what the proponents of these doctrines consider of primary significance for the economy, on the mechanisms that influence its main focus, and on the appropriate stance and role for public policy [12].

The major concern of Neoclassical economics, oriented to market-determined price signals, is the allocation of resources to maximize the economic well-being of the population, given the distributions of wealth and income. Therefore, their focus is on efficiency and the role of investment in physical capital as the driver of economic growth, being technological innovation viewed as exogenous to what influences economic growth [12]. Keynesian economics are demand oriented, based primarily on short-term processes, through which optimal economic performance could be achieved by influencing aggregate demand (i.e., total spending in the economy) through activist stabilization and economic intervention policies by the government, being the role or impact of innovation not relevant to influence public policies. Thence, knowledge and innovation, as the basis for development and growth, are not central to these two doctrines.

Schumpeter [13] claimed that institutions, entrepreneurs, and technological change were at the heart of economic growth and that creative destruction is crucial in capitalism. For Schumpeterian economics, innovation based on entrepreneurship is essential for economic development, and the role of public policy is to facilitate investment in activities that foster knowledge creation, such as research and development (R&D) and education, and to encourage entrepreneurs to innovate [12]. Consequently, due to the incongruity of these three economic frameworks, the public policies, to foster entrepreneurship and innovation, have different weights because the valuation of the role of innovation and entrepreneurship in sustaining economic growth differs among these doctrines.

Being the aim of this chapter to understand and access the impact and the role of innovation and entrepreneurship in economic growth, we start from the assumption that a country's competitiveness is, partially, justified by the value created as a result of the investments it carries out in knowledge generation activities (e.g., R&D) and knowledge deployment activities (e.g., innovation and entrepreneurship). Technology transfer, defined as [14] the process of transferring scientific findings (i.e., knowledge generated through R&D) from one organization to another for the purpose of further development and commercialization (i.e., knowledge deployed through innovation and entrepreneurship) is, thus, a key activity to enable knowledge-based economies. Innovation, understood as the reconfiguration of (knowledge generated) elements into a more productive combination [10], takes a broader meaning in knowledge-based economies and as so, new knowledge and innovation are the basis of a nation's competitive advantage creation and a driver for economic success. To sustain this assumption, this chapter will review and analyse input and output indicators of competitiveness and their correlation with a country's economic performance.

First, we will review literature related to competitiveness, innovation and knowledge-based economies, and knowledge valorization chain. We will base the case that economic competitiveness should be analysed in terms of investments in knowledge. To that end, we will cross data from some countries GDP with publicly available indexes, namely the knowledge economy and global competitiveness index, using Pearson's correlation coefficient (r_{xy}). Afterwards, correlation results will be crossed with some countries' overall position in their economic stages of development, and conclusions will be postulated. To emphasise the need for public policies to reinforce the downstream activities in the knowledge valorization chain, data from the Innovation Union Scoreboard [15] for Portugal will be used to illustrate the actuality of the European Paradox.

2.2 Literature review

Policies for science, technology and innovation aim to create and deploy knowledge. Science, understood as a system for acquiring knowledge that uses observation and experimentation to describe and explain natural phenomena, plays a key role as an input for economic processes, but science, by itself, does not create economic value. For knowledge generated through science (or R&D) to have an impact on a country's competitiveness, it has to be deployed through a value chain that converts R&D into marketable products or services. Simply put, science has to originate an invention (i.e., new product or service concepts that derive from scientific results), which, in turn, may generate an innovation (i.e., the realization of an invention for societal or economic benefit in order to allow for the generation of opportunities to create value from knowledge) and, finally, the innovation needs to be commercialized (i.e., the opportunities generated through innovation need to be converted into societal or economic value).

The knowledge base of an economy can be defined as [5] "the capacity and capability to create and innovate new ideas, thoughts, processes and products, and to translate these into economic value and wealth, … and economic wealth is created through the creation, production, distribution and consumption of knowledge and knowledge-based products" [5]. The Centre for International Competitiveness, host of the World Knowledge Competitiveness Index (WKCI), adds that economic growth and technological change are the most important applications of the knowledge-based economy concept [5].

In this section, the surrounding concepts of value creation based on knowledge, and the relationships between innovation and competitiveness, to sustain a knowledge-based economy, will be reviewed.

2.2.1 Innovation

The notion of economic growth is constrained and driven by knowledge creation [5] and the key to efficiency in an innovation process involves the interaction between basic and applied research, the basis of technology creation [16]. Innovation can be defined as [4]: the implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organizational method in business practices, workplace organisation or external relations. The innovation process steps are all scientific, technological, organizational, financial and commercial activities which actually, or are intended to, lead to the implementation of innovations. Some innovation activities are themselves innovative; others are not novel activities but are necessary for the implementation of innovations. Innovation activities also include R&D that is not directly related to the development of a specific innovation. Innovation, the realization of an invention for societal or economic benefit, is a catalyst for economic growth, once it enables the generation of opportunities to create value from knowledge. Furthermore, "… the interaction among university, industry, and government is the key to innovation and growth in a knowledge-based economy." [10].

Economic growth, in knowledge-based economies, is driven by the innovative capacity supported by new knowledge and new technologies, as so the economic crisis that began in 2007 added impetus to support innovation, namely to find new ways to accelerate technology commercialization and to mobilize funds [17]. Being innovation a key component of the long-term strategy for economic growth, there is an urgent need to move these innovations quickly from the lab into the market [17]. Nevertheless, many discoveries are slow in getting to the market, and some of them will probably never get there. In this context, the technology commercialization process plays an important role, driving new ideas that will result in new venture creation or licensing of technology to established firms.

The innovation process was first characterized in Joseph Schumpeter's work [13], written in the first half of the twentieth century, in which the general distinction between radical and incremental innovation was recognized. This distinction was made based on the assumption that technology direction is driven either by (i) marked demand or by (ii) advances in science. Innovation can emerge from technological and non-technological knowledge. Technology can be described as the practical application of knowledge in a particular area. In innovation-driven economies, the possibility of generating more value by only integrating and adapting exogenous technologies tends to disappear. In those economies, technological breakthroughs are the basis of productivity gains. Dewar & Dutton [18] correlated innovation and the degree of technological knowledge, arguing that the major difference between incremental and radical innovation is the degree of novel technological knowledge embedded in it. Being so, innovations can be classified based on the degree of new knowledge as: (i) radical innovations, that contain a high degree of new knowledge, and (ii) incremental innovations, that have a low degree of new knowledge.

Radical innovation, concerned with the exploration of new technology, is associated with a high level of uncertainty, especially in the early stages of the exploration process due to the technology embryonic nature. However, if it can succeed, it becomes a key driver of growth, profitability and competitive advantage. Schumpeter's work [19], [20] main argument was that the nature of radical technological change undermines the very foundation of large firms' competitive advantages.

Taking into account the knowledge driver of new technology, radical innovation has a parallelism with technology push and incremental innovations with the market pull or demand pull. In contrast, an innovation based upon market pull has been developed by the R&D function in response to an identified market need [21]. On the same topic, Christensen [22] defined disruptive technologies as ones that change the value proposition in a market.

Contrary to the market pull strategy orientation, where the technology is a response to a market need, in a technology push strategy, process activities are focused on pushing the discovery to the end user, without concern of the market attractiveness and applications of developed technologies to products [23], as so, the technology has to find a market gap to succeed.

Technology push can occur between an entity that holds a specific technological knowledge and another that has an interest in obtaining the right to use this knowledge, typically from research centres to firms, between or within firms. The willingness of firms to proceed with the development of the technology, to transform it into a new product or service to be introduced into the marketplace, is influenced by its expectations about the returns that they will capture from commercialization (risk/return ratio) if they are successful. These expectations, based on the technology future economic benefit, are dependent upon the level of information about the technology itself. As a result of this asymmetric information, many discoveries are slow getting to the market, and some of them will probably never get there, but when they enter the market, the value created for the firm can be significant.

2.2.2 Competitiveness

The Global Competitiveness Report of the World Economic Forum [1], defined competitiveness as the set of institutions, policies, and factors that determine the level of productivity of a country.

Competitive economies drive productivity enhancements that support high incomes by ensuring that the mechanisms enabling solid economic performance are in place [1]. Public policies are needed to overcome the current economic challenges, but also to establish the fundamentals of long-term economic growth.

Being that economic growth, in knowledge-based economies, is driven by the innovative capacity supported by new knowledge and new technologies, competitiveness creates the necessary environment for entrepreneurship to emerge and prosper. Furthermore, entrepreneurship drives competitiveness, upgrades and enables economic diversification acting as a driver of growth and innovation. Technology transfer, being an entrepreneurship enhancer, serves as an enabler of economic growth creating new businesses, developing existing ones and creating new jobs. In an entrepreneurship model, knowledge is created and transmitted for economic use as well as for disciplinary advances, in this context, the capitalization of knowledge becomes the basis for economic and social development [10].

The World Knowledge Competitiveness Index[2] 2008 [24] is led by US metropolitan area of San Jose, the home of Silicon Valley, due to its investment in knowledge-intensive business development, in particular in the fields of high-technology engineering, computers, and microprocessors. In second place is the metropolitan area of Boston, a region that thrives on high levels of intellectual and financial capital. This data reinforces the current line of thought, that economic growth requires continued entrepreneurial innovation and expansion. Also, the European Commission [3] stated one of the priorities in the European Union is to have a smart growth, reinforcing knowledge and innovation as drivers of future growth, by improving the quality of education, strengthening research performance, promoting innovation and knowledge transfer, making full use of information and communication technologies and ensuring that innovative ideas can be turned into new products and services that create growth, quality jobs and help address European and global societal challenges.

The “attempt at new business or new venture creation, such as self-employment, a new business organization, or the expansion of an existing business, by an individual, a team of individuals, or an established business” is defined as entrepreneurship [25]. The concept of entrepreneurship when related to knowledge-based economic development initiatives, is focused on stimulating technologically based initiatives in universities via patenting, licensing, start-up creation, and university-industry partnerships based on knowledge creation [26]. The creation of new knowledge expands the set of technological opportunities and so, the entrepreneurial activity involves not only the search for opportunities, but also the exploitation of intra-temporal knowledge spillovers, not appropriated by incumbent firms [7]. Entrepreneurs are actively seeking opportunities to generate value, and so, they are an important key to bringing those discoveries to the market. Schumpeter described entrepreneurs as the “promoters of new combinations”, individuals who can both see new possibilities and evaluate market needs [7]. With this recognition has come the acceptance of the crucial role of entrepreneurs in innovation and growth and the significant contribution of innovation and growth to prosperity and economic welfare.

Being the current macroeconomic environment constraining the growth of global economy, sustainable policies are necessary but not sufficient to restore healthy growth [17]. Improvements in competitiveness support long-term jobs and growth prosperity, indicators have been used by organisations including government agencies, aid agencies and research institutions to assess the competitiveness of a nation in the context of knowledge-based economies. Those indexes are the Knowledge Economy Index (KEI) and the Global Competitiveness Index (GCI). The Mansfield study

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[2] The **WKCI** is an integrated and overall benchmark of the knowledge capacity, capability and sustainability of each region, and the extent to which this knowledge is translated into economic value, and transferred into the wealth of the citizens of each region. As such, the competitiveness of a region will depend on its ability to anticipate and successfully adapt to internal and external economic and social challenges, by providing new economic opportunities, including higher quality jobs.

[11], a famous example of return studies on the effect of innovation on growth, concludes that "…there is a statistically significant and direct relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity, its expenditures on applied R&D are held constant". Yet, literature review shows that there is no consensus on the relation between research and its outcome, Etzkowitz [10] states that "there is only a presumption that the relationship is strengthening, or can be strengthened even when it is weak". In order to reinforce or counter this thesis, we will cross data on the countries' knowledge economy and global competitiveness official indexes, with their GDP, to test correlation type and strength.

2.2.3 Knowledge valorization

Science, technology, and innovation, foster competitiveness, productivity and job creation, acting as important mechanisms for sustainable growth in knowledge-based economies. Knowledge valorization, the transfer of knowledge from Research and Development (R&D) organizations to other parties, envisaging the creation of social and economic value from it, is fundamentally driven by the fact that industrial economies need to change their development paradigm from one based on resource exploitation to a new one based on knowledge and innovation. There are three major interpretations of the concept of transforming knowledge generated through R&D into value [27]: (i) knowledge valorization, (ii) knowledge commercialization and (iii) knowledge capitalization. The concept of knowledge valorization is commonly used and can be traced back to the Lisbon Agenda and the policy measures designed to turn the European economy into the most dynamic knowledge-based economy in the world. The concept of transforming knowledge into value includes three major phases [28]:

i. Knowledge acquisition: amassing the relevant internal and external information required for the transfer of knowledge is collected and quickly deploying this information to its potential users.
ii. Knowledge processing: assess the market value of the relevant research and package the knowledge with market potential for business requirements.
iii. Knowledge dissemination: delivering the knowledge package to businesses and assisting in the technology deployment.

In a value creation approach, the knowledge transfer process can be viewed as a set of interconnected activities each one contributing to value creation in each process stage until new knowledge reaches the interested parties.

To understand the mismatch between knowledge production and knowledge deployment, referred in the European Paradox, it is important to understand the innovation process itself. The R&D term covers (i) basic research, (ii) applied research and (iii) experimental development [29]. Experimental development is systematic work, drawing on existing knowledge gained from research or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. R&D covers both formal R&D in R&D units and informal or occasional R&D in other units. Applied research refers to original research undertaken in order to acquire new knowledge. The Frascati Manual [29] defines basic research as the experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. Basic research aims, by definition, towards the acquisition of new knowledge, playing a vital role in innovation processes.

As a side-line, Berghman, Matthyssens, and Vandenbempt [30] conceive value innovation as the creation of new and substantially superior customer value by redefining the business models, roles and relationships in the industry. The term ‘Value Chain’ was first used by Michael Porter in his book "Competitive Advantage: Creating and Sustaining Superior Performance" [31] as the whole series of activities that create and build value at every step of the process. From this point of view, it can be stated that value will be created by delivering innovative products with high-quality information [32].

2.3 Knowledge-based economies performance data overview

Knowledge, being an intangible asset, cannot be easily quantified or predicted, but it is possible to assess its effect or outcome. For that purpose, several indicators have been developed to capture the impact of knowledge creation and deployment in nations’ competitiveness. In this section, we will cross knowledge and productivity data in order to test the correlation between investments in innovation and education and levels of growth. To that end, we will use the scores from the annual reports of the following indicators: The 2012 Global Competitiveness Index (GCI) developed by World Economic Forum [1] and the 2012 Knowledge Economy Index (KEI) developed by the World Bank. The countries’ scores will be crossed with their GDP per capita[3], in order to determine their correlation. As stated before, Knowledge Economy involves long-term investments in education and innovation capability, variables defined as pillars in both indexes and being so, they will also be correlated with GDP for the second level of analysis.

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[3] **GDP per capita** is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources (World Bank).

2.3.1 Knowledge Economy Index (KEI)

The World Bank's Knowledge Assessment Methodology is a tool that produces the Knowledge Economy Index (KEI), an aggregate index representing a country's or region's overall preparedness to compete in the Knowledge Economy (KE). For that purpose, it takes into account whether the environment is conducive for knowledge to be used effectively for economic development [33]. The KEI is calculated based on the simple average of 12 normalized performance scores of a country on 4 pillars related to the knowledge economy. Each pillar can be defined as followed:

i. Economic Incentive and Institutional Regime: The quality of economic policies and the availability of institutions that permit efficient mobilization and allocation of resources and stimulate creativity and incentives for the efficient creation, dissemination, and use of existing knowledge, are accessed in this pillar through a set of three variables, namely: (i) tariff and nontariff barriers, (ii) rule of law, and (iii) regulatory quality.
ii. Innovation and Technological Adoption. The effectiveness of, firms, research centres, universities, consultants, and other organizations, innovation systems is evaluated, taking in account that the system is an enabler of, knowledge revolution, knowledge assimilation and local needs adaptation. The used variables are: (i) royalty and license fees payments and receipts, (ii) patent applications granted by the US Patent and Trademark Office, and (iii) scientific and technical journal articles.
iii. Education and Training. This pillar measures a country's educational levels and workers training efficiency to create and use knowledge. The applicable variables are: (i) average years of schooling, (ii) secondary enrolment, and (iii) tertiary Enrolment.
iv. Information and Communications Technologies Infrastructure. Measures the country's infrastructure that can facilitate the effective communication, dissemination, and processing of information and knowledge. Its variables are: (i) telephones per 1,000 people, (ii) computers per 1,000 people, and (iii) internet users per 10,000 people.

Chen & Dahlman [34] emphasizes that investments in the four knowledge economy pillars are necessary for sustained creation, adoption, adaptation and use of knowledge in domestic economic production, which will consequently result in higher value-added goods and services. This would tend to increase the probability of economic success, and hence economic development, in the current highly competitive and globalized world economy. To identify the existence or not of a correlation between public investments made in innovation and education and the country wealth, scatter diagrams (x,y) were developed. Figures, 2.1, 2.2 and 2.3 represent the relationship between GDP country's data (x) with knowledge economy indexes (y), namely the global indexes and the innovation and education pillars.

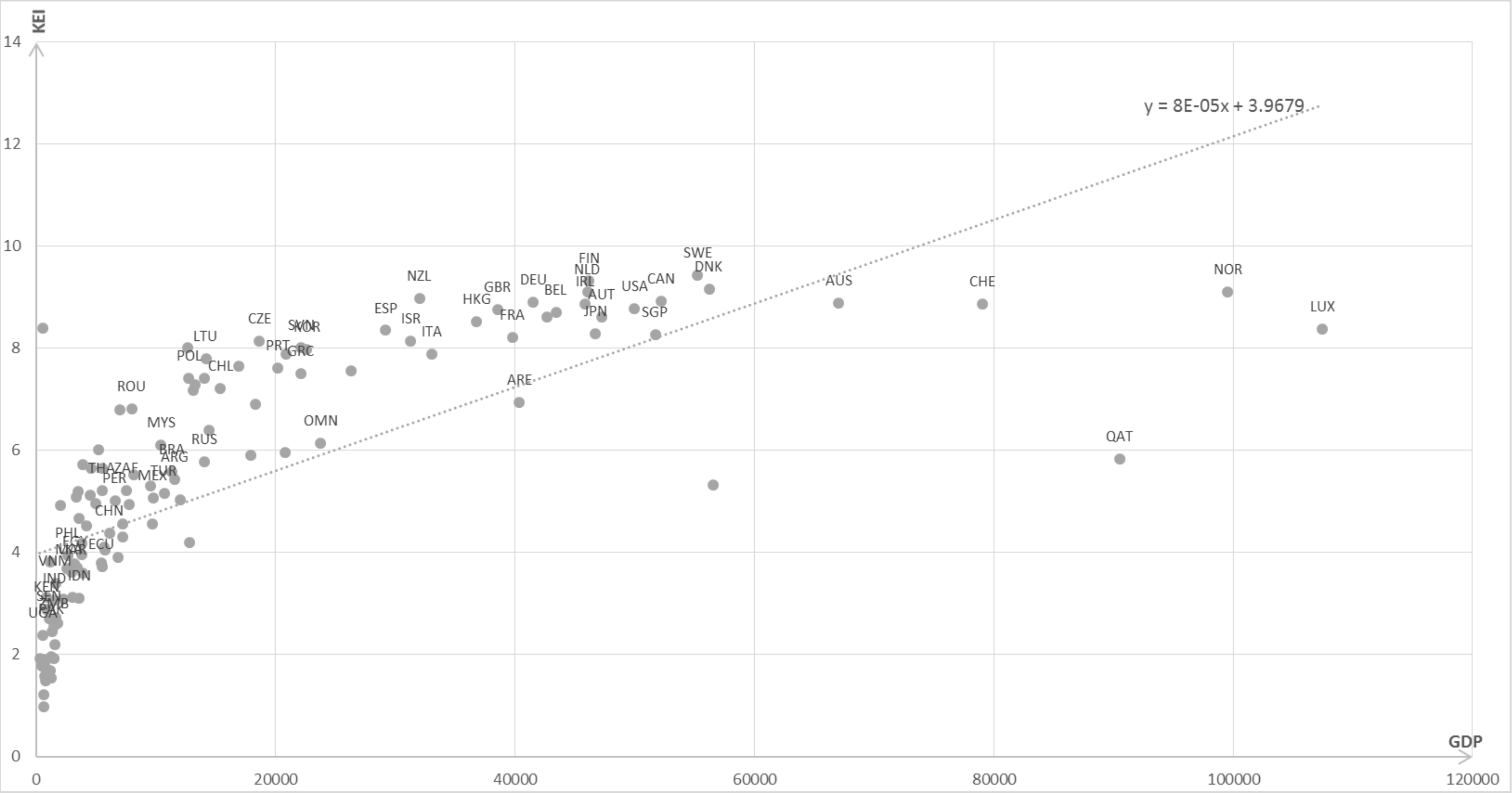

Figure 2.1: GDP per capita vs KEI (2012)

Data are in current U.S. dollars. Source: World Bank national accounts data, and OECD National Accounts data files.

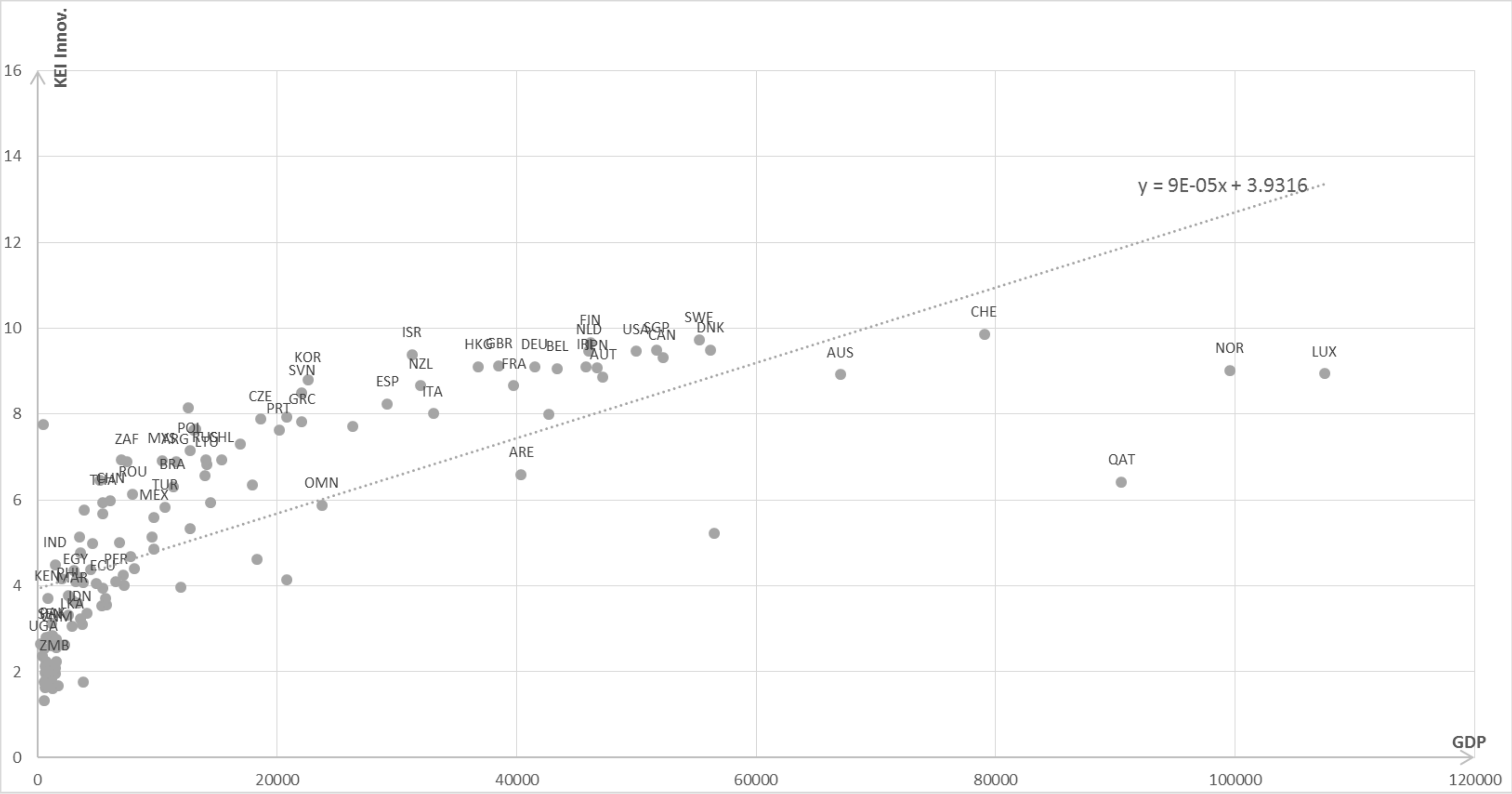

Figure 2.2: GDP vs KEI Innovation (2012)
Data are in current U.S. dollars. Source: World Bank national accounts data, and OECD National Accounts data files.

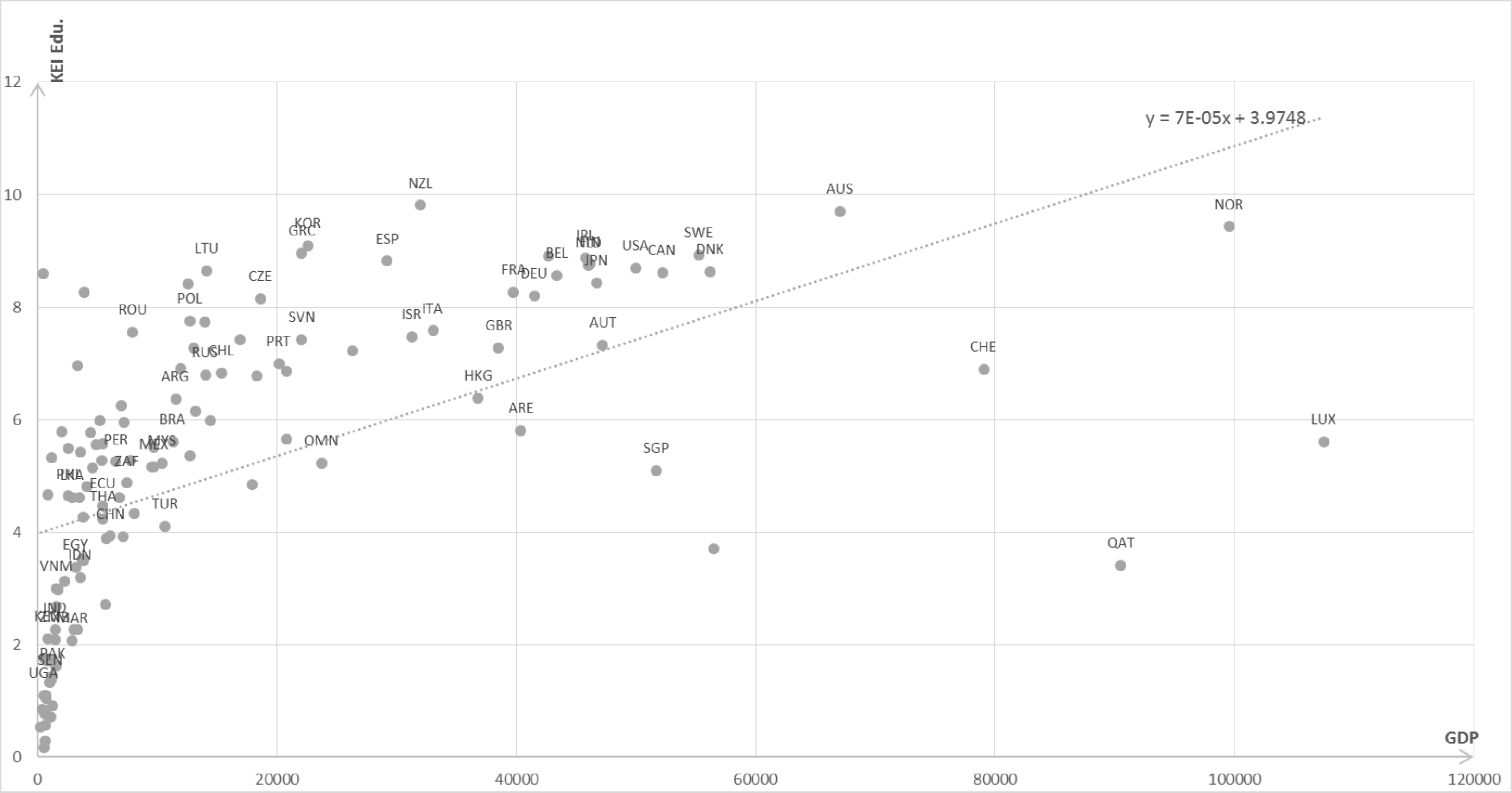

Figure 2.3: GDP vs KEI Education (2012)
Data are in current U.S. dollars. Source: World Bank national accounts data, and OECD National Accounts data files.

2.3.2 Global Competitiveness Index (GCI)

The Global Competitiveness Report [1] ranks the world's nations according to the Global Competitiveness Index (GCI). GCI is a structured, systematic and comprehensive approach to identify and measure the drivers of economic performance of more than 140 economies. The report notes that as a nation develops, wages tend to increase and that in order to sustain higher income, labour productivity must improve for the nation to be competitive. For this reason, the GCI separates countries into three specific stages: factor-driven, efficiency-driven, and innovation-driven, each implying a growing degree of complexity in the operation of the economy. In a factor-driven stage, countries compete based on their factor endowments, primarily unskilled labour and natural resources. Companies compete on the basis of prices and sell basic products or commodities, with their low productivity reflected in low wages. To sustain competitiveness at this stage of development, countries need to focus mainly on well-functioning public and private institutions (pillar 1), appropriate infrastructure (pillar 2), a stable macroeconomic framework (pillar 3), and good health and primary education (pillar 4).

As wages rise with advancing development, countries move into the efficiency-driven stage of development, when they must begin to develop more efficient production processes and increase product quality. At this stage, competitiveness becomes increasingly driven by higher education and training (pillar 5), efficient goods markets (pillar 6), efficient labour markets (pillar 7), developed financial markets (pillar 8), the ability to harness the benefits of existing technologies (pillar 9), and its market size, both domestic and international (pillar 10). Finally, as countries move into the innovation-driven stage, they will only be able to sustain higher wages and a higher standard of living, if their businesses are able to compete by providing new or unique products. At this stage, companies must compete by producing new and different goods using the most sophisticated production processes (pillar 11) and through innovation (pillar 12). The impact of each pillar on competitiveness varies across countries, in function of their stages of economic development. Therefore, for GCI calculation purposes, pillars are given different weights depending on the per capita income of the nation.

Scatter diagrams (x,y) presented in Figures 2.4, 2.5 and 2.6 represent the relationship between GDP country's data (x) and the global competitiveness index, innovation and education pillars.

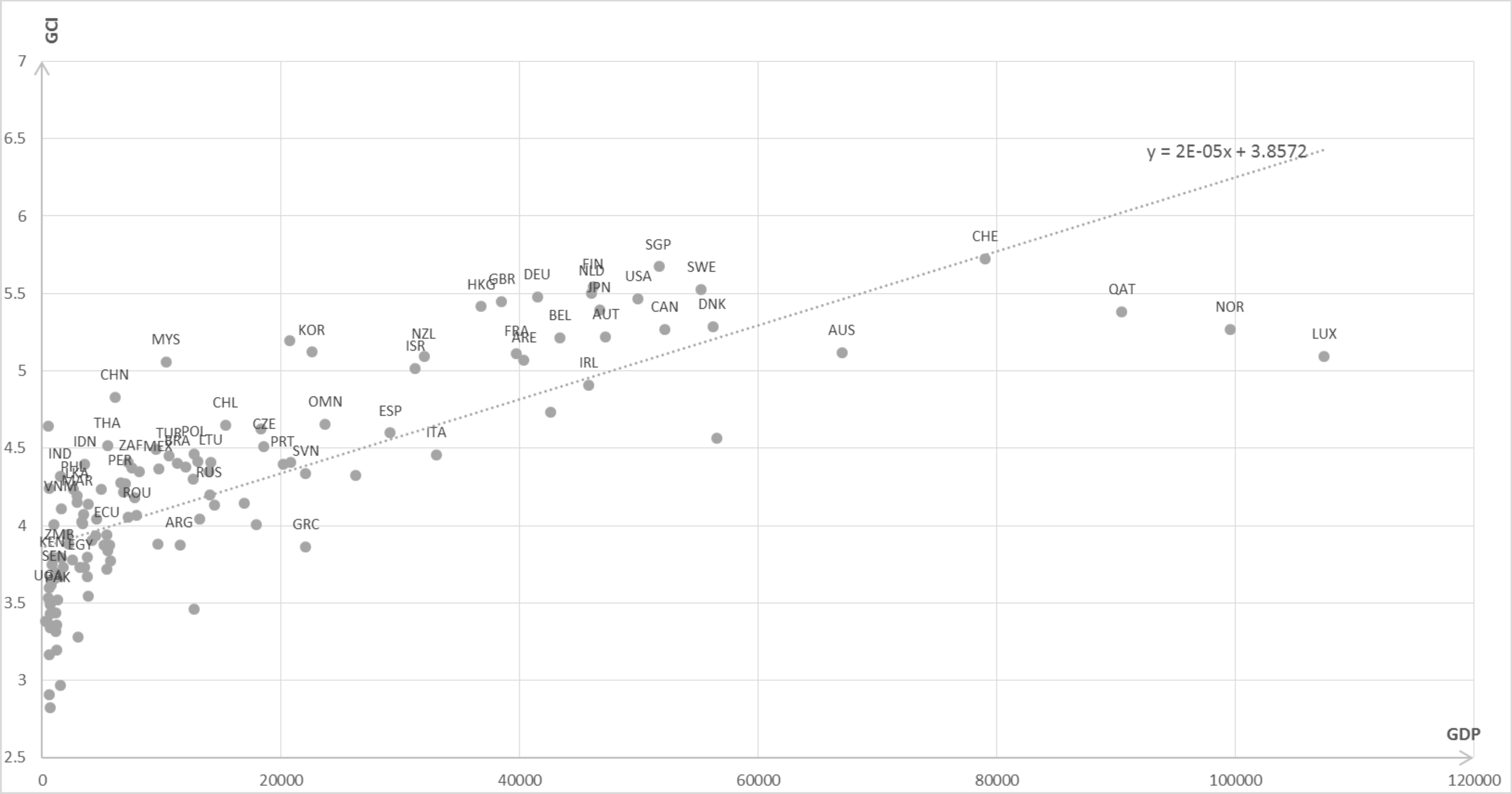

Figure 2.4: GDP per capita vs GCI (2012)
Data are in current U.S. dollars. Source: World Economic Forum.

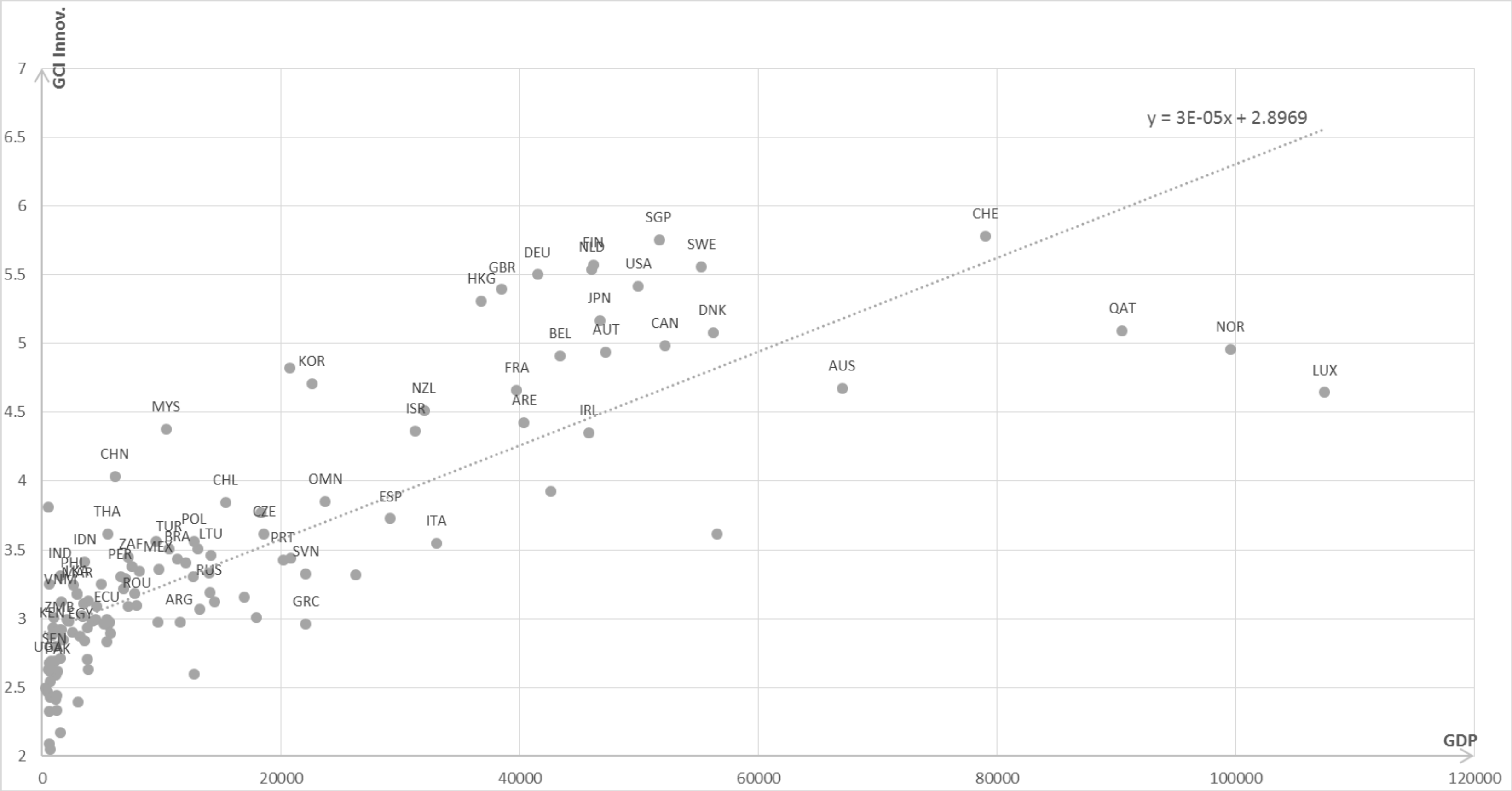

Figure 2.5: GDP vs GCI Innovation (2012)
Data are in current U.S. dollars. Source: World Economic Forum.

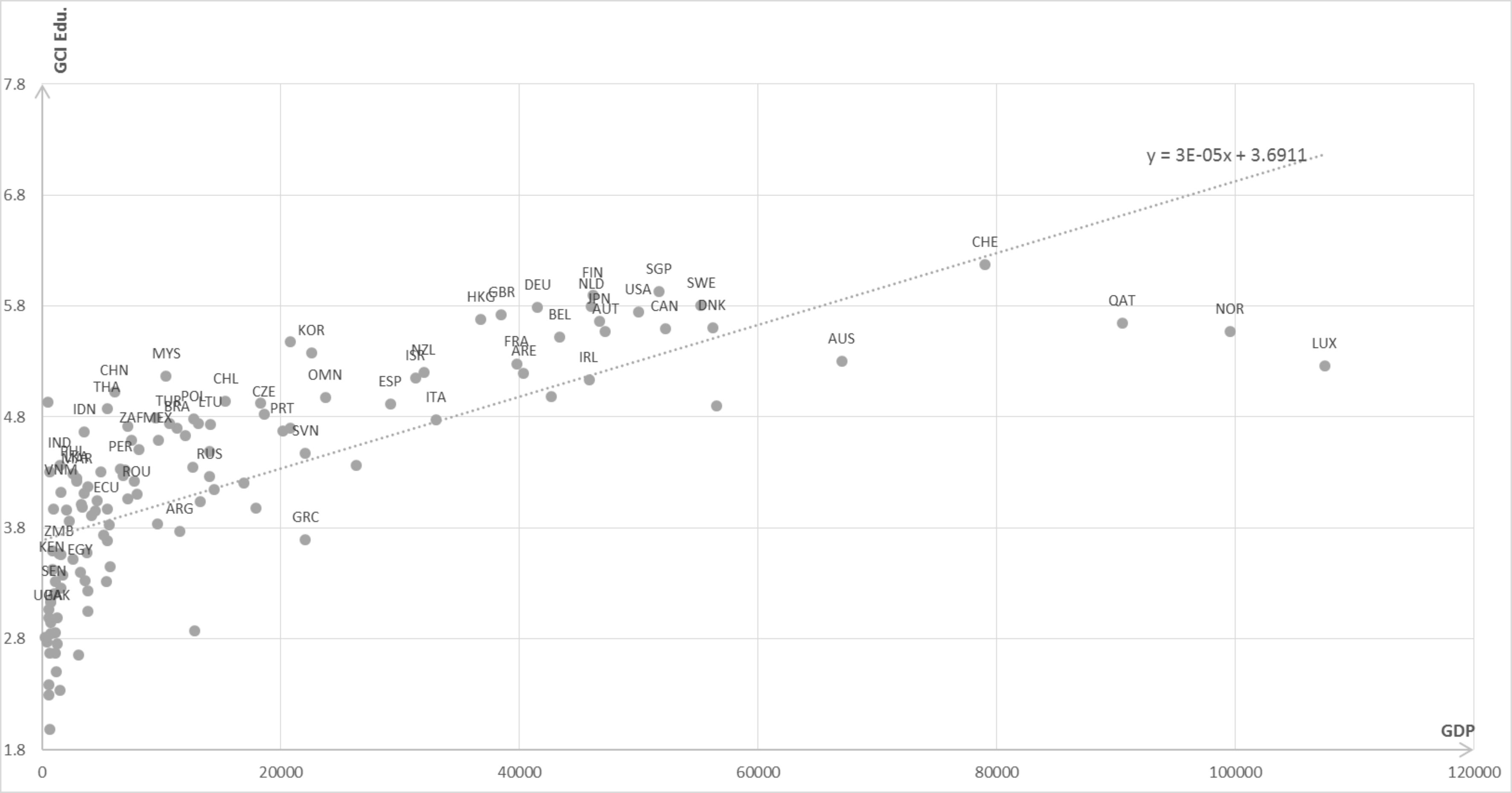

Figure 2.6: GDP vs GCI Higher Education and Training (2012)
Data are in current U.S. dollars. Source: World Economic Forum

2.3.3 Data correlation analysis

Literature review pointed to a link between knowledge and economic growth, establishing knowledge as a driver of productivity [7], [8], [35], and assumes that return rates to R&D are consistent with the view that knowledge, an innovation input, is related to economic growth [5]. We extended the existing literature by testing the hypothesis that there is a positive correlation between countries' economic performance and their investments in R&D.

To that end, we considered the array of economies scored in the Knowledge Economy Index (KEI) and Global Competitiveness Index (GCI) for explaining the economic performance. The above scatter diagrams (x,y) (Figures 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6) represent the relation between the impact of knowledge investments on economic growth (measured by Knowledge Economy Index and Global Competitiveness Index) through the economy's income levels, GDP per capita. The relation of these variables, where x represents de GDP per capita and y represents KEI and GCI index, is assessed by the occurrence of spatial nuts in all graphs. The trend line shows that GDP per capita is positively affected by both drivers, innovation (R&D intensity) and education. As shown in Table 2.1 there is a correlation between GDP and the analysed indexes. Except for some countries outliers, like Qatar, Norway and Luxemburg, on one side and Senegal, Uganda and Zambia, on the other, which exerts enough influence to lower the correlation coefficient, the linear relationship would be perfect.

Table 2.1 Pearson Correlation values

	$r_{x,y}$	$y = ax + b$
(GDP, KEI)	*0.72*	*y= 8E-05x + 3.96*
$(GDP, KEI\ Ino.)$	*0.74*	*y= 9E-05x + 3.93*
$(GDP, KEI\ Edu.)$	*0.57*	*y= 7E-05x + 3.97*
(GDP, GCI)	*0.78*	*y = 2E-05x + 3.85*
$(GDP, GCI\ Ino.)$	*0.82*	*y= 3E-05x + 2.89*
$(GDP, GCI\ Edu.)$	*0.73*	*y = 3E-05x + 3.69*

A positive correlation, for all peer data (x,y) can be postulated. Based on the statistical analysis, namely the Pearson correlation values r_{xy} between the described variables, we can infer that knowledge plays a major role in a country's economic performance and that value creation depends increasingly on a better production, diffusion and use of knowledge. Having researched the correlation results, between public investments made in innovation and education and the performance of knowledge-based economies, the next step is to cross these results with countries' overall position in the economic stage of development.

The World Economic Forum has based its competitiveness analysis on the Global Competitiveness Index (GCI), a comprehensive tool that measures the microeconomic and macroeconomic foundations of national competitiveness. This tool is based on a weighted average of many different components, each measuring a different aspect of competitiveness. Based on these variables, it groups economies in line with the stages of development, in:

i. factor-driven economies,
ii. efficiency-driven economies, and
iii. innovation-driven economies.

Table 2.2 represents the list of economies per stage of development. The World Economic Forum [1] uses two criteria to allocate countries into stages of development: (i) GDP per capita at market exchange rates, and (ii) the share of exports of mineral goods in total exports. Accordingly, a country's productivity will increase as it becomes more competitive and wages will rise with advancing development, what leads them to move into the efficiency-driven stage of development, when they must begin to develop more efficient production processes and increase product quality. At this point, competitiveness is increasingly driven by higher education and training, efficient goods markets, well-functioning labour markets, developed financial markets, the ability to harness the benefits of existing technologies, and a large domestic or foreign market.

The latest Global Competitiveness Report [1] shows that the top 10 competitive countries remain dominated by a number of European countries, with Switzerland, Finland, Sweden, the Netherlands, Germany and the United Kingdom among the most competitive economies. Along with the United States in 7th place, Singapore remains the second-most competitive economy in the world, and Hong Kong SAR and Japan placing 9th and 10th.

According to the report, Switzerland's strengths are related to innovation and labour market efficiency. Switzerland's scientific research institutions are among the world's best, and the strong collaboration between its academic and business sectors, combined with high company spending on R&D, ensures that much of country's research output is translated into marketable products and processes, reinforced by a strong intellectual property protection. Singapore's competitiveness is related with the strong focus on education, providing individuals with the skills needed for a rapidly changing global economy. Finland's strength, the 2nd most innovative country in Europe, is the result of a strong focus on education over recent decades, which has provided the workforce with the skills needed for high levels of technological adoption and innovation.

Table 2.2 Countries/economies at each stage of development

	Stage 1: factor driven	Transition from stage 1 to stage 2	Stage 2: Efficiency driven	Transition from stage 2 to stage 3	Stage 3: Innovation driven
GDP per capita (US$)	<2,000	2,000–2,999	3,000–8,999	9,000–17,000	>17,000
Countries	Bangladesh	Algeria	Albania	Argentina	Australia
	Benin	Azerbaijan	Armenia	Bahrain	Austria
	Burkina Faso	Bolivia	Bosnia Herzegovina	Barbados	Belgium
	Burundi	Botswana	Bulgaria	Brazil	Canada
	Cambodia	Brunei Darussalam	Cape Verde	Chile	Cyprus
	Cameroon	Egypt	China	Croatia	Czech Republic
	Chad	Gabon	Colombia	Estonia	Denmark
	Côte d’Ivoire	Honduras	Costa Rica	Hungary	Finland
	Ethiopia	Iran, Islamic rep.	Dominican Republic	Kazakhstan	France
	Gambia,	Kuwait	Ecuador	Latvia	Germany
	Ghana	Libya	El Salvador	Lebanon	Greece
	Guinea	Mongolia	Georgia	Lithuania	Hong Kong SAR
	Haiti	Philippines	Guatemala	Malaysia	Iceland
	India	Qatar	Guyana	Mexico	Ireland
	Kenya	Saudi Arabia	Indonesia	Oman	Israel
	Kyrgyz	Republic Sri Lanka	Jamaica	Poland	Italy
	Lesotho	Venezuela	Jordan	Russian Federation	Japan
	Liberia		Macedonia, FYR	Seychelles	Korea, Rep.
	Madagascar		Mauritius	Trinidad and Tobago	Luxembourg
	Malawi		Montenegro	Turkey	Malta
	Mali		Morocco	Uruguay	Netherlands
	Mauritania		Namibia		New Zealand
	Moldova		Panama		Norway
	Mozambique		Paraguay		Portugal
	Nepal		Peru		Puerto Rico
	Nicaragua		Romania		Singapore
	Nigeria		Serbia		Slovak Republic
	Pakistan		South Africa		Slovenia
	Rwanda		Suriname		Spain
	Senegal		Swaziland		Sweden
	Sierra Leone		Thailand		Switzerland
	Tajikistan		Timor-Leste		Taiwan, China
	Tanzania		Ukraine		United Arab Emirates
	Uganda				United Kingdom
	Vietnam				United States
	Yemen				
	Zambia				
	Zimbabwe				

source: world economic forum 2012 [1]

As countries move into the innovation-driven stage, wages will have risen by so much that they will be able to sustain the higher wages and the associated standard of living, only if their businesses are able to compete with new and/or unique products, services, models, and processes. At this stage, companies must compete by producing new and different goods through new technologies and the most sophisticated production processes or business models [1].

Although productivity can be improved by adopting existing technologies, innovation-driven economies, in order to maintain a competitive edge, have to move toward higher value-added activities. This progression requires: investment in research and development (R&D), the presence of high-quality scientific research institutions, collaboration in research and technological developments between universities and industry, and intellectual property protection models [1]. Considering the three groups of countries, per stage of development, and also the one grouped in the transition stages, the clusters identified in Figures 2.1, 2.2, 2.3, 2.4, 2.5, and 2.6 are also present in Table 2.2.

2.4 Innovation Union Scoreboard data overview

Knowledge based economies competitiveness, characterized by the process of production, dissemination, and application of knowledge [1], [33], [38], is increasingly dependent on the success of research and innovation systems as well as the investments made in this systems. Hence, successful innovation process depends on much more than simply new knowledge production. Once ideas have been developed, they must be nurtured through a series of stages of development requiring increasing amounts of financial investment leading ultimately to commercialization. Cooperation efforts, between research centres and industry, should be intensified to spark innovation, the creation of new businesses and the transfer and dissemination of knowledge [8]. The missing link, in these efforts, stands on the translation of the knowledge produced in research and development (R&D) organisations to the societal sectors, in order to create value. The key term in this translation process is knowledge valorization, meaning the formal transfer of knowledge resulting from basic or applied research in R&D organizations (universities, research institutes or companies) to other parties in order to create social and economic value from this knowledge.

In Europe, over the last decades, a significant investment in science and technology has increased the generation of scientific findings, however this investment was not accompanied by an identical effort in the deployment of the knowledge generated. The substantiation of this mismatch between knowledge generation and deployment can be traced back to 1995, when the European Commission [36] coined the term 'European Paradox', referring to the failure of most European countries to convert the significant investment carried out in R&D into economic benefits and jobs creation [37].

In this section, data from the 2014 Innovation Union Scoreboard (IUS) [15] for Portugal is used to illustrate the actuality of the European Paradox and the need for policies to reinforce the downstream activities in the knowledge valorization chain.

2.4.1 Innovation Union Scoreboard

Knowledge-based economies' competitiveness, is increasingly dependent on the success of research and innovation systems as well as the investments made in these systems. Consequently, successful innovation process depends on much more than simply new knowledge production. In this context, it is important to consider both the production of new knowledge and the resources that a country is able to mobilize to deploy this knowledge.

Nowadays, there is a large set of innovation indicators that aim at measuring the output from innovative processes, the resources needed, and the processes that must be implemented in order to turn innovation inputs into innovative outputs.

The Frascati Manual was the first formal guide for gathering R&D data, back in the 60's [29]. However, dealing specifically with collecting and interpreting innovation data, the Oslo Manual (1992) is much more recent [4], [39] and so, coherent methodological guidelines for innovation data have only been available since the 1990s.

The Innovation Union Scoreboard [15] is a model to evaluate a country's innovation capacity, in the context of knowledge transfer, based on a model of innovation performance indicators. To analyse Portugal's context regarding the knowledge valorization chain (i.e., the set of activities from knowledge production to knowledge deployment), the Innovation Union Scoreboard will be used.

For a better grasp of Portugal's sizeable increase in knowledge production over the last decade, a set of relevant indicators are presented in Figure 2.7, in which one can observe an increase in (i) the investment in science and technology as a percentage of the GDP (2.1 times), (ii) the number of researchers (2.8 times) and (iii) the number of papers (3.2 times), over the last decade. The data used to plot the charts in Figure 2.7 was obtained from the Network for Science and Technology Indicators – Ibero-American and Inter-American [40].

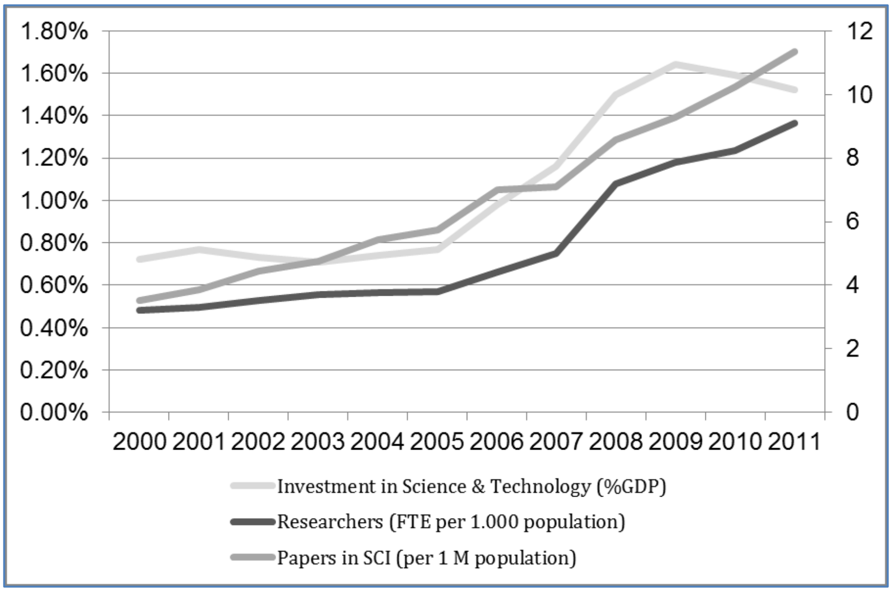

Figure 2.7: Portugal science and technology indicators evolution over the last decade

Innovation Union Scoreboard (IUS) [15] provides a comparative assessment of the research and innovation performance of the twenty-eight EU Member States (plus six neighbouring countries), being the most relevant and up-to-date statistical publication to analyse the Portuguese context regarding the knowledge valorization chain (from knowledge production to value creation through knowledge). The IUS report on the state-of-the-art of innovation performance in EU members and some other countries is published yearly and was developed by the European Commission to provide a comparative evaluation of the innovation performance in regard to the Lisbon Strategy. A comparison with leading global competitors, like the USA, Japan, Korea, and BRIC countries is also a part of this report. The Innovation Union Scoreboard 2014 [15] places the Member States into four different innovation performance groups, as follows:

i. Innovation Leaders: Denmark (DK), Finland (FI), Germany (DE) and Sweden (SE) with innovation performance well above that of the EU average;
ii. Innovation followers: Austria (AT), Belgium (BE), Cyprus (CY), Estonia (EE), France (FR), Ireland (IE), Luxembourg (LU), Netherlands (NL), Slovenia (SI) and the United Kingdom (UK) are with innovation performance above or close to that of the EU average;
iii. Moderate innovators: Croatia (HR), Czech Republic (CZ), Greece (EL), Hungary (HU), Italy (IT), Lithuania (LT), Malta (MT), Poland (PL), Portugal (PT), Slovakia (SK) and Spain (ES) performing below that of the EU average;
iv. Modest innovators: Bulgaria (BG), Latvia (LV) and Romania (RO) with innovation performance well below that of the EU average.

The Scoreboard collects data for 25 indicators (partially shown in Table 2.3), capturing 8 innovation dimensions that represent 3 main areas of the innovation process [41], namely the enablers, the firm activities, and the outputs. Enablers capture the main drivers of innovation performance external to the firm in three innovation dimensions: (i) Human resources measuring the availability of a high-skilled and educated workforce: New doctorate graduates per 1000 population aged 25-34; Percentage population aged 30-34 having completed tertiary education; Percentage youth aged 20-24 having attained at least upper secondary level education (ii) Open, excellent and attractive research systems measuring the international competitiveness of the science base: International scientific co-publications as % of total scientific publications of the country; Scientific publications among the top-10% most cited publications worldwide as % of total scientific publications of the country; Non-EU doctorate holders as % of total doctorate holders of the country, and (iii) Finance and support dimension measuring the availability of finance for innovation projects and the support of governments for research and innovation activities: Public R&D expenditures (% of GDP); Venture capital (% of GDP).

Table 2.3 - Innovation Union Scoreboard selected indicators

Area	Dimension	Indicator	Ref.
Enablers	Human resources	New doctorate graduates per 1000 population aged 25-34	**A**
	Open, excellent and attractive research systems	Scientific publications among the top-10% most cited publications worldwide as % of total scientific publications of the country	**B**
	Finance and support	Public R&D expenditures (% of GDP)	**C**
		Venture capital (% of GDP)	**D**
Firm activities	Linkages & entrepreneurship	Public-private co-publications per million population	**E**
	Intellectual assets	PCT patent applications per thousand million GDP (in PPP€)	**F**
Outputs	Innovators	High-growth innovative firms (% total number of firms)	**G**
	Economic effects	Employment in knowledge-intensive activities as % of total employment	**H**
		License and patent revenues from abroad as % of GDP	**I**

Firm activities area captures the innovation efforts at the level of the firm in 3 innovation dimensions: (i) Firm investments measuring the investments that firms make in order to generate innovations: Business R&D expenditures (% of GDP); Non-R&D innovation expenditures (% of total turnover); (ii) Linkages & entrepreneurship measuring entrepreneurial efforts and collaboration efforts among innovating firms and also with the public sector: SMEs innovating in-house (% of all SMEs); Innovative SMEs co-operating with others (% of all SMEs); Public-private co-publications per million population and (iii) Intellectual assets measuring different forms of Intellectual Property Rights (IPR) generated as an output in the innovation process: PCT patent applications per thousand million GDP (in PPP€); PCT patent applications in societal challenges per thousand million GDP (in PPP€); Community trademarks per thousand million GDP (in PPP€); Community designs per thousand million GDP (in PPP€).

Outputs capturing the effects of firms' innovation activities in 2 innovation dimensions: (i) Innovators measuring the number of firms that have introduced innovations onto the market or within their organizations and the presence of high-growth firms: SMEs introducing product or process innovations as % of SMEs; SMEs introducing marketing or organizational innovations as % of SMEs; High-growth innovative firms (% total number of firms) and (ii) Economic effects measuring the economic success of innovation in employment, exports and sales due to innovation activities: Employment in knowledge-intensive activities as % of total employment; Medium and high technology product exports as % of total product exports; Knowledge-intensive services exports as % of total services exports; Sales of new-to-market and new-to-firm innovations as % of turnover; License and patent revenues from abroad as % of GDP.

2.4.2 Data analysis

To characterize the Portuguese context regarding the knowledge valorization chain, a subset of 9 indicators were selected (see Table 2.3) as being the ones that better capture knowledge production and value creation through knowledge.

Figure 2.8 shows Portugal's positioning among the 28 EU Member States (one exception being indicator D – venture capital – for which values from only 20 member states are available). It is evident from this chart that Portugal performs better in the upstream activities of the knowledge chain (i.e., knowledge production) than on the downstream activities (i.e., value creation from knowledge) when compared to its EU counterparts.

If one looks at the time series depicting the normalized values of these indicators (a value of one being the highest score among all 28 EU members plus the six neighbouring countries), presented in Figure 2.9 (for the upstream indicators) and Figure 2.10 (for the downstream indicators) it is clear (i) the significant gap of Portugal's performance in the downstream indicators when compared to its EU counterparts, (ii) that for these downstream indicators the performance has not improved significantly over the years reported (one should note that although each time series refers to a period of five years, not all time series refer to the same period) and (iii) the relative good performance in the enabler indicators (i.e., the upstream indicators) in spite the sizeable degradation in the indicator for new doctorates (possibly attributable to the impact of the economic crisis).

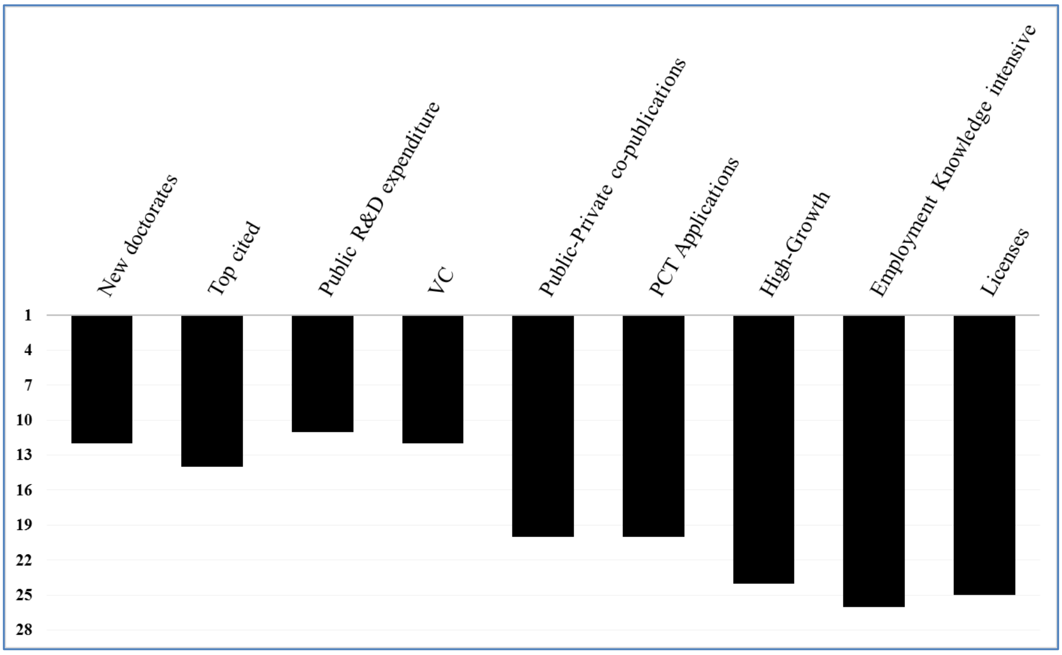

Figure 2.8: Portugal’s positioning relative to the 28 EU member states for the knowledge valorization chain indicators

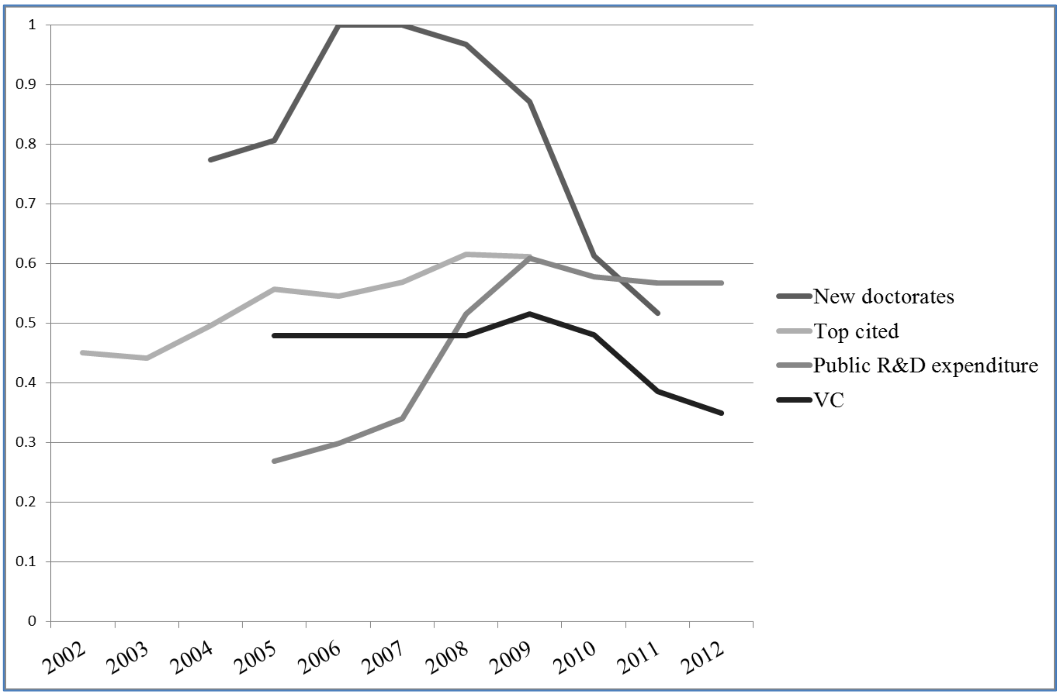

Figure 2.9: Time series for the knowledge chain upstream indicators

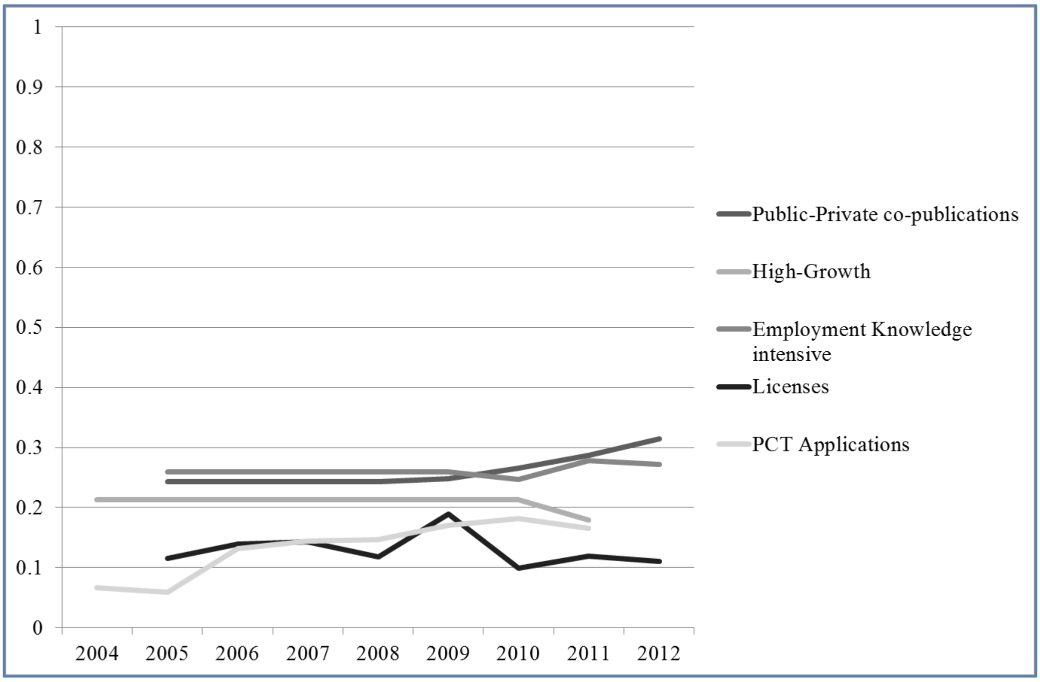

Figure 2.10: Time series for the knowledge chain downstream indicators

Knowledge value will be created by delivering innovative products with high-quality information [32]. To increase R&D effectiveness, it is important to fully understand the ultimate value of a project very early in development and know how this information can be leveraged in individual perspectives and trade-offs in portfolio decision making. The determinants of overall value are likely to be different depending on the perspective represented all along the process, from the lab to the market [32]. These multiple nodes, towards the process, decrease the probability of success, acting as barriers. The relevant literature identified a set of barriers to knowledge valorization, namely:

i. The lack of alignment between research publication and intellectual property protection [42], [43];
ii. The lack of alignment between the skills required for knowledge valorization and the incentives of the research career [44];
iii. The limited competencies to connect technical knowledge to a commercial opportunity [45];
iv. The conflicts of interest among the different stakeholders in the process of knowledge valorization [46];
v. The lack of an entrepreneurial culture among the researchers [47];
vi. The limited availability of pre-seed funding [48];
vii. The asymmetry of information between researchers and investors, making the assessment of the knowledge value (i.e., the pre-money valuation) difficult to estimate [49].

To overcome these barriers, specific policies need to be put in place in order to reinforce the downstream activities in the knowledge valorization chain, namely long-term cultural changes, e.g., the lack of an entrepreneurial culture, supporting the Europe 2020 strategy [3] of smart growth.

As a future development of this research, we will address the hypothesis that the European Paradox still holds for most European countries by comparing the IUS knowledge chain indicators for the EU countries with the same indicators from other countries that look to perform better, as the United States of America or Japan.

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3 TECHNOLOGY COMMERCIALIZATION MODELS

3.1. Introduction

Technology transfer activities, from research labs to the market, are increasingly important as a source towards a country’s economic development and competitiveness, based on the fact that, acquisition of technology and its diffusion foster productivity growth. Technology transfer has taken a lead role in creating new businesses, in the sustainable development of existing businesses, and the creation of new jobs [1], [2]. But this only happens if the technology valorization process is occurring in parallel. The valorization of the scientific and technological knowledge takes place when it is transferred, creating value through the creation of new products, new production systems or for providing more efficient services. Technology commercialization, related with technology-based economic development initiatives, is focused on stimulating technology valorization via patenting, licensing, start-up creation, and research-industry partnerships [3]. To this end, the European Commission [4] recommends to “... promote the identification, exploitation and, where appropriate, protection of intellectual property, in line with the strategy and mission of the public research organisation and with a view to maximising socio-economic benefits.”

Although a technology has unlimited potential value at its discovery stage, literature review pointed to the existence of risks, associated with the development of the technology and with the process itself, all along the transfer path, from the discovery stage to the market side (technology recipients and users) [5]–[8]. Impediments occur in every stage of the process, and ultimately, research output fails to be developed and brought to market for practical use, not substantiating the initially perceived value.

In order to propose a new model for technology commercialization, a study on the proven approaches to commercialize technology, along with their strengths and weakness, must be performed. This will be the purpose of the 3rd chapter. To that end, we will start by assessing the technology commercialization process., from a critical point of view. Then, we will review theoretical technology commercialization models, focusing on their specific stages, activities, and core enablers. In order to deeply understand all process elements, financing forms, type and nature of involvement of process stakeholders, and enablers to overcome process gaps (like it seems to be the case of proof of concept centres and technology accelerators), will be analysed.

3.2 Technology commercialization

Technology commercialization has had a political focus since the Bayh-Dole Act (BDA) enacted in 1980 by the United States Congress to spur the transfer of technology from university research to commercialization [3], [9]. It required the university’s faculty members, students or staff members who recognize or discover a new technology or invention, that has commercialization potential, to disclose the invention to their institution's Technology Transfer Office (TTO) [9], [10]. This process leads to a technology push strategy, a model where new inventions are pushed through Research and Development (R&D) to the market toward finding an unmet market need [11]. In other words, in a technology push process, the stimulus for new products and processes comes from research output, with the objective to make commercial use of this new knowledge, standing from a new knowledge valorization perspective, the focus of this work. In this view, process activities are the focus on pushing the discovery to the end user without concern (in the initial stages) for market attractiveness and applications of the developed technologies to products [12].

A process is, according to Davenport [13]: "a structured, measured set of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on how work is done within an organization, in contrast to a product focus's emphasis on what. A process is thus a specific ordering of work activities across time and space, with a beginning and an end, and clearly defined inputs and outputs: a structure for action. (...) Taking a process approach implies adopting the customer's point of view. Processes are the structure by which an organization does what is necessary to produce value for its customers."

Following this perspective, a process has to be seen as a set of linked activities that take an input, the discovery, and transform it to create an output, a new product or service that fulfils an unmet, or ill met, market need. Ideally, the transformation that occurs in the process should add value to the input and create an output that is more useful and effective to the recipient [14].

Since the Bay-Dole Act that a broad number of sources provide definitions for technology commercialization processes. Jolly [15] described technology commercialization process as: "performing successfully a range of things, each adding value to technology as it progresses." Friedman and Silberman [16] defined process commercialization as a process whereby invention or intellectual property from academic research is licensed or conveyed through use rights to a for-profit entity and eventually commercialised. The European Investment Fund [17] defined technology transfer or commercialization of research as the process of transferring scientific findings from research laboratories to the commercial sector. For the propose of this work we adopted the Association of University Technology Managers (AUTM) [18] definition (see Chapter 1), meaning the process of transferring scientific findings from one organization to another for the propose of further development and commercialization. Therefore, the process involves a formal transfer of rights to use and commercialize these findings. In a valorization approach, we add to the AUTM definition the fact that, technology commercialization process has to be seen as a set of interconnected activities, each one contributing to add value to the technology in each process stage and to reduce its commercialization risk. Standing from this perspective, McDevitt et al. [19] recent work examines the benefits provided by the technology transfer process, as follows:

i. Revenue generation provider, fostering continuous research for inventors and research organizations.
ii. Increased research funding opportunities and the development of research partnerships.
iii. Promotes a culture of entrepreneurship and innovation, through the recognition of the practical application of the research outputs and its effects and benefits to society.
iv. Increases prestige and recognition for the discoveries made at the research centres, resulting in effectiveness improvements in fundraising efforts.
v. Public benefit, improving the quality of life.
vi. Energizes economies and offers advances that impact sustainability, resulting in economic development.

In summary, the commercialization of new technologies creates the basis for long-term growth if its output can be integrated into new products and services for public benefit.

3.3 Technology commercialization models

In order for a technology to achieve its maximum potential value, there are elements that grant an effective flow from stage to stage in the technology valorization process, namely process milestones, process stakeholders and decision points, which must be flexible to be adapted to each project specificities. From the AUTM technology transfer definition, it can be postulated that, in its simplest form, the transfer process involves researchers, transfer organizations and firms, and three main stages of research, technology development and technology commercialization. Reviewed literature points to several models to commercialize technology that actively provided support and benefits to the surrounding system. These models will be reviewed in this section.

The Technology Transfer Office is referred in the literature [5], [20], [21] as an intermediary between suppliers of innovation and those who can potentially commercialize these innovations. Friedman and Silberman [16] work, to asses TTO's productivity, described a technology transfer process that departs from the invention disclosure to the TTO, which has the option to patent the invention. Once the new technology is patented, the university owns its intellectual property rights and can license the patented technology to another entity. The next step occurs when an individual or a commercial company secures a license for the patented technology. After this licensing agreement is executed, and if there are commercial uses of the license, the institution may begin to earn license income from the transferred technology (through, e.g., royalties).

Siegel and Phan [22], based on institutions and agents engaged in the commercialization of university-based intellectual property literature, namely Friedman and Silberman's work, presented a model, where the TTO assumes the role of a boundary spanner, a structural hole to mediate the flow of resources and information within the network of technology transfer stakeholders (see Figure 3.1).

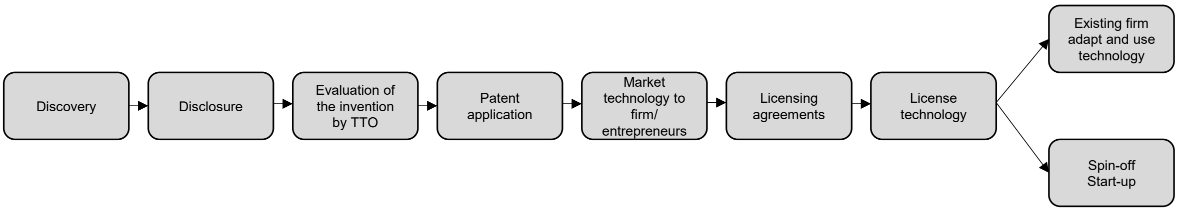


Figure 3.1: A process model for University Technology Transfer
Adapted from Donald Siegel and Phan [22]

The process begins when the researcher disclosures the invention to the TTO. The TTO, after evaluating the invention [5], decides to patent it or not. After the patent being granted, the next step is the marketing of the technology in order to find a licensee that is willing to develop it. When a licensee is found, a licensing agreement is negotiated in which the returns to the university are defined (through, e.g., royalties, equity share or upfront, and milestone fees), and, eventually, the technology is adapted and used by licensees, sometimes with researcher involvement [20], or can result in the creation of a spin-off or start-up.

The Stage and Gate model was developed by Robert Cooper [23] as the conclusion of many years of research into New Product Development (NPD) success factors. For several years, leading companies have adopted idea-to-launch processes, such as stage-gate, to launch new product projects. There are usually four to seven gates, depending on the particular project and the firm that is developing it. During each stage, a specific part of the NPD process is carried out. Being technology development projects, by their nature, high-risk projects with many unknowns and technical uncertainties [24], Cooper [25] proposed an adaptation of the Stage and Gate process for technology development that consists of three stages and four gates (see Figure 3.2).

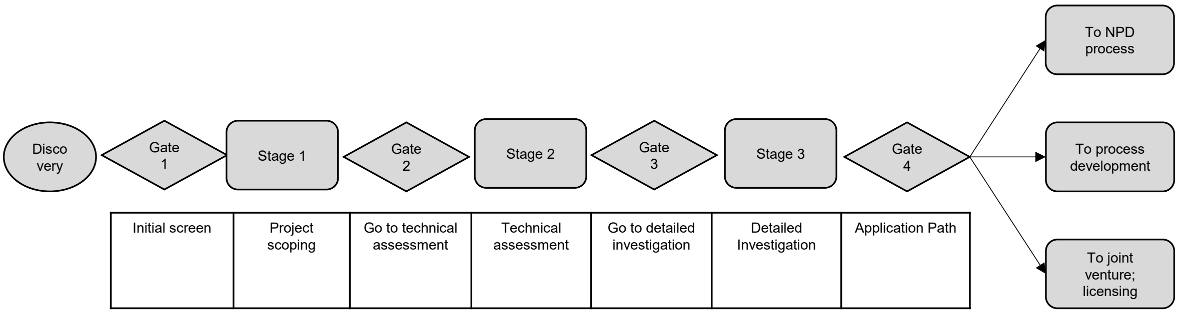


Figure 3.2: Stage and Gate technology development process model

Adapted from Cooper [25]

Each Stage consists of a set of activities undertaken to acquire the vital information to reduce project uncertainty and risk. The Gates are the project decision points to decide either to stop the development or to move to the next stage, requiring extra funding and resources. The Stages outcomes consist of a specific set of deliverables.

The process starts with the discovery, followed by the gate 1, the idea screen. Once this gate represents the initial decision and commitment to invest in the project, the idea screen is based on qualitative criteria to asses, namely: (i) business strategy fit, (ii) strategic leverage, (iii) probability of technical and commercial success, and (iv) contribution to profitability.

In stage 1 the scope of the project is defined and the forward plan is mapped. Stage 1 activities are related to conceptual and preparation work, and include technical literature review, Intellectual Property (IP) search, competitive alternatives assessment, resource gaps identification, and a preliminary technical assessment. Gate 2 represents the decision point to begin the experimental or technical work. Similarly to gate 1, in gate 2 qualitative valuation is performed to rate and prioritize technology development projects. The aim of stage 2 is to demonstrate the technical or laboratory feasibility of the idea, based on initial or preliminary experimental work. Stage 2 activities include: undertaking conceptual technological analysis, executing feasibility, experiments, developing a partnership network, identifying resource needs and solutions to resource gaps, and assessing the potential impact of the technology. Gate 3 is concerned with a detailed technical investigation based on new information from stage 2 deliverables. Gate criteria are those listed for gate 1. The involvement and insights of the corporate head of technology, other senior technology or R&D people, corporate marketing or business development, and the heads of the involved business managers is pointed as crucial, once the decision to pass this gate represents a heavy commitment decision. The purpose of stage 3, the detailed investigation stage, is to implement the full experimental plan, to prove technological feasibility, and to define the scope of the technology and its value. This stage also involves the execution of other activities focused on defining commercial product or process possibilities, undertaking market, manufacturing and impact assessments on these possibilities, and preparing an implementation business case.

In gate 4, the applications path, the results of technical work are reviewed to determine the applicability, scope and value of the technology. Conclusions about the commercial prospects for the technology, based on technical work and commercial scoping can result in one of the following paths: (i) new product development, (ii) new or improved production process, and (iii) licensing opportunity or a joint venture.

The technology commercialization model proposed by the European Investment Fund [17] includes three major phases (see Figure 3.3): (i) the origination phase; (ii) the concept and opportunity testing phase and (iii) the exploitation and start-up phase.

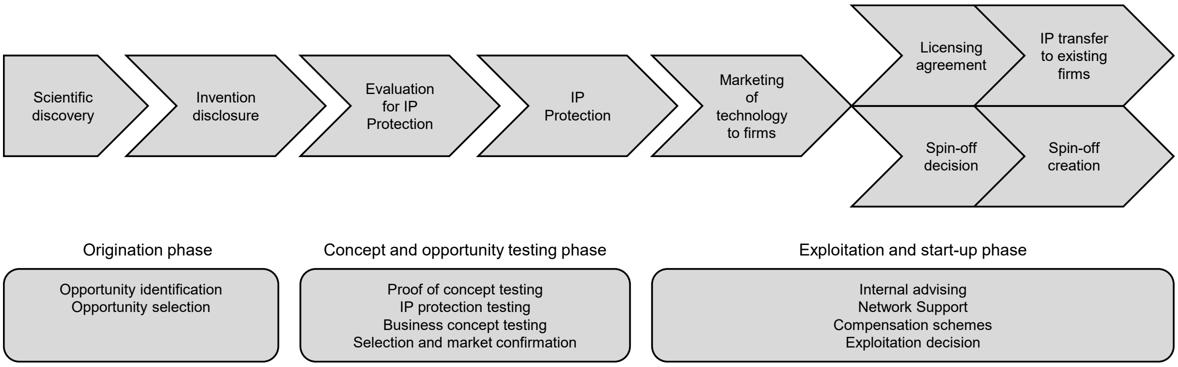


Figure 3.3: European Investment Fund Technology Process Model
Adapted from European Investment Fund [17]

In the origination phase, the opportunity is identified throughout researcher invention disclosure. After the invention had been disclosed, the TTO conducts patent searches and market analysis, to determine the commercialization potential and to decide on whether: to license to an existing company or to create a new business start-up. The second stage, the concept and opportunity testing phase, is referred as the stage during which the scientific opportunity is tested and partially validated from a technical, intellectual property and a business point of view. To that end, the following tests are covered: Proof of Concept (POC), IP protection and business concept. This phase ends when there is a confirmation and selection of an existing business opportunity (a potential market). The last phase, the exploitation of the scientific discovery, starts either through a licensing agreement or a spin-off decision, ending in the technology IP transfer to an existing firm, or a spin-off venture. The main activities are related with exploitation strategy definition, internal advising and network support, and the establishment of compensation schemes.

The technology transfer process, employed by the Massachusetts Institute of Technology (MIT) [26], represents an application of the previously described model (Figure 3.3). It includes several stages that can vary in sequence and often occur simultaneously, represented in Figure 3.4.

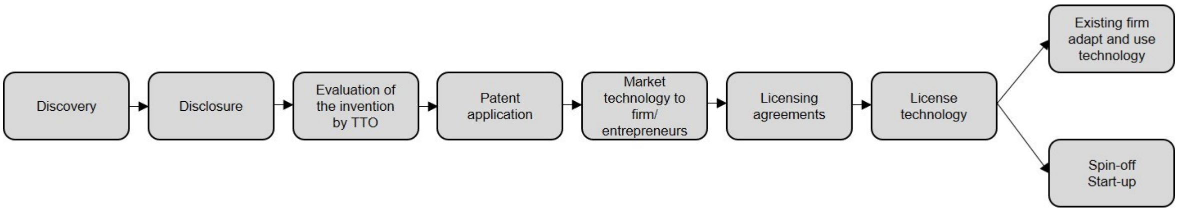


Figure 3.4: Massachusetts Institute of Technology Transfer Process
Adapted from MIT [26]

In pre-disclosure the researcher contacts with the Technology Licensing Office (TLO) to discuss the invention and to obtain guidance concerning the disclosure, evaluation, and protection processes. Then a written notice of invention is sent to the TLO, that proceeds with its assessment (invention disclosure). In the assessment stage, that represents the beginning of the formal technology transfer process, the TLO reviews the invention disclosure, conducts patent searches, and analyses the market and competitive technologies to determine the invention’s commercialization potential. The evaluation process will guide towards the strategy, on whether to focus on licensing the technology to an existing company or creating a spin-off. Patent protection is the stage in which the protection for an invention is pursued to encourage third-party interest in commercialization. In the marketing stage, the TLO, with researcher involvement, identifies potential candidate companies that have the expertise, resources, and business networks to bring the technology to the market, involving either partnering with an existing company or forming a start-up. If the case is to create a spin-off venture, the TLO will work to assist the founders in planning, creating and finding funding. If the best commercialization path is to license it to one or more existing companies, the TLO will seek potential licensees and work to identify mutual interests, goals and plans to commercialize the technology entirely.

The licensing stage includes a license agreement, used with both strategies: a new spin-off venture or licensing to an established company. An option agreement is sometimes used to enable a third party to evaluate the technology and its market potential for a limited time before licensing it. The commercialization stage occurs when the licensee company continues the advancement of the technology. This stage may entail further development, regulatory approvals, sales and marketing support, training, and other activities. Revenues received by MIT from licensees are distributed to inventors and departments, research centres and to the MIT General Fund to fund additional research and education.

As for conclusions for this section, it can be stated that reviewed models, in existing academic and professional literature, typically include as main stages: scientific discovery, invention disclosure to a TTO, evaluation of invention for IP protection, protection decision, market and licencing technology to a firm for future development and commercialization, or to a spin-off or start-up creation, licensing agreement, and technology commercialization. Table 3.1 summarizes reviewed models’ main stages.

Table 3.1.Technology Commercialization Models Stages

A process model for University Technology Transfer, Siegel and Phan [22]	Technology Development Stage & Gate, Cooper [25]	European Investment Fund Technology Process Model [17]	Massachusetts Institute of Technology Transfer Process [26]
	Idea creation	Scientific discovery	Pre-disclosure
Invention disclosure		Invention disclosure	Invention disclosure
Evaluation of invention for IP protection	Project Scoping Technical Assessment	Evaluation of invention for IP protection	Assessment
IP protection decision	Detailed Investigation	IP protection decision	Protection
		Marketing of technology to firms	Marketing to find or form a license
Spinout creation Licensing agreement	New product development New Process Development Licensing agreement or joint venture	Spinout creation Licensing agreement	Start-up Licensing agreement
Commercialization	Commercialization	Commercialization	Commercialization
Revenues: royalties, equity, sponsored research		Proceeds	Revenue

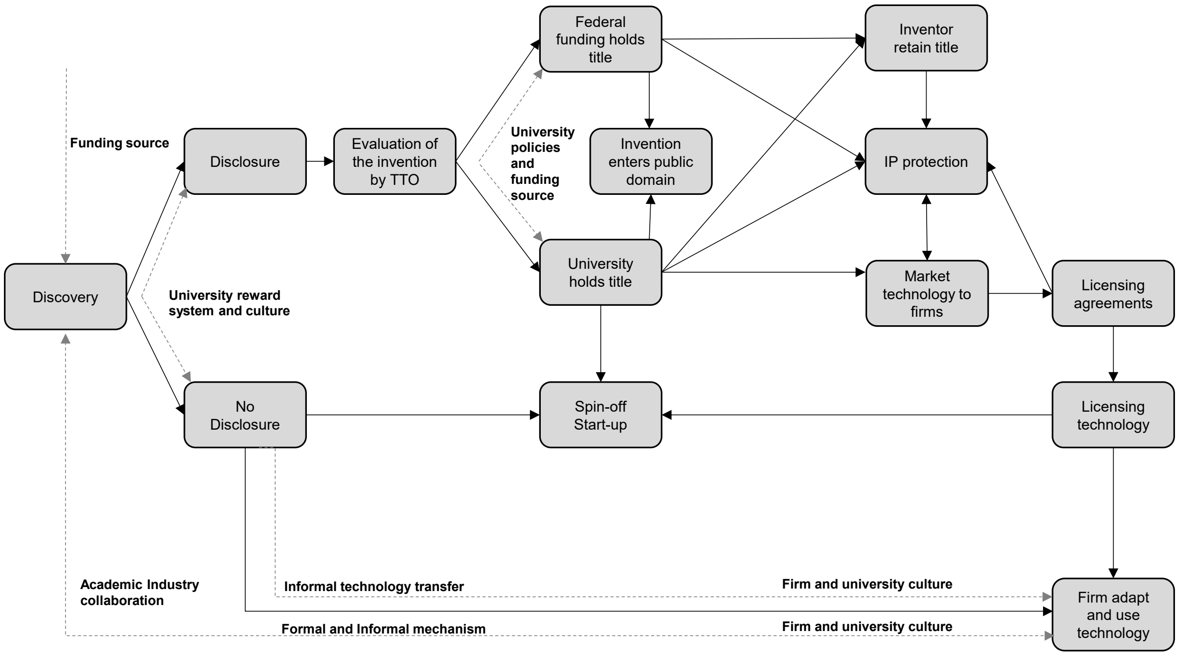
3.4 Linear versus Non-linear Models

Harmon et al. [1] described technology transfer process as a linear sequence of steps, from development to licencing, in order to transfer the technology in one direction, from research to market. According to the reviewed models, technology change, regardless of performance and maturity, happens in a series of sequential stages, organized in a way to assure that the preceding stage must be cleared before moving onto the next stage, assuming technology commercialization process as a linear process.

Nevertheless, Bradley et al. [27], argue that linear models of technology transfer are no longer sufficient to account for the nuances and complexities of technology transfer practices, and pointed as linear model limitations the following categories and subcategories: (i) Inaccuracies: strict linearity and oversimplification; (ii) Composition: one-size-fits-all, overemphasis on patents (iii) Inadequacies: formal versus informal mechanisms, organizational culture, and reward systems. On the contrary, non-linear models require a dialogue in each process stage, often in iteration, with the condition that new actors and decision makers will not only set the appropriate outputs but also set the inputs for the subsequent process stages.

Bradley et al.'s [27] proposal (Figure 3.5) represents an alternative view, "that better capture the progression of the university towards an entrepreneurial institution and engine of economic growth."

This model, as well as the reviewed linear models, begins with a scientific discovery, adding a distinction between different inventors: university scientists, graduate students and research teams. Once the inventor decides to disclose the invention to the TTO, the TTO will identify, together with the inventor, technology uniqueness and value proposal, and perform an analysis on technology conditions to be patentable, potential technology applications, benefits and differentiating competing solutions.



Solid black arrows indicate processes of technology transfer; grey dashed arrows indicate factors that influence these processes.

Figure 3.5: Model of university technology transfer.
Adapted from Bradley et al. [27]

Marketing the invention, acquiring IP protection, negotiating licensing agreements, and pecuniary returns steps, can overlap and occur simultaneously (for e.g., the invention can be marketed before acquiring IP protection and, if the invention seems promising, the university might choose to apply for patents or copyrights). Once the technology has been protected and successfully marketed, and a licensing agreement concluded, the technology is officially licensed to a firm, organization, or entrepreneur. If the technology has been licensed to an entrepreneur, such as the researcher or to an outside party, a spin-off venture or start-up company is established. In the case that the technology has been licensed to an existing firm, the firm then adapts and uses the technology.

In the case that the researcher chose to bypass the TTO, the technology transfer process is carried out through informal mechanisms (e.g. consulting, joint publications, presentations and conferences, and other communication processes between and among faculty members and industry contacts). Note that, in this model, it is assumed that the researcher and the firm, that is developing the invention, often maintain a continued working relationship by means of academic-industry collaboration. Industry collaboration can involve consulting, research contracts, the establishment of joint labs, and other partnerships between the university and the firm.

Wessner [28] states that the process from discovery to commercialization involves constant challenges and market signals that can often be indistinct or even absent and, as so "the innovation process is better understood as a nested system of feedback-loops between basic research, applied research, development and commercialization (…) After a long tedious innovation process, the development phase often leads to the conclusions that the inventions actually don't work at a reasonable cost, or there is no market for them." The Wessner innovation process includes three major overlaps between various stages of research and development and feedback loops through which learning occurs. The process often ends up with new, unanticipated applications, because when the planned application does not work on the market, the innovators will try to change to a new technology application form. A representative example of Wessner non-linear innovation process is shown in Figure 3.6.

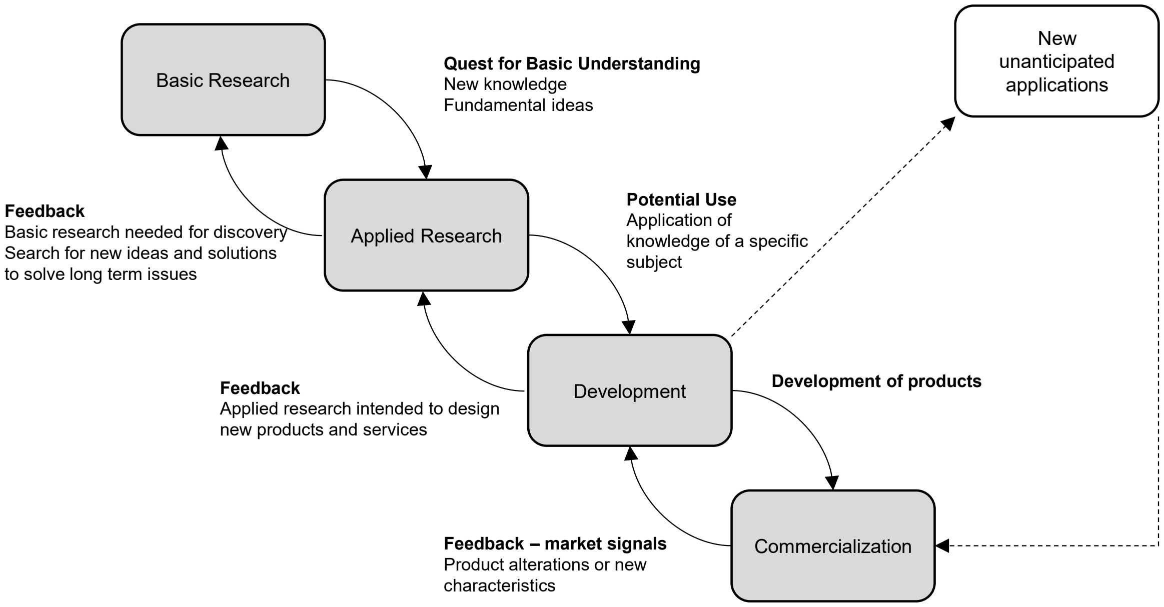


Figure 3.6: Non-linear model of innovation
Adapted from Wessner [28]

The Technology Entrepreneurship and Commercialization model (TEC), developed at North Carolina State University in 1995 [29], was a pioneering methodology to help firms cross the so-called "Valley of Death" that occurs at the front end of innovation when promising technologies fail to generate commercial rewards. Structured as an algorithm, the methodology is based on work done by graduate students from business, engineering or science, and mentors with business experience (see Figure 3.7).

The goal of the ideation phase is to develop a set of prioritized product concepts with strong hypothesized linkages between the unique capabilities of the technologies and customer or market needs. These linkages are described in terms of initial product concepts. Phase 1 and Phase 2, opportunity evaluation phases, are structured around questions and analytical tools that guide technology commercialization functional and strategic assessment covering technology, legal, marketing, organization, manufacturing, financial, industry and competitive issues. Phase 1 objective is to eliminate product ideas, not technologies, based on fatal flaws. Phase 2 aim is to create a business case. The proposed model runs a number of iterations that seeks to collect inside information through contacts with potential users or applicators.

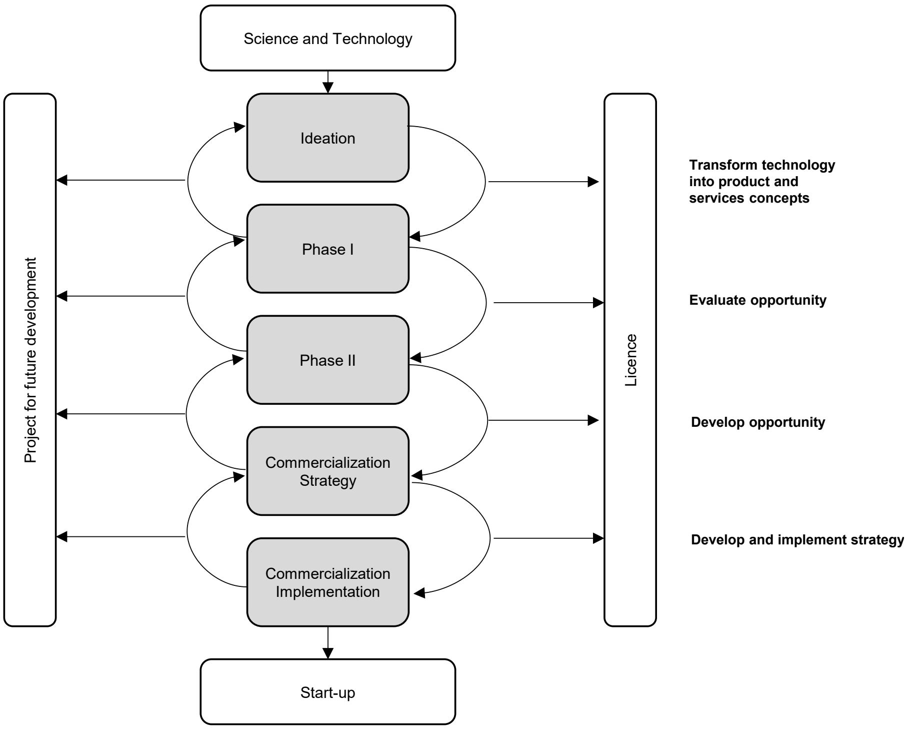


Figure 3.7: TEC algorithm
Adapted from TEC [29]

Stanford University developed a similar approach, initially proposed by Steve Blank, based on his book *Four Steps to Epiphany* [30]. Later, the concept of lean start-up, proposed by Eric Ries, was incorporated into its structure [31] and the development of Osterwalder [32], the Business Model Canvas. Blank identified iterative cycles of trial and error as the way to overcome the discontinuities of the process, as represented in Figure 3.8.

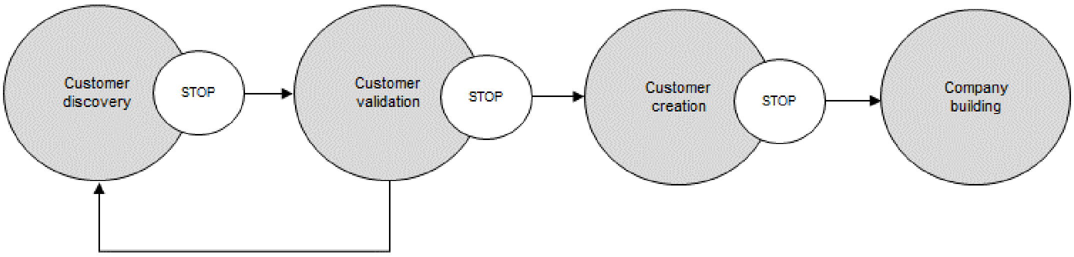


Figure 3.8: Customer Development Model
Adapted from Blank [30]

The Customer Development Model is defined as [4] "a set of objectives and milestones that are meaningful for a start-up." Customer Development Model questers the assumptions underpinning a start-up by systematically testing them in the marketplace, as so, is characterized by an iterative and flexible process that reflects the ambiguous nature of starting a new business and launching new markets. According to Blank, assumptions must be treated as hypotheses that need to be tested and validated. Through this systematic process, a learning and discovery loop will be created in order to help prioritize work and improve the timing of when to launch and scale the start-up. This approach can be applied by start-ups to improve their success, by developing a better understanding of their customers. Steve Blank assumes that new products can be an illusion if never sold to customers and that markets can be extremely dangerous if not well understood, whereas what counts are the users of products, the people who make markets, i.e. the customers. Blank indicates as a process enabler, first the interaction with potential customers, before designing and developing the product in an iterative manner (bottom-up), and then during the product development.

Blank's model is a four stages sequence, identified by the author as somehow neglected in linear models, and partially described in the commercialization stage of the Bradley et al. model [7]. In the first stage, customer discovery, the focus is on the understanding of customer's problems, preferences, and buying behaviour. The aim of the customer validation stage is to develop a replicable sales process. The purpose of the customer creation stage is to generate demand and identify and tease out potential customers. The company building stage focuses on building organization scale up and on the business plan execution. Blank's model can, in this perspective, be described as a stage added to Wessner's model [2].

The objective of Chapter 5 will be to propose a new model, a knowledge valorization model that aims to reduce the fragilities identified by reviewed linear and non-linear models and to reinforce the process enablers that will be reviewed in this chapter's next section.

3.5 Process enablers

This section will synthetize, based on the reviewed literature and on the analysed models, technology transfer process enablers and nodes with an emphasis on the methodology used to move from stage to stage.

The scientific discovery stage has as its main activity the opportunity identification, and core enablers are referred as: (i) the invention disclosure before any public disclosure, and (ii) the scientific or technical observation towards a potential commercial or research value.

The invention disclosure has as its main activities the invention description (formal disclosure) and opportunity selection. The propensity to disclosure inventions can be influenced by research centres internal policies as well as by perceived potential for monetary gain [33] [34]. Referring to this stage, Mohan and Rao [35] stressed the importance of research centres marketing themselves to the industry by designating someone in-charge, for negotiating and promoting their capabilities. Invention revenue potential, the probability of success, the development costs evaluation, the availability of a list of research sponsors, entrepreneurial culture and a licensing officer assignment, were identified as core stage enablers.

After an invention is disclosed to the TTO, they have to evaluate and decide whether or not to pursue a patent. The Proof of Concept (POC) test and the business model elaboration, main activities of the evaluation of the invention for the IP protection stage, have as enablers: the establishment of revenue sharing with research sponsors, the commercialization strategy definition, the level of researcher involvement, and technology value proposition description. Inventor declaration rights establishment and the availability of social networks can facilitate the IP protection decision.

Patenting imposes a cost that, from an economic perspective, is worth incurring only if the royalties from licensing those patents exceeds the average cost of patenting [36]. Litan et al. [37] state that, as a result, many TTO focus their time and resources primarily on the technologies that appear to promise the biggest and fastest payback. Siegel et al. [21] referred that the key obstacles to an effective technology transfer are related to cultural differences between universities and firms, incentive structures for faculty, and staffing and compensation practices. Given the high cost of filing and protecting patents, some institutions are reluctant to file for a patent if there is no explicit interest expressed by the industry [22]. The existence of a technology transfer agent, an intermediary, is pointed in literature as a core process enabler. Literature [27] [38] refers that a technology transfer agent facilitates the process by acting as a mediator between research and industry, leveraging the technology information gap between discovery and market potential, and between process stakeholders [21], and thus reducing technology uncertainty and risk. In this line of thought, Hoppe and Ozdenoren [39] have demonstrated that an intermediary with the expertise to evaluate the value of new inventions, and match the profitable ones with potential investors, can assist in the decision to move forward to the next stage. Technology value definition, a non-confidential opportunity prospectus for partners and investors, the researcher commercial involvement definition, the identification of companies with expertise, resources and networks to bring the new technology to the market, and a confidentiality disclosure agreement, signed by the licensee, were identified as stage enables in reviewed models.

In the transfer process from licensing to the creation of a spin-off or start-up company, network support is crucial, as well as an early stage high-risk platform provider. A high level of involvement with the inventor, can smooth the process and act as an enabler. Spin-offs are pointed out to be an effective commercialization vehicle for uncertain technologies and for encouraging investor involvement [40]. The two key determinants of start-up establishments are related to the ability of the researcher and research centres to assume equity in a start-up in lieu of licensing fees [41]. Nerkar and Shane [42] concluded that technology firms are less likely to fail if they exploit radical technology and have broad scope patents that are contingent on the industry environment. Steffensen et al. [43] described the degree of support that a spin-off company receives from the university as an important enabler for its success, and the time-consuming negotiations of IP rights and competition between the spin-off and university for scarce resources were pointed as process obstacles. Rothaermel et al. [44] referred that “scholars in this stream have found university policy, faculty, TTO’s, underlying technology, investors, founding teams, networks in which a firm is embedded, and external conditions to affect the creation of new firms. Different organizational policies, such as attitude toward surrogate entrepreneurs, preferred methods of technology transfer, equity investments, intellectual property protection, and the developmental model, all play a role in contributing to or inhibiting the spin-off.”

If technology licensing agreement and IP transfer are the preferred route for commercialization, compromise on the terms and conditions of the license between parts are often required. Licensing is not equally effective across all technologies, so the incentive to become more commercially focused has led universities to concentrate patenting in fields in which knowledge is transferred effectively through licensing [45]. Thursby et al. [46] concluded that, when licenses are executed, the researcher involvement is core for finding licensees. Reviewed models also pointed as process enablers the internal advising and the elaboration of a plan for commercial development, or a business model operationalization, shared by licenses. Being the technology at an embryonic stage of development, it typically requires further development before market introduction. Once half of the licensed inventions are only a proof of concept at the time of the license, in the commercialization stage, the inventor’s involvement in the development and adaptation is referred in the literature [46], [47], as well as in reviewed models, as an enabler for commercial success. In the end, if the technology transfer succeeds, compensation distribution schemes are referred as the stage enabler.

In summary, in order to represent a dynamic view of the technology transfer, Bradley et al. [27] identified the enablers that contribute to technology transfer performance as: research funding structures, research activities, research legal environments, and the institutional settings.

3.6 Process stakeholders

Innovation process implies the availability of new ways and means of producing and delivering solutions through products or services that carry benefits perceived by the end user, requiring, as a starting point, knowledge availability for these new ways and means of production and availability. It is generally accepted that new waves of technology are derived from the opening of new areas of knowledge, that result from basic research. This stage of technology development requires contributions from process stakeholders and not just from the technology inventor. Having a preponderant role within the process, the inventor has to clearly identify the technology application capabilities, a projection of the benefits that the application of the technology will give to potential products or services, and also, an assessment of comparative advantages of these benefits in relation to those granted by other solutions.

The successful translation of the technology uniqueness in innovative properties, must be performed in concrete product attributes, which in turn allows that its implementation will benefit end users. This progression has to be done in an integrated and iterative manner, focusing on market research results, checking in each step the technology value proposition, based on its value and feasibility of implementation. This activity involves social skills, including the ability to interact with potential customers and users, and to observe and understand their needs, as well as highly technical skills, that allows an in-depth knowledge of technology potential and available processes that will make it available to users. The implementation of these steps is not obvious to researchers, usually a subject specialist in a specific area of knowledge, who publishes and has knowledge of what is publishable material, neither is for an industrial property agent, whose activity is related with the technology novelty requirement check through searches in various databases. A push technology valorization process needs to be done involving a team, bringing together the necessary skills to carry out the proposal and the validation of hypotheses by an iterative method. Each process step attributes are difficult to measure or verify except in the process outcome. Blank [4] proposes that each attribute needs to be considered as a working hypothesis for next step iteration. The construction of these hypotheses and their iterative validation with marketed stakeholders is a possible methodology to be applicable for a planning exercise [3], [4], [10] and the lack of proper planning is the cause of most failures.

The technology valorization process requires very different skills and expertise in specific economic and regulatory applications, and cannot be done individually, but should be done in cohorts, leading to the emergence of innovation networks. Following this point, Nicolaou and Birley [48] stressed the importance of social networks in fostering entrepreneurial ventures, helping in the creation of new markets for ideas and technologies, facilitating the opportunity identification process, providing access to a wide range of resources, bringing about timing advantages, supplying a source of status and referrals, facilitating the exchange of intellectual property between parties and the signing of research contracts, or the creation of spin-offs. These network members, engaged in the commercialization of intellectual property, are the so-called process stakeholders [22]. Siegel [22] contends that the network of stakeholders involved in each stage of the transfer process is crucial to its success, and that the productivity of technology transfer is ultimately determined by the competencies of process stakeholders, or, as Inkepen et al. [49] stated, those affected by the process output, and their incentives to engage in entrepreneurial activities.

To understand the potential importance of the organizational model for technology commercialization, it is crucial to have a clearly defined value proposition for each of the stakeholders, required skills, as well as their motives and process responsibility. From relevant literature [15]–[17], [22], [27] and the previously described models, different stakeholders were identified per process stage, as follows:

i. Scientific discovery, made by inventors: researchers, scientists, graduate students and research teams.
ii. Invention disclosure: inventors and TTO staff.
iii. Evaluation of invention for IP protection involves inventors and TTO staff.
iv. The IP protection decision has the participation of inventors, TTO staff and specialized attorneys.
v. Marketing of technology to firms: inventors, TTO staff, firms, entrepreneurs, technology transfer agent (intermediary).
vi. Technology licensing, or spin-off /start-up creation involves inventors, TTO staff, firms and entrepreneurs.
vii. Commercialization, involves firms and entrepreneurs and, in some cases where technology is in an embryonic stage, technology inventor.

Academic career trajectory encourages and rewards the production of new scientific knowledge, this being done most efficiently through publications in scientific journals [50]. Their value proposition relies on technology valorization and entrepreneurial skills acquisition, that allows them to embed economic and social valorization criteria in the knowledge generated through their research. The risk reward profile of each available option will depend on the entrepreneur’s abilities and resource access, while the final arbitrage between the entrepreneurial option and the outside option will be driven by individual preferences and, in particular, by risk attitudes [50]. The inventor’s motives, whose contribution to the process is to generate new knowledge, includes the recognition within the scientific community, financial gain and the desire to secure additional funding for graduate assistants, post-doctoral fellows, and laboratory equipment and facilities [5].

Literature reviewed, pointed to the TTOs as the network key element, whose main objective is research output identification with potential commercial interest and strategy definition for its exploitation. In this line of thought, Siegel et al. [21] defined TTO as “an ‘intermediary’ between suppliers of innovations (researchers and scientists) and those who can potentially (help to) commercialize them, i.e. firms, entrepreneurs, and venture capitalists. TTOs facilitate commercial knowledge transfers of IP resulting from research through licensing to existing firms or start-up companies of inventions or other forms.” TTOs play a key role in [49] engendering academic entrepreneurship by engineering synergistic networks between academics and venture capitalists, advisors, and managers, who provide the human and financial resources necessary to start a company, and by providing company formation expertise. Accordingly, required skills are related with IP protection and network access. Their primary motive is [5] to protect and market intellectual property. Secondary motives include promoting technological diffusion and securing additional research funding via royalties, licensing fees, and sponsored research agreements. Their value proposition is to work with inventors and firms to structure commercialization deals providing high-level support. In the marketing stage, some TTO subcontract attorneys specialized in patent, trademark, and intellectual property law.

Firms and entrepreneurs have the responsibility to [5] commercialize new technologies, being their primary motives the financial gain, throughout access to new technology and qualified personnel, skills and knowledge enhancement of its scientific workforce (absorption capacity), and to maintain proprietary control over new technologies. Their main skill relies on business development capabilities. The stakeholders value proposition and skills, in the technology transfer process, are summarized in Table 3.2.

At this point, it is important to note that literature denotes a process node [21], related with the asymmetric information between process actors, based on the fact that firms typically cannot assess the quality of the invention ex ante, while inventors may find it difficult to assess the commercial profitability of their inventions. The study of these asymmetric views, based on contributions to decrease technology risk and increase technology value, will be the aim of Chapter 4.

Table 3.2. Stakeholders value proposition and skills

Stakeholder	Value preposition	Skills
Inventor	Technology knowledge	Technology valorization and entrepreneurial skills acquisition that allow them to embed economic and social valorization criteria in the knowledge generated
TTO	Work with inventors and firms to structure commercialization deals providing high-level support	IP protection and network access
Firms and entrepreneurs	Generate future returns through the investment	Business development

It is also important to stress that, in order to reach its ultimate value, technology requires large amounts of capital to be scaled up, where financing represents a key process enabler. The next section will be dedicated to this analysis.

3.7 Financing

Funded research aims to develop a clear process that links research to development, with the expectation that the development outputs will be acquired and applied to generate innovative products and services. In the present economic context, the innovation financing networks have an increased relevance, being crucial to avoid the financing gap between the technology commercialization process stages. The financing gap describes a situation in whereby typical sources of early-stage funding, typically Business Angel (BA) investments, dry up while late-stage sources of funding, venture capital, are not yet available. This pushes new technologies into the namely Valley of Death [29], [51], [52]. The optimal case would be if the different forms of financing were available in all stages of technology development, from its embryonic stage to fully development [53].

The embryonic stage of development is the case that represents a higher risk, and the technology value is only perceived by its inventor, representing a high risk for the investor to finance its development. At the late stage, technology value is perceived by all stakeholders, and it has a target market. In this section, the forms of financing for seed, start-up, early, expansion and later stage of technology development will be reviewed, based on the fact that capability to accurately evaluate technology value and readiness for product development is essential for risk reduction and, thus, for fund flow.

Being that financing is dependent on the technology's maturity, it is crucial to outline technology maturity stages. According to Price Waterhouse Coopers and European Private Equity & Venture Capital Association (EVCA) [54], [55], there are different stages of development that need different types of funders. In the seed stage, the initial stage of development, financing is provided to research, assess and develop an initial concept. The seed stage financing also comes from entrepreneurs self-financing their ventures, commonly referred as FFF (founders, friends and family) or by public funds that support basic research [56]. According to the Bradley et al. [27], funding sources that facilitate discovery, includes federal contracts, federal grants, private grants, corporate contracts, donations, and venture capital funds.

To support the pursuit of technology development, it may need other external sources of seed capital, such as angel investments or venture capital. Business angel investors, who are often experienced entrepreneurs or business people, have become increasingly recognised as an important source of equity capital at the seed and early stage of company formation [54]. They operate in a segment which falls in between informal founders, friends and family financing and formal venture capital investors [57]. By definition, a BA is [58] an individual investor that invests directly (or through their personal holding) their own money, predominantly in seed or start-up companies with no family relationships. BAs make their own investment decisions and are financially independent, i.e. a possible total loss of their investment will not significantly change the economic situation of their assets.

Venture capital (VC) [17] is a subset of private equity and is used to describe the investment made in early stages (seed and start-up) or expansion ventures, which have the potential for sustainable growth. VC refers to capital investments made for the launch, early development, or expansion of a business. Offsetting the high risk the investor takes, is the expectation of higher than average return on the investment.

In summary, venture capital is a financial capital provided to early-stage, high-potential, high risk, growth start-up companies, typically involve high risk investments with a correspondingly potentially high return on equity. In contrast, BA are individual investors who also invest in a company in exchange for equity but, in some cases, also invest in exchange for a seat on the company board. They often take an active part in the company that they have invested in and fill a role as an adviser or non-executive director [59]. Venture capitalist aims to identify novel technologies that have the potential to generate high returns at an early stage of development. Nevertheless, the incentive for funding this type of investment, is to ensure as high of a return to its investors as possible, in the form of technical expertise or capital.

In the start-up stage, financing is provided to a company for product development and initial marketing. The company may be in the process of being set up or may have been in business for a short time, but has not sold its product commercially. Early stage financing is dedicated to the company that has a product or service in testing or pilot production. In some cases, the product may be commercially available, usually in business less than three years and may or may not be generating revenues. In this context, it is crucial to address the funding gap created by investors who prefer to fund larger, later-stage enterprises by providing services to inventors which allow them to develop and prove their inventions as viable in the marketplace. In the Bradley et al. model (see Figure 3.5), POCC are seen as organizations that allow inventors to evaluate the commercial potential of their research, enabling early-stage products to be developed and to test prototypes. A proved concept makes it easier for inventors to obtain funding from outside investors, like BAs or venture capitalists (VC), for further product development [27]. Proof of Concept Centres will be the object of review in the next section.

Expansion stage financing applies when new product or service is in production and commercially available. The company, usually in business more than three years, demonstrates significant revenue growth, but may or may not be showing a profit. Later stage venture is available when financing is provided for the expansion of an operating company, which may or may not be breaking even or trading profitably. Later-stage venture tends to finance companies already backed by VCs, and therefore involves third or fourth (or subsequent) rounds of financing, which may include spin-offs of operating divisions of existing private companies and established private companies. Because the commercialization of scientific research is particularly risky and uncertain, a strong scientific reputation, evidenced through vigorous publication and formidable citations, provides a greatly valued signal of scientific credibility and capability to any anticipated commercialised venture or project [60].

3.8 Proof of concept centres

Before new technologies can be positioned to attract private capital for commercial development, further research must be performed in order to prove its feasibility. At the core of this transition process is the technology Proof of Concept (POC) [17], essential to attract investment and development partners from the industry and from the venture community. As reviewed in the previous section, angel investors and venture capitalists increasingly invest in later stages of development, and so, researchers face difficulty finding early stage funding to develop and test prototypes and to conduct market research. Maia and Claro [61], argued that this is the most critical phase in technology commercialization, the phase that "...occurs between invention and product development, when commercial concepts are created and verified, appropriate markets are identified, and protectable Intellectual Property (IP) may have to be developed. This Proof of Concept (...) phase has a funding gap, caused by information and motivation asymmetries and institutional gaps between the Science and Technology and Business enterprises."

Proof of Concept Centres (POCCs) are emerging as successful structures to address the described challenges [6], [8], [27]. Bradley et al. [8] listed the barriers, that hinders the success of technology transfer, potentially addressed by the POCCs: (i) entrepreneurs tend to be older and often lack relevant business skills, (ii) researchers are not always inclined to re-direct their research toward transferable technologies, (iii) researchers often lack the social networks necessary for successful technology transfer, (iv) research policies (e.g., promotion and tenure, financial, and intellectual property) do not always provide sufficient incentives to engage in technology transfer, and (v) external funding for start-ups is often difficult to obtain. The same authors [8] referred to POCCs as “a collection of services to improve the dissemination and commercialization of new knowledge from universities in order to spur economic development and job growth.”

Maia and Claro [61] proposed the following definition for a POCC: an organization working within or in association with the research, to provide funding, mentoring, and education, in a customizable support to POC activities in technology commercialization, i.e., the development and verification of a commercial concept, the identification of an appropriate target market, and the development of additional required protectable IP.

POCCs are a growing technology infrastructure in the United States, and an important element of national innovation system [8]. Being focused on relatively early stages of technology development, POCCs have the potential to impact most of the technology transfer process services, that include seed funding, business and advisory services, incubator space, and market research. Their study, based on the US Census Bureau regions, indicates that in 2013, there were 32 operational POCCs in the US. Regardless of our investigation, no evidence was found relative to the existing numbers in Europe.

According to Ewing Kauffman Foundation [2], based on the study of two POCCs (the Deshpande Centre at the MIT School of Engineering and the Von Liebig Centre at the University of California San Diego Jacobs School of Engineering), the combination of seed funding with advisory services and educational initiatives, and the plug innovators into outside funding and collaboration networks are key complementary elements of success. As a conclusion, the study suggested that the location for the creation of a new POCC: (i) must be related with the production of innovative and marketable technologies, (i) is not adverse to collaboration with external networks and groups, (iii) has TTOs that are willing to work with a centre to assist in the commercialization process, (iv) must be able to find an administrative team and advisors who are “hubs” in the local venture capital, technology, and industry networks, and (v) has a strong social network in the surrounding community, including advisors, angel investors, venture capitalists, and interested firms for grantees to partner with.

In summary, POCCs can be defined as [27] organizations that address the funding gap caused by investors who prefer to fund larger, later-stage enterprises by providing services to inventors which allow them to develop and prove their inventions as viable in the marketplace. Accordingly, Proof of

Concept Centres are of extreme importance to bridge the gap between research and the early stage of a marketable technology. Additionally, to this process enhancer is the process lead time, or the forms to reduce it. This will be addressed in the following section.

3.9 Technology accelerator

Standing from the point that process lead time is a technology transfer process enhancer, Miller and Bound's recent work [58] refers to an accelerator concept, presented as a new way of incubating technology start-ups. Their work lists the general features of an accelerator, as an application process that: (i) is open to anyone, yet highly competitive, (ii) enables the provision of pre-seed investment, usually in exchange for equity, (iii) focuses on small teams, not individual founders, (iv) provides time-limited support comprising programmed events and intensive mentoring, and (v) supports start-ups in cohort batches rather than individual companies. The technology accelerator stakeholders were identified by Petersson et al. [62], in the work *Study of Seed Accelerators and Their Defining Characteristics,* as being the start-ups, the investors, and the programme mentors.

Accelerator programmes are growing worldwide, as a recent type of funding technology start-ups, with an increasing number of active programmes, primarily in the United States, but also in Europe. Y Combinator, the first seed accelerator in the world, established in 2005 in Silicon Valley by Paul Graham, had the purpose to help promising start-ups form their businesses in exchange for equity. It was followed by TechStars in 2006 and Seedcamp in 2007, whose basic idea relied on the fact that many start-up mistakes can be avoided with access to more mentorship and support. Top rated seed accelerator programmes in Europe include Seedcamp (based in London) and Startupbootcamp (pan European accelerator with programme locations and office spaces based in Copenhagen, Madrid, Dublin, London and Berlin).

Accelerator programmes derive many of its characteristics from the business incubator, widely described in the literature [62]. Business incubators are often found in and near Universities, and provide inexpensive office space and mentorship to entrepreneurs and their companies. Just like seed accelerator programmes, incubators focus on companies in the earliest stages of development, and both models involve an application process for admission. An incubator can be defined as [17] "an organisation that provides facilities (office/laboratory space) or business advisory services to start-up companies in exchange for cash, equity, or a combination. These organisations can be public, private (both profit and non-profit), or public/private ventures. They may be focused on a particular industry, sector, or geographic area. Each incubator has its own criterion for admission and graduation. "Virtual" incubators provide services without providing physical facilities. Business incubators are committed to nurturing entrepreneurs, start-ups and small companies at an early stage in their ventures."

The differences between both models, an incubator and an accelerator, relies on how much equity is taken in the participating companies, and how each model generates revenue. Business incubators generally take no equity in start-ups, run as non-profits and charge start-ups for rent and services. Seed accelerators generally take an equity stake in their start-ups, just as for-profit ventures, and provide entrepreneurs with start-up funding.

Through an open application process, seed accelerators support the start-ups with funding, mentoring, training and events for a definite period of time (usually three months), in exchange for equity. While traditional business incubators are often government-funded, generally take no equity, and focus on biotechnologies, medical technology, clean technologies or product-centric companies, accelerators are driven almost exclusively by private investors, and concentrated in the web and mobile sectors.

Lean start-up is one of the new management methodologies used by accelerators [63], a method for developing businesses and products first proposed in 2011 by Eric Ries [31]. According to his book, start-ups can shorten their product development cycles by adopting a combination of business-hypothesis-driven experimentation, iterative product releases, validated learning, and by so, reduce the costs of a new business creation. Entrepreneurs in these start-ups translate their vision into business model hypotheses, and then the hypotheses are tested using a series of minimum viable products, each of which represents the smallest set of features needed to rigorously validate a concept. Based on test feedback, entrepreneurs must decide whether to persevere with their business model, changing some model elements, or abandon the start-up.

Another concept that has gained traction within the lean start-up movement is the Business Model Canvas by Alexander Osterwalder [32]. This strategic management and entrepreneurial tool allow the description, design, challenge, invent, and pivot of a business model. Canvas represents a way of developing business models based on nine key concepts: (i) customer segments, (ii) value propositions, (iii) channels, (iv) customer relationships, (v) revenue streams, (vi) key resources, (vii) key activities, (viii) key partnerships and (ix) cost structure. Thence, Canvas is used as an iterative tool to refine and describe the business model.

The study of *Seed Accelerators and Their Defining Characteristics* [62], concluded that these methods are widely practised and pointed that there is no single methodology used by all studied accelerators. Despite the positive feedback, given on technology accelerator programmes, Miller and Bound [63] stated that the business model for running an accelerator programme is yet to be proven, and presented a list of areas that require future research. The first is related to the fact that the performance and the impact of the accelerator programmes are difficult to measure. As so, they suggested that, in addition to the traditional incubation performance indicators (such as job creation, talent attraction, stimulation of private investment and business survival), the impact on individual entrepreneurs and on the environmental conditions for building businesses and innovating should be measured. Secondly, being a new phenomenon, there is a need for further structured quantitative research of their impact, in order to understand the creation model of high-growth companies.

Thirdly, despite the proven fact that the accelerator model works well in the web and mobile sectors, because of the lack of necessary capital, there is a need to prove that this is a model that could be widely applicable.

Following the review of technology commercialization models, process enablers, process stakeholders, financing, proof of concept centres and technology accelerators, the next chapter aims to identify ways to decrease technology risk and increase technology value, from the asymmetric information between the process stakeholder’s point of view.

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4 TECHNOLOGY VALUE AND RISK

4.1 Introduction

Technology commercialization, a transfer process that brings new technologies to the market, based on research and development (R&D) activities for the purpose of further development and commercialization [1], aims to create economic and social value from this transfer. As previously stated (Chapter 3.1), in a value creation approach, the technology commercialization process can be viewed as a set of interconnected activities, each one contributing to the technology value creation in each process stage until the new technology reaches the end user. Based on this perspective, it can be stated that the value will be created by delivering innovative products with high-quality information [2].

Standing from a value creation point of view, Paul et al. [2] refer that "to increase R&D effectiveness it is important to fully understand the ultimate value of a project very early in development and know how this information can be leveraged in individual clinical plans and trade-offs in portfolio decision making. The determinants of overall value are likely to be different depending on the perspective represented all along the process, from the lab to the market."

The fact that firms typically cannot assess the quality of the invention ex ante, while inventors find difficulty in assessing the commercial profitability of their inventions, it is referred to in literature [3] as a process node, and denoted as the asymmetric information between process stakeholders (Chapter 3.6). Following this perspective, Shane [4] stated that nevertheless the increasing understanding of the opportunity exploitation process, knowledge has advanced very little on how entrepreneurs identify opportunities, formulate business ideas, and evaluate them. The understanding of how the business ideas, formulated by entrepreneurs, affect their decisions to exploit opportunities, and what influence the difficulty and risk inherent in the pursuit of opportunities have on the exploitation decision is pointed as the critical issue.

Which approaches should be implemented in order to decrease the technology risk and increase its value? The purpose of this chapter is to answer this question from the asymmetric information between process stakeholder's point of view. To that end, we will start with a brief background on innovation strategy concepts, namely the technology push and the market pull. Afterwards, based on a push strategy, we will review technology risk and value. Then we will assess information asymmetry and, by consequence, technology commercial barriers, from different perspectives: stakeholders, financing, and risk reduction elements.

4.2 Technology valuation

Technology transfer process moves the results from research and development (R&D), in a multi stage and gate model, in order to increase technology maturity level to a point that it is ready for commercialization, reaching its maximum potential (see Chapter 3). Following this perspective, it can be postulated that transfer process is linked with technology valuation and valorization progression. Being the aim of this section the focus on technology valuation process, it is important to start by defining its surrounding concepts, namely, R&D, innovation and innovation strategies, technology value and technology risk.

Research and Development (R&D), as defined in the Frascati Manual [5], is the comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. The presence in R&D of an appreciable element of novelty and the resolution of scientific or technological uncertainty, i.e. when the solution to a problem is not readily apparent to someone familiar with the basic stock of common knowledge and techniques for the area concerned, is the basic criterion for distinguishing R&D from related activities [5]. In this context, R&D being the source of new knowledge, act as a catalyst for social and economic value creation, through innovation.

According to the Oslo Manual [6], innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations (see Chapter 2.2). Two main types of innovation can be defined [6]: (i) marketing and organizational innovation, and (ii) technological product or process innovation. The latter stage of innovation (technological innovation), which covers new technologically implemented products and processes and significant technological improvements in products and processes, is the one tied to the term innovation for the purpose of this work. Dewar and Dutton [7] also classified innovation based on technological knowledge embedded on innovation as: (i) radical innovations: the ones that contain a high degree of new knowledge, and (ii) incremental innovations: the ones that have a low degree of new knowledge. Literature shows that radical and incremental innovations are the strategies to commercialize innovation, and are defined as technology push and market pull, respectively [8].

In the literature on innovation, there is also a distinction between technology push and market pull strategies. When a new invention is developed by R&D, based upon a response to an identified market need, the market pull, or technology pull, was the adopted strategy [9]. On the contrary, if an innovation is pushed through R&D to market, an unmet market need has to be found, we are faced with a technology push strategy. In other words, technology push innovation comes from radical changes in technology without any modification of the meaning of products [10]. Christensen [10] refers to these radical innovations, coined by the author as disruptive technologies, as the ones that change the value proposition in a market.

In this line of thought, from the firm's and entrepreneur's perspective, for whom value proposition is generating future returns through the investment (see 3.6), value creation begins by identifying what value to provide to customers [11], who capture value. Value creation can be then defined as [12]–[14] innovation that establishes or increases the consumer's valorization of the benefits of consumption. When value is created, consumers will either (i) be willing to pay for a novel benefit, (ii) be willing to pay more for something perceived to be better, or (ii) choose to receive a previously available benefit at a lower unit cost, which often results in a greater volume of purchases. In parallel, value capture is determined by the perceived power relationships between buyers and sellers [15]. Research has described this value creation process as a three-phase process [11]: (i) value proposition, (ii) exchange value, and (iii) value in use, where the value is created, captured and evaluated. For an extensive value definition review see Bowman and Ambrosini [15]. In this work, we will focus on technology value creation at its origin phase, the value proposition point, the novel benefit to consumption.

Technology has an untamed potential value at its origin phase, the value proposition point. In each step of the commercialization process, the maximum value that it can create is limited by the value acquired at the precedent stage. Technology valuation is usually based on its future economic benefit [16] and, rates of return are generally estimated by computing the benefits, including discounted future benefits, versus the costs of innovation. Other common measures are [16]: (i) the projected future sales and income from R&D projects in the pipeline; (ii) customer or consumer evaluation of product quality and reliability; (iii) estimates of the effectiveness of the transfer of new technology to manufacturing lines; and (iv) percentage of research project outcomes published in technical reports.

Listed measures can be pointed as unstable, based on the fact that the real value of technology can only be precisely calculated after the technology reaches end users. Following this assumption, Schuh et al. [17] presented a new approach based on a balanced methodology. The proposed methodology valuates the technology related intangibles, according to International Accounting Standards Board's expected cash flow approach. According to this, technology value is monitored along its whole life cycle, from development stage until market commercialization. This approach incorporates the flexibility of technology decisions but also the dependence of the technology's real value based on external factors.

Hoppe and Ozdenoren [18] presented a theoretical model to explore the conditions under which innovation intermediaries, such as Technology Transfer Offices (TTOs), emerge to reduce technology transfer uncertainty. In their model, firms seek to invest in inventions, but they cannot estimate technology value with certainty. Intermediaries, such as TTOs, are able to make a sunk investment, by acquiring the expertise to locate new inventions, sort profitable from unprofitable ones, and assess the efficiency level of potential licensees. The authors showed that the fixed set-up costs of TTOs can be recovered if the size of the invention pool is large enough to exploit the economies of sharing expertise. Also, that the intermediary may reduce the uncertainty problem, the downstream integration of activities, as far as the decoupling point reduces uncertainty and [4] increases the scope for value capture. If decoupling happens to occur at the point where a firm can claim intellectual property in the technology, licensing would be optimal.

Being licensing strategies driven by the technology valuation in question, it is important to close this section with potential licencing technology classifications. Markman et al. [19], based on TTOs interviews, divided the technology valuation into four overlapping stages (conceptualized along two continuums of uncertainty: ambiguity, regarding whether a particular technology has market application, and ambiguity, regarding the robustness of the legal protection over the IP) as follows: early-stage inventions, proof of concept, reduced to practice, and prototyping. An early-stage technology refers to discoveries based on basic research with highly uncertain market potential and in unclear IP protection status. In the proof of concept stage, the new technology has been developed to the point that it shows signs of having the proposed effect. At reduce to practice stage, an experiment on the idea has been replicated several times, and the intended results have been reliably and repeatedly reproduced. The prototyping stage, refers to a technology with a relatively clearer market application and more robust legal protection, meaning that the technology can produce desired results.

4.3 Technology valorization and risk reduction

Technology valorization, based on its future economic benefit, can differ totally from its original cost. Once this benefit can only be precisely calculated after an effective commercialization, technology needs to be valued along transfer process stages in terms of commercialization risk perceived. The identification and implementation of risk reduction activities will increase technology value.

Knowing that economic rents can only be produced from the creation of superior customer value, value innovation can be conceptualized as the creation of new and substantially superior customer value by redefining the business models, roles and relationships in the industry [20]–[22]. The fact that not all firms are able to leverage their capabilities for successful outcomes suggests that more work is needed to understand the implementation of a value-based logic. Following this perspective, technology stage and performance, maturity valorization and readiness stage for product development comprehension, are essential for risk reduction in the commercialization process.

Technology performance and maturity follow an S-curve when the performance and maturity (y-axis) is plotted against time (x-axis). After the discovery, technology is in an embryonic stage, and the maturity is characterized by slow growth, followed by a rapid and sustained growth. Simultaneously, the risk of moving the technology to the market curve is at its maximum value at the discovery, with a tendency to decrease over time (see Figure 4.1).

Figure 4.1: S-Shaped curve representing technology performance and maturity index across time of development

According to the literature review [23], four elements influence the technology adoption process: technology innovation type, technology communication channels, time, and the social system. These elements work in conjunction with one another: diffusion. Diffusion of innovations [23] is a theory that seeks to explain how, why, and at what rate new ideas and technology spread over time through cultures.

According to the author, the diffusion of innovation (see Figure 4.2) occurs through a five–step process: knowledge, persuasion, decision, implementation, and confirmation. If the innovation is adopted, it spreads via various communication channels. During communication, the idea is rarely evaluated from a scientific standpoint, but rather from a subjective perception of the innovation influence diffusion, which is a process that occurs over time. Finally, social systems determine diffusion, norms on diffusion, roles of opinion-leaders and change agents, types of innovation decisions, and innovation consequences.

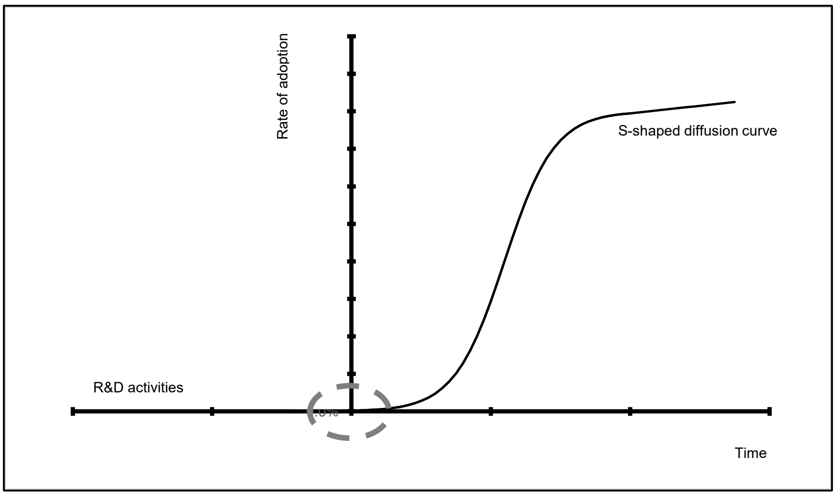

Figure 4.2: Innovation Diffusion.
Adapted from Rogers [23]

The innovation-decision period is the length of time required to pass through the innovation-decision process. The rate of adoption is the relative speed with which an innovation is adopted by members of a social system. Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system, in an S-curve.

Due to technology nature, risk and uncertainty change, along the technology maturity process, each industry type has a different view of the technological evolution or maturity, resulting in different S-curves. Farrukh et al. [24], based on their research results in the aerospace, pharmaceutical and telecommunication sectors, proposed a solution for technology valorization in terms of a timeline of technology development (see Figure 4.3).

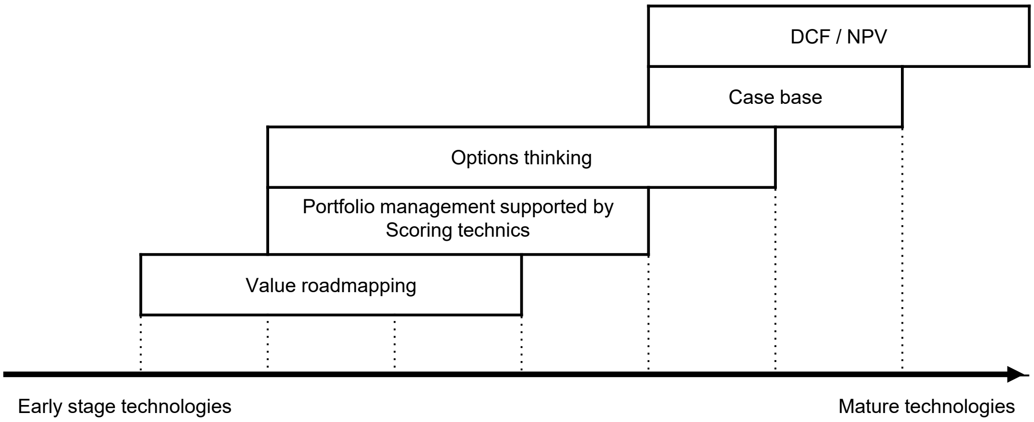

Figure 4.3: Timeline view of technology valorization approaches.
Adapted from Farrukh et al. [24]

The authors described their view of technology valorization timeline as follows: “some tools may be fundamentally more appropriate for use on a mixed portfolio of technology projects or for monitoring a technology as it matures in terms of readiness. Scoring tools appear to be one example if implemented appropriately with criteria that change in emphasis with increasing technological maturity. Approaches such as road-mapping and options thinking are methods of documenting gut feel for further discussion.” After a technology is mature enough for the marketplace, the necessary locus of integration shifts backwards. In these circumstances, companies ought to focus on individual pieces that add value [25].

Following this approach, Mankins [26] described technology added value goals over time as followed. First, the investment in R&D should result in improvements in relevant performance parameters for the new technology being advanced. Secondly, the technology R&D effort should result in overall technology maturation. And finally, the technology R&D investments, at each stage, should result in reduced risks for subsequent R&D that might be pursued.

The literature reviewed identified different perspectives concerning time based views of technology valorization [24], [26]–[28], methodologies approaches that describe stages of technology development at an organisational level. The Stage and Gate technology development process model (Chapter see 3.3) can be used to structure technology development projects, where the immediate deliverable, is not a new product or new manufacturing process, but new knowledge or capability [27]. The Technology Readiness Levels (TRL), developed by NASA in the 1980s, is a methodology to assess technology maturity along the development timeline. Mankins defined TRLs [28] as a systematic measurement system that supports assessments of the maturity of a particular technology and a consistent comparison of maturity between different types of technology. Technology Readiness Levels original definitions included seven levels:

Level 1. Basic Principles Observed and Reported
Level 2. Potential Application Validated
Level 3. Proof-of-Concept Demonstrated, Analytically and/or Experimentally
Level 4. Component and/or Breadboard Laboratory Validated
Level 5. Component and/or Breadboard Validated in Simulated or Real Space Environment
Level 6. System Adequacy Validated in Simulated Environment
Level 7. System Adequacy Validated in Space

In his paper, Mankins [26] expanded NASA’s TRL definitions from seven to nine levels and proposed the “Technology Readiness and Risk Assessment” (TRRA) methodology, including the technology need value as a weighting factor that is based on the assessed importance of a particular technology development. Figure 4.4 represents a technology development from this point of view, including both processes, the technology risk reduction, and the simultaneous course of performance improvement and overall technology maturation. From the point that R&D is concluded, and development begins, the performance and maturity curves have a similar behaviour as the S-shaped value curve represented in Figure 4.1 and Figure 4.2.

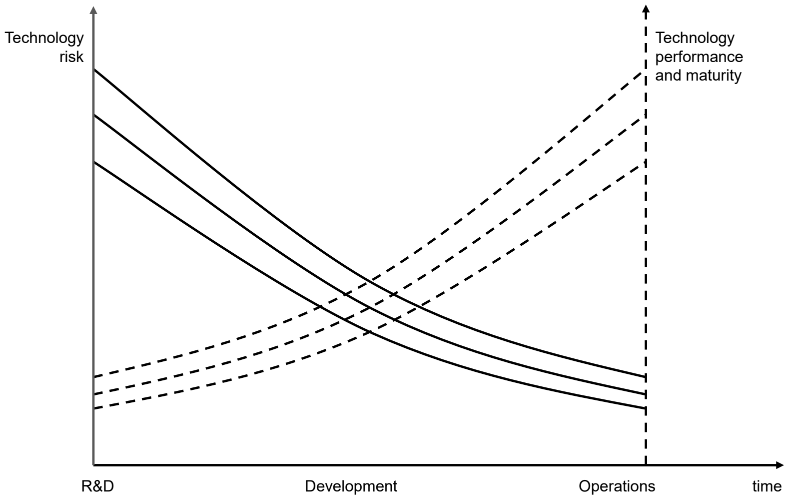

Figure 4.4: Technology development R&D programme implementation.
Adapted from Mankins [26]

Mankins [26] proposed a scenario for technology development that considers three factors involved in technology readiness and risk assessment as a result of R&D efforts: performance, maturation, and risk. According to the author, this new approach aimed to provide a “new toolkit for an effective management of advanced technology (...) and a consistent and analytically based assessment of the technology readiness and risks in a given investment portfolio.” Recently, this list had been adapted by the European Commission work Programme 2014-2015, Horizon 2020 - The Framework Programme for Research and Innovation[4], as follows:

Level 1. TRL 1 – basic principles observed
Level 2. TRL 2 – technology concept formulated
Level 3. TRL 3 – experimental proof of concept
Level 4. TRL 4 – technology validated in lab

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[4] Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly €80 thousand million of funding available over 7 years (2014 to 2020) – in addition to the private investment that this money will attract. It promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market. (https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020)

Level 5. TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
Level 6. TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
Level 7. TRL 7 – system prototype demonstration in operational environment
Level 8. TRL 8 – system complete and qualified
Level 9. TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies, or in space)

Technology Readiness and Risk Assessment (TRRA) approach involves [26] clarity, transparency, crispiness, and usefulness. These characteristics require, first, clear decision criteria for determining both risks and technology readiness and that these criteria should be analytically grounded in order to allow independent evaluation and verification of results. Secondly, the process for technology risk and readiness assessment should be formal and consensus based, in order to allow managers and independent observers to understand both the process, the interim steps in the assessment and its results. Tertiary, decisions during assessment should be crisp, timely, and keyed to annual R&D and system programme budget planning requirements and made by senior management. Last, the processes used for making decisions should also produce the basis for advocacy of the results.

In summary, standing from a technology push point strategy, our understanding is that value generator mechanisms should be incorporated during technology transfer process key activities, as well as technology maturity and risk assessment indicators, in order to reduce technology risk and increase commercialization chances. Based on this perspective, technology value must be seen as a curve with a positive trend all along the commercialization process, in opposition of the risk perceived, that should have a negative trend.

4.4 Asymmetric information

Scientific research ultimate goal is to improve the human condition, therefore, technology commercialization serves not only researchers and society, but also all stakeholders involved in the process. Rothaermel et al. state that current research lacks a complexity in models, or richness in data to understand the interdependent processes across many different stakeholders involved in technology commercialization [29]. Nevertheless, Siegel et al. [3] pointed the asymmetric information, regardless of the value of the inventions, between process stakeholders as a node in the commercialization process. They stated that “firms typically cannot assess the quality of the invention ex ante, while researchers may find it difficult to assess the commercial profitability of their inventions.” Bowman and Ambrosini reinforced this statement arguing that [15] economic decisions are made on the basis of knowledge each stakeholder might possess, and as so, technology value is assessed subjectively, based on each stakeholder’s perception. In other words, the transition from discovery, to a prototype, to a product requires bridging the technology informational value gap between discovery and market potential and the information gap between process stakeholders, namely the ones that are positioned at the process extreme points, research and application.

Due to a diversity of environments that surround these stakeholders, consistent differences exist related with their information levels. For instance, the potential entrepreneur may not have the level of information or knowledge to be acquainted with the novel technology, in order to explore its full potential and, as a result, technology based ventures face a number of significant barriers [30]. Researchers have a lack of knowledge about the market and firms want knowledge about technical aspects. Jensen and Thursby [31] stated that in the early stage of development, inventors, who have often worked on the invention for a number of years, have better information regarding the feasibility of the invention than any other process stakeholder. As a result, they modelled the licensing transaction as a case of information asymmetry, whereby the inventor maintains valuable information pertinent to the invention that is not contained in the licensing contract or patent documentation.

Following this line of research, Lowe [32] stated that “Inventions that require significant inventor involvement to transfer tacit knowledge will be less likely to be licensed by incumbent firms, due to high post license transaction costs. Rather, inventors can internalize the gains from their tacit knowledge by starting a firm, thus embedding their tacit knowledge in a more developed form of the technology.”

Antelo [30] defined the lack of information over the patent value across licensors and potential licensees the double asymmetric information, explaining that “before contracting, the lack of information over the patent value may affect both parties, licensor and potential licensees, equally and, nevertheless, after contracting, each licensee, by using the new technology, may privately learn her own value.”

4.4.1 Asymmetric information and financing

New technologies may have multiple different commercial applications [33] and their commercialization strategy can be either licensing or a start-up creation. The stakeholders involved in a technology commercialization process will be affected by information asymmetry, and by consequence, in the required technology exploitation form, and the needed venture capital to promote its development to a maturity level that allows its commercialization.

Furthering the study of the informational gap, in order to understand the reasons surrounding the existence of the expression “valley of death”, the technology commercialization funding gap will be analysed in this section. To that end a quantitative analysis on venture capital investments made in the USA and Europe, per technology stage of development and per industry cluster, will be presented in this section.

The technology commercialization process stages may vary from model to model, in sequence or activities (see Chapter 3). In the licensing model, the technology owner grants user rights in the form of a licensing agreement, allowing the licensee to embed it into new products, in return of a licensing fee or royalty income. When a new company emerges during the development phase, to fully explore the new technology and search for its market position, it is considered as a start-up company. The European Investment Fund [34] defined a start-up as a highly innovative, newly formed company with high growth potential. Start-ups, characterized by their risk-reward profile, are usually funding by seed and venture capital, were founders exchange cash for equity. If this is the case, there is an enormous informational gap between the funder and the knowledge owner, especially in the case of business angels, a form of seed capital. However, many start-ups are initially funded by the founders themselves and, in many cases, the researcher is a founder, what diminished the gap. Despite the type of investment, the incentive is to ensure of a return to its investors (namely venture capitalists) as high as possible, usually in the form of technical expertise or capital. In this line, venture capitalists aim to identify novel technologies that have the potential to generate high returns at an early stage of development.

A venture capital, according to European Investment Fund [34], is a subset of private equity, reported to the investment made in unlisted companies in early stages (seed and start-up) or expansion venture, which have the potential for sustainable growth. Venture capital refers to capital investments made for the launch, early development, or expansion of a business. Offsetting the high risk the investor takes, is the expectation of higher than average return on the investment. Based on this definition, venture capital can be described as a financial capital provided to early-stage, high-potential, high risk, growing start-up companies.

Amount invested per stage of development

Ventured capitalist invested an average amount of $42.25 thousand million per year in the USA, from the year 2000 to 2014, with an average of 4000 investment deals per year [35]. Seed stage had an average amount of investment of $1.26 thousand million, early-stage $8.03 thousand million, expansion stage $14.7 thousand million, representing the highest value of investments, and later-stage $9.7 thousand million. The average amount of investment per deal curve has a different behaviour, once in this case, the investments are increasing all along the development stages. Seed stage had the lowest amount, with $3.44 thousand million, followed by early-stage with $5.4 thousand million, expansion stage $9.6 thousand million and later stage $ 11.11 (see Figure 4.5).

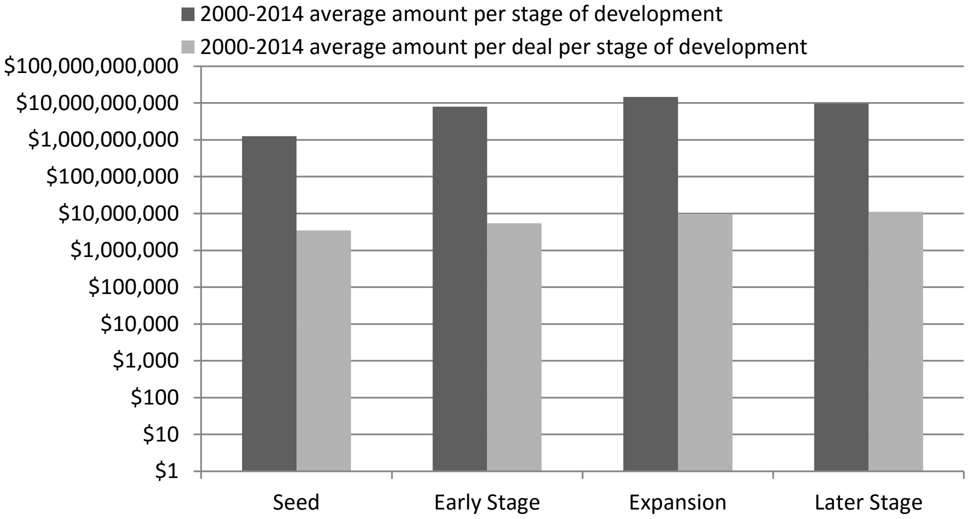

Figure 4.5: USA average amount invested (in $) from year 2000 to 2014: (i) per stage of development and (ii) per stage of development per deal.
Adapted from PWC [35]

Around 4.6 thousand million Euros was the average amount of venture capital invested in Europe [36], from 2007 to 2013. Later-stage[5] had an average amount of €2.4 thousand million, start-up €1.98 thousand million, and seed €0.1 thousand million (note that European data only considers three stages for technology development). Around 4.5 thousand million Euros was the average amount of venture capital invested in Europe, from 2007 to 2013 (see Figure 4.6).

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[5] **Seed:** Financing provided to research, assess and develop an initial concept before a business has reached the start-up phase. **Start-up**: Financing provided to a company for product development and initial marketing. The company may be in the process of being set up or may have been in business for a short time, but has not sold its product commercially. Other **early-stage**: Financing to a company that has completed the product development stage and requires further funds to initiate commercial manufacturing and sales. It will likely not yet be generating a profit. **Later-stage venture**: Financing provided for the expansion of an operating company, which may or may not be breaking even or trading profitably. Later-stage venture tends to finance companies already backed by VCs, and therefore involves third or fourth (or subsequent) rounds of financing.

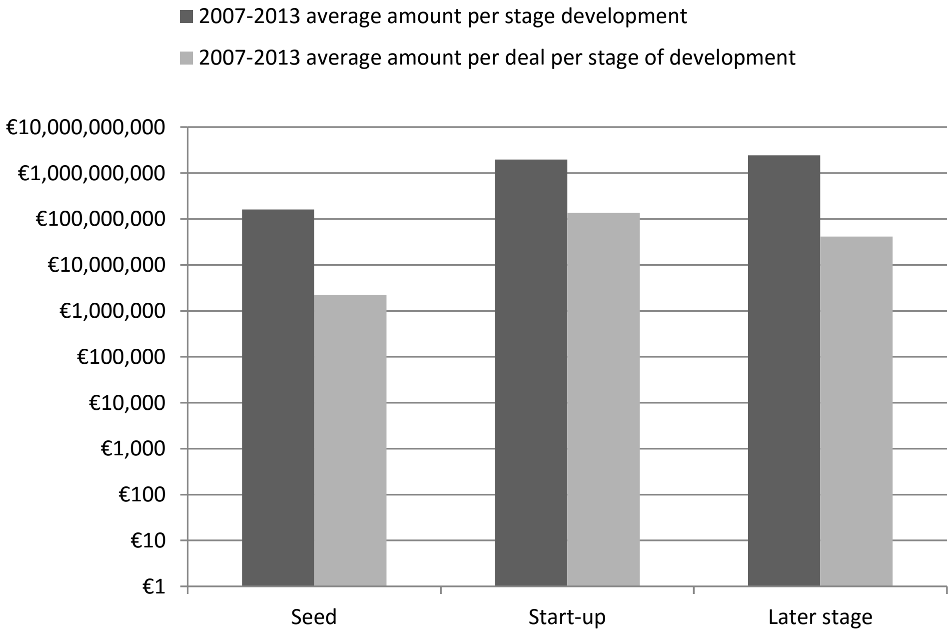
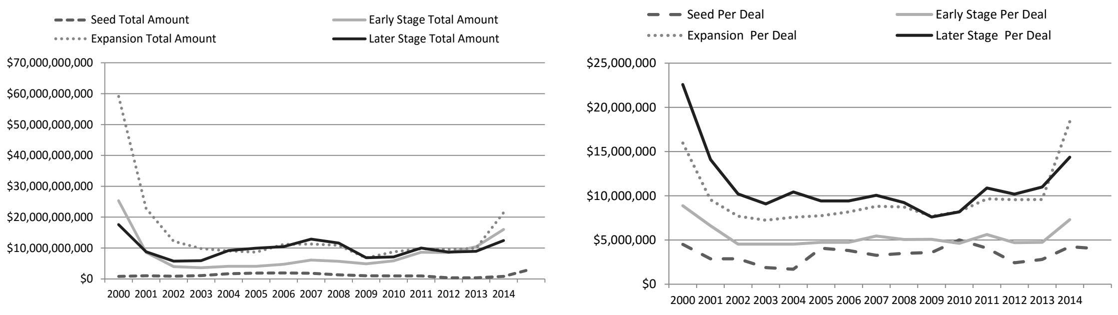


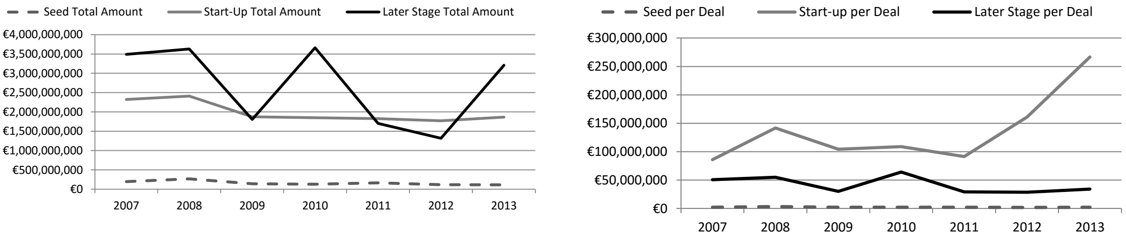
Figure 4.6: Europe average amount invested (in €) from year 2007 to 2013:
(i) per stage of development and (ii) per stage of development per deal.
Adapted from EVCA [36]

What concerns the investments made per year in the USA, a highlight is made for the year 2000 that had the highest value, what can be explained by the dot-com bubble. Nevertheless, what we can observe in Figure 4.7, representing namely the total amount invested per year and the total amount invested per year per deal, is that, as stated before, the amount invested is increasing along the technology development stages, what can be explained the technology risk reduction.



a) b)

Figure 4.7: USA total amount invested per year (in $) from year 2000 to 2014: a) per stage of development, and b) per stage of development per deal.
Adapted from PWC [35]



a) b)

Figure 4.8: Europe total amount invested per year (in €) from year 2007 to 2013: a) per stage of development, and b) per stage of development per deal.
Adapted from EVCA [36]

Concerning Europe, the highlight goes to the years 2008 and 2013 (see Figure 4.8). Comparatively to the USA graphs, a different behaviour in investments per deal can be denoted, once a higher risk stage (meaning start-up), had a higher absolute value invested per deal than later-stage. But again, reservation goes to the fact that in Europe data from early-stage investments are coupled.

Investments by Industry

The software industry received the highest level of funding for all industries with an average of $7,6 thousand million invested from 2000 to 2014 in the USA. In regard to investments per deal, higher investment went to the biotechnology, networking and equipment industries with an average amount of $10 million each (see Figure 4.9). Consumer goods and retail industry had the highest level of investment in Europe with an average amount of €6.8 million, closely followed by business and industrial products industry (see Figure 4.10). On the other hand, the financial services industry had the higher investment per number of companies from the year 2007 to 2014.

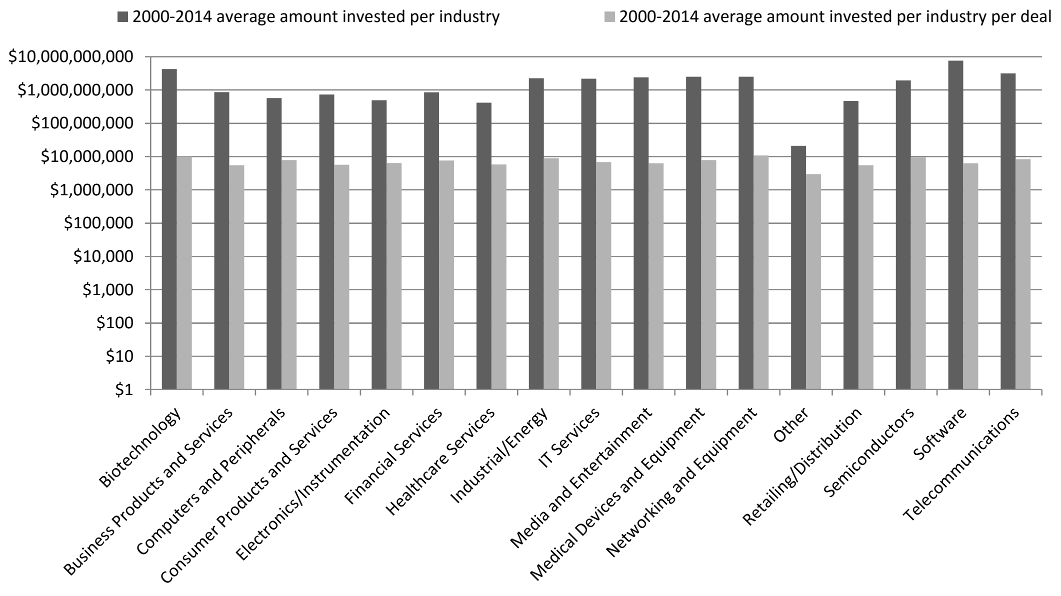


Figure 4.9: USA average amount invested (in $) from year 2000 to 2014 (i) per industry and (ii) per industry per deal.
Adapted from PWC [35]

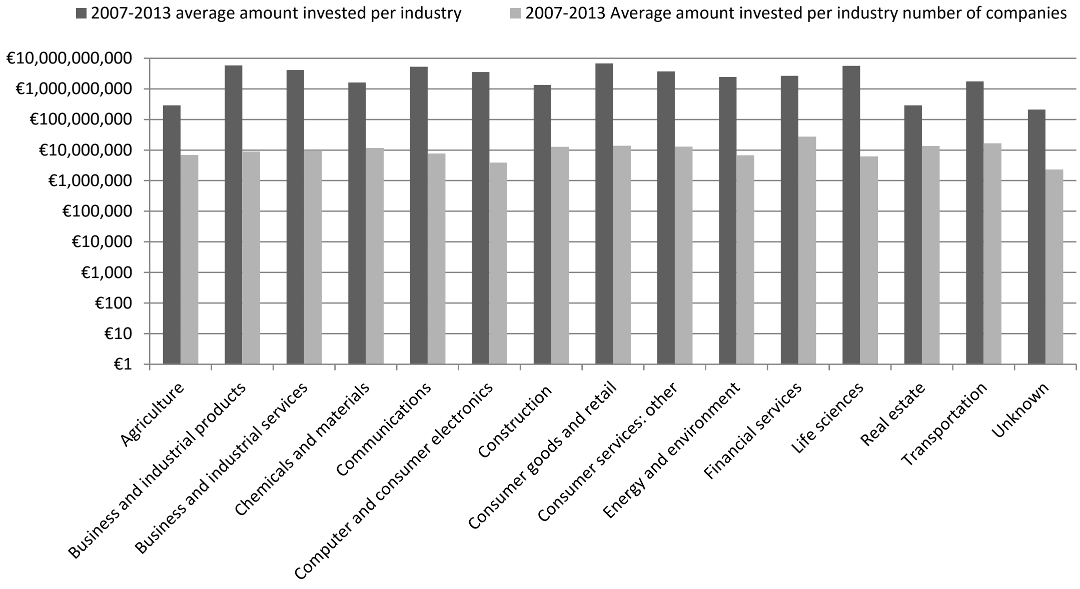
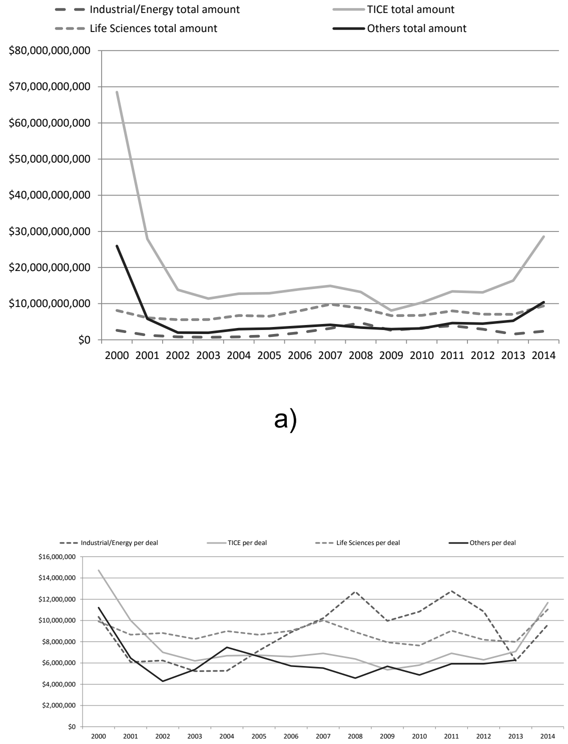


Figure 4.10: Europe average amount invested (in €) from year 2007 to 2013 (i) per industry and (ii) per industry per number of companies.
Adapted from EVCA [36]

Regardless of the investments made, per industry clusters: (i) USA's Industrial and Energy cluster had the lowest value, followed by Others, and Life Sciences, TICE had the highest value (see Figure 4.11) (ii) Europe's Life Sciences cluster has the lowest amount, followed by TICE and Industrial/Energy. Others[6] had the highest value invested (even if financial services industry are excluded from this cluster) (see Figure 4.12).

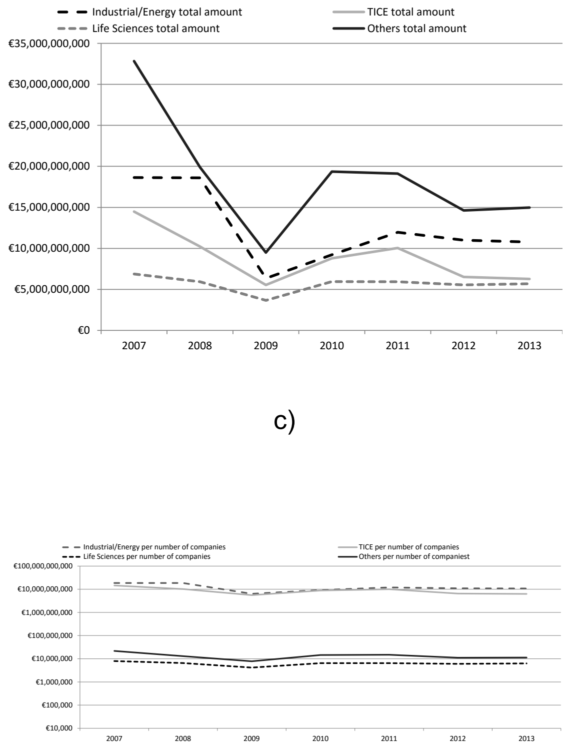
The total amount per deal invested in the USA shows that the Industrial/Energy sector represents the cluster with the highest growth in the last decade (see Figure 4.11), as well as in Europe (see Figure 4.12).



a)

b)

Figure 4.11: USA total amount invested per year (in $) from year 2000 to 2014: a) per industry, and b) per industry per deal.
Adapted from PWC [35]



c)

d)

Figure 4.12: Europe total amount invested per year (in $) from year 2007 to 2013: c) per industry, and d) per industry per company.
Adapted from EVCA [36]

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[6] Others include: Agriculture, Chemicals and materials; Construction; Consumer goods and retail; Consumer services: other; Financial services; Real estate; Transportation and Unknown.

4.5 Technology value and risk and information gap reduction

Based on the addressed points, it can be stated that uncertainty is tightly linked to new technology development, and it will be very difficult to predict its future gains. Due to technology's embryonic nature, at the time the license is executed, we assume that no stakeholder involved in the process can ensure that it will end in commercial success. What we can consider is, if the risk is reduced through information leverage, regardless technology value, success probability will increase. In this section, methods towards these objectives will be reviewed.

Dahlin and Behrens [37] developed a classification of technological radicalness that helps new technology identification before its commercial success. In the author's own words "... technologies might be radical in a technological sense without having significant market impact, since the market impact of a technology is affected by many non-technological conditions. (...) Early detection of inventions with the potential to start a radical change in an industry might also be useful for managers and policy makers, since they could then evaluate the technology and plan a response at an earlier stage." As a consequence, they stated that in order to be considered a successful radical invention, technology needs to be (i) novel: dissimilar from prior inventions; (ii) unique: dissimilar from current inventions; and (iii) must be adopted: needs to influence the content of future inventions. These three criteria suggest that time periods should be used to analyse each invention, past, present and future, in which the invention is valuated and determinate to be either similar or dissimilar to other invention.

The authors argue that, being their definition based on a three stage cumulative classification, presents the advantage of being focused on the technical content and on time effects over technology development. Therefore, this approach can be used to identify and assess radicalness in inventions across technological fields, diminishing the information gap regardless of technology valuation between process stakeholders.

Literature review indicates that another solution to reduce asymmetric information is when the researcher founds his own technological-based firm, a technology-based start-up venture, being directly involved in the technology development. In spite of the relevance of this statement, it raises the following question: having the researchers chosen to be in the lab, are they willing to become entrepreneurs? Many inventors lack resources and business experience, and even lack the willingness to do so. Although this could be a way to reduce the risk based on the information gap, is not a solution to technology commercialization licensing strategy path.

When the decision is to license the patent to a firm, a contract is signed, a license fee has to be paid and a period of further development follows. In order to speed up the technology development process, and thus improve its success probability, literature review suggests the involvement of the technology inventor. In this line of thought, it can be questioned if the co-development as a source of co-creation can act as a risk reduction element. Jensen and Thursby's [31] theoretical work showed that, although technology managers consider inventor cooperation for further development, crucial for commercial success, this is only true if “inventor's return is tied to the licensee's output when the invention is successful”. Their work surveys indicated that the vast majority of university inventions require some inventor involvement in late technology development and that this will potentially attenuate the effects of informational asymmetries, and thus, the probability of success depends on the inventor’s development effort. Friedman and Silberman’s [38] work also defended that a successful technology transfer requires continued involvement of the inventor. In this line of though, European Investment Fund [34] added that, to ensure continuous inventor involvement, incentive mechanisms have to be in place as a stake in the revenues generated. We have been observing this in the models analysed as a form of royalties or equity shares.

To finalize, Hoppe and Ozdenoren [18] have demonstrated that an intermediary with the expertise to evaluate the value of new inventions, and match the profitable ones with potential investors, can assist in the innovation decision. This can guide towards a form of risk reduction, and an accurate technology valorization by a stakeholder that speaks both languages, the inventor’s and the firm’s, reducing the informational asymmetry.

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5 A MODEL FOR TECHNOLOGY COMMERCIALIZATION

5.1. Introduction

R&D institutions, namely universities, play a key role in national and regional economic development. One important mechanism through which universities contribute to economic growth is by fostering the creation of social and economic value by converting knowledge generated through scientific research to innovation.

Cripps et al. [1], quoting a strategy study from The Scottish Enterprise, identified a number of channels by which innovation from the commercialization of university and other public research can take place, namely publication, education/training, collaborative research, contract research, industrial consultancy, licensing, spin-off ventures, and joint ventures.

The model for technology commercialization proposed in this chapter only accounts for the channels that involve protectable intellectual property rights (IPR) owned by the R&D institutions that can be transferable to companies, i.e., licensing and spin-off ventures.

In general, the technology transfer models described in Chapter 3 follow the multi-stage process described by Thursby and Thursby [2]. In the first stage, an invention disclosure occurs when a new technology is developed by researchers (the recipient of this disclosure being the Technology Transfer Office – TTO), in the second stage, these disclosures are intermediate inputs to patent applications and, in the third stage, some of the patents are licensed (to an existing company or a spin-off). In between these stages, there are decision points (or actions) that determine the advancement of the disclosure between the stages. If a researcher files an invention disclosure, the TTO decides whether the invention should be patented. In making this decision, the TTO typically attempts to assess the commercial potential of the invention. Sometimes, companies or entrepreneurs have already expressed sufficient interest in the new technology to warrant the filing of a patent. If the industry expresses little interest in the technology, R&D institutions may be reluctant to file for a patent, given the high cost of filing and protecting patents. When a patent is filed and awarded, the R&D institutions typically attempt to “market” the invention, by contacting companies that can potentially license the technology or entrepreneurs who are capable of launching a start-up venture based on the technology [3].

As pointed out by Siegel et al. [4], the key stakeholders in the technology transfer process are researchers (who developed the new technologies), technology transfer officers (who mediate the flow of resources and information within the network of technology transfer stakeholders), and company managers and entrepreneurs (who are potential licensees of the technologies).

A study carried out by Thursby et al. [5] concluded that most of the licensed research is in a very early stage of development, exacerbating information asymmetries between licensors and potential licensees. As pointed out by Siegel et al. [6], this information asymmetry impacts the valuation of the invention, because companies typically cannot assess the quality or usefulness of the invention ex ante, while researchers and technology transfer officers may find it difficult to assess the commercial profitability of their inventions. This information asymmetry may lead to a valuation mismatch [7], where the licensors are perceived as placing a value too high on the invention, in part because they are aligned to maximize income generation, while potential licensees are unwilling to meet this valuation because of the uncertainty of generating future returns from it.

Also contributing to this information asymmetry (and consequently to the valuation of the invention) is the fact that most of the inventions developed by university researchers are platform technologies, i.e., have a wide range of applications across industry sectors [8] and, as so, they are positioned upstream in one or several industry value chains. This fact contributes to the difficulty in valuing the invention because it entails the need for industry specific and application specific complementary innovations, thus leading to high-sustained levels of technology and market uncertainty [9].

Traditionally, for the university, licensing revenue is tracked as one of the most important outputs of the technology commercialization process and one of the central goals of its TTO [10], [11] and, regardless of the level of detail embedded in the technology commercialization models described in Chapter 3, none of them contribute to a detailed stage of evaluation of the invention, simply stating that such a stage exists. So, in this chapter, we present a model to support technology transfer officers in sustaining a valuation for technology-based inventions.

The chapter starts by providing a contextualization of the model, highlighting some relevant features of key concepts involved in technology commercialization and then details the proposed technology commercialization model.

5.2 Contextualizing the model

5.2.1 Science and Researchers

The input to the technology commercialization process is a research output that a researcher produces, that may solve a significant problem and/or may have significant value (i.e., an invention). For the owner of this invention to appropriate the value it may create, the underlying intellectual property (IP) needs to be protectable and thus needs to be (i) new (i.e., must have some new characteristics that are not found in prior state of the art), (ii) not obvious (i.e., cannot be derived by someone with some knowledge of the subject of the invention), and (iii) needs to have an industrial application.

Not all research leads to scientific outputs that can be considered inventions, and relevant literature divides science into basic research (i.e., experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view) and applied research (i.e., original investigation undertaken in order to acquire new knowledge, directed primarily towards a specific practical aim or objective) [12].

Basic research is essentially disclosed through publications and the incentives for cumulative knowledge production are mainly in the form of career rewards. Applied research is essentially disclosed through patents (when disclosed) and the incentives depend on the degree to which a researcher can appropriate the ensuing technology and, thus, create value from the generated knowledge, through the commercialization of the technology [13], [14].

Stokes [15] reframed the prevalent distinction between basic and applied research, by proposing that research can have simultaneously both applied and basic characteristics. The author proposed two dimensions (see Figure 5.1) along which research might be motivated, namely: (i) the quest for fundamental understanding (vertical axis) and (ii) the consideration for use (horizontal axis).

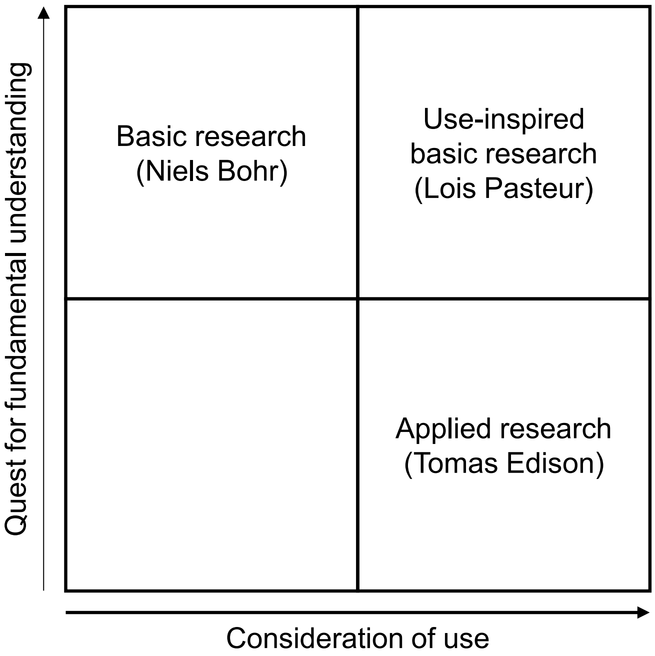

Figure 5.1 Stokes classification of research.
Adapted from Stokes [15].

The top left quadrant (Bohr's quadrant) represents the prevailing notion of basic research and the bottom right quadrant (Edison's quadrant) refers to purely applied research. Where Stokes' classification departs from the prevailing one is depicted in the top right quadrant (Pasteur's quadrant). As Stokes points out, Pasteur never carried out a study that was not applied, but, however, his key contributions to science covered the entire field of microbiology and changed the way the cause and prevention of disease are viewed. So, Pasteur’s quadrant enlightens a path where applied goals are not inherently opposed to scientific creativity and exactitude. So, researchers in this quadrant can disclose either through publications in scientific journals and/or through patenting and, thus, they are the ones that have the incentives better aligned to commercialize the inventions they discover.

Several studies (e.g., [16]–[18]) confirm that researchers in Pasteur’s quadrant are the ones that are more active in technology commercialization and, simultaneously, have scientific paper outputs comparable with the researchers doing basic research.

5.2.2 Technology

Although research activities are the backbone of scientific knowledge production, the deployment of this knowledge to create social and economic value requires it to be embedded in a technology.

Defining the concept of technology is not easy, and the term technology has been defined from different perspectives (for a discussion on the different definitions of technology see, e.g.,[19]). Galbraith [20] defines technology as “the systematic application of scientific and other organized knowledge to practical tasks” and Mesthene [21] defines the term as “the organization of knowledge for the achievement of practical purposes”. These are two of the most widely quoted definitions of technology and, from these definitions, it is quite clear that the knowledge produced through scientific research needs to have a practical application to be a technology from which value can be created. So, for the purpose of this work, the object of technology commercialization is the knowledge that has a practical application and, thus, technology is the starting point of the technology commercialization process.

Sahal [22] is one of the few authors that wrote about alternative concepts of technology and the ensuing confusion resulting from poorly specified concepts. He notes, referring to technology commercialization, that the transfer object (i.e., the technology) must rely on a subjectively determined but specifiable set of processes and products and so, simply focusing on the product is not sufficient for the transfer and diffusion of technology, because it is not merely the product that is transferred, but also knowledge of its use and application. This analysis highlights the crucial role of the scientist in the process of technology commercialization, because he grasps the ‘know-how’ required for a successful transfer of the technology.

This need for the involvement of the researcher(s), that developed the knowledge embedded in the technology to be commercialised, is also stressed by the nascent level of development of most of the technologies resulting from scientific research. Jensen and Thursby [23], reporting on a survey involving 62 Technology Transfer Offices (TTO) of US universities, concluded that "… when they are licensed, most university inventions are little more than a "proof of concept." No one knows their commercial potential because they are in such an early stage of development. Indeed, they are so embryonic that additional effort in development by the inventor is required for a reasonable chance of commercial success." This study was updated by Thursby et al. [5] and similar conclusions were reached: "Most inventions which evolve from university research are disclosed at a very early stage of development, and so have generally uncertain market potential and require substantial additional development before they can be brought to the market if they ever make it that far."

The level of development of a technology can be described in a Technology Readiness Level (TRL) scale (see Chapter 4.4), that consists of 9 levels (see Table 5.1). NASA introduced the TRL scale in the 70s to assess the maturity of a technology prior to integrating it into a system. Table 5.1 presents a version of the TRL scale proposed by the European Commission [24].

Table 5.1: Technology Readiness Levels

TRL	Description
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment
6	Technology demonstrated in relevant environment
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment

The actual meaning of each level in the TRL scale is highly dependent on the science/industry field to which it is applied, but as a general rule, TRL 1 to TRL 4 are the levels in which the involvement of the research team that developed the technology is crucial.

Another relevant aspect for technology commercialization relates to the breadth of the technology. Technology breadth refers to [8] its ability to support a wide range of products that can be applicable over a wide range of industry sectors (broad technologies are usually referred to as 'generic technologies'). From a technology commercialization point of view, the broadest the technology the more complex is the path to commercialization, because one has to devise its target applications and the target markets for each of these applications, in order to select the ones that capture more value from the technology. The broadness of a technology also impacts the complexity of the patent portfolio required to protect it effectively [25] and, as so, should be accounted for in the technology commercialization process. Shane [26], in the context of university spin-offs formation, cites five benefits of broad technologies, namely: (i) the flexibility to pursue alternative market applications, (ii) the diversification of risk and the amortization of R&D costs across separate applications, (iii) the establishment of a product pipeline that allows for short, medium and long-term revenue opportunities, (iv) the possibility to compare applications in different markets, and (v) the attractiveness for investors of the breadth and scope of opportunities that can be generated by the technology. This implies that, very early in the technology commercialization process, possible applications of the technology for different market segments need to be identified and prioritized, so that the ones with more attractive features (e.g., higher value captured, shorter time to market or fewer regulatory barriers) are selected for commercialization.

The technology positioning in the industry value chain is a third important aspect that should be accounted for in the technology commercialization process. According to Porter’s [27] industry value chain model (a model that depicts the primary and supporting activities performed by a firm or by a group of firms to convert raw materials and information into products and services of value), technologies can be placed in an upstream or downstream position in an industry value chain, depending on the distance of the applications enabled by the technology to the consumer (downstream being closer to the consumer).

Technologies in an upstream position generate intermediate parts that are integrated in devices that incorporate technologies further downstream in the value chain and, as so, are dependent on downstream design and process innovations and may depend on complementary innovations. So, developers of these upstream technologies do not deal directly with consumers that use the applications in which the technology may be applied, making it difficult for them to assess consumer needs, manage market experimentation, and gather useful feedback for rapid product interactions.

Customers of these intermediate parts (i.e., device integrators further downstream, they themselves sometimes supplying intermediate products to other integrators further downstream) have a utility metric for each performance attribute [28] and thus, even if a unique performance attribute, or bundle of attributes, is perceived to be useful by the integrator, its value can only be demonstrated once the part is embedded in a specific application, and the consumers utility for that attribute, or bundle of attributes, validates the value [28]. Thus, upstream technologies require a “technology push” commercialization strategy because many consumers in their potential markets do not perceive utility ex ante [9].

Upstream technologies are associated with very long development and adoption times, and high technological and market risk (e.g., Maine and Garnsey’s report that Polypropylene, Teflon, Kevlar and Carbon fibre – technologies that are upstream in the value chain of a wide range of industries - took 17 to 35 years to reach 50% of their peak annual sales [9]).

For the successful commercialization of such technologies, it is mandatory that very early in the process, an in-depth analysis of the possible paths to the market be carried out in order to create maximum value for the developer of the technology.

5.2.3 Risk and value

One of the main issues in technology commercialization, that has a significant impact on the valuation of the technology, is the asymmetry of information that exists between licensor (who does not have the tools required to access the commercial potential of the technology) and potential licensees (who do not have the resources to access the quality and usefulness of the technology) (see Chapter 4.4). This information asymmetry may lead to a valuation mismatch [7], where the licensors value the technology in excess, in part because they are aligned to maximize income generation, while potential licensees are unwilling to meet this valuation because of the uncertainty of generating future cash flows from it (see Chapter 4.5). The fact that most of the licensed research is in a very early stage of development [5] amplifies the information asymmetry between licensors and potential licensees. Since most of the technologies developed at R&D institutions are at an embryonic level of development (TRL 1-2), they pose a higher level of risk for the potential investor.

The two main factors of risk perceived by the licensee are technological and business development related. Technological risk arises from the uncertainty regarding the success of replicating laboratory specifications in product prototypes and viable production processes [29]. Business development risk arises from the uncertainty on whether a viable business can be created from a product enabled by the technology.

Technology risk materializes on, e.g., (i) longer than expected development times, (ii) technological fatal flaws (e.g., the technology does not perform at all or does not scale-up), or (iii) displacement by newer technologies [30]. Technology risk is a function of (i) technology readiness level, (ii) R&D degree of complexity, and (iii) technology need value [31]. When researchers only know basic principles (low degree of technology readiness), fundamental scientific breakthroughs are needed to increase technology readiness, or a wide range of complementary technological innovations are needed (high degree of R&D complexity) and, if the technology is critically important to the product or service (high degree of technology need value), then technology risk is highest.

Business development risk materializes on, e.g., (i) market fatal flaws (e.g., the customer needs that the product enabled by the technology is meant to address is not strong enough to build a viable business), (ii) longer than expected time to market (usually involves running out of funds), (iii) unpredicted regulatory hurdles, (iv) difficulty in demonstrating value for a specific application, or (iv) the IP is compromised. Business development risk is a function of (i) positioning in the value chain,

(ii) IP and regulatory landscape, (iii) strength of market need, and (iv) fit with market need [30]. When a product, enabled by a technology, is upstream in the value chain, if it needs to navigate a complex regulatory framework, cannot be patented, and is not able to demonstrate a good fit with a pressing market need, then the business development risk is highest.

Obviously, technologies that are further down the path to market, and/or for which it can be sustainably demonstrated that they create significant value by fulfilling an unmet (or ill met) market need, entail a smaller risk and, thus, are more attractive to licensees.

To characterize the business development level of a technology, an adaptation of the Technology Readiness Level to the business environment (termed Business Readiness Level - BRL) is presented in Table 5.2.

Table 5.2: Business Readiness Levels

BRL	Description
1	Problem/solution validated
2	Product concept defined
3	Value proposal validated
4	Functional and strategic assessment
5	Business model defined
6	Development roadmap defined
7	Financial projections built
8	Licensing plan
9	Market validation

The scale starts with a validation that the problem the technology is meant to address exists, and that the solution enabled by the technology solves the problem (BRL 1). BRL 8 assumes that a sustained licensing plan exists and the information asymmetry is significantly reduced. Of course, the lowest risk is when the product, enabled by the technology, is validated by the market (implying that there are revenues generated from the product). One should note, that for both these readiness level indexes, there is no time scale implied. So, e.g., in the case of BRL, it can take months to go from BRL 1 to BRL 8 and years to go from BRL 8 to BRL 9.

Figure 5.2 illustrates, from the licensee perspective, the relationship between perceived risk (or conversely, value) and the technology and business levels of development. The curves illustrate set levels of perceived risk, and the arrow shows the direction of decreasing risk (or conversely, increasing value).

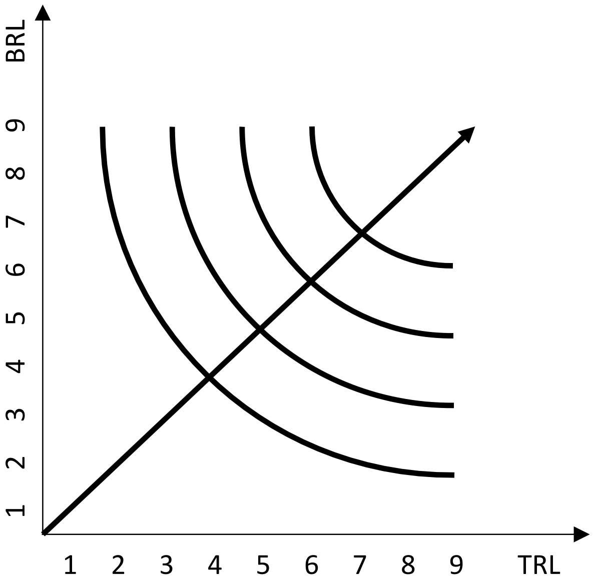

Figure 5.2: Licensee's perceived risk and value of the technology

Diminishing the technological risk typically requires a high level of investment over long periods of time because of the costs related to R&D, manufacturing scale-up, regulatory issues, etc. [9]. As a rule-of-thumb, the required investment is relatively low up to TRL 4 and then increases sensibly moving to TRL 9 (of course, the absolute values and the actual scale of growth strongly depend on the technology type). Regarding business development, moving from TRL 1 to TRL 8 does not involve high costs (essentially, human resources), but the investment for moving from TRL 8 to TRL 9 can be very steep. Figure 5.3 shows a typical relationship of the cumulative investments required for technology and business development.

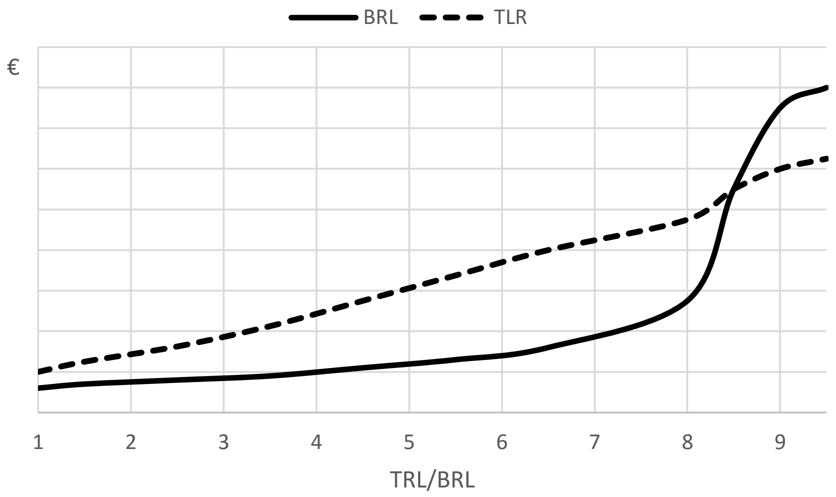

Figure 5.3: Investment requirements for lowering risk

From a technology commercialization perspective, the former arguments indicate that more readily commercializable technologies pose lesser risks to the licensee, who is attracted to technologies with lower risks. So, R&D organisations interested in increasing the rate of licenses must invest time and funds in an infrastructure that would increase the commercializability of technologies and reduce any perceived risk associated with the investment.

5.3 Proposed technology commercialization model

The technology commercialization models reviewed in Chapter 3 follow the three-stage process described by Thursby and Thursby [2]: (i) invention disclosure, (ii) patent application, and (iii) technology licensing. In the decision to apply for a patent, the TTO attempts to assess the patentability and the commercial potential of the technology. After deciding to apply for a patent the TTO attempts to "market" the technology, by contacting companies that can potentially license the technology.

These models fail in providing the details of the decision process and, thus, in helping the decision maker (i) to find the 'tipping point' that balances the investment required in moving the technology closer to the market and the value created by such an investment, and (ii) to evaluate the commercialization prospects of the technology, namely its value. In summary, the classic models of technology commercialization do not prescribe any actions that could be carried out to reduce the information asymmetry between licensors and licensees. Usually to circumvent the lack of knowledge that arises from asymmetric information, the parties (licensors and licensees) agree on licensing terms that include an upfront payment, milestone payments upon completion of specific stages of the technology development, and royalties on sales. In the licensing negotiations, two issues usually arise. First, since the total amount of these payments depend on the value of the technology, one needs to be able to provide the rationale used to set a value on the technology, so that there is a starting point to discuss possible disagreements between the parties. The second issue relates to the structure of the licensing contract itself, i.e. which of the three types of payments should be used, and in which amounts. The parties can have different opinions on the value of each of the three types of payments, and the structure of the contract can influence the licensee's behaviour when further developing the product, by providing (dis)incentives to invest appropriately [32]. These issues can be only solved if a licensing plan is developed by the licensor, and the usual technology commercialization models do not capture the steps needed for such an endeavour.

The proposed technology commercialization model (depicted in Figure 5.4) aims at providing the licensor of a technology a roadmap towards building a licensing plan that will help him (i) decide on whether and when to apply for a patent, (ii) build the rationale for valuing a technology, and (iii) assess the investment required to further develop the technology.

Although the model does not define a specific stage in which to decide whether and when to apply for a patent (unlike the reviewed models in which this decision is carried out at a very specific stage), it helps build the information required for such a decision to be made. Regarding the decision on whether or not to patent, the model contributes towards the development of a business case to support the assessment of the commercial viability of the technology. Regarding the timing, although as a general rule, the patent application should be made as late as possible, the exact point in time in which the decision to patent should be taken depends on the trade-off among several issues (see, e.g. [33]). An early patent application can be justified because, e.g., (i) the researchers are pressured to publish, (ii) the technology is easy to reverse engineer or discover independently, or (iii) the technology field is evolving quickly. Delaying the patent application allows to, e.g., (i) better ascertain the commercial viability of the technology, (ii) defer the costs of patenting, or (iii) delay the patent expiration date, which is particularly important in the case of patents for the pharmaceutical industry, in which, due to the long regulatory path, the commercial life of the drugs is relatively short.

The model departs from the realization by the researcher(s) that the knowledge generated through his research activities may have a practical application (i.e., it is a technology or invention). A technology description should then be prepared providing (i) a general description of how the technology works, (ii) a description of the technology capabilities (i.e., what it does), (iii) a description of the type of problems the technology is aimed to solve and how it will solve them, (iv) an explanation of the technology readiness level attributed to the technology, and (v) any information relevant for assessing the patentability of the technology (e.g., previous publications or presentations, first draft of the claims). The main purpose of the technology description should be to provide sufficient information to enable an in-depth search of competing technologies.

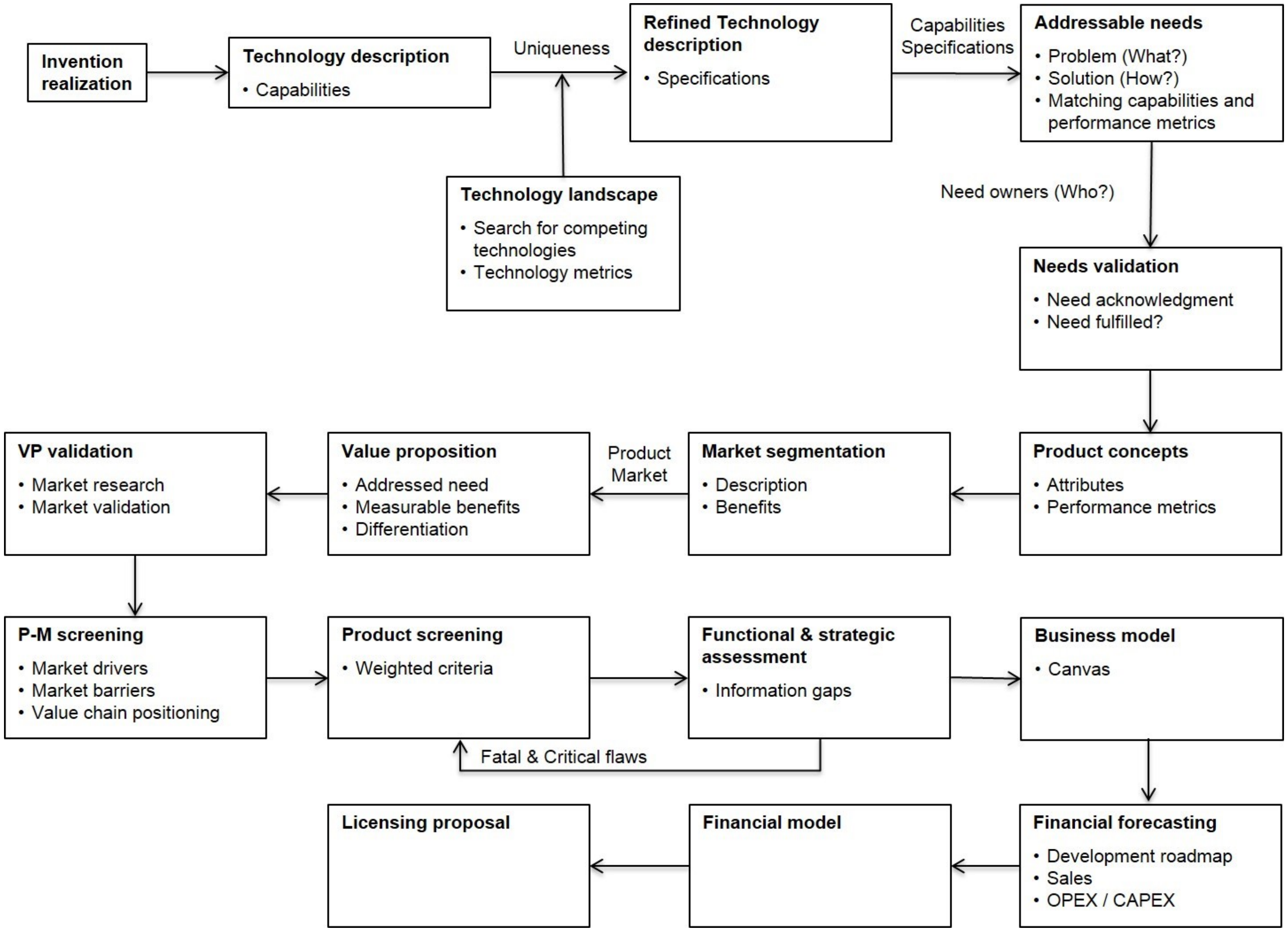

Figure 5.4: Proposed technology commercialization model

This structured search uses keywords derived from the technology description to map the technology landscape around the proposed technology. Searching patent and scientific journals databases, together with the gathering of public information on products and technologies from companies operating in the industrial sectors, in which the technology can be applied, will contribute towards the mapping of competing technologies (already developed or in development). Technology landscape mapping will allow to identify: (i) the unique capabilities embedded in the technology, and (ii) the key performance metrics used by the industry to set the specifications (i.e., the measurable performance parameters) that will measure the product concepts derived from the technology. This step is crucial to identify the uniqueness of the technology and, consequently, to understand where the value will be captured in the product concepts that will be derived from the technology. This step can also contribute to identifying potential licensees for the technology.

The technology landscape mapping should lead to a revised version of the technology description that will then include: (i) an analysis on competing technologies and how the proposed technology compares with them in terms of capabilities (i.e., technology uniqueness), (ii) a list of the specifications used by different industrial sectors to access the performance of products derived from the technology, and (iii) 'red flags' to take into account regarding patentability of the technology (namely, freedom to operate issues).

Using the capabilities and the specification metrics (not actual specification values) gathered in the previous steps, a set of addressable needs should be identified. Addressable needs are problems (or 'pain points' [34]) that potential customers may have for which a solution can be derived from the technology. For each pair (Problem, Solution) identified, the set of matching capabilities and performance metrics derived from the technology to enable a solution to the problem should be listed. During this step, the 'owner' of each need (i.e., a general functional description of an executive that in the potential customer organization has the problem) should be identified, so that in the next step this 'owner' can validate the problem (i.e., acknowledge that the problem exists) and that the proposed solution may solve the problem (at this stage, the description of the Problem, Solution needs to be done at very generic level, not to compromise the IP).

The goal of the next stage is to develop a set of product concepts with strong hypothesized linkages, grounded on the unique capabilities of the technologies, between the previously validated (Problem, Solutions) pairs. The product concepts should highlight the product attributes (i.e., the characteristics of the product that offer benefits to the customer), listing the relevant specifications for each attribute. The next stage aims at identifying multiple market opportunities for each of the product concepts developed in the previous stage. For each market segment, the specific needs covered by the product concept should be identified, together with the benefits that are enabled by the product concept for that specific market segment.

One has to bear in mind that a single technology is a platform that enables a variety of applications that can be competitive in several markets. At this stage of the proposed technology commercialization process, a wide range of Technology-to-Product-to-Market linkages (TPM) [35] should have been developed. The number of TPM linkages will greatly depend on the platform potential of the technology and its positioning in the value chain (the further upstream, the more TPM linkages are likely to be derived). From this stage onward, the goal is to successively screen these TPM linkages, using market information to select the product concept that will provide the largest benefit to the licensor.

In the first stage of this phase, a value proposition should be developed in order to facilitate the collection of the market information required to test and refine the assumptions embedded in each TPM linkage. A value proposition is a statement, in a simple prescriptive format, which defines the product, the potential target customer, and the rationale for this potential customer to buy the product (eventually over a competing product). So, the value proposition should stress the addressed needs, the measurable benefits and the differentiation over the competitors' products. The value proposition, for each product concept, should then be validated via a collection of qualitative and quantitative market research and potential customers' feedback. This information should also be complemented with a listing of market drivers and barriers and value chain positioning (to help determine the ease to reach the consumer and, thus, the eventual difficulty to gather complementary assets to reach the market) in order to select the product concept that seems most promising to be licensed (a set of weighted criteria, defined on a case-by-case basis, can help prioritizing the product concepts to support the decision).

The next stage involves undertaking both a functional and a strategic assessment of the selected product concept. The components of the functional assessment may include items related to: (i) technology (e.g., performance advantages, feasibility issues), (ii) patentability (effectiveness of IP protection), (iii) market (e.g., market size or distribution channels), (iv) manufacturing/operations (e.g., ease of scaling-up or raw materials availability, and (v) regulatory (e.g., cost and time length of regulatory pathway). The functional assessment should be built on a case-by-case basis, as it is greatly dependent on the industry sector addressed by the product concept, and should focus on every issue that may hinder the product concept development. The functional assessments can be scored quantitatively. For the strategic assessment, a set of management tools should be employed: e.g. industry mapping; SWOT analysis; Porter's Five Forces; and Value Chain analysis. The goals of both these assessments are to: (i) support the search for 'fatal flaws', i.e. factors that make the product concept less desirable to move forward, and (ii) help uncover information gaps that still need to be addressed. If 'fatal flaws' are found, then, the next most desirable product concept should be assessed. At the end of this stage, there is enough information on the topics covered by both the functional and strategic assessments that, a decision on the product moving forward should be well sustained.

All the information amassed so far will then be condensed in a business model, using a business model development tool (e.g., Business Model Canvas [36] or Lean Canvas [34]). The role of the business model is to help build a case on how value will be captured from the selected product concept, which is grounded on the technology to be licensed, namely through:

i. the articulation of a value proposition, i.e. how value is created for the users by the offering based on the product concept;
ii. the identification of a market segment, i.e. of the users to whom the technology is useful (and for what purpose) and the description of the way revenue is generated from the product concept;
iii. the definition of the structure of the value chain, i.e. the set of activities that are required to create and distribute the product concept to the selected market segment and of the complementary assets needed to support the product concept position in this chain;
iv. the definition of the items required to estimate the cost structure and profit potential of the product concept, given the value proposition and the value chain structure chosen;
v. the description of the position of the product concept within the value network, linking suppliers and customers, including identification of potential complementors and competitors;
vi. the formulation of the *competitive strategy* by which the product concept will gain and hold an advantage over competing products.

The information gathered to develop the business model will then support the development of a financial forecast that aims at contributing toward the valuation of the product concept to be licensed. The financial forecast should consist of two parts: (i) a detailed analysis of the actions, risks and costs involved in developing the product concept up to a market ready stage (development roadmap), and (ii) an estimation of the revenues, capital expenditures (CAPEX) and operations expenses (OPEX) for a reasonable time length after the product concept is introduced to the market. This financial forecast should then be inputted to a standard financial model that will allow sustaining the valuation of the product concept and the terms of a licensing agreement.

The final stage consists of the development of a licensing plan that will condense all the relevant information gathered throughout the process, and that will be used to support the negotiations of a licensing agreement.

The proposed technology commercialization process is highly iterative because, as one moves through the different process stages, relevant information is amassed that can affect decisions taken in previous steps, that may justify a retrace to a previous step (for the sake of simplicity, these iterations are not depicted in Figure 5.4).

An important characteristic of the proposed technology commercialization model is that it requires the involvement of the researcher(s) throughout the different stages leading to the development of the licensing plan. This involvement is a relevant aspect because: (i) a significant portion of the knowledge generated by the researcher(s) remains latent (i.e., it is uncodified, but it is codifiable), having the researcher(s) involved in the development of the licensing plan is the only way to capture this knowledge, (ii) the licensee will most likely want to get the support of the researcher(s) throughout the product concept development stage and, by getting him/her involved in the development of the licensing plan, he/she will have amassed a vast amount of information that will ease the collaboration between the licensor and licensee.

Finally, the major goals that justify the development of a licensing plan are: (i) to increase the value of the license through the reduction of the business development risk, (ii) to provide information to the licensor that will allow judging if a further investment in the development of the technology is justifiable (taking into account the trade-off between the investment required to lower the technology risk and increase the potential value of the technology), (iii) to support the decision on whether and when to patent, and (iv) to provide sustained information that will support the licensing negotiations. Regarding this last goal, it is important to note that, although the information asymmetry between licensor and licensee is not totally eliminated at the end of this process, the licensor should have compiled a vast amount of information that contributes to significantly reduce the information asymmetry between the parties involved in the license negotiation.

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6 TECHNOLOGY COMMERCIALIZATION ASSESSMENT

6.1 Introduction

Based on the management adage: “Only what is measured can be managed”, it can be stated that decision making must be made based on information availability and assessment. In order to understand the needed changes to improve the ability to perform, organisations should conduct systematic organisational assessments. An assessment is a diagnostic tool, or a systematic process to help organisations obtain data regarding their performance and the factors that affect performance, to identify important factors that aid or impede their achievement of results, and to situate themselves with respect to competitors.

A Balanced Scorecard is a strategic planning and management system that translates an organisation’s mission and strategy into a coherent set of performance measures, as it [1] “captures the critical value-creation activities created by skilled, motivated organisational participants”. Retaining emphasis on achieving financial objectives, including its financial drivers, it measures the organisational performance across four balanced perspectives: financial measures, customer knowledge, internal business processes, and learning and growth, offering a balance between short-term and long-term objectives, between desired outcomes and performance drivers of those outcomes, and between hard objective measures and softer, more subjective, measures.

Technology commercialization, like any process, aims to create value for each stage, and as so, its performance needs to be measured. Furthermore, following this perspective, it is important to note that technology funders are increasingly trying to deepen their understanding of the technology performance which they fund (per stage of development), to better grasp its capacities towards the achievement of its ultimate value.

Being the Balanced Scorecard a valuable tool to reveal the value drivers for long-term financial and competitive performance, providing a report to assist in decision making, we suggest its application regarding a Knowledge Valorization Unit (KVU). For the purpose of this work we consider a KVU any organisation whose mission is to foster knowledge valorization generated through research by providing researchers with a set of specific services to help them build a compelling business case for product or services fostered by technologies they developed through research.

In this Chapter, the theoretical foundations of the Balanced Scorecard, and its key objectives, will be reviewed, resulting in a Balanced Scorecard strategy map proposal that identifies primary strategic goals that should be pursued by a KVU.

6.2 Balanced Scorecard model

The Balanced Scorecard, created by Robert Kaplan and David Norton [1], is a performance measurement framework, that adds strategic non-financial performance measures to traditional financial metrics, to give managers a balanced view of organisational performance. Increasingly, the focus has shifted from accounting for a tangible asset to valuing assets that are harder to define, ultimately intangible assets. According to the authors [1], “more than just a measurement system, the Balanced Scorecard is a management system that can channel the energies, abilities, specific knowledge held by people throughout the organisation toward achieving long-term strategic goals.”

Developing the Balanced Scorecard involves a formal strategic planning process that starts with the organization’s mission and vision statement, and the project team identification. Then it is mandatory to develop a strategy to deliver the mission stated. The challenge of this step is to clearly define the organisation’s strategy, its competitive advantages, and distinguishing characteristics. In order to achieve more efficient results, high-level strategic themes should be defined, each relating to a key customer group, linking the vision to the individual performance by establishing specific tasks for each stakeholder involved.

Subsequently, the critical internal processes, that enable the achievement of strategic customer objectives in the strategic themes, must be identified, as well as the objectives of development for improving the organization’s learning, growth, and financial perspectives. After the strategy map and strategic objectives are formulated, the initial set of measures for all established objectives needs to be developed. Like any process, it requires continual analysis, assessment and re-evaluation, which demands a way to interpret the metrics and to adjust the organisation’s strategy based on the process feedback.

This section will focus on the review of the Balanced Scorecard theoretical foundations, as a tool to be applied to a KVU which integrates a descriptive mission, perspectives and stakeholder relationships, based on technology value measurements.

6.2.1 BSC Perspectives

The aim of the Balanced Scorecard is to translate a business unit’s mission and strategy into tangible objectives and measures. To achieve this, it combines information from multiple areas across an organisation, connecting financial data, business processes, and customer (donors, constituents, and collaborators) reactions to obtain a balance between internal and external measures, between objective measures and subjective measures, and between performance results and the drivers of future results.

By measuring the organisational performance across four balanced perspectives, the Balanced Scorecard complements traditional financial indicators with measures for customers, internal processes, and innovation and improvement activities [1], [2], which in turn must all be linked to the organisation's strategic vision (see Figure 6.1).

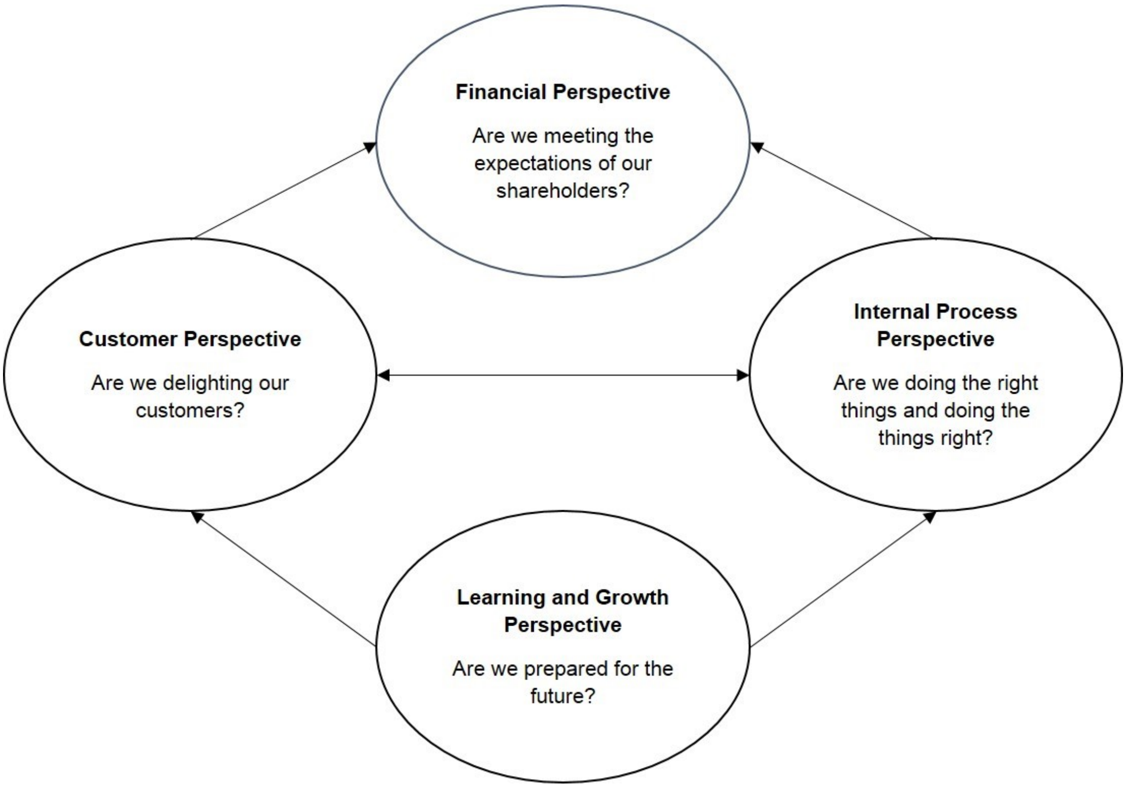

Figure 6.1: The Balanced Scorecard
Adapted from Kaplan and Norton [1]

Organisations, including non-profit [3], [4], must have a clear view of their financial situation. In the Financial Perspective, Kaplan and Norton do not disregard the traditional need for financial data. In this perspective, the question: ”To succeed financially, how should we appear to our customers?” must be posed and, it must include the measurement of operating income, return on capital, and economic added value. Timely data on funding sources, cost of services, and overhead costs must be incorporated into the strategic plan to provide a clear view of the situation, providing a solid basis for operations and build confidence with funders and other sources of revenue.

The Customer Perspective is related with the shareholders' experience, measured by their satisfaction and retention, resulting in a leading indicator of future decline. The questions to be answered are based on the following internal interrogations: “To achieve our vision, how should we appear to our customers?”, and “If we succeed, how will we look to our customers?".

The Internal Process Perspective refers to internal business processes. Metrics based on this perspective allow managers to know how well the organization is running, and whether its products and services conform to customer needs (the mission). The internal process perspective is based on the following demand: “To satisfy our customers, funders, and mission, in what business process must we excel at?”.

The Learning & Growth Perspective looks at human capital: “To achieve our vision, how must our people learn, communicate, and work together?” Chosen metrics should guide managers in focusing training funds, for knowledge workers to be in a continuous learning mode, a necessity in the current climate of rapid technological change. Needed skills to advance the mission, such as donor development, marketing and branding, leadership, communications, and the use of technology, should also be taken into account.

6.2.2 BSC Strategic themes and Strategy Map

Porter [5] defines strategy as the creation of a unique and valuable position involving a different set of activities and postulates, that competitive strategy is about being different, by deliberately choosing a different way to deliver a mix of values and activities. Thus, strategy requires trade-offs in a competitive environment, to decide on what to accomplish, but also on what not to do. Being a strategy a set of hypotheses about cause and effect relationships [1], it should be expressed, by a sequence of if-then statements, and on what organisations aim to accomplish, translating the objectives into quantifiable operational measures, instead of plans to do it [1], [4].

The Strategy Map represents [6], [7] a communication tool used to tell a story of how value is created for the organisation. It shows a logical step-by-step connection, between strategies, in the form of a cause-and-effect chain. Generally speaking, performance improvement, in the objectives found in the Learning & Growth perspective, enables the organization to improve its Internal Process perspective objectives, which in turn enables the organization to create desirable results in the Customer and Financial perspectives. By adopting strategic performance measures, organisations can bring focus to their mission as well as the needed information for all involved [4], leveraging information asymmetries, information between process stakeholders, and [4] a more efficient marketplace that rewards effectiveness, resulting in higher benefits to society.

From the standing that [8], “a value proposition creates value for a customer segment through a distinct mix of elements catering to that segment’s needs”, we grouped the expanded view of the KVU stakeholders into distinct segments with common value needs, as follows:

i. Funders: future revenues resulting from technology-based project value creation;

ii. Researchers: economic and social valorization of new knowledge as a result of their research;
iii. Research centres: future revenues from their intellectual property rights;
iv. Firms and entrepreneurs: access to technology-based projects deal flow, properly scrutinized and with investment-ready business plans; and
v. Community: investments in R&D valuation, by raising qualified entrepreneurship, in order to enable the country's economic development paradigm change.

6.2.3 BSC Metrics

Performance measurement systems enable focus and accountability to processes [4]. For that being the case, it is important to denote that [1] "every measure selected for a Balanced Scorecard should be an element of a chain of cause-and-effect relationship that communicates the meaning of the business unit's strategy to the organisation." In addition, being the objective of the selected core output measures (lagging indicators), and the performance driver measures (leading indicators) to identify the measures that best communicate the meaning of a strategy, every measure must be [2], specific, measurable, attainable, relevant, and time-based (SMART).

Being the Scorecard a balance between objectives, easily quantified outcome measures and subjective, somewhat judgmental, performance drivers of the outcome measures [1] "should represent a balance between external measures, for shareholders and customers, and internal measures of critical business processes, innovation, and learning and growth, as so (…) they are balanced between the outcome measures (results from past efforts), and the measures that drive future performance."

Nevertheless, the fact that each strategy is unique, every scorecard should be unique. Kaplan and Norton [1] have identified some core output measures that repeatedly appear on scorecards, as follows:

i. Core financial measures: return on investment/ economic value added, profitability, revenue growth, cost reduction, and productivity;
ii. Core customer measures: market share, customer's acquisition, customer's retention, profitability and customer satisfaction; and
iii. Core Learning and growth measures: employee's satisfaction, retention, and productivity.

Despite the voluminous list of possible metrics, selecting successful metrics is a subjective process that is highly individualized for each organisation's strategy. Table 6.1 represents some examples of metrics used in some technology commercialization programmes [9]–[20], per technology transfer process stage.

Table 6.1. Technology Commercialization metrics

Scientific discovery	**N. º of research agreements with firms:** All contracts where a firm funds to perform research on behalf of the firm, with the results usually provided to the firm. Include collaborative agreements where both partners provide funding and share the results.
Invention disclosure	**N.º of inventions disclosures,** with positive assess for commercial application. **N. º of publications:** number of papers or conferences publications.
IP protection	**N. º of patents applications:** new patent application.
License	**N. º of license executed:** Include all licenses, options and assignments (LOAs) for all types of IP (copyright, know-how, patents, trademarks, etc.). **Gross license revenue:** Money generated by licensing operations before deduction of expenses.
Spin-offs creation	**N. º spin-offs or start-ups established:** a new company expressly established to develop or explore disclosure IP or know-how. **Nº of researchers employed in a start-up or spin-off.** **Established turnover of active spin-off.** **Spin-off pre-money valuation:** the valuation of a company or asset prior to an investment or financing. **Total capital raising:** capital from investors or venture capital sources. **N. º of licenses applied**: to new product, services or processes**.**
Licensing to existing firm	**N. º of licenses applied**: to new products, services or processes.
Proceeds	**Royalty revenue per license:** typically agreed upon as a percentage of gross or net revenues derived from the use of the asset or a fixed price per unit sold of an item of such.

6.3 Strategy Map for a Knowledge Valorization Unit (KVU) proposal

Being that a country’s economic growth is constrained and driven by knowledge creation (see Chapter 2), the technology transfer process aims to create added value to national and economic needs, such as education and economic competitiveness. The technology transfer process, from invention disclosure to commercialization, and, furthermore, to public welfare, occurs over a long period of time, making the demonstration of the referred cause and effect very difficult.

Based on the above statements, in this section we present a strategy map for a KVU, starting from the premise that its long term objective is knowledge valorization that will result in economic growth. For the proposal, we based the case on the generic multi-stage technology transfer model described in Chapter 3, as a three stages process [21]: invention disclosure, patent application, and licensing. In order to reach its mission and strategic goals, manage its performance, and to be accountable, the KVU must identify, define, and perform a set of activities related with the referred model, namely, disclosure, evaluation for commercial potential, IP protection, market technology to firms or entrepreneurs, negotiation, and licencing towards market introduction.

Knowledge Valorization Unit (KVU) Strategy Map proposal

KVU Mission: To foster knowledge valorization generated through research, by providing to researchers a set of specific services to help them build a compelling business case, for product or services, fostered by technologies they developed through research.

KVU Vision: To create a leading KVU that generates value for its stakeholders, by maximising the use of knowledge created by researchers, that is financially self-sustainable.

KVU Stakeholders: Process stakeholders were grouped, based on their role in the commercialization process: (i) researchers: knowledge creation; (ii) takers: knowledge capture; (iii) partners: support knowledge valorization; and (iv) Funders: knowledge development financing.

KVU Strategy themes

Based on the fact that [2] an organisation's strategy (must) describe how it intends to create value for its shareholders, customers, and citizens, we propose the following strategy themes for the KVU:

1. Knowledge capture: capture knowledge created through research;
2. Knowledge valorization: foster the valorization of knowledge created through research;
3. Involve the eco-system: accrete knowledge valorization chain eco-system; and
4. Sustainability: generate sufficient revenues to cover operational costs.

The strategy map will be built with these strategic themes as the basis for the Knowledge Valorization Unit Strategy Map. Figure 6.2: KVU Strategy Map Proposal, shows a logical step-by-step connection between strategic objectives (shown as grey rectangles on the map) in the form of a cause-and-effect chain, for the involved stakeholders.

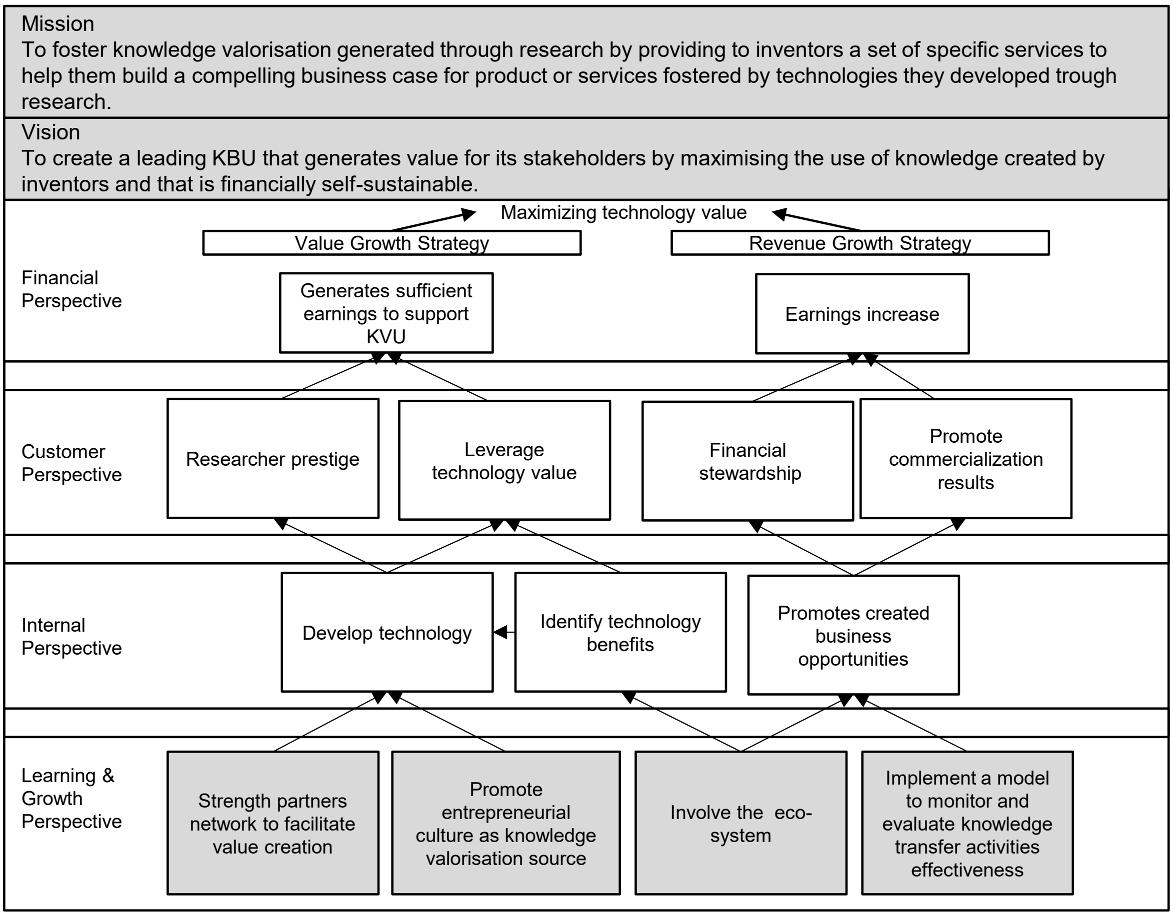

Figure 6.2: KVU Strategy Map Proposal

Strengthening partner networks will facilitate value creation and promote an entrepreneurial culture, as a knowledge valorization source, enabling knowledge creation (Learning & Growth perspective). Technology development (Internal perspective), will leverage technology value (Partner perspective) as well as researcher prestige (Researcher perspective), and in turn enables the KVU to create desirable results in the Customer Financial perspectives: technology value creation perceived and earnings that allow supporting the KVU.

The eco-system involvement (Learning & Growth perspective), supports and facilitate the identification of technology benefits (Internal perspective), leveraging technology value (Partners perspective), resulting in increased earnings (Financial perspective).

The implementation of a model to monitor and evaluate knowledge transfer, and the involvement of the eco-system (Learning & Growth perspective), will promote the creation of business opportunities (Internal perspective), and commercialization results (Takers perspective) that, matching with financial stewardship (Funders perspective), will lead to an increase in earnings (Financial perspective).

Lastly, we must refer that, following the Balanced Scorecard approach helps to ensure that the specific measures chosen for the strategy map will drive performance toward the KVU goals, based on the recognition of trade-offs between operational excellence, reached target population, and results, and helps to assure that the measures reflect the interaction between process stakeholders.

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7 CONCLUSIONS

7.1 Overall Conclusions

Competitiveness is determined by the ability to innovate and effectively exploit the economic potential of technological advances. The capability of converting new knowledge, generated through scientific research, to the market is a key element to spur competitiveness.

The starting point of this research was based on the assumption that economic competitiveness should be analysed in terms of investments made in knowledge, concluding that, as countries move into the innovation-driven stage, wages will rise in such a way that they will only be able to sustain the higher wages and the associated standard of living if their businesses are able to compete with new and/or unique products, services, models, and processes [1]. Hence, it must be denoted that the deployment of this knowledge requires it to be embedded in a technology, so that it is able to create social and economic value.

Following this perspective, we stated that the technology commercialization process has to be viewed as a set of interconnected activities, each one contributing to the technology value creation and risk reduction, namely for the purpose of further development and commercialization of the technology.

The main contribution of this research was to provide a methodological approach for technology commercialization that sustains technology valuation. For this purpose, we began this research by reviewing the existing technology commercialization models, focusing on the identification of process stages and activities, key stakeholders, and technology valuation.

The technology commercialization models described in Chapter 3 follow the multi-stage process described by Thursby and Thursby [5]. In the first stage, an invention disclosure occurs when a new technology is developed by researchers (being the recipient of this disclosure the TTO). In the second stage, these disclosures are intermediate inputs to patent applications. The decision whether to patent the invention is based on technology uniqueness and benefits identification (proof of concept), commercial potential evaluation, and financial analysis. In the third stage, some patents are licensed to an existing company or to a spin-off venture. In between these stages, there are decision points that determine the advancement of the disclosure towards the next process stage.

Through literature review, we identified a set of barriers of knowledge valorization:

i. The lack of alignment between research publication and intellectual property protection [6], [7];
ii. The lack of alignment between the skills required for knowledge valorization and the career research incentives [8];
iii. The limited competencies to connect technical knowledge to a commercial opportunity [9];

iv. The conflicts of interest among the different stakeholders in the process of knowledge valorization [10];
v. The lack of an entrepreneurial culture among the researchers [11];
vi. The limited availability of pre-seed funding [12];
vii. The asymmetry of information between researchers and investors, making the assessment of the knowledge value (i.e., the pre-money valuation) difficult to estimate [13].

The key stakeholders in the technology transfer process, pointed out by Siegel et al. [14], include the researchers, whose contribution to the process is the discovery of new knowledge, the technology transfer offices, assume the responsibility to protect and market intellectual property and to mediate the flow of resources and information within process network, and firms and entrepreneurs, who are the potential licensees of the technologies.

Knowledge value will be created by delivering innovative products with high-quality information [15]. One of the main issues in technology commercialization, that has a significant impact on the valuation of the technology, is the fact that during this process firms typically cannot assess the quality or usefulness of the invention ex ante, while researchers and TTOs may find it difficult to assess the commercial profitability of their inventions [13], which may lead to a technology valuation mismatch [16]. To increase R&D effectiveness, it is important to fully understand the ultimate value of a project at an early stage of development, and understand how this information can be leveraged in individual perspectives and trade-offs during the portfolio decision-making, once the determinants of the overall value are likely to be different, depending on the perspective represented along the process [15]. The models described in Chapter 3 do not detail a stage for the evaluation of the invention, failing in providing details of the decision process.

The proposed model for technology commercialization integrates relevant information from technology commercialization process stakeholders, in order to provide the licensor of a technology a roadmap towards building a licensing plan. In contrast with the reviewed models, the proposed model does not define a specific stage to decide to apply for a patent, but instead, it helps build the information required for such a decision to be made. Hence, the model will help the licensor of a technology to: (i) decide on whether and when to apply for a patent, (ii) build the rationale for valuing a technology, and (iii) assess the investment required to further develop the technology.

The model starts with the awareness, from the researcher, that the knowledge generated through his research activities may have a practical application. Afterwards, a technology description should be provided containing sufficient information to enable an in-depth search of competing technologies.

Technology landscape mapping will allow the identification of unique capabilities embedded in the technology and the key performance metrics used by the industry to set the specifications. The technology landscape mapping should lead to a revised version of the technology description.

Based on the capabilities and specification metrics, a set of addressable needs (i.e. problems that potential customers may have for which a solution can be derived from the technology) should be identified. For each pair (Problem, Solution) identified, the set of matching capabilities and performance metrics derived from the technology, to enable a solution to the problem, should be listed. Next aim of the next stage is to develop a set of product concepts with strong hypothesized linkages, grounded on the unique capabilities of the technologies, and based on the previously validated (Problem, Solutions) pairs. This stage is followed by the identification of multiple market opportunities for each of the developed product concepts.

From this stage onward, the goal is to successively screen Technology-to-Product-to-Market linkages by using market information to select the product concept that will provide the largest benefit to the licensor. To that extent, in the first stage of this phase, a value proposition should be developed (validated via a collection of qualitative and quantitative market research and potential customer feedback). In the next stage, a functional and a strategic assessment of the selected product concept are developed. The information gathered during these assessments must properly sustain the decision to move forward with the product development.

All the information collected will then be condensed in a business model to help build a case on how value is captured from the selected product concept. Based on the business model, a financial forecast should be developed, with the aim of contributing towards the valuation of the product concept to be licensed. The final stage consists of the development of a licensing plan that will condense all the relevant information gathered throughout the process, that will be used to support the negotiations of a licensing agreement.

In the last chapter of this research, an assessment tool for a Knowledge Valorization Unit (KVU), was proposed based on the Balanced Scorecard. This could be a valuable tool to reveal the value drivers for long-term financial and competitive performance. We based the assessment for a KVU, defining its mission and vision, and ending with a generic KVU Strategy Map, that intends to create value for its stakeholders with the following strategic themes: (i) Knowledge capture: capture knowledge created through research, (ii) Knowledge valorization: foster the valorization of knowledge created through research, (iii) Involve the eco-system: accrete knowledge valorization chain eco-system, and (iv) Sustainability: generate sufficient revenues to cover operational costs.

7.2 Proposal for Future Research

Although it is not consensual that from the array of public policies available to induce growth, the policies that foster innovation lead to higher growth, political leaders have recognised that, to increase competitiveness, economies need to change their development paradigm based on the exploitation of resources to a new paradigm based on knowledge and innovation.

The next stage of this research will address the hypothesis that the European Paradox still holds for most European countries, by comparing the Innovation Union Scoreboard knowledge chain indicators for the European Union countries with the same indicators from other countries that look to perform better, such as the United States of America or Japan.

Secondly, through this research, we noted that there is widespread interest in innovation, namely in entrepreneurial ventures, and a lack of data showing such growth. We also denoted that the available data show results regardless of the type of entrepreneurship. The different types of entrepreneurship were defined by Steve Blank [17], based on their specific goals and funding models, as: (i) small-business start-ups, (ii) scalable start-ups, (iii) viable start-ups, (iv) lifestyle start-ups, and (v) corporate start-ups.

Small business start-ups are a small-scale ventures that seek enough profitability to support a living for the owner and a small group of employees. Based on the fact that the returns are not attractive to risk capital investors, these ventures face a dearth of funding. Scalable start-ups take an innovative idea and search for a scalable and repeatable business model that could turn it into a high growth profitable company, entering into a large market and taking share away from incumbents, or by creating a new market and growing it rapidly. Scalable start-ups typically require external risk capital to create market demand and scale. Viable start-ups are technological start-ups who want to build a business big enough to eventually be acquired and are characterized for being created with small investments of money. When some entrepreneurs go out on their own to pursue a passion or work as a contract programmer or designer, they are creating lifestyle start-ups. Corporate start-ups are ventures that are launched within the limits of a larger, more established business that seeks new innovation and new business models.

The analysis of the impact of a country's innovation and knowledge framework, and its contribution towards economic growth, stratified by the different types of entrepreneurship, will be the object of study during the next stages of the on-going research. To that extent, time series data for the relevant indexes, namely Knowledge Economy Index and Global Competitiveness Index, will be crossed with countries GDP per capita.

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