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Planning and exploitation of new production technologies in public-funded R&D

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Dissertation

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In loving memory of
Tia Cecília, Tia Hermínia, Tia Fernanda, Tio Manuel, and Primo Zé,
who also left us during this time

In loving memory of Lena and Berto

In loving memory of my proud Mum and Dad

To my darling Sónia

To the youngest, cutest generation:
Catarina, and Camila and Clara,
and Bernardo, António, and Francisco,
you (will) have this magical world in your hands.
Grow slow, grow wise, and especially, grow happy.

Gratitude

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Abstract

The European Union (EU) has long been determined in achieving a substantial contribution from Science and Technology to sustainable growth. It invests intensely in Research and Development (R&D) programmes to produce leading innovation in an increasingly demanding global environment. The associated immense and complex R&D ecosystem comprises countless players, heterogeneously interacting to provide solutions or address their challenges. During long and risky R&D processes, those players frequently achieve excellent results but, even despite recent progress, also fail often at creating, delivering, and capturing the corresponding societal and economic value.

The research presented in this dissertation seeks to contribute to address this critical matter from the perspective of new production technologies. This technological field, due to its broad and horizontal character, has the potential to tackle grand challenges, since it has a positive direct impact in multiple societal and economical aspects.

We first present a study about the fit between strategic roadmapping and project planning, focusing on the alignment of R&D activities with market needs and strategic innovation lines. Such projects were promoted by an unprecedented national cluster-level initiative in Portugal and developed between 2011 and 2013, aiming to address the technological needs of manufacturing sectors and technology developers. We thus analyse two large-scale projects and observe that even though a significant fit is found, a variety of factors (e.g., the existence of more sector-specific needs, call budgets and parameters such as consortium composition requirements or technology priorities, availability of resources, or

even the difficulty to align agendas and goals among project partners) lead to the presence of partial misalignments. Awareness of these misalignments may assist in proactive influencing, at an early stage, of the definition of call parameters, or provide opportunities and incentives to improve the basic alignment of project consortia members. New projects may also be independently developed, intending to close identified gaps, as well other activities that build on and complement the funded projects to minimize the impact of the misalignments. The architecture of future projects can also be configured to maximize the potential for application and impact of strategic innovation lines on relevant sectors.

Then, we present two other studies, these using a sample of 61 technologies resulting from European-funded R&D projects, collected in the scope of a European-level initiative that took place between 2012 and 2015, focusing on determinants of successful technology exploitation, as well as technology and context patterns in EU-funded R&D projects.

In the first of those, we propose a 4-stage exploitation scale and use an ordered probit regression to analyse potential determinants for successful technology exploitation. The association with exploitation was found to be individually significant for technological advantage, technology readiness level (TRL), owner proximity to market, and innovation context, and not significant for platform potential, existence of intellectual property rights, and consortium dimension. The findings suggest several recommendations for policy makers, including the need to provide process-oriented support to commercialization or the need to strengthen markets for technology in Europe, as well as for managers in organizations that participate in EU-funded projects, including the need to identify and adopt best practices, in face of the heterogeneity revealed, e.g., by the non-significance of multiple potential determinants of commercialization.

In the second of those studies we use a hierarchical cluster analysis to identify five patterns of technology and context in EU-funded R&D projects. As a result, we call them “Full Appropriability”, “Patent Pending”, “Resource Based”, “Agent of Change”, and “Network Explorer”, names that summarize their main characteristics. While our findings point to the existence of a number of distinct patterns for participation in European projects, with different sets of purposes, opportunities and challenges, the terms of reference for European calls hardly acknowledge this diversity, failing to feature a portfolio of customised requirements or support instruments that may improve the effectiveness of those participations. These can range from, e.g., requiring and supporting research and technology organizations in moderate innovator countries in carrying out formal invention disclosures and patentability assessments for the outcomes of their participation, to explicitly requiring and supporting large-sized consortia in explicitly developing evidence-based forward-looking collaboration concept notes, or strategically aligning in their portfolios of activities longer-term lower TRL advances and nearer-term higher TRL results to meet more immediate needs.

The outcomes of the research presented in this dissertation are motivated by and seek to address an existing sense of urgency in the study of the planning and exploitation of new technologies, and the need to assist policy-makers and managers of R&D organizations in increasing funding impact. In this context, we analyse three main stages from the R&D process: planning, exploitation, and dynamics, and ultimately identify opportunities for improvement and suggest specific guidelines that contribute in achieving a superior performance and impact of R&D and its commercial valorisation.

KEYWORDS

Innovation; Strategy; Public Policy; European Union; Framework Programme; R&D Policy; Roadmap; Technology Exploitation; Technology Commercialization; Exploitation Scale; Funding Instruments; Ordered Probit Regression; Hierarchical Clustering Analysis; Manufacturing Industry.

Resumo

A União Europeia (UE) está há muito empenhada em conseguir uma contribuição substancial da Ciência e Tecnologia para um crescimento sustentável. Investe intensamente em Investigação e Desenvolvimento (I&D) para produzir inovação de vanguarda num contexto global cada vez mais exigente. Este imenso e complexo ecossistema de I&D abrange inúmeros agentes, interagindo heterogeneamente para desenvolver soluções ou endereçar os seus desafios. Durante longos e arriscados processos de I&D, estes agentes conseguem atingir resultados excelentes, mas, mesmo apesar de recentes progressos, falham frequentemente na criação e captura do respetivo valor societal e económico.

A investigação apresentada nesta dissertação procura contribuir para endereçar este tema crítico da perspetiva das novas tecnologias de produção. Esta área tecnológica, dado o seu largo espectro de aplicação, tem o potencial de contribuir para a resolução de grandes desafios, dado ter um forte impacto em múltiplos aspetos societais e económicos.

Começamos por apresentar um estudo acerca da adequação do planeamento de projeto a um *roadmap* estratégico estudando o alinhamento das atividades de I&D com necessidades de mercado e linhas estratégicas de inovação. Estes projetos foram promovidos por iniciativa inédita de um cluster a nível nacional desenvolvida entre 2011 e 2013 em Portugal com o objetivo de endereçar as necessidades tecnológicas de setores industriais e dos produtores de tecnologia para a indústria. Analisamos dois projetos de grande escala e observamos que, apesar do significativo alinhamento encontrado, uma diversidade de fatores (e.g., a existência

de necessidades setoriais mais específicas, orçamentos e parâmetros de *calls* tais como requisitos para a composição dos consórcios ou prioridades tecnológicas, disponibilidade de recursos, ou mesmo a dificuldade em alinhar agendas e objetivos dos parceiros de projeto) leva à presença de desalinhamentos parciais. Uma consciencialização desses desalinhamentos poderá auxiliar a uma influência pró-ativa, numa fase inicial, na definição dos parâmetros das *calls*, ou de proporcionar oportunidades e incentivos de melhoria do alinhamento básico entre os membros de consórcios. Novos projetos poderão também ser independentemente desenvolvidos de forma a encerrarem as lacunas identificadas, bem como outras atividades que se baseiem e complementem os projetos financiados para minimizarem o impacto dos desalinhamentos. A arquitetura de projetos futuros pode também ser configurada para maximizar o potencial de aplicação e o impacto das linhas estratégicas de inovação nos setores relevantes.

De seguida apresentamos outros dois estudos, estes utilizando uma amostra de 61 tecnologias resultantes de projetos europeus de I&D financiado, recolhida no âmbito de uma iniciativa a nível europeu que decorreu entre 2012 e 2015. Focam-se nos determinantes para o sucesso da exploração comercial de tecnologia, bem como nos padrões tecnológicos e contextuais de projetos de I&D europeus.

No primeiro desses estudos propomos uma escala de exploração com 4 etapas, e utilizamos uma regressão probit ordenada para analisar potenciais determinantes para o sucesso da exploração comercial. A associação com a exploração foi encontrada como sendo individualmente significativa para vantagem tecnológica, *technology readiness level* (TRL), proximidade do dono ao mercado, e contexto de inovação, e não significativa para potencial de plataforma, existência de direitos de propriedade intelectual, e dimensão do consórcio. Estas conclusões sugerem diversas recomendações para as políticas públicas, incluindo a necessidade de proporcionar apoio ao processo de comercialização ou a necessidade de reforçar os mercados de tecnologia na Europa, bem como para a gestão em organizações que participem em projetos europeus financiados, incluindo a necessidade de identificar e adotar as melhores práticas, face à heterogeneidade revelada, e.g., pela não-significância de diversos potenciais determinantes para a comercialização.

No segundo desses estudos utilizamos uma análise hierárquica de clusters para identificar cinco padrões de tecnologia e contexto em projetos europeus de I&D.

Chamamos a estes padrões "Apropriação Total", "Patente Pendente", "Baseado em Recursos", "Agente de Mudança" e "Explorador da Rede", nomes que resumem as suas principais características. Enquanto que as nossas conclusões apontam para a existência de um número de padrões distintos para participação em projetos europeus, com diferentes conjuntos de objetivos, oportunidades e desafios, os termos de referência das *calls* europeias raramente reconhecem esta diversidade, falhando em propor um portfólio de requisitos customizados ou instrumentos de apoio que possam aumentar a eficácia dessas participações. Estes podem variar entre, e.g., exigir e apoiar as organizações de investigação e tecnologia em países moderadamente inovadores a levarem a cabo comunicações de invenção formais e avaliações de patenteabilidade dos resultados da sua participação, a declaradamente exigir e apoiar consórcios alargados a explicitamente desenvolverem notas conceptuais colaborativas de visão de futuro baseadas em evidência, ou estrategicamente alinhar nos seus portfólios de atividades desenvolvimentos de longo prazo e TRL baixo com resultados de curto prazo e TRL elevado para resposta a necessidades mais imediatas.

Os resultados da investigação apresentados nesta dissertação são motivados por, e pretendem contribuir para, endereçar um existente sentido de urgência no estudo do planeamento e exploração de novas tecnologias, e na necessidade de apoiar os decisores políticos e os gestores de organizações de I&D a melhorarem o impacto do financiamento. Neste contexto, identificamos diversas oportunidades de melhoria e sugerimos diretrizes específicas que podem auxiliar na obtenção de um desempenho superior no I&D e na exploração comercial.

Palavras-chave

Inovação; Estratégia; Políticas Públicas; União Europeia; Programa-quadro; I&D; Roadmap; Exploração de tecnologia; Comercialização de tecnologia; Escala de exploração; Instrumentos de financiamento; Regressão Probit Ordenada; Análise Hierárquica de Cluster; Indústria transformadora.

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List of Abbreviations and Acronyms

COMPETE	Programa Operacional Competitividade e Internacionalização / *Operational Programe for Competitiveness and Internationalization*
CORDIS	Community Research and Development Information Service
EFFRA	European Factories of the Future Research Association
EC	European Commission
EU	European Union
Eurostat	Statistical Office of the European Communities
EXPLORE	Extended Exploitation of European Research Projects' Knowledge and Results
FCT	Fundação para a Ciência e Tecnologia / *Science and Technology Foundation*
FP	Framework Programme
HCA	Hierarchical Cluster Analisys
INESC TEC	Instituto de Engenharia de Sistemas e Computadores, Tecnologia e Ciência / *Institute for Systems and Computer Engineering*, Technology and Science
IP	Intellectual Property
IPR	Intellectual Property Rights
MANUFUTURE	European Technology Platform for Manufacturing

NACE	European Classification of Economic Activities
NASA	National Aeronautics and Space Administration
NMP	Nanosciences, Nanotechnologies, Materials, and new Production Technologies
NSF	National Science Foundation
Oprobit	Ordered Probit regression
PPP	Private Public Partnership
PRODUTECH	Cluster das Tecnologias de Produção / *Production Technologies Cluster*
PSI	Novos Produtos e Serviços para a Indústria Transformadora / *New Processes and Innovative Technologies for the Production Technologies Industry*
PTI	Novos Processos e Tecnologias Inovadoras para a Fileira das Tecnologias de Produção / *Processes and Technologies to Industry*
R&D	Research and Development
R&D+I	Research, Development, and Innovation
RQ	Research Question
RTO	Research and Technology Organization
S&T	Science and Technology
SBIR	Small Business Innovation Research
SME	Small and medium-sized enterprise
STTR	Small Business Technology Transfer
TRL	Technology Readiness Level
WAv	Weighted Average
WSD	Weighted Standard Deviation

1.

Introduction

1. Background

The European Union (EU) and its Member States make a relentless effort to create more jobs and economic value based on Science and Technology. They strongly promote innovation through large Research and Development (R&D) Programmes in order to push the limits of competitiveness and sustainability and assume a global-leading role.

These R&D Programmes aim to respond to a fast-paced, ever-changing world, where new societal and economic trends and challenges emerge. They are vastly diverse ranging from globalization, to aging population, to urbanization, or to resource consumption. Consequently, very distinct needs, either broad or specific, must be addressed by excellent Science and Technology. This is partially achieved through projects developed under those Programmes, through a combination of public and private funding and involving a diversity of stakeholders: universities, Research and Technology Organisations (RTOs), companies, and policy-makers. In such complex ecosystem, the innovation value chain often starts at early-stage, fundamental R&D, then further developed into different solutions during a long, costly, and risky process, until potentially reaching a commercial stage in the form of products or services.

Nevertheless, it has been recognized that, even though Europe produces excellent science, the conversion of this knowledge into economic value still faces large obstacles (European Commission, 2010; Dosi et al., 2006). This apparently inefficient process ultimately undermines competitiveness and growth, draining immense resources, and has therefore to be critically addressed. Consequently, the alignment of R&D funding and activities with trends and challenges has to be complemented with enhanced dissemination and exploitation efforts, while involving all relevant stakeholders along the innovation value chain according to their specific roles (European Commission, 2010).

R&D projects deriving from public-private funding have to address specific call topics resulting from extensive long-term roadmaps developed at several geographic and thematic levels. The alignment with topics and goals is mandatory but several degrees of freedom are allowed, which may frequently lead to misalignments, intentional or not, critical or not. Nonetheless, projects and consortia often excel at delivering relevant and consistent results with significant impact and potential value. They, however, face significant hurdles and risks during the exploitation stages towards commercialization, a complex combination of numerous factors.

The so-called "valley of death" (Markham, 2002) is real and occurs during the first years after technology development. During this period, exploitation does not happen and funding may not be easily available. It is a critical stage that can "kill" a technology, leading to a waste of the resources committed to its development and future value. Several determinants and barriers play a crucial part to successful exploitation, e.g. from technology characteristics, to project consortium, or the innovation context. It is noteworthy that, e.g., technology maturity, and its consequent proximity to the market, may affect exploitation possibilities since a technology with direct market application may be better received rather than one distant from it, needing more development effort and resources. This market application can be better assured when appropriate organisations are involved in developing and up-taking the technology in favourable innovation ecosystems.

It is straightforward to assume that improved exploitation of developed technologies results in more intense positive impact in society and economy, especially with enabling technologies with broad application in several economic sectors. This impact is achieved, on the one hand, by a more efficient use of resources committed to technology development, and on the other by the creation of more value to organisations commercializing project results as well as to those applying them to overcome their challenges.

One of such relevant application areas is the manufacturing industry. Due to its wide and transversal character, manufacturing has the potential to address grand societal challenges, since it has direct impact on business, social welfare, environment, and resources. Improved exploitation of enabling manufacturing technologies that can be applied to several sectors has a rich and complex architecture, impacting diverse interlinked value chains. The innovation process of developing and exploiting manufacturing technologies stretches from early stages of R&D until the market, not only to companies but also often to end-user customers.

In such context, public policies are perhaps the most important enabling instrument to promote R&D exploitation. Europe's and Member States' policies aim at assuring a smart, sustainable and inclusive growth (European Commission, 2012) by efficiently investing in R&D in order to develop and commercialize new technologies able to provide solutions to societal challenges. However, frequently many funding mechanisms appear to be too general not taking into account e.g. ecosystems' characteristics (Clarysse et al., 2014). Here, a redesign with a narrow focus could enable more effective exploitation.

Public policy should evidently help organisations overcome technology's valley of death by stimulating exploitation determinants, leaping barriers, or even supporting characteristics often overlooked. Moreover, policy should be designed or improved to include patterns and characteristics such as needs and challenges, technological, consortia, or even gaps. Overall, public policy can decrease the technological development and exploitation risk, while increasing its success from which all stakeholders in the innovation value chain could benefit from.

It was considering this challenging and motivating environment that we decided to develop our research about, following our long interest and work in strategic innovation management. We were intensely involved in two pivotal moments for public-funded R&D: one in Portugal between 2011 and 2013, and the other at European level between 2012 and 2015. From both, we could access and gather especially rich information in the area of innovation in manufacturing technologies on which we would build our research upon aiming to develop relevant contributions.

On the one hand, during the period between 2011 and 2013, we coordinated the first technology roadmap for manufacturing technologies in Portugal, under the scope of PRODUTECH, the Portuguese cluster for production technologies. As this was interlinked with two structural projects at national level about to start, we saw here an opportunity to assess the fit between these two initiatives. The conclusions for this analysis were expected to be valuable to the following strategic planning, as it eventually was the case. The analysis and conclusions are detailed in the article

"Prioritizing innovation in Portuguese production technologies", this work's next chapter.

Then, on the other hand, during 2012 the European Commission's (EC) Directorate-General Research and Innovation, responsible for EU policy on research, science and innovation, launched a call for proposals whose goal was to develop an exploitation framework for EU R&D-based technologies and propose recommendations for the corresponding policy improvements. This was a late stage of Framework Programme 7 (FP7) (2007-2013) and the main objective was to feed these recommendations in the following Horizon 2020 programme (2014-2020). We achieved the funding for the project that carried out this broad and stimulating task along with 13 other partners across Europe. Being part of the coordination and management team, we could immersively collect information, later used to develop this research work.

Departing from gaps and opportunities identified in the literature, we aim to study what determines successful technology exploitation and what hinders it, as well as which patterns emerge from technologies resulting from EU-funded R&D projects and the context in which they were developed in. For each perspective, we wrote the corresponding article: "Determinants for commercial exploitation: the case of European-funded R&D projects in manufacturing technologies" and "Technology and Context Patterns in European-funded R&D projects in manufacturing: a clustering analysis". These comprise this thesis' chapters 3 and 4, respectively. In both, our insights suggest recommendations for policy and management improvement, mainly related to call design and conditions, time, technological and contextual determinants to exploitation (as innovative advantage, market-readiness, owner type and location, among others), and diversity in R&D dynamics (such as organizations in specific mature or less advanced ecosystems, capturing value in more advanced ecosystems or exploring future possibilities).

In conclusion, the 3 articles comprising this research focus, respectively, the R&D process input stage, the output stage, and the transformation. The first article contributes with theoretical insights and practical recommendations aiming to a superior R&D planning in similar contexts as the studied one; the second article also provides theoretical and practical contributions towards an improved understanding and achievement of results' exploitation in the context of European-funded R&D projects in the area of manufacturing; finally, the third article aims, as well, to present theoretical and practical contributions to an enhanced knowledge and management of R&D process dynamics in the same context.

2. Research Gaps and Questions

The improvement of public policy must be evidence-based in order to be more targeted, thus more effective and successful. During our work with public-funded projects, we had detected several research opportunities whose results would possibly help redesigning and improve funding instruments. Due to our involvement in such projects at national and European levels, we were interested in studying and explaining several phenomena concerning project planning and results.

Our involvement in the referred projects lead to accessing and carefully collecting available data, and thus shaped our research timings. By revising literature, we were able to confirm our research opportunities and define possible research paths. The research focus was initially inductive as it arose from the exploratory work with the case study and the collected sample. Afterwards, research was complemented with a deductive approach, supported by evidence about gaps and opportunities identified in the literature, derived into the corresponding research questions (RQs).

Firstly, we have confirmed that the essential motivation for developing an innovation roadmap is to align product and technology developments with business goals and needs (Lee et al., 2011). I.e., a roadmap is mostly a guiding tool for improved efficiency when addressing challenges. To what public-funded R&D is concerned, its roadmaps comprise strategic innovation lines, usually defined according to identified challenges by sectoral stakeholders and then gathered into thematic areas. R&D projects are subsequently developed according to those themes, respective topics, often with required types of participants, and allocated budget. In addition, project participants frequently complement each other with their capabilities considering research areas and position in the innovation value chain (Paier and Scherngell, 2011). A significant alignment between those requirements (both market needs and strategic innovation lines) and project development results should exist as this expectedly leads to improving the overall innovation performance and resulting impact (Beers and Zand, 2014).

We consequently derived the following two RQs, concerning our first article:

RQ 1.1. Are national structural projects for manufacturing overall aligned with market needs and European strategic innovation lines?

RQ 1.2. Are there any critical misalignments?

From studying project design at national level, we then moved on to analysing project results at European level, where we were able to reach a larger scale. We compiled and analysed a sample of 61 technologies resulting from EU-funded R&D projects in the area of manufacturing. We wanted to know more about how the exploitation process is conducted after the end of such projects. In this sense, that how question was mapped into technology and context characteristics that may promote or prevent commercial exploitation.

The reference to the Valley of Death (Markham, 2002) is evident. It mainly is the gap between technology development and its commercialization (or respective efforts). Organisations have the resources, personnel and structure necessary for technology development, while others have the resources for commercialization activities as marketing, sales, promotion, production, and distribution. These types of organisations frequently work in the same consortium (e.g. RTOs and Companies), but technologies have nevertheless to overcome that gap on the road to exploitation. For the following article, our next RQ tries to answer one possible boundary dimension of the valley (Markham et al., 2010) taking into consideration the data sample we collected:

RQ 2.1. Is there a clear time length for the valley of death?

However, time is evidently not the only dimension to be relevant for successful technology exploitation. This occurs as a complex combination of many other antecedents and factors as referred in the literature (Kirchberger and Pohl, 2016; Jung et al., 2015; Rahal and Rabelo, 2006; Astebro, 2003; Heslop et al., 2001). From there, we have selected technology and context-related characteristics identified in literature as determinants for exploitation.

We identified Technological Advantage as a result of several literature references: Technology Assessment and Technology Radicalness (Kirchberger and Pohl, 2016); Innovativeness (radical/incremental) (Jung et al., 2015); improved operation compared to the alternatives (Astebro, 2003); significant identifiable and quantifiable benefits, distinct advantages over competing products, or if the technology is state-of-the-art or major breakthrough (Heslop et al., 2001); the nature and sophistication of the technology, technology uniqueness and superiority, technology's significant benefits and advantages as identified and perceived by the user, technology's quantifiable benefits and advantages as perceived by the user when compared to current competing products, technology's sustainable competitive advantages and superiority as perceived by the user, and the newness and the non-obviousness in the technology (Rahal and Rabelo, 2006).

Kirchberger and Pohl (2016) also point out that the capability to develop diverse products from the same technological base is another important factor for exploitation. Thus, a technology's Platform Potential enable organisations to better leverage investments during commercialization (Krishnan and Gupta, 2001). Successful commercialization of diverse products of the same family depends on the technological platform they derive from by diverse adaptations in order to satisfy specific market needs (Simpson, 2004).

The EC officially employs the Technology Readiness Level (TRL) scale to assess technology maturity or market proximity (European Commission, 2014). The literature highlights the importance of the Development Stage of the Technology (Kirchberger and Pohl, 2016; Rahal and Rabelo, 2006) as applied research leads to improved technology commercialization (Jung et al., 2015; Astebro, 2003) while the lack of application may deter exploitation (Gilsing et al., 2011).

Intellectual Property Rights (IPR) are arguably inherent to R&D and its success (Link and Scott 2013) and it is even considered a main exploitation determinant (Kirchberger and Pohl, 2016). Additionally, Rothaermel et al. (2007) claim that patenting is closely related relevant research, on its turn linked to concrete applications and commercial value.

In the context of this research work, R&D is always performed in consortia, smaller or larger. Literature refers that consortium dimension impacts technology commercialization (Kirchberger and Pohl, 2016). On one hand, some authors claim that large and diversified consortia possibly develop technologies with successful exploitation (Spanos et al., 2015). On the other hand, it is also argued that small consortia (but diversified as well) are expected to produce more successful technologies in terms of exploitation (Arroyabe et al., 2015) since larger consortia may induce opportunistic behaviour by partners and consequently produce a negative effect. Finally, another opinion can also be found stating that output additionality (related to successful introduction of new products) does not increase with the number of partners (Clarysse et al., 2009). It is clear that Consortium Dimension is worth studying, given such contrasting claims.

Then, to what ownership is concerned, some authors support that the organization type owning the technology may influence its exploitation (Kirchberger and Pohl, 2016). In fact, Fabrizi et al. (2016) argue that R&D in collaboration makes universities (far from the market) and RTOs (interface organisations) concerned about ownership and possible commercialisation of inventions, while companies (in the market) may benefit less from this type of R&D. Also, research about the network context of university-based technologies was suggested (Rothaermel et al., 2007). The settings where a university or RTOs act as the market party are rarely mentioned in the research (Kirchberger and Pohl, 2016).

Finally, even if R&D is performed in broader or narrower consortia, we believe that the efforts of commercialization are likely performed by technology owners. Therefore, location (Chiesa and Piccaluga, 2000) and respective Innovation Context where Owner organisations are inserted in seem to likely have a relevant role in the way exploitation is achieved. Several authors point out context characteristics to be determinant for exploitation, such as Industry Closeness and Resource Availability (Colyvas et al., 2002), or innovation policy and funding (Jung et al., 2015; Rasmussen, 2008). Overall, national, cultural, or policy factors that affect technology transfer mechanisms (Gilsing et al., 2011), the respective different geographies (Broekel and Graf, 2012), and different incentive systems that explain certain behaviours and outcomes (Rothaermel et al., 2007) are certainly worth studying.

The statements and gaps found in literature above summarized lead us to investigate how true they are to our sample's technologies and context:

RQ 2.2. Which characteristics are significantly determinant to successful exploitation?

After analysing determinants for technology exploitation, we aim next to understand how project development can be translated into patterns and what relevant insights can be extracted from that. We focus on the technological and contextual aspects (Astebro, 2004), utilizing the same previous variables, but this time with a different perspective and goal.

Technological Advantage is positively influenced by diversity in consortia (Becker and Dietz, 2004). Additionally, consortium partners should assess the know-how they can deliver to the project in order to achieve a certain technology maturity (that can be measured by TRL) for successful exploitation (Barbolla and Corredera, 2009). Most often, projects in consortia develop platform technologies due to their complementary expertise, this way sharing and reducing risks and costs (Halman et al., 2003). It is referred that research should focus on different organizational contexts, from which we have targeted European collaborative R&D. Their results can later be further developed and adapted towards diverse products with focused applications to target specific markets or customers (Beers and Zand, 2014; Allarakhia and Walsh, 2012; Chai et al., 2012) and therefore increasing their exploitation opportunities. In such R&D framework, IPR is a concern that should be tackled before and during projects, since it may promote or hinder exploitation success. Different consortium partners may have different, often conflicting, goals in the project (Allarakhia and Walsh, 2012; Lhuillery and Pfister, 2009).

Project consortia as a team likely determine the success of a technology (Belderbos et al., 2006). Literature highlights the need of researching about R&D consortia, namely their Dimension since it impacts team dynamics, in order to improve exploitation-supportive public policy (Spanos et al., 2015; Duysters and Lokshin, 2011; Becker and Dietz, 2004). Previous research identifies different types of project partners with a clear division between industry and academia (Spanos et al., 2015), and, more interestingly to our work, between Universities, RTOs, and

Companies (e.g. Von Raesfeld et al, 2012; Kang and Kang, 2010; Lhuillery and Pfister, 2009; Aschhoff and Schmidt, 2008; Belderbos et al., 2006; Miotti and Sachwald, 2003), with increasingly market proximity in that "scale" (Albors-Garrigós et al., 2014). These types of organisations participating in R&D projects eventually own the resulting technologies, possibly following a path towards commercial exploitation. Lastly, the innovation context in which organisations are embedded is regarded as a key determinant to successful R&D (e.g. Beers and Zand, 2014; Paier and Scherngell, 2011; Scherngell and Barber, 2009). Specifically, the location of the technology owner is a driver we aim to analyse.

We derived the following RQ:

RQ 3. Which technology and context patterns emerge from our sample?

3. Thesis outline

The next chapter is the first article of our research. We were involved in the development of the first technology roadmap and consequent structural projects in the newly created Portuguese cluster for production technologies and gathered data during its early stages. This paper studies the alignment between the cluster's two large projects of technological development with national strategic innovation lines and the manufacturing sectors' (the customers) needs. These strategic innovation lines designed at national level were derived from the corresponding European Technology Platform MANUFUTURE, aimed to align R&D activities with market needs and challenges, and were transferred to the national context.

Following the cluster's earlier work in this area, we firstly focus on the technological innovation priorities (the market needs) of nine of the most relevant manufacturing sectors in Portugal, with a traditional character but investing (or willing to invest) in R&D. These priorities are then mapped with the projects' activities and participants (type, effort, and budget) to assess the alignment.

We conclude that the main strategic innovation lines for technological development are horizontal between industries: new or improved manufacturing processes, operations management, and sustainability. We also find an overall relevant alignment of the projects with the innovation strategy. This information confirms a good project planning and design and indicates the potential for a positive broad impact of the project results. On the other hand, some partial misalignments, mainly in the project participation and activities, are found. They may be explained by numerous factors, as industry-specific questions, participant availability, or funding calls criteria, among others. We finally provide several recommendations both to management and policy makers, in order to improve project and policy design so that the identified gaps can be efficiently addressed. This chapter describes our involvement in the cluster's projects at national level, providing insights about projects' planning phase

The following chapters three and four describe our work at European level, namely about the exploitation and R&D dynamics, respectively, from the project results and context perspectives. We were deeply involved in the design, management, and execution of the European-funded project EXPLORE (Extended Exploitation of European Research Projects' Knowledge and Results, 2013-2015, grant agreement no. 609226, FP7) whose main goals were: (1) to support and promote the commercial exploitation of R&D results developed in previous EU-funded projects; (2) to provide recommendations to the European Commission for policy improvement concerning technology commercial exploitation. This challenging project provided a rich pool of data on which we could base our research that resulted in an empirical study for policy recommendations, to which we developed a conceptual framework that may be applied to other industries and contexts.

Therefore, chapter three details the statistical description and analysis (using an ordered probit regression) from a sample of 61 technologies resulting from European R&D projects in the area of manufacturing and mainly collected during the referred EXPLORE project. Based on that study, we identify determinants associated with commercial exploitation which allow us to provide contributions to improve both public policy and management. We also propose a 4-stage exploitation scale, and clearly identify a gap of 3 years between the end of the project and the eventual market exploitation.

Several determinants are found to be significantly associated with commercial exploitation: Technological Advantage, where incremental innovation promotes exploitation; technology maturity, where more developed technologies are more efficiently exploited; the type of Owner organization, where companies being in the market can better commercialize technologies; and the Innovation Context they are embedded in, where Innovation Leader countries provide a more exploitation-supportive environment. From these and other results, we are able to suggest public policy improvements to address technology exploitation drivers and challenges as well as propose recommendations to provide organizations information to better plan and design their projects and exploitation paths.

The following chapter, number four, comprises the second part of the work based on the same sample of technologies resulting from EU-funded R&D projects. Here, our goal is to study patterns of technologies and context. Therefore, employing a Hierarchical Clustering Analysis (HCA), we identify patterns (clusters) and find main similarities and differences between them.

We identify five clusters considering their technology and context variables. Due to their characteristics, we name them “Full Appropriability”; “Patent Pending”; “Resource Based”; “Agent of Change”; “Network Explorer”. There is a clear distinction between those whose technology owner is located in innovation leading countries and moderately innovative ones. Those in innovation leading countries, there is a further distinction between having or not IPR, maturity level and platform potential. On the other hand, clusters featuring owners in moderately innovative countries, also have considerably innovative technologies. The main differences are related to ownership (two clusters with RTOs and the other mostly Companies and Universities in large consortia), IPR, maturity, and platform potential.

In our discussion, we deepen those observations and insights, with the goal of providing recommendations to improve public policy. These may target the most common characteristics, as well as to other types that may be overlooked or even missing, taking into account both technological and contextual features, since often funding instruments disregard this diversity of configurations, leading to poor efficiency results. In addition, we also address management, since the conclusions of this work can be considered in order to better select funding calls consortia, or during project development towards successful results.

The last chapter concludes this research providing a global overview of the context, what and how was accomplished during this work, a summary of the findings, as well as our main contributions.

2.

Prioritizing innovation in Portuguese production technologies

Prioritizing innovation in Portuguese production technologies

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Abstract

In today's demanding global context of competition, companies have to carefully manage and prioritize their technological innovation. They often participate in collaborative initiatives such as clusters to increase their research, development, and innovation capacity through cooperation with other organizations. This is the case of production technology companies in Portugal and their cluster PRODUTECH, an unprecedented initiative with public-private funding. The cluster also comprises science and technology organizations, and industrial firms from 9 manufacturing sectors. Together they shape an innovative ecosystem in the country to provide new technological solutions to the market with a common strategy.

In this exploratory case study, we describe and analyse the initial steps of PRODUTECH's roadmapping process intended to align technology development with strategic goals. Our analysis spans from a preliminary sectorial survey to the

cluster's on-going R&D and innovation projects. We study the priorities attributed by the different sectors to strategic innovation lines for production technologies, and how they are reflected in the projects. The main priorities are related to the technological development aiming to address needs and challenges about new or improved manufacturing processes, operations management, and sustainability. We find an overall strong level of alignment, suggest motives that may explain some partial misalignments, and provide ideas for future developments based on such information.

1. Context and objectives

It is widely recognized that the rapid pace of change in science and technology, intensified competition, and globalization have substantially increased the complexity of technology innovation management (e.g. KOSTOFF; SCHALLER, 2001). Technology change has become critically important, but related decisions are also increasingly challenging, mainly due to the complex and dynamic nature of technology, market and industry development, reflected in increasing uncertainty about future conditions.

Several tools have been created and are currently broadly applied to better address such circumstances. One of them is Technology Roadmapping, which supports technological innovation management decisions in these challenging contexts in order to align technological development with organizational goals. It has been widely applied in industries such as semiconductors (e.g. WALSH, 2004) or energy (JEFFREY et al., 2013), large companies (e.g. PHAAL et al., 2001), or even government agencies (e.g. HOFFMAN; DAIM, 2006). There are several definitions for the roadmap process (e.g., PHAAL et al., 2011, AMER; DAIM, 2010, GARCIA; BRAY, 1997), but the main underlying rationale is to align product and technology developments with business goals and needs (LEE et al., 2011). In fact, a technology roadmap identifies paths technological development for meeting certain performance objectives. Usually, a single path may be selected and a plan developed. Nevertheless, in face of high uncertainty, multiple paths may be identified to reduce risk.

With these global motivations, PRODUTECH, the Portuguese cluster of production technologies, is developing a technology roadmap for the sector. In fact, the improvement of the technological foundations of manufacturing firms through the development and integration of advanced knowledge-based enabling technologies has been considered critical for their competitiveness (EFFRA, 2010).

This process aims at supporting the development of technologies to supply nine relevant and traditional Portuguese manufacturing sectors: footwear, textile, ceramics and glass, cork, leather, stone, metalworking, wood and furniture, and moulds. These are the main customer sectors of the production technologies industry. The cluster is a partnership between industrial companies, either technology developers (providers) or manufacturing firms (customers), sectorial organizations, and entities from the National Scientific and Technology System (S&T). By promoting cooperation between these organizations, it aims at developing turnkey integrated solutions for customer sectors.

In this context, PRODUTECH is currently developing two collaborative and structural projects: PSI – New Products and Services for the Manufacturing Industry – is targeted to the customer sectors, and PTI – New Processes and Innovative Technologies for the Production Technologies Industry – is targeted to the technology developers. Figure 1 represents the targets and the relative positioning of the two projects. The "Production Technologies" groups represent both companies and S&T organizations, and the "User Sectors" group represents both manufacturing companies (customers) and sectorial Technology Centres.

MALERBA (2002) considers innovation as an interactive process among a wide variety of actors, as firms do not innovate in isolation. Innovation has to be seen as a collective process, in which firms interact with other firms as well as with non-firm organizations such as universities, research centres, government agencies, financial institutions and others. Joint R&D projects are carried out in consortia with a diverse set of partners which leads to learning opportunities with regard to both cooperation and innovation skills and is therefore expected to improve organizations' innovation performance (BEERS; ZAND, 2014).

The selection of R&D partners depends therefore on the type of complementary resources organizations need to access, which, in turn, depends on their skills and expertise (MIOTTI; SACHWALD, 2003).

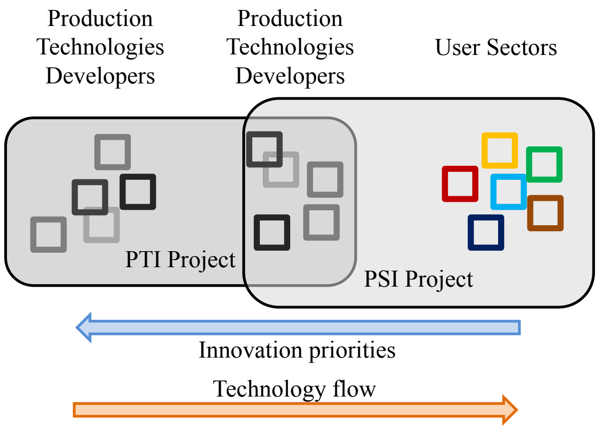

Figure 1 - Organization of PRODUTECH's projects

Prior to the creation of these two projects, PRODUTECH carried out an early stage identification of areas of alignment between the technology needs of customer sectors, the available offer from technology providers, and the European and national priorities for the development of production technologies. The projects were then designed with these early inputs, mainly due to time constraints related to the deadlines to apply for national funding. After their approval, and mostly in the scope of PSI, PRODUTECH involved more intensely the customer sectors in the early roadmapping work for identifying their concrete technological needs and challenges in order to fine-tune the technological development lines.

In this paper, we focus on these early stages of PRODUTECH's roadmapping process as an exploratory case study of the alignment between customer needs and challenges, strategic innovation lines, and project activities in production technologies. We start by analysing the results of the cross sectorial survey on areas and priorities for technology development, and then study the alignment of those results with the cluster's strategic innovation lines, derived from European initiatives, as well as with the structural projects currently under development.

The remainder of the paper is structured as follows. Next, we describe the methodology applied in this study. Then, we present and discuss the results, focusing first on the outcomes of the sectorial survey, i.e., the priorities assigned to the different strategic innovation lines, and later on their alignment with the efforts allocated to PRODUTECH's structural projects. We conclude with some implications for the cluster's roadmap and R&D+I projects, as well as for the management of misalignments between stated and realized innovation priorities.

2. Methodology

The alignment analysis of project activities with strategic innovations lines and market needs was inspired in and adapted from the literature concerning the priorities between organizations' project management practices and their business strategy (Milosevic and Srivannaboon, 2006). These authors developed an empirically based theoretical framework that shows the impact of business strategy on project management, as well as the effect of project management on business strategy, and discusses the mechanisms used to strengthen that alignment. In our case study, the business strategy is related to both the technology-push perspective given by the previously defined strategic innovations lines and by the market-pull perspective given by the identified customer needs, while project management refers to R&D planning comprising its activities, consortia formation, and budget/effort allocation.

To allow a bottom-up identification of areas and priorities for technology development within each manufacturing customer sector, an initial semi-structured survey was prepared and distributed to the Portuguese Technology Centres of each of the 9 sectors. These centres are representative of their sectors, playing a key role in their innovation activities, and counting on the participation of numerous leading manufacturing companies.

The main data collected in the survey consisted of a list of potential areas for technological innovation (related to needs, challenges, and trends), their importance to the sector in Portugal, as well as corresponding justifications and examples. The respondents were asked to rate the priority of each area of technological innovation on a three-point Likert-like scale ("low," "medium," and "high" priority). The priorities were mostly stated explicitly. However, in some sectors, only contextual descriptions were provided about how important certain innovations would be, along with their potential applications. In these cases, we interpreted, discussed, and agreed on their priorities. In two sectors – metalworking and footwear – no explicit or implicit data on priorities were provided. As the administration of the survey allowed the centres some leeway in their replies, some did not use the format that was distributed. In these cases, the replies were later adapted to fit the original format of the survey.

The identified areas were categorized according to PRODUTECH's strategic innovation lines (based on MANUFUTURE's[1] and EFFRA's[2]): *Environment* (sustainable use of resources as water or raw materials), *Energy Efficiency* (energy savings and usage optimization), *Energy* (e.g. introduction of renewable energy sources in the production processes), *Operations Management*, *Customer-Supplier Integration* (as during the product development process), *New Business Models*, *New Manufacturing Processes*, and *Optimization of Manufacturing Processes* (EFFRA, 2010). Along with these existing lines, two new themes were created to accommodate other topics mentioned by the sectors: *Support to Product Development*, and *Intellectual Property Protection Technologies*.

To further control impacts from the survey administration limitations described above, the survey results and subsequent classification were analysed and validated by three members of PRODUTECH's management team, with knowledge and experience relevant to technological innovation in the different manufacturing sectors.

We then performed a preliminary analysis of the priority data, looking for initial insights into the relationship between strategic horizontal innovation areas and the sectorial application of production technologies. Considering the "low", "medium",

[1] MANUFUTURE is the European technology platform on future manufacturing technologies
[2] EFFRA is the European Factories of the Future Research Association

or “high” priorities of the innovation areas set by the industrial sectors, we attributed the value 3 to “high”, 2 to “medium”, and 1 to “low” in order to perform a quantitative assessment. In addition to their priorities, the data collected feature a variable number of innovation areas identified for each strategic innovation line. In order to look simultaneously at these two dimensions, which reflect different aspects of the importance of a strategic innovation line (the presence of a large number of opportunities, or their individual high priority), we used a set of complementary, classic descriptive statistics indicators: the average and the sum of priorities, as well as the number of topics identified, for each theme-sector pair, and individually each theme and sector.

Finally, in order to analyse the alignment between project activities and the priorities referred by the industrial sectors, we focused on PRODUTECH’s structural projects. For this purpose, we collected and analysed project data on: 1) topics addressed; 2) number and types of organizations involved; and 3) budget. We then compared the priorities stated in the survey with the actual effort allocation (percentage of budget and number of participants) and participation of different organizations (S&T, sectorial, companies) in the referred projects.

3. Results and discussion

3.1. Priorities in strategic innovation lines

We firstly analysed the innovation priorities stated by the different industrial sectors to: 1) rank strategic innovation lines; 2) identify horizontal and niche strategic innovation lines; and 3) rank the sectors according to an innovation awareness criterion.

A summary of the results is provided in tables 1, 2, and 3, for the average, sum, and count of priorities, respectively.

The rankings of the strategic innovation lines according to each of the indicators were identical, thus showing a reasonable robustness in the identification of the most relevant themes as a whole and per sector. We also performed a sensitivity analysis of the rankings with a systematic variation of the values in each cell. As a result, each theme did not move up or down more than one position thus showing a reasonable robustness.
The top three strategic innovation lines identified were *Optimization of Manufacturing Processes*, *New Manufacturing Processes*, and *Environment*.

Table 1 - Average of Priorities

Average of Priorities	Sector									
Strategic Line	Stone	Textile	Wood&Furn.	Moulds	Ceramics	Cork	Leather	Footwear	Metalwork	Total Aver.
Optimization of Manufacturing Processes	2.4	2.5	2.5	2.3	2.0	3.0	3.0	n/av.		2.51
New Manufacturing Processes	3.0	2.4	3.0	3.0	1.8	1.9	1.5	n/av.	n/av.	2.36
Environment	2.5		3.0	3.0	2.0	2.5	2.3	n/av.	n/av.	2.19
Operations Management	3.0	2.5		2.0	3.0	2.0		n/av.	n/av.	1.79
Support to Product Development		2.5	3.0	2.0				n/av.	n/av.	1.07
Energy Efficiency	3.0		3.0		n/av.					0.86
Energy	2.0				2.0					0.57
Customer-Supplier Integration		3.0							n/av.	0.43
Intellectual Property Protection Technologies		3.0								0.43
New Business Models									n/av.	-
Average per sector	1.59	1.58	1.45	1.23	1.19	0.94	0.68	n/av.	n/av.	

n/av. = not available

blank cells = no priority was stated to the pair Sector / Strategic Line

Table 2 - Sum of Priorities

Sum of Priorities	Sector									
Strategic Line	Textile	Wood&Furn	Ceramics	Moulds	Cork	Stone	Leather	Footwear	Metalwork	Total
Optimization of Manufacturing Processes	27	10	14	20	6	12	3	n/av.		92
New Manufacturing Processes	31	6	9	6	15	3	6	n/av.	n/av.	76
Environment		24	4	3	5	5	7	n/av.	n/av.	48
Operations Management	5		12	2	2	3		n/av.	n/av.	24
Support to Product Development	8	6		4				n/av.	n/av.	18
Energy Efficiency		3	n/av.			3				6
Energy			2			2				4
Customer-Supplier Integration	3								n/av.	3
Intellectual Property Protection Technologies	3									3
New Business Models									n/av.	-
Sum per sector	77	49	41	35	28	28	16	n/av.	n/av.	

n/av. = not available

blank cells = no priority was stated to the pair Sector / Strategic Line

Table 3 - Count of Priorities

Count of Priorities	Sector									
Strategic Line	Textile	Ceramics	Wood&Furn.	Moulds	Cork	Stone	Footwear	Leather	Metalwork	Total
Optimization of Manufacturing Processes	11	7	4	9	2	5	4	1		43
New Manufacturing Processes	13	5	2	2	8	1	1	4	1	37
Environment		2	8	1	2	2	1	3	1	20
Operations Management	2	4		1	1	1	1		1	11
Support to Product Development	3		2	2			3		1	11
Energy Efficiency		1	1			1				3
Energy		1				1				2
Customer-Supplier Integration	1								1	2
Intellectual Property Protection Technologies	1									1
New Business Models									1	1
Count per sector	31	20	17	15	13	11	10	8	6	

blank cells = no priority was stated to the pair Sector / Strategic Line

Technology with application in the *manufacturing process* is at the ranking top, either through aspects of process capability *optimization*, or through *new* capabilities allowing the exploitation of new materials or the improvement of product sustainability (EFFRA, 2010). Besides introducing new products, manufacturing firms can also develop innovative manufacturing technologies. Each of these innovation types can be a source of competitive advantage in itself (KIRNER et al., 2009).

Environment was the following priority, with the sectors expressing a broad concern with sustainability and increasingly stricter policies and regulations. It is also a reflection of a wider corporate social responsibility. These sustainability concerns point towards the development of new production concepts changing the way manufacturers design, build, and support products, processes, and services (EUROPEAN COMMISSION, 2014) that can also be related both to *Support to Product Development*, which has been attributed a considerable importance (ranking fourth), and to *New Business Models*, even if this strategic innovation line was mentioned only once which may appear too few given its apparent transversal character.

Operations Management ranks fourth, with an importance that naturally follows manufacturing technology, as new or higher performance processes, machines and production systems require new methods and tools for managing and improving operations (EFFRA, 2010).

On the other hand, the low ranking of *Energy* and *Energy Efficiency* may seem somewhat surprising, as these are frequently considered a foundation of sustainable manufacturing. They usually are a priority in manufacturing industry, as reflected in European Framework Programme funding (ARNOLD, 2012). They often are embedded in other thematic projects, and therefore may be considered a “given fact”.

Customer-Supplier Integration and *Intellectual Property Protection Technologies* are new strategic innovation lines that emerged from the survey. They are here regarded as narrow priorities since they were referred by a reduced number of sectors only. They are, nevertheless, quite relevant overall, as pointed out e.g. by PETERSEN (2005), and LINK, SCOTT (2013), respectively.

The analysis considering the sum of priorities and the number of topics also led to nearly identical sector “innovation” rankings, pointing to the most active sectors in terms of identification of needs.

Observing the count of priorities, the top four strategic innovation lines have priorities stated by 7 to 9 of the 9 sectors and thus have a strong potential for broader horizontal innovation efforts and impact. The remaining strategic innovation lines appear to be more sector-specific, and potentially more suitable for niche-oriented efforts.

The substantial alignment that was found between the European Production Technologies strategic innovation lines (reflected in Portugal by PRODUTECH) and the customer needs identified in the sectorial survey may be explained by the bottom-up approach carried out when developing the strategic technology roadmap conducted by EFFRA. The overall method consisted in gathering contributions from relevant stakeholders, not only from production technology developers, but also from industrial customer sectors. The main misalignments are clearly *Energy* and *Energy Efficiency*. This may be partially explained by the current notion in the different industries that these are basic areas in manufacturing and in production technologies, and therefore assumed as a pre-requisite, as referred above.

3.2. Alignment with the structural projects

In a following stage, we assessed how PRODUTECH's R&D+I collaborative projects PSI and PTI reflect the priorities of the strategic innovation lines stated by the industrial sectors.

PSI (Table 4) aims at developing new products and advanced services to be applied in the manufacturing sectors as customers of the production technologies. This project promotes collaboration between organizations with complementary profiles, namely S&T, production technology developers, and technology users (manufacturing companies). These organizational profiles are referred by several authors (e.g. VON RAESFELD et al., 2012).

Complementary profiles, competences, and capabilities are in line with the observation of BEERS, ZAND (2014). They refer that those complementarities between knowledge and resources from multiple areas of expertise and application domains are necessary for successful development and introduction of innovations.

On the other hand, technology developers also need to have access to innovative production systems. Following the same rationale from PSI project, in PTI project (Table 5) PRODUTECH is developing technologies and other supporting tools for developers. In this project, however, the profiles involved are restricted to S&T organizations and production technology developers, acting as both suppliers and customers.

As measures of the effort put into each strategic innovation line , we used two classic innovation inputs indicators: the number of participating organizations and the budget. We categorized these indicators according to the type of organization involved.

The projects and the strategic innovation lines are broadly aligned. Only three of the lines with lower average priorities are not represented in the projects: *Support to Product Development*, *Customer-Supplier Integration,* and *Intellectual Property Protection Technologies*. Table 6 presents the relationship between the lines and the projects, distributing the effort indicators (number of participants and budget percentage) by participant profile.

Table 4 - PSI project details

PSI Project

Project Topic	Content	Participants					
		S&T Organizations	#	Prod. Tech. Developers	#	User Companies	#
Intelligent production systems	Design and development of tools to be embedded in production systems, providing superior efficiency and autonomy	R&D+I	3	Machine tools and systems	4	Metalworking	2
		Tech. Centres	5	Control and automation	2	Wood and furniture	2
				Software	2	Textile	1
Flexible and efficient production systems	Monitoring and management of production systems' availability to minimize downtimes due to setups and tool change	R&D+I	3	Machine tools and systems	5	Metalworking	1
		Tech. Centres	2	Control and automation	1	Wood and furniture	1
				Consultancy	1		
Operations management and logistics for customized products	Design and development of tools and systems to cost efficient manufacturing of competitive customized products	R&D+I	5	Machine tools and systems	3	Metalworking	3
		Tech. Centres	5	Software	5	Wood and furniture	1
				Consultancy	1	Textile	1
						Footwear	1
Networked production systems	Integration of production systems, industrial equipment, and information systems	R&D+I	2	Machine tools and systems	2	Metalworking	2
		Tech. Centres	2	Software	2	Wood and furniture	1
						Textile	1
Energy and environmental efficiency	Development of eco-efficiency evaluation tools and systems for integrated management of renewable energy sources	R&D+I	4	Control and automation	1	Metalworking	2
		Tech. Centres	5	Software	1	Wood and furniture	1
						Textile	1

Table 5 - PTI Project details

PTI Project

Project Topic	Content	Participants			
		S&T Organizations	#	Prod. Tech. Developers	#
Business models and support tools	Design and implemention of new business models in the production technologies industry, good practices, evaluation tools	R&D+I	2	Machine tools and systems	2
				Software	2
Advanced tools for the development of new products, systems, and services	Eco-design and eco-efficiency, engineering design, modelling and simulation, methods for development of "all-in-one" systems	R&D+I	6	Machine tools and systems	6
		Tech. Centres	3	Software	1
Systems and applications for flexible and mobile robotics	Rapid programming and control, felixble robotics, mobile robotics	R&D+I	5	Machine tools and systems	4

Table 6 – Project participants and budget (PSI + PTI)

	Strategic Line of Innovation							
	Optimization of Manufacturing Processes, New Manufacturing Processes		Operations Management		Environment, Energy Efficiency, Energy		New Business Models	
Participant profile	# participants	% budget	# participants	% budget	# participants	% budget	# participants	% budget
Prod. Tech. Developers	18	24.0%	11	9.2%	3	2.4%	4	1.0%
S&T Organizations	16	22.0%	10	6.5%	9	6.7%	2	2.0%
User Companies	6	3.0%	6	2.0%	4	3.5%	n/ap.	n/ap.
Total	40	49.0%	27	17.6%	16	12.6%	6	3.0%

The top strategic innovation lines (*Optimization of Manufacturing Processes* and *New Manufacturing Processes*) are carefully dealt with in both projects with considerable number of participants and budget percentage allocated. They are divided in four development topics: intelligent production systems, flexible and efficient systems, networked systems, and advanced tools for the development of new products, systems, and services. These topics feature the largest number of participants (40) and receive the largest total budget share (49.0%), reflecting the highest priority ranking for the two lines.

It has been referred (TOMLINSON, 2010) that for traditional industries such as Textile or Ceramics, higher levels of supplier cooperation are significant in raising the level of innovation, and specifically that process innovation is enhanced through closer supplier collaboration. Improved performance in manufacturing processes (either new or optimized) can be measured by speed, efficiency, and quality, as indicators of process innovation output (KIRNER et al., 2009).

The second largest share, both in terms of participants (27) and in terms of budget (17.6%), is dedicated to the *Operations Management* line.

The strategic innovation lines *Environment*, *Energy Efficiency*, and *Energy* are brought together under a single topic related to energy and environmental efficiency, with 16 participants and assigned budget share of 12.6%. This allocation of effort switches the priority between *Environment* and *Operations Management*, when comparing to the survey results (tables 1, 2, and 3).

The *New Business Models* line has a small budget of 3.0% and 6 participants. This modest level of resources is in line with its low and niche priority.

Table 7 summarizes our analysis of the fit between the priorities stated in the survey and the efforts allocated to each innovation line in the projects. Each strategic innovation lines is matched with the corresponding project topics, which are ordered from the highest to the lowest amount of effort allocated. In each cell, the colours reflect the priorities (high = red, medium = yellow, low= green; and reference to one strategic innovation line only = grey). "U" marks the presence of User Companies and "T" marks the presence of Technology Centres.

Table 7 - Alignment between innovation priorities and allocation of effort in the projects

		Sector								
Strategic Line	**Project Topic**	Wood and Furn.	Stone	Textile	Moulds	Cork	Leather	Ceramics	Footwear	Metalwork
Optimization of Manufacturing Processes New Manufacturing Processes	Intelligent Production Systems Flexible and Efficient Systems Networked Production Systems Advanced Tools for the Development of New Products, Systems, and	U	T	U T	T	T	T	T	T	U T
Operations Management	Operations Management and Logistics for Customized Produtcs	U		U T		T	T		U T	U T
Environment Energy Efficiency Energy	Energy and Environmental Efficiency	U	T	U T	T		T			U T
New Business Models	Business Models and Support Tools									U
Support to Product Development	*Not addressed*									
Customer-Supplier Integration	*Not addressed*									
Intellectual Property Protection Technologies	*Not addressed*									

U – User Company; T – Technology Centre
Red = high, yellow = medium, green = low; grey = one strategic innovation line only

The top two strategic innovation lines *Optimization of Manufacturing Processes* and *New Manufacturing Processes,* and their corresponding project topics, have gathered the participation of every sector. They can therefore be considered truly horizontal strategic innovation lines. The related production technology developments can have a wide application and impact, as there is a strong alignment between the stated needs and the participating organizations.

Operations Management presents considerable misalignments. Some sectors that did not consider this a priority line are however participating in the corresponding project topics, whereas others that stated this line as a high priority have no participation. As the participating user companies and technology centres cover 6 of the 9 sectors, this can still be considered a horizontal topic, however presenting critical misalignments. This may compromise the results application in the interested sectors not participating in the developments.

The topics related with *Environment*, *Energy Efficiency* and *Energy* have a reasonable alignment with the strategic innovation lines, as the sectors that pointed out the highest priorities are participating in the corresponding developments, either through User Companies or through Technology Centres. The *Environmental* line is quite transversal. Participants again come from 6 of the 9 sectors.

New business models has the participation of a user company from the only sector that referred this strategic innovation line in the survey. Surprisingly, no Technology Centre is participating in this project topic.

Some of the misalignments between stated priorities and allocated effort might be related to a lack of fit with the priorities of available funding calls. PRODUTECH's PSI and PTI projects were both funded by national programmes supported within the European Union's Seventh Framework Programme. Frequently, these funding programmes also require specific combinations and bounds (lower and upper) on the number of participants and their profiles, which constrain consortium compositions. These constraints can also arise from budget limitations, as was the case of PRODUTECH's projects.

R&D programmes assign a preferential evaluation to projects presented by allied partners, eventually competitors, in consortia (SCHIAVONE; SIMONI, 2011). In such contexts, the project promoters and coordinators need to manage carefully the composition of the consortia to make sure that the agendas and goals of the specific participants are aligned. In particular, for a cluster like PRODUTECH, avoiding the transformation of co-opetition into competition among the participant organizations is a critical concern. In addition, many members of PRODUTECH had never cooperated before, a fact that increases the complexity of project setup and management, and therefore of aligning stakeholder innovation priorities with project effort allocation.

4. Conclusions

In this paper, we have analysed the early stages of the technology roadmapping process carried out in the Portuguese cluster of production technologies, PRODUTECH. This analysis is an exploratory case study about the alignment between needs and challenges, funding opportunities, and projects in technological development and innovation. We evaluated the results of a survey on areas and priorities for technology development conducted across nine relevant and traditional Portuguese manufacturing sectors as customers of production technologies. We then studied the alignment of those results with the cluster's strategic innovation lines, derived from European initiatives, as well as with the structural projects currently under development in the cluster.

The survey results allowed us to identify the themes – and therefore related production technologies – which seem to be more important across sectors. They mainly are related to new or improved manufacturing processes, operations management, and sustainability concerns. It was possible to confirm a substantial alignment between the European strategic innovation lines and the needs identified by the customer sectors in Portugal. These results may support the development of a high-level roadmap, and they may also be an important input for planning large projects involving many participants and with broad industrial impact. In this sense, we wanted to understand how well PRODUTECH's structural projects were aligned with the needs of the sectors and with strategic innovation lines. In our analysis, we found a significant alignment between them, thus pointing out to a broad impact of project results.

However, we have also identified partial misalignments between the innovation priorities stated in the survey and both the effort allocation and participant number in the cluster's projects. These may arise due to a variety of factors, such as existence of more sector-specific needs, calls' budgets and parameters (e.g. requiring a certain consortium composition within each project activity, or the development of certain technologies as priority themes), availability of resources, or even the difficulty to align agendas and goals among project partners.

Based on these results, PRODUTECH – and other clusters – can be more aware of the identified misalignments and proactively seek to relax boundary conditions thus increasing flexibility in order to adapt the projects to increase their impact. This can be, for instance, aiming to influence, at an early stage, the definition of the calls' parameters, or provide opportunities and incentives to improve the basic alignment of the cluster's members. The cluster may also develop new projects, intending to close identified gaps, as well as carry out other activities that build on and complement the funded projects to minimize the impact of the misalignments. Finally, the architecture of future projects in the cluster can also be configured to maximize the potential for application and impact of each strategic innovation lines on the relevant sectors.

The generalizability of our conclusions is limited due to the intrinsic features of the case study research design, and to our focus on a specific cluster in a specific context. However, this opportunity to explore a rich set of cross-sectorial data is, to the best of our knowledge, rare. This fact makes these results valuable to technology clusters with comparable organizational, activity, and funding structures.

It is, moreover, relevant to suggest avenues for future research on an important topic that, also to the best of our knowledge, has received scarce attention in the literature. In that sense, it would be very interesting to replicate our work to other early roadmapping processes in other collaborative initiatives or clusters worldwide. Other noteworthy line of research would be to follow-up PRODUTECH's activity after the end of the studied projects in order to understand how the alignments/misalignments influenced the impact of project results.

Finally, following the roadmapping process carried out within PRODUTECH, our work also points out paths for future technological projects in this and other clusters, as well as generally in production technologies and industries.

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3.

Determinants for commercial exploitation: the case of European-funded R&D projects in manufacturing technologies

Determinants for commercial exploitation: the case of European-funded R&D projects in manufacturing technologies

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Abstract

A vast amount of money is globally invested in Research and Development (R&D) activities in a tremendous effort to push the boundaries of science and technology. It aims to create new solutions to increasingly faster and demanding societal and economic needs and challenges. Europe is no exception, where large funding programmes have been supporting countless R&D projects over the years. Despite excellent R&D results, commercial exploitation is difficult and too frequently unsuccessful. This is a major source of funding inefficiency since no economic value is eventually created from such investments.

In this exploratory work, we depart from a sample of 61 technologies resulting from European-funded R&D projects in the area of manufacturing to identify determinants for commercial exploitation. We support our work on descriptive statistics and an ordered probit regression, from which we derive insights expecting to contribute to the improvement of policy-making and management.

Among other contributions, we propose an exploitation scale and show that full commercial exploitation mostly occurs 3 years after the end of the R&D project. Also, in order to achieve successful exploitation, technologies must present considerable incremental innovation and have clear application- and market-readiness. On the other hand, technologies with lower market readiness seem to require increased support from policy. We could not confirm that, as stated by

literature, platform potential, intellectual property rights, or larger consortia favour exploitation, which may point out the need to further support on these areas in the analysed context. Technology ownership by companies seems to facilitate exploitation. This may reinforce the notion of needed increased support for other types of owners, as universities, which have less-ready technologies. Finally, the innovation context can determine exploitation success, indicating the need of policy supporting commercialization in less innovative countries.

Keywords

Innovation; Strategy; Public Policy; European Union; Framework Programme; R&D Policy; Technology Exploitation; Technology Commercialization; Exploitation Scale; Funding Instruments; Ordered Probit Regression; Manufacturing Industry.

1. Introduction

The European Union (EU) faces increasing global competition, in particular at the upper ends of global value chains (European Commission, 2015). The European manufacturing industry, in particular, is striving to regain global competiveness and cultivate sustainability, in order to be able to withstand the pressure of global markets in the long term. Fulfilling the needs of the manufacturing industry in this reality requires strong investments in R&D and fast diffusion of newly accumulated knowledge into new products and services, processes and business models. R&D activities, either basic or applied, provide key inputs to innovation processes. Their outcomes are integrated into novel products and processes, which in turn are introduced in the market and subsequently diffuse (European Commission, 2015).

The EU pushes for R&D and innovation to keep its manufacturing industry competitive and sustainable, but effective exploitation of R&D outcomes appears to be lagging. It has been acknowledged that there exists a vast amount of accumulated knowledge (e.g., in publications) deriving directly from research activities in Europe. However, the transformation of this knowledge into competitive and sustainable innovation and ultimately into novel products and services capable of creating economic and social value is perceived as unsatisfactory, with a complex set of factors limiting this fuller realization of the potential from research results.

Over the years, EU-funded projects and programmes have created novel technologies, products and services for the manufacturing industry. Even though the know-how accumulated during several framework programmes (FPs) is vast, the R&D outcomes appear not to have been exploited to their fullest potential.

A crucial point is that research is necessary, but not always sufficient for achieving economically significant innovations. The commercial exploitation of research results for innovative activities continues to be inadequate, notably in areas where there might be opportunities for enhancing Europe's industrial competitiveness (European Commission, 2010).

These relationships between science, technology and industrial exploitation are related to an interpretation concerning European weaknesses in industrial innovation known as the 'European Paradox'. Such a paradox refers to the conjecture that EU countries play a leading global role in terms of relevant scientific output, but lag behind in the ability to convert this strength into wealth-generating innovations (Dosi et al., 2006).

Therefore, more attention should be given to the ways how commercial exploitation of research may be enhanced. The dissemination and exploitation of research results has been a crucial aspect of successive FPs in need of considerable strengthening (European Commission, 2010).

The portfolio of available funding mechanisms has been considered insufficiently appropriate to help translate research results into innovative products, processes and services, missing support, e.g., to smaller projects staged through multiple rounds of funding, or the creation of effective institutional innovation capacity in research centres. Overall, by design, FP7 targeted research more than innovation, and was more successful at achieving research objectives than supporting demand-driven innovation (European Commission, 2015).

During recent years, multiple initiatives have emerged as part of a broad effort aimed at improving the exploitation of research results. From science parks to research consortia, from incentives to licensing to the fostering of collaborations, or the involvement of regional development policies, multiple efforts have been deployed (Chiesa and Piccaluga, 2000).

The study presented in this paper seeks to contribute to an improved understanding of the determinants of commercial exploitation of technologies resulting from EU-funded R&D projects, looking specifically at a sample of projects carried out in the important area of manufacturing, and focusing on two main perspectives: technology and consortium. The paper is organized as follows: chapter 2 sets the theoretical background, chapter 3 presents the data and research methodology, chapter 4 describes the results, chapter 5 outlines the findings and implications, and chapter 6 closes with limitations, and future research.

2. Literature review

In their literature review, Kirchberger and Pohl (2016) identify and summarize the key understandings of technology commercialization that have been adopted in the literature, in successive encapsulated layers: (1) the overall process of commercial application and exploitation of technology; (2) there included, the process of transferring technology through licensing or other collaborative activities; and (3) here included, the process of transferring a technology-based innovation from the developer of the technology to an organization utilizing and applying the technology for a marketable product.

Most frequently, technology-based innovations are transferred from the developer to the market-taker or user during collaborative projects, or by later licensing the technology. Our interested is directed to the factors that may contribute to a successful commercialization resulting from that collaborative process, a particular exploitation stream that is a part of the broader process of technology commercialization.

Technology commercialization is a very complex process and its success depends on many different factors (Kirchberger and Pohl, 2016). There has been a considerable volume of research, using a variety of analysis methods, on the determinants of R&D project performance, including the factors leading to its success (Astebro, 2003), understood as technology exploitation or commercialization. Multiple authors have identified in their work, including in several literature reviews, numerous factors and antecedents for successful technology commercialization (Kirchberger and Pohl, 2016; Jung et al., 2015; Rahal and Rabelo, 2006; Astebro, 2003; Heslop et al., 2001).

The introduction of innovations in the market is regarded as an indicator of a successful R&D outcome (Hottenrott and Lopes-Bento, 2014). Furthermore, the measurement of R&D efficiency throughout commercialisation stages is important (Chun et al., 2015). Nevertheless, little is known about the measurement of successful commercialization of technologies, and research could focus on establishing scales of technology commercialization success, as well as exploring the dynamic aspects of technology commercialization, such as factors and situations leading to exploitation (Kirchberger and Pohl, 2016).

Supported by the literature, we describe in this section factors related to the two perspectives of interest for our research:

- Technology, concerning the technological features of the R&D outcomes

  Identifying technologies with significant potential for commercial application is always primarily based on their assessment along a set of determinants related to technological characteristics that may influence exploitation. The literature has suggested several such determinants, possibly crucial to successful licensing and commercialization (Rahal and Rabelo, 2006), from which we have selected four that may be analysed with our sample.

- Context, concerning the factors related to the R&D team and its background

  It has been argued that success in transfer comes with a range of people skills and resources, including cross-functional teamwork, shared culture, and involvement of different types of organizations in the innovation process (Heslop et al., 2001). We have therefore also considered highly relevant the analysis of consortium characteristics that may determine successful technology exploitation, in spite of an apparent lower attention from research to this perspective.

2.1. Technology

Several authors have identified in their research multiple technology-related factors associated with successful commercialization. They have grouped those factors in specific topics, that we relate to our sample's characteristics: Technological Advantage, Platform Potential, Technology Readiness Level (TRL), and Intellectual Property Rights (IPR). We detail these four determinants for exploitation next.

2.1.1. Technological Advantage

Kirchberger and Pohl (2016) identify Technology Assessment and Technology Radicalness, while Jung et al. (2015) refer Innovativeness (radical/incremental), as characteristics that determine the innovative character and corresponding potential value of a new technology concerning customer or user impacts. We have associated our sample's Technological Advantage attribute with these factors.

Technological Advantage is present when the innovation works better than the alternatives (Astebro, 2003), when the technology offers significant identifiable and quantifiable benefits, when the product/process has distinct advantages over competing products, or when the technology is state-of-the-art or a major breakthrough (Heslop et al., 2001). Other relevant factors related to Technological Advantage mentioned in literature (Rahal and Rabelo, 2006) are the nature and sophistication of the technology, its uniqueness and superiority, significant benefits and advantages as identified and perceived by the user, quantifiable benefits and advantages as perceived by the user when compared to current competing products, sustainable competitive advantages and superiority as perceived by the user, and newness and non-obviousness.

Technological Advantage may be expressed in an innovation evaluation scale. Along this scale, novelty affects technology innovation and inimitability, i.e., advantage, in a curvilinear manner, first positively and then negatively when development is excessively risky or uncertain (Spanos et al., 2015). This means that reasonably, but not too, innovative technologies are most likely to be successful, resulting in commercial exploitation. Technology innovation uncertainty can be defined as a function of the types of knowledge required to successfully complete its development. This knowledge is frequently unavailable, incomplete or unreliable, resulting in a risky development. Such conditions tend to be present for radically different technologies, which are thus difficult to copy by competitors. On the other hand, projects building on past research are more likely to result in innovation impacts, since innovation is mainly incremental, and thus less risky or uncertain (Spanos et al., 2015).

2.1.2. Platform Potential

The capability to create different product concepts from a same technological base is another important factor for technology exploitation (Kirchberger and Pohl, 2016). We have related our sample's Platform Potential attribute with such factor as identified in the literature. This potential is a likely enabler of commercial exploitation, since it is expected that the higher the platform attributes of a particular technology, the more markets or applications it can address, thus increasing the possibilities of commercialization. Simply put, a technology that is core or platform (Heslop et al., 2001) may have diverse applications (Jung et al., 2015), whereas a niche-oriented technology is developed to address a very specific need.

Product platforms are component and subsystem assets shared across a product-family and therefore can serve multiple product lines in the market. The leading principle behind the platform concept is to balance the commonality potential and differentiation needs within a product family. A basic requirement therefore is the decoupling of elements to achieve the separation of common (platform) elements from differentiating (non-platform) elements (Halman et al., 2003).

Companies invest in platform-based product development as a way to manage the complexity of offering greater product variety while shortening lead times and reducing costs, due to increasing global competition. Product platforms enable a firm to better leverage investments in product design and development. While the platform approach offers a number of benefits, it also imposes certain additional costs (Krishnan and Gupta, 2001).In addition, it has been argued that the key to a successful product family is the product platform from which it is derived either by adding, removing, or substituting one or more modules in the platform or by scaling the platform in one or more dimensions to target specific markets (Simpson, 2004). On the other hand, market formation is characterized by growth in multiple niche markets for which the technology is superior (Pinkse and Van den Buuse, 2012).

With this in mind, we expect a higher platform potential to contribute to improved technology exploitation since it can provide more diverse products, whereas at the other end of the scale, i.e., for niche-application technologies, only very specific and defined customer needs may be addressed.

2.1.3. TRL

TRL is a systematic metric and measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology (Mankins, 1995). Deriving from the original NASA scale of technology readiness, the European scale was adapted by the European Commission in order to classify technologies resulting from European R&D projects and is widely used in such context. This scale also comprises 9 levels and provides a measure of technology maturity throughout its development cycle, from inception (TRL 1 – basic principles observed) to real environment testing (TRL 9 – actual system proven in operational environment) (European Commission, 2014a).

It is important to point out the importance of the Development Stage of the Technology, i.e., how ready it is for commercialization (Kirchberger and Pohl, 2016; Rahal and Rabelo, 2006), since has been recognized that more applied research leads to higher rates of technology commercialization, thus very much linked to technology maturity (Jung et al., 2015; Astebro, 2003). In our sample these factors are matched with the TRL attribute. It has been observed that, e.g., technologies developed at universities may present more fundamental and less applied characteristics and therefore feature lower levels of commercialization, namely to companies (Kirchberger and Pohl, 2016). This determinant is related as well to market readiness, understood as whether the technology has immediate market uses (Heslop et al., 2001) or rather needs further developments (Rahal and Rabelo, 2006).

It has been recognized that a major barrier for exploitation is the lack of application-readiness of scientific knowledge (Gilsing et al., 2011), whereas the presence of an application focus can contribute to promoting it. For this reason, higher TRLs, featured by more mature, application-ready and closer-to-market technologies, are expected to be associated with better commercialization performance, while lower TRLs are expected to be associated with wider exploitation gaps, with further developments required towards market-ready products.

There are, however, possibilities of commercializing lower TRL technologies through the so-called markets for technology (Arora et al., 2001). Here, early-stage, emerging technologies are fully exploited at a development stage still far from the market (final products). This opens broader opportunities for creating value from these developments and decreases the risk intrinsic to a full innovation cycle. Organizations targeting lower TRL R&D, such as Universities, may benefit from such commercialization strategy.

2.1.4. IPR

IPR may include patents, copyrights, or trademarks, among others. It has been argued that the creation and protection of Intellectual Property (IP) is endogenous to the evolution of R&D projects, and more specifically the success of subsidized R&D (Link and Scott, 2013). Additionally, there are complementarities between patenting and scientific performance, and individuals with higher research performance are also successful at engaging in real world problems and creating commercial value (Rothaermel et al., 2007).

IPR, understood as the ability of the developer of a technology to obtain property rights and protect the research, are also mapped to our sample's characteristics, and have been identified by Kirchberger and Pohl (2016) as a main exploitation success factor. However, their level of influence on commercialization may depend on other technology attributes, e.g., with more advanced (closer to market) technologies, IPR may become less important. Other authors have analysed more detailed IPR topics, such as whether complete and clear patent and literature searches are carried out, the existence of dominant patents, whether the inventor holds the patent, technology confidentiality (absence of oral or written disclosures), prior technology claims, and IP strength and exclusivity (Rahal and Rabelo, 2006; Heslop et al., 2001).

Furthermore, it has been previously found that employment growth from public support to small firm R&D increases with the level of IPR obtained from that support (Link and Scott, 2013).

2.2. Context

The literature mentions several factors that determine technology exploitation success, related with consortia formation in R&D projects. Next, we detail three that may be analysed with our sample: Dimension, Owner, and Innovation Context.

2.2.1. Consortium Dimension

Kirchberger and Pohl (2016) refer that Team Size affects technology commercialization. In our work, we have related Consortium Dimension with this factor. The number of members of the development team impacts the way the technology is exploited since consortia with a larger number of members allow for larger and broader developments for a certain project duration, and for the inclusion of more diversified project partner profiles. On the other hand, more limited consortia may be more focused and oriented to specific developments.

It has been previously argued that large, diverse consortia are more likely to develop technologies resulting in successful outputs (Spanos et al., 2015). In contrast, Arroyabe et al. (2015) claim that the key characteristics of R&D projects resulting in exploitation are heterogeneity and a low number of partners. A larger number of partners may also increase the chances of opportunistic behaviour by some of the partners, with a negative effect on project performance, and a lower likelihood of exploitation success. Moreover, Clarysse et al. (2009) have found that output additionality (related to innovation outputs such as the introduction of new products) does not increase with the number of partners in a project.

2.2.2. Owner

The type of source (organization) owning the technology may also impact its commercialization outcome (Kirchberger and Pohl, 2016). We relate the Owner attribute in our sample with the technology source, i.e., the type of organization that becomes the owner of the technology at the end of the R&D project. Colyvas et al. (2002), e.g., point out that especially for embryonic technologies, university ownership facilitates technology commercialization.

The importance of value chain partner complementarity on both application development and commercial performance of public R&D has been recognized. In fact, collaboration with research organizations, suppliers and customers has been found to have a positive impact on innovation novelty (Von Raesfeld et al., 2012). Still related to value chain complementarity, another very important dimension for successful collaboration in European FP R&D projects is thematic distance, i.e., it is more likely that organizations choose similar partners with respect to the thematic profile of their FP participations. This indicates that the thematic instruments (i.e., the sub-programmes) target existing communities quite well (Paier and Scherngell, 2011), and consequently, a strong specialization exists in the topics, which may lead to improved exploitation outcomes.

From the literature, three main organisation types participating in R&D projects, across the full R&D value chain, were identified as relevant to our research: Companies (industrial end), Research and Technology Organizations (RTOs) (in the middle, with an interface role), and Universities (academic end) (Fabrizi et al., 2016; Eurostat, 2014; and Von Raesfeld et al., 2012).

Previous studies have found that while all these organization types (institutional sectors) benefit from joint R&D projects, the main beneficiaries are universities and research centres, while private companies benefit less. Fabrizi et al. (2016) argue that cooperation makes universities and public research centres more concerned about appropriability and possible commercialisation of inventions.

Additionally, in some cases, commercial agreements may be associated with employment gains for firms. This is expected to occur when such agreements can allow small firms to earn returns on the new technology developed with the subsidized R&D. Nevertheless, they may also be associated with lower employment growth for the firm (usually SME), in cases in which employment growth induced by the innovation is experienced in other firms that have licensed the technology or purchased its rights (Link and Scott, 2013).

2.2.3. Innovation context

The location of research institutions has been highlighted by Chiesa and Piccaluga (2000) as an important factor to be considered in the exploitation of research results. Similarly, Broekel and Graf (2012) have called attention to the importance of furthering the study of diverse geographies for knowledge networks that carry out research.

Colyvas et al. (2002) point out the importance of Industry Closeness and Resource Availability, characteristic of the technology owner's region, as determinants of technology exploitation. Innovation Context (geography and innovation score) is the attribute of our sample that we have related with such factors. More specifically, an innovation context featuring technical capacity, market strength, and links to key business partners, should lead to increased technology commercialization success. The availability of resources for commercialization, in the form of funding, venture capital, suitable personnel, or support infrastructures (e.g., incubators) also impacts its outcome. Furman et al. (2002) refer that public policy plays an important role in shaping a country's national innovative capacity, including available R&D, human capital investment, innovation incentives, cluster circumstances, and the quality of linkages. Jung et al. (2015) mention policy and funding as additional key factors that influence technology commercialization. The importance of national innovation policies to exploitation has also been highlighted by Rasmussen (2008). Overall, the literature has hinted at the relevance to exploitation success of the factors that contribute to the innovation score attribute in our sample.

3. Research context and methods

3.1. Sample identification context and process

Our sample comprises 61 technologies in the area of advanced manufacturing (production) developed in FP6 (2002-2006) and FP7 (2007-2013) projects within the selected theme of "Nanosciences, Nanotechnologies, Materials, and new Production Technologies" (NMP) (with similar names and goals in FP6 and FP7) and focused on new production technologies. These technologies are critical because they act as enablers of innovation, competitiveness, and sustainability across the manufacturing industry.

The objective of the industry-oriented NMP theme was to support the transformation of European industry towards a knowledge-based industry thus becoming more competitive and sustainable. This required the development of new production concepts to change the way manufacturers design, build, and support products, processes, and services (European Commission, 2014b).

The sample was mainly collected during the European project EXPLORE (Extended Exploitation of European Research Projects' Knowledge and Results, 2013-2015, grant agreement no. 609226, FP7). The project's main goals were (1) to support and promote the commercial exploitation of R&D results developed in EU-funded projects in the topic of production technologies, and (2) to provide recommendations to the European Commission for policy improvement concerning technology commercial exploitation. The focus on new production technologies from the NMP theme intentionally excluded project results in nanosciences, nanotechnologies, and materials.

The first author worked three years in the EXPLORE project, from concept development, consortium formation, and proposal writing, through work development and coordination, to closure and evaluation. While managing and co-coordinating the project, the first author managed, e.g. the systematic collection of technologies with commercial exploitation potential. This work comprised the identification, evaluation, full characterization, and selection of the technologies, and contacts with owners and organizations for potential take-up, providing a deep and broad knowledge about the technologies.

After that cycle, the first author also co-organized and participated in numerous matchmaking events and bilateral meetings in several European countries, to present technologies selected according to the audience, mainly comprised of companies and public authorities. Often, discussions about public policy to support technology exploitation were fostered in order to collect broad feedback about the topic to be conveyed to decision-makers. Afterwards, negotiations with consortia were promoted, leading to new projects aimed at transforming technologies into market products, including the selection of available funding at several levels, when required (e.g., European Union's Fast Track to Innovation Pilot). The whole work in this project enhanced a global view of European R&D in manufacturing.

In detail, the sample collection task included an initial search for EU-funded R&D projects in the topic of "Nanotechnologies, Materials, and Production technologies" (NMP), which resulted in 437 such projects. From these, 152 were then selected, as the ones related to "Production" only, our focus. A second round of selection reduced the number to 57 projects which had had the participation of EXPLORE participants, and whose leaders were contacted personally, by telephone or email. From those, 27 responded to our contact with the identification and characterization of 46 technologies that resulted from their projects. Afterwards, 15 additional technologies were directly identified by EXPLORE participants and characterized by their owners, and thus added to the sample, leading to a total of 61 technologies. The owners characterized their corresponding technologies using a template prepared during an EXPLORE project task (in Annex).

The whole procedure for sample collection was carried out between June 2014 and April 2016, in the three stages detailed below:

<u>A – Top-down approach</u> (June – September 2014)

1. Firstly, the projects from which the technologies would be derived were selected. Two searches were conducted in EU's Community Research and Development Information Service (CORDIS), in the "Projects & Results" section.The two searches started with the setting of two filters: for "Subject", the option "Industrial Manufacture", our focus and the closest one to the area of advanced manufacturing, and for "Content Type", the option "Project", our means to finding the resulting technologies.
   1.1. Then, the option "FP6-NMP" in the filter "Programme" was selected, leading to a total of 296 such projects.
   1.2. After disabling the "FP6-NMP" option, the option "FP7-NMP" in the same filter was selected, leading to a total of 141 such projects.

   A total of 437 R&D projects were found.

   Only projects from FP6 and FP7 were addressed. Projects from previous programmes and resulting technologies (e.g. FP5) would either be outdated or have too low TRLs (due to their goals). More recent projects (from the Horizon 2020 programme) had not yet produced relevant technologies at the time of sample collection and were not included as well.

2. As mentioned previously, since the "NMP" funding programmes targeted "Nanotechnologies, Materials, and Production technologies" topics, a further

selection was made to select "Production"-related projects, in order to identify the resulting production technologies only. Accordingly, the previous sets of projects were reduced to 72 FP6-NMP and 80 FP7-NMP projects related to production technologies, thus a total of 152 R&D projects.

3. In these new sets of projects, those which had the participation of EXPLORE project partner organizations or any connection to them were chosen, in order to improve the quality in information collection.

   The 14 EXPLORE partner organizations were located in 11 different and geographically dispersed European countries. Those countries and the specific regions where the EXPLORE partners were located feature diverse socio-economic profiles, namely in terms of indicators such as population, gross domestic product, employment, manufacturing sectors, or innovation performance. From the 14 partners, six were RTOs (43%), four were Universities (29%), two were sectorial associations (14%), one (7%) was a science park, and another (7%) was a governmental regional economic development agency. Their activity covered most of the relevant project topics, as well as a broad spectrum of manufacturing sectors, and they had a vast experience and participation in European-funded R&D projects.

   The close relationship of the EXPLORE partners to those projects allowed a faster identification and more accurate characterization of resulting technologies. The number of projects was at this stage further reduced to 29 FP6-NMP and 28 FP7-NMP, in a total of 57 R&D projects.

4. Considering these sets of projects, the EXPLORE partner who participated in each project reached out to the contacts in charge of the resulting technologies. They were asked if they had technologies with potential for commercial exploitation. This meant that the technologies had to be either (1) not yet commercially exploited, or (2) available for further exploitation in other applications or industrial sectors.
5. A total of 46 technologies (9 from FP6-NMP and 37 from FP7-NMP) were identified and characterized in detail by the contact in charge of each technology, using a specific template prepared by the EXPLORE project consortium. The technologies were derived from 6 FP6-NMP projects and 21 FP7-NMP projects.

B – Bottom-up approach (July – October 2015)

6. Furthermore, the EXPLORE partners were asked to identify more relevant technologies derived from EU-funded R&D projects targeted to Production. This additional round led to the identification and characterization of 15 other technologies (14 FP7-NMP and 1 LIFE+ funding programme).

C – Conclusion (February – April 2016)

7. The information about the 61 technologies (9+37+14+1) was validated (and updated when needed) by the corresponding contact via email or telephone.

The higher number of projects and technologies from FP7-NMP may be explained by two main reasons: (1) the FP6-NMP funding programme was targeting R&D projects with lower TRLs, and therefore with lower exploitation potential; and (2) a longer time had passed since the development of FP6-NMP technologies, which might have led some to become outdated.

The details of the sample can be observed in the Annex.

3.2. Sample description – Exploitation stages

Our objective in this study is to better understand the determinants for commercial exploitation. We, thus, had to define the stage where each technology is at in its path from the lab to the market. Since, to the best of our knowledge, no scale was available in the literature, we therefore propose an *exploitation scale* resulting from our need to organize the technologies according to their position in the exploitation process as well as from the identification of such gap in the literature, previously referred. The scale thus intends to classify the technology commercialization status in its path towards the market and comprises four exploitation stages. Accordingly, we define exploitation stage as the indicator for the progress of the technologies along the exploitation process towards commercialization.

Each stage's name was inspired in literature about commercialization. An initial idea of a 2-stage scale ("Not exploited", or "Exploited") did not reflect the necessary detail of each technology's exploitation efforts and soon evolved to this more complete 4-stage one.

The sample's 61 technologies have been classified according to these four different exploitation stages:

- 1 – No exploitation – nothing has happened with the technology since its development;
- 2 – Demonstration in relevant environment – the technology was demonstrated in an environment from which several conclusions about its performance in a "real" setting or implementation can be extracted ("relevant environments" can be either factory or lab pilot lines);
- 3 – Pre-exploitation – although at this stage there is not yet a product in the market, there is a contract or agreement (e.g., license or purchase) to commercially exploit the technology, which may still require further development;
- 4 – Full exploitation – the technology has become a commercial product, which is either ready to be introduced to the market or is actually being sold.

These four levels allowed a meaningful division among the various exploitation statuses.

3.3. Sample description – Technology

3.3.1. Technological Advantage

The classification proposed by Abernathy and Clark (1985) was adapted for the sample's Technological Advantage attribute, concerning its innovation profile assessment. The scale is the following:

- 1 – Low innovation (merely reinforces existing competences);
- 2 – Little innovation (incremental innovation character);
- 3 – Considerable innovation (significant technological change);
- 4 – High innovation (radical / disruptive innovation character).

The evaluation of the level of innovation for each technology was carried out as a self-evaluation by the owner. Afterwards, considering the technology description, each evaluation score was externally analysed, validated, and changed, if needed, by peers.

3.3.2. Platform Potential

In order to develop an assessment of Platform Potential, we explored a functional perspective (Simpson et al., 2001) via two characteristics: (1) the technology areas, and (2) the industrial sector(s) of application (i.e., markets).

3.3.2.1. Technology Area

Technology areas are broad horizontal themes that can categorize technologies considering their application, independently of, e.g., their industrial market. One technology may focus on one or several technology areas.

Starting from a series of high-level technological themes, a bottom-up approach was carried out to define the technology areas. This was mainly built on the analysis of the challenges and needs in terms of technological innovation for each manufacturing sector in the context of the EXPLORE project. The result was an initial list of 14 technology areas.

Then, a top-down approach was followed with a workshop held with sectorial experts to discuss and evolve those technology areas towards a consensual detailed list. Some items were redefined, others were merged, and new ones were identified, resulting in a second iteration of the list with a total of 18 technology areas.

Afterwards, the technology areas were detailed according to the outcomes of the workshop, and the related research and innovation priorities from the Factories of the Future – Multi-annual roadmap for the contractual PPP under Horizon 2020 (European Commission, 2013).

The direct use of this classification in 18 technology areas would have resulted in an excessive granularity in our analysis, and instead we adopted a simpler classification for each technology as having single or multiple technology areas of focus, depending on whether the technology was originally targeting one or more technology areas, respectively.

3.3.2.2. Application Sector

We also asked the technology owners to identify one or more industrial sectors of application of their technologies, according to the NACE rev. 2 classification (Eurostat, 2008).

Similarly to the technology areas, the direct use of this classification would also have resulted in excessive granularity, and the same classification approach was adopted: each technology was classified as having single or multiple industrial sectors of application.

3.3.2.3. Merging the two classifications

From the two classifications – technological areas and industrial sectors of application – a platform potential classification was derived, as illustrated in Table 1.

Table 1 - Platform Potential classification

Technology Area	Industrial Sector	→	Platform Potential
Single	Single	→	Low
Single	Multiple	→	Medium
Multiple	Single	→	Medium
Multiple	Multiple	→	High

3.3.3. TRL

Our sample collection focused on technologies with some degree of exploitation potential, and consequently technologies with TRL 1 (basic principles observed) and TRL 2 (technology concept formulated) were not considered. Therefore, the selected technologies span from TRLs 3 (experimental proof of concept) to 9 (actual system proven in operational environment) and were classified using the European Commission's TRL scale (2014).

Again, to address excessive granularity, we defined the following three classes, supported by a rational of relatedness among TRLs:

- 1 - TRL 3-4 – lab: comprising TRLs 3 (experimental proof of concept) and 4 (technology validated in lab), thus the stages where technologies are still in the laboratory environment;
- 2 - TRL 5-6 – environment: comprising TRLs 5 (technology validated in industrially relevant environment) and 6 (technology demonstrated in industrially relevant environment), thus the validation and demonstration stages in environments close to real environment, such as pilot lines;
- 3 - TRL 7-9 – exploitation: comprising TRLs 7 (system prototype demonstration in operational environment), 8 (system complete and qualified), and 9 (actual system proven in operational environment – competitive manufacturing), thus comprising the final development stages of complete demonstration and readiness for market introduction.

It is important to distinguish between the official TRL scale and the Exploitation Stages we propose in this work. The former provides the technology's market maturity assessment, i.e., how developed a technology is considering its potential market introduction as a product. The latter is intended to describe the position of a certain technology in the exploitation process, i.e., what kind of efforts have been made to commercialize it in the market. A technology may, e.g., have a low TRL and be fully exploited in the market, or may have a high TRL and not be exploited at all.

3.3.4. IPR

The technology owners were also asked if the technologies had any kind of IPR. In a broad sense, IPR comprises forms such as patents, copyright and related rights, trademarks, trade secrets, industrial designs, and description of inventions (European IPR Helpdesk, 2018). The expected answer was simply "yes", or "no".

3.4. Sample description – Context

3.4.1. Consortium Dimension

The consortia that developed the technologies in our sample have very diverse sizes, ranging from 6 to 49 partners. We have adopted a classification of consortia sizes considering three classes:

- 1 – small (less than or equal to 12 partners);
- 2 – medium (between 13 and 17 partners);
- 3 – large (equal to or more than 18 partners).

This distribution aimed in part at being balanced, in the end including approximately 1/3 of the total number of technologies in each group.

3.4.2. Owner

The owners of the technologies included in our sample can be:

- 1 – Companies (e.g., start-up, SME, large company; technology provider or user);
- 2 – RTOs;
- 3 – Universities (including all higher education institutions).

3.4.3. Innovation context

We considered each technology's country to be the country of location of its owner, and in order to provide a measure of the support available in the corresponding innovation context, we used the Country Innovation Score Label, a classification from the European Innovation Scoreboard (European Commission, 2017). This initiative provides a comparative analysis of innovation performance in EU Member States, other European countries, and regional neighbours, assessing relative strengths and weaknesses of national innovation systems and assisting countries in identifying areas that they need to address. The Country Innovation Score Label is a form of grouping the numerous innovation scores of each country.

In our analysis, we use the scoring from 2014, the year of our first collection of sample information. The category names below are the so-called "Performance Groups", while the values are the thresholds observed in the interactive tool provided by the EU (European Commission, 2017). The Innovation Score groups are:

- 1 – Modest Innovator (<0.25) (not present in this sample);
- 2 – Moderate Innovator (0.25<x<0.47), corresponding to the location of our sample's technology owners in Italy, Portugal, Greece, or Spain (ordered by decreasing innovation score);

- 3 – Strong Innovator (0.47<x<0.63), corresponding to the location of our sample's technology owners in Belgium, United Kingdom, or France (ordered by decreasing innovation score);
- 4 – Innovation Leader (0.63<x<1.0), corresponding to the location of our sample's technology owners in Switzerland, Finland, Denmark, Germany, or The Netherlands (ordered by decreasing innovation score).

3.5. Research methods

3.5.1. Descriptive statistics

First, we compute a variety of classic statistical measures for our sample: (1) the joint sample distributions for the exploitation stage (dependent variable) and each of the independent variables Technological Advantage, IPR, and Innovation Context; and (2) the sample Weighted Averages (WAv) and Weighted Standard Deviations (WSD) of the exploitation stage for each class of the remaining independent variables Platform Potential, Technology Readiness Level, Dimension, and Owner. In doing so, our goal is to present information clearly, in a practical and simple format, depending on whether we wish to highlight trends or proportions, respectively.

3.5.2. Multivariate Analysis

To further investigate the relationship between the independent and dependent variables, we use an Ordered Probit regression (oprobit). The oprobit model is used to estimate relationships between an ordinal dependent variable and a set of independent variables. We also examine the main effect of each independent variable.

The data preparation and all the analysis were carried out using, respectively, the R system for statistical computing, version 3.4.3 x64 (R Development Core Team, 2014) in RStudio, version 1.1.442 (Racine, 2012), and STATA Version 13 (StataCop).

4. Findings

4.1. Descriptive statistics

No technologies at exploitation stage 4 – Full exploitation had been developed in projects which had finished less than three years before we collected our sample (Figure 1). This observation is in line with the typical existence of a significant timespan associated with overcoming the Valley of Death between the end of development and the beginning of commercial exploitation (Markham, 2002). For this reason, in the following analyses we divide the sample into two sub-samples: one with more recently developed technologies, whose projects ended less than three years before we collected the sample (<3y), and the other with technologies with a longer post-development timespan, whose projects ended three or more years before we collected the sample (≥3y).

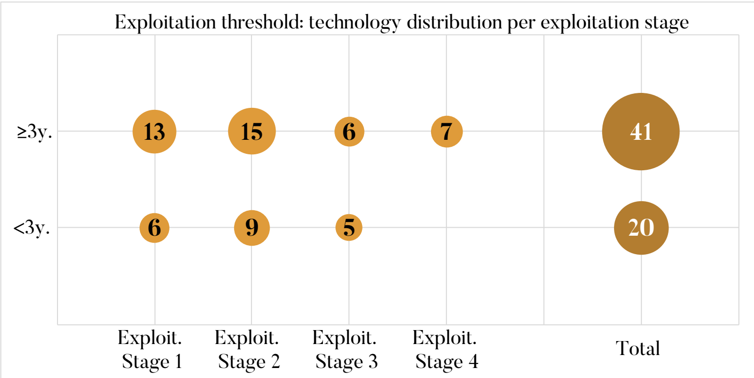

Figure 1 – Exploitation threshold: technology distribution per exploitation stage

As Figure 1 shows, although no recently developed technologies had yet achieved full exploitation, they could be found in all other exploitation stages.

The following sections present descriptive statistics for each of our variables.

4.1.1. Technology

4.1.1.1. Technological Advantage

Overall, according to the distributions presented in Figure 2, technologies evaluated as featuring Considerable Innovation are in general more advanced in terms of exploitation than those evaluated as featuring Little Innovation. This is clearly visible in both sub-samples. In addition, six out of the seven fully exploited technologies belong to the Considerable Innovation category.

No technologies were self-evaluated as having Low Innovation, and only three as having High Innovation. We do not address the latter due to the very small number of cases.

The observed distributions suggest Spanos et al.'s (2015) claim on how novelty affects technology innovation and inimitability (its advantage) in a curvilinear manner, positively at first and then negatively when a development is excessively risky or uncertain. Consequently, in order to increase exploitation opportunities, technology should be considerably innovative (presenting relevant novelty), rather than just slightly innovative (little advantage) or highly innovative (possibly disruptive, thus with greater risk and uncertainty). However, the support of our data to this statement has to be taken with caution given the very reduced number of technologies in the 4 – High Innovation level.

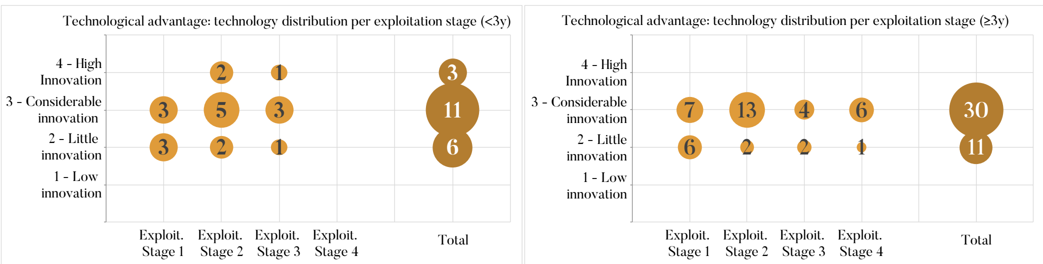

Figure 2 – Technological Advantage: technology distribution per exploitation stage

4.1.1.2. Platform Potential

The data on exploitation stage according to Platform Potential, included in Table 2, are in line with the hypothesis that a high Platform Potential would promote technology exploitation (we naturally exclude from this analysis the technology with low platform potential in the <3y sub-sample). The technologies with higher platform potential are, on average, more advanced in the exploitation scale, and therefore closest to market (Kirchberger and Pohl, 2016).

Table 2 – Platform potential: exploitation stage weighted average and weighted standard deviation

	WAv	WSD	Total
<3y	1.95	0.76	20
1 - low	3.00	0.00	1
2 - medium	1.82	0.75	11
3 - high	2.00	0.76	8
≥3y	2.17	1.07	41
1 - low	1.80	0.84	5
2 - medium	1.94	1.24	16
3 - high	2.45	0.94	20
Total	2.10	0.98	61

4.1.1.3. TRL

Large differences between TRL intervals in terms of average exploitation stage can be observed in our sample (Table 3). The analysis of exploitation stage as a function of TRL interval is in line with the initial observation that more mature, useful, and application-ready technologies are more commercially viable and more easily exploited (Gilsing et al., 2011; Barbola and Corredera, 2009). Consequently, the higher the TRL, the higher the exploitation stage, as can be observed in Table 3, for technologies in both sub-samples.

Table 3 - TRL intervals: exploitation stage weighted average and weighted standard deviation

	WAv	WSD	Total
<3y	1.95	0.76	20
1 - TRL 3-4 - lab	1.50	0.71	2
2 - TRL 5-6 - environment	1.92	0.79	12
3 - TRL 7-9 - exploitation	2.17	0.75	6
≥3y	2.17	1.07	41
1 - TRL 3-4 - lab	1.50	0.52	12
2 - TRL 5-6 - environment	2.00	0.88	19
3 - TRL 7-9 - exploitation	3.30	1.06	10
Total	2.10	0.98	61

4.1.1.4. IPR

We observe in our sample that the number of technologies without IPR is almost twice the number with IPR (40 to 21), and at exploitation stages 1, 2, and 3, the ratio of technologies without IPR to technologies with IPR is approximately constant, which does not support Link and Scott (2013), when the authors note that IP protection is endogenous to the evolution of R&D projects.

Focusing on the ≥3y sub-sample, the percentage of fully-exploited technologies within technologies with IPR (20%) is larger than within technologies without IPR (15%). This observation is in line with the claims of Link and Scott (2013), and Rothaermel et al. (2007), regarding the commercial success of IPR-protected research.

Figure 3 shows the joint distribution of IPR and exploitation stage.

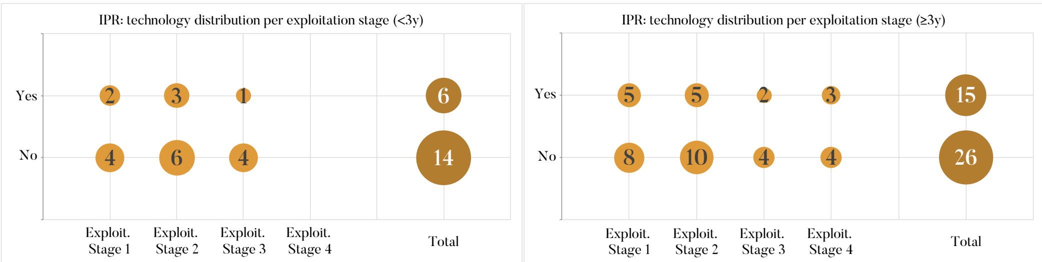

Figure 3 – IPR: technology distribution per exploitation stage

4.1.2. Context

4.1.2.1. Consortium Dimension

When considering the ≥3y sub-sample, the larger the consortia size, the higher is the average technology exploitation stage (Table 4). This fact is in line with the argument by Spanos et al. (2015) that large consortia are more likely to develop successful technologies, but somewhat contradicts the claim by Arroyabe et al. (2015) that a low number of partners in R&D projects is key to technology exploitation, since a large number of partners may increase the possibility of opportunistic behaviours. However, given the small differences between the WAvs, this assumption should be considered prudently. In the <3y sub-sample, the WAv does not increase from small to medium consortia (only one large consortium is present in this sub-sample).

Although it is not reasonable to suppose that an ever-increasing number of partners is the key to more successful exploitation, it may be logical to expect medium to large consortia to be better able to accommodate different types of partners with diverse R&D capabilities and position in the innovation value chain, than small consortia, and thus better support exploitation success. On the other hand, small consortia may be more efficient for some particular cases, such as the development of specific niche solutions with defined targets and applications. In any case, functional diversity leads to a variety of knowledge intake and synergetic effects necessary to develop and commercialize novel products (Beers and Zand, 2014).

Table 4 – Consortia sizes: exploitation stage weighted average and weighted standard deviation

	WAv	WSD	Total
<3y	1.95	0.76	20
1 - small	2.00	0.89	11
2 - medium	2.00	0.53	8
3 - large	1.00	0.00	1
≥3y	2.17	1.07	41
1 - small	2.00	1.18	11
2 - medium	2.17	1.11	12
3 - large	2.28	1.02	18
Total	2.10	0.98	61

4.1.2.2. Owner

Technologies in the <3y sub-sample and owned by RTOs are more advanced in the exploitation process than those belonging to Universities (only one company is present in this sub-sample).

However, when considering the ≥3y sub-sample, the picture is considerably different: technologies owned by Companies are the most advanced in the exploitation scale (highest WAv) possibly due to the embedness of Companies in the market, then Universities have, somewhat surprisingly, the second largest WAv, well in the second half of the exploitation scale, thus closer to commercialization, and finally RTOs with technologies less advanced in the exploitation process (with a WAv actually lower than in the <3y sub-sample).

When technologies are still young, RTOs likely play a role in advancing them in the exploitation process so they can later be more easily transferred to industry. This way, RTOs fulfil their interface role in the R&D value chain (Albors-Garrigós et al., 2014). A potential explanation for the lower value for the WAv in the ≥3y sub-sample could be a successful early transfer of technologies to industry, leading to a higher proportion of technologies at earlier stages of exploitation remaining in the portfolios of RTOs.

It is apparent that Universities are more challenged in exploiting their younger technologies, but later their technologies achieve relevant exploitation, even if they are early-stage, embryonic technologies (Colyvas et al., 2002). Universities may exploit them most likely as part of their third mission and as an additional source of funding for their R&D activities, e.g., in markets for technology (Arora et al., 2001), thus still in their emerging stages and far from high TRLs (Kirchberger and Pohl, 2016; Colyvas et al., 2002).

Table 5 – Owner organisation type: exploitation stage weighted average and weighted standard deviation

	WAv	WSD	Total
<3y	1.95	0.76	20
1 - Company	1.00	0.00	1
2 - RTO	2.13	0.74	15
3 - University	1.50	0.58	4
≥3y	2.17	1.07	41
1 - Company	2.57	0.00	7
2 - RTO	1.86	1.13	22
3 - University	2.50	0.80	12
Total	2.10	0.98	61

4.1.2.3. Innovation Context

The more recently developed technologies feature similar exploitation stage patterns for both Moderate Innovator and Innovation Leader countries (Figure 4), suggesting that the innovation performance of the technology owner's country does not have an influence on their exploitation stage.

For the technologies with a longer post-development timespan (Figure 4), it can be observed that owners in Moderate Innovator countries have achieved full exploitation for three out of 26 technologies (12%), whereas owners in Innovation Leader countries have achieved a higher rate of full exploitation, of four out of 13 technologies (31%). Moderate Innovator countries have more technologies at lower exploitation stages than Innovation Leaders, which suggests the presence of more challenges in converting R&D into economic value.

We do not address the results for Strong Innovator countries due to the presence of only four related cases in our sample.

The observed behaviours may be associated with the technology owners' broader national innovation contexts, including aspects such as innovation-supportive public policies, available public and private funding, R&D and technological capabilities, industrial structure, among others, as highlighted by Rasmussen (2008) and Furman et al. (2002), or the successful adaption of technologies to local (innovative, mature, and competitive) requirements such as technical standards, market regulations, and customer preferences (Beers and Zand, 2014).

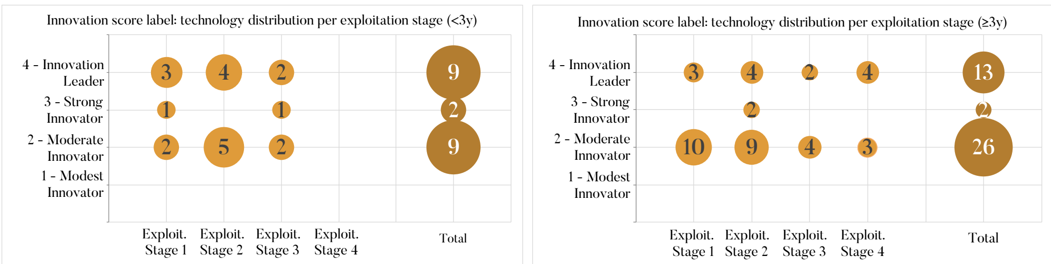

Figure 4 – Technologies distribution per exploitation stage and country innovation score label

4.2. Multivariate analysis

Our first analysis focused on the main effects of the variables (Table 6). The association with exploitation was found to be individually significant for: Technological Advantage – in line with Kirchberger and Pohl (2016), Jung et al. (2015), and Spanos et al. (2015); TRL – agreeing with Jung et al. (2015), Gilsing et al. (2011), and Astebro (2003); Owner – supporting Kirchberger and Pohl (2016), and Von Raesfel et al. (2012); and Innovation Context – similarly to Jung et al. (2015), Rasmussen (2008), Colyvas et al. (2002), Furman et al. (2002), and Chiesa and Piccaluga (2000).

It was not found to be significant for: Platform Potential – differently from Kirchberger and Pohl (2016); IPR – unlike Kirchberger and Pohl (2016), and Rothaermel et al. (2007); and (Consortium) Dimension – unlike Kirchberger and Pohl (2016), Arroyabe et al. (2015), Spanos et al. (2015), and Clarysse et al. (2009).

Table 6 – Variables' main effect

	df	chi2	P>chi2
Technology_Advantage	2	6.60	0.037**
Platform_Potential	2	3.35	0.187
TRL	2	5.16	0.000***
Consortium_Dimension	2	1.91	0.385
Owner	2	6.01	0.050**
Innovation_Context	2	8.54	0.014**

* - low significance level: <10%
** - significance level: <5%
*** - high significance level: <1%
Note: IPR's main effect (non-significant) is given in Table 7 since it is a 2-level variable

We then tested and analysed the results of each transition level of each independent variable (Table 7 and Table 8), as described next.

In addition to being significant overall, Technology Advantage shows significant differences between the "Little innovation" level and the two higher levels, "Considerable innovation" and "High innovation". The difference between levels "Considerable innovation" and "High innovation" was not found to be significant. According to these results, in order to achieve fuller exploitation, technologies do need to feature more than just a small advantage, with novelty affecting technology innovation and inimitability, at least positively at first (Spanos et al., 2015). As mentioned previously, our sample has only three cases characterized as "High innovation", which hampers comparative analysis possibilities, in particular regarding the impact of excessively risky or uncertain developments (associated with the highest level of technological advantage) on exploitation.

In addition to also being significant overall, TRL features significant differences between all levels. This is in line with the initial observation based on descriptive statistics, confirming that the TRL (proximity to market) is positively associated with exploitation success.

Table 7 - oprobit results for each transition level of each independent variable

	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Technology_Advantage						
[2 - Little innovation as reference]						
3 - Considerable innovation	0.932	0.423	2.20	0.028**	0.102	1.761
4 - High innovation	1.797	0.828	2.17	0.030**	0.173	3.421
Platform_Potential						
[1 - low as reference]						
2 - medium	-0.974	0.559	-1.74	0.082*	-2.070	0.122
3 - high	-0.629	0.634	-0.99	0.321	-1.871	0.612
TRL						
[TRL34 - lab as reference]						
TRL56 - environment	1.214	0.450	2.70	0.007**	0.331	2.096
TRL79 - exploitation	2.854	0.578	4.94	0.000***	1.721	3.988
IPR						
[no as reference]						
yes	0.051	0.366	0.14	0.889	-0.666	0.768
Consortium Dimension						
[1 - small as reference]						
2 - medium	0.029	0.400	0.07	0.942	-0.755	0.813
3 - large	0.598	0.475	1.26	0.208	-0.333	1.528
Owner						
[Company as reference]						
RTO	-1.345	0.553	-2.43	0.015**	-2.429	-0.261
University	-0.804	0.541	-1.49	0.137	-1.864	0.256
Innovation_Context						
[4 - Innovation Leader as reference]						
2 - Moderate Innovator	-1.037	0.406	-2.56	0.011**	-1.832	-0.242
3 - Strong Innovator	-1.746	0.732	-2.39	0.017**	-3.181	-0.312
/cut1	-0.928	0.897			-2.686	0.830
/cut2	0.578	0.899			-1.185	2.340
/cut3	1.620	0.911			-0.166	3.406

* - low significance level: <10%
** - significance level: <5%
*** - high significance level: <1%

Although the descriptive statistics suggested a positive association with Platform Potential, the effect was not found to be overall significant. The association with IPR was also not found to be significant, but in this case in line with the preceding descriptive statistics analysis.

Table 8 – Other tests for each transition level of each independent variable

	df	chi2	P>chi2
Technological Advantage 3 - Considerable innovation ↔ 4 - High innovation	1	1.36	0.244
Platform Potential 2 - medium ↔ 3 - high	1	0.72	0.397
TRL TRL56 ↔ TRL79	1	4.66	0.000
Consortium Dimension 2 - medium ↔ 3 - large	1	1.53	0.216
Owner RTO ↔ University	1	1.64	0.201
Innovation Context 2 - Moderate Innovator ↔ 3 - Strong Innovator	1	1.14	0.286

Consortium Dimension was not found to have a significant association with exploitation success, and no significant differences between its levels were found either, also in line with the analysis of the descriptive statistics. Although ownership was overall found to be significant, only the difference between the "RTO" and "Company" levels was found to be significant. The stronger focus of companies on exploitation would naturally suggest expecting this kind of result. The small numbers of "Company" and "University" owned technologies in our sample may justify the fact that the difference between these two levels was not found to be significant.

In line with the analysis of the descriptive statistics, Innovation Context was found to be overall significant, and significant differences were found between the highest level, "Innovation Leader", and the other two levels, "Strong Innovator" and "Moderate Innovator". This confirms the previously outlined arguments that owners located in Innovation Leader countries are more effective in the exploitation of their technologies.

5. Discussion and implications

In this study we have analysed a sample of 61 technologies resulting from European R&D projects during FP6 and FP7 in the area of manufacturing technologies, looking for determinants for successful technology exploitation.

Although R&D European projects must in general include exploitation plans, most technologies do not achieve any type of commercial exploitation during the project or even in the valley of death lasting at least three years after the R&D project ends, although they may reach any of the first three exploitation stages. European policy and funding instruments should better recognize the nature of the commercialization process, and on the one hand adjust expectations regarding what can and cannot be achieved during R&D projects, as well as provide more suitable support to commercialization in the Valley of Death phase, along the lines, e.g., of NSF's portfolio of Innovation Corps, SBIR and STTR programmes.

Technological Advantage is one of the determinants for which we found a significant association with exploitation, our analysis showing that technologies must in general feature more than marginal innovation to reach higher exploitation stages, and full exploitation in particular. The level of application- and market-readiness also features a significant association with exploitation, a fact that may be related with the timespan required for exploitation, as technologies that are developed with lower TRLs will typically require that some organizations (usually project participants such as technology provider companies or RTOs in partnership with technology provider companies) take the technology and further develop it towards higher application- and market-readiness, a long, costly, and risky process. Consequently, policy making should redesign and reinforce funding to projects developed upon previous R&D results, increasing their application- and market-readiness.

The conspicuous absence from our sample of full exploitation for lower TRLs hints at the thinness of markets for technology in Europe. Policy intervention would therefore be critical to address failures in this market, possibly across the whole set of relevant players in the market, such as universities.

Although prior literature has identified platform potential and IPR as favouring exploitation, these effects were not significantly visible in our analysis. This is an important result from our work, as it raises the hypotheses that the consortia may not be creating these attributes appropriately or may not be leveraging them appropriately for commercialization, thus revealing potentially important aspects for policy and managerial improvements.

The same happens with the consortium dimension, with the benefits of large consortia, i.e., access to a fuller set of required capabilities and value chain complementarity, even if at the risk of opportunistic behaviours from some partners, not materializing in improved exploitation outcomes.

In turn, company ownership tends to be positively associated with exploitation, with an effect that is significant in the comparison with RTOs, and almost significant with universities (which may be due to the small sample size for both companies and universities). This reinforces the argument presented above on the attention that the market for technologies critically requires in Europe from policy makers.

Finally, innovation context support, as measured by the innovation score of the technology owner's country, is also positively associated with exploitation, with Innovation Leader countries featuring a higher concentration of technologies at higher exploitation stages. The strengthening of innovation contexts in Moderate or even Strong Innovator countries needs to continue to be a policy priority.

Our findings also have managerial implications for companies, RTOs, and universities participating in European R&D projects and concerned with commercialization. In particular, there seems to be significant heterogeneity of managerial practices, as revealed, e.g., by the non-significance of platform potential, IPR and consortium dimension to commercialization, suggesting that these players should seek to identify and adopt best practices. Our other findings also directly suggest other managerial implications.

6. Limitations and future research

One limitation of our work is the fact that our sample is not perfectly random, as a result of the characteristics of the data collection process. Nevertheless, our assessment of potential biases provides confidence in the robustness of the findings. In addition, the study was restricted to technologies resulting from R&D projects funded by the European Union during FP6 and FP7 in the area "Nanotechnologies, Materials, and Production technologies" and the specific topic "Production", and the results may not be generalizable to other areas.

The possibilities for future research in this area are broad and we believe can help support improved decisions concerning the context of European-funded R&D projects. Our study can, e.g., be further developed in a wider and deeper sample to enable generalization of results. This may include other R&D areas and topics such as nanotechnology, advanced materials, or biotechnology. In addition, a longitudinal study would be of interest to better understand the progress of technologies throughout the exploitation process. Finally, it would also be worthwhile analysing a new, similar sample of technologies resulting from Horizon 2020 projects. This would allow comparisons between the exploitation behaviour of technologies developed within FP6/FP7 and developed within Horizon 2020, as a complementary means to evaluating the impact of more recent policies to support technology exploitation.

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Annex

Table 9 – Sample technologies and variables

#	Technology Name	Exploitation Stage (1..4)	Years since project finished	Technology Advantage	Platform Potential	TRL interval	IPR	Dimension	Owner	Innovation Context
1	A Novel Coaxially Laser-Assisted (COLA) Cold Spray System	1 - No exploitation	<3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	1 - small	RTO	3 - Strong Innovator
2	Accurate robot positioning for robotic drilling through stiffness compensation and sensor based compensation	3 - Pre-exploitation	≥3y	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	2 - medium	RTO	4 - Innovation Leader
3	AIV - Internal chip extraction system	1 - No exploitation	≥3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	1 - small	RTO	2 - Moderate Innovator
4	Assembly Product and Process Template Selector and Tracker	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	1 - low	1 - TRL 3-4 - lab	yes	3 - large	University	2 - Moderate Innovator
5	Business Intelligence and Analytics for Manufacturing and Retail	1 - No exploitation	≥3y	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	2 - medium	RTO	2 - Moderate Innovator
6	CableBOT- Parallel Cable Robotics for Improving Maintenance and Logistics of Large-Scale Products	3 - Pre-exploitation	<3y	4 - High innovation	3 - high	2 - TRL 5-6 - environmen	yes	1 - small	RTO	2 - Moderate Innovator
7	Change Propagation Manager	1 - No exploitation	≥3y	2 - Little innovation	2 - medium	1 - TRL 3-4 - lab	no	2 - medium	RTO	4 - Innovation Leader
8	CODICE toolkits	1 - No exploitation	≥3y	3 - Considerable innovation	1 - low	2 - TRL 5-6 - environmen	yes	1 - small	RTO	2 - Moderate Innovator
9	Collaboration infrastructure for managing business networks	1 - No exploitation	≥3y	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	RTO	2 - Moderate Innovator
10	Conceptual off site industrialization process for FRP transport infrastructures	1 - No exploitation	≥3y	2 - Little innovation	2 - medium	1 - TRL 3-4 - lab	no	3 - large	RTO	4 - Innovation Leader
11	Cooperative Robot for stud welding operation in shipbuilding.	1 - No exploitation	<3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	RTO	2 - Moderate Innovator
12	DIGIMET	2 - Demonstration in relevant environment	<3y	4 - High innovation	2 - medium	2 - TRL 5-6 - environmen	yes	2 - medium	RTO	2 - Moderate Innovator
13	Dynamic Job Rotation Tool	3 - Pre-exploitation	≥3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	3 - large	University	2 - Moderate Innovator
14	EMF concept on roll formed parts	1 - No exploitation	≥3y	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	yes	3 - large	RTO	2 - Moderate Innovator
15	ENEMAC Simulator - energy simulation of machine tools	2 - Demonstration in relevant environment	<3y	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	no	2 - medium	RTO	2 - Moderate Innovator
16	Factory Layout Planner (FLP)	4 - Full exploitation	≥3y	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	3 - large	University	4 - Innovation Leader
17	Factory Simulation Libraries	4 - Full exploitation	≥3y	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	3 - large	Company	2 - Moderate Innovator
18	Flexible Robotic Fixtureless Assembly of Multi Functional Material-based products	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	no	3 - large	University	2 - Moderate Innovator
19	Formal digital representation language(s) of production modules and concept for usage.	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	yes	2 - medium	University	4 - Innovation Leader
20	Hydrogel waveguide sensor	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	yes	2 - medium	RTO	2 - Moderate Innovator
21	idkBLUE - Portable multichannel Machine-Tool oriented energy consumption monitoring system	2 - Demonstration in relevant environment	<3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	2 - medium	RTO	2 - Moderate Innovator
22	Improved laser sintering process for aluminium	4 - Full exploitation	≥3y	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	2 - medium	RTO	4 - Innovation Leader
23	Inductive infrared thermography on metallic component	3 - Pre-exploitation	<3y	3 - Considerable innovation	1 - low	2 - TRL 5-6 - environmen	no	1 - small	RTO	3 - Strong Innovator
24	Integrated safe@sea PPE system for fishermen	3 - Pre-exploitation	≥3y	2 - Little innovation	1 - low	3 - TRL 7-9 - exploitation	yes	2 - medium	RTO	2 - Moderate Innovator
25	Integrated tool for plant configuration, simulation and performance visualization	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	yes	3 - large	RTO	2 - Moderate Innovator
26	iRAMP3 - Inelligent Reconfigurable Machines for Smart Plug&Produce Production	1 - No exploitation	<3y	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	Company	2 - Moderate Innovator
27	IT-Integration of cloud-managed Dynamic Manufacturing Networks	3 - Pre-exploitation	<3y	2 - Little innovation	3 - high	3 - TRL 7-9 - exploitation	no	1 - small	RTO	4 - Innovation Leader
28	Knowledge Association Engine	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	3 - large	University	2 - Moderate Innovator
29	Knowledge Repository	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	3 - large	University	2 - Moderate Innovator
30	Laser cutting monitoring systems	4 - Full exploitation	≥3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	1 - small	RTO	2 - Moderate Innovator
31	Last milling machine for footwear rapid customized production/prototyping	1 - No exploitation	≥3y	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	RTO	2 - Moderate Innovator
32	LeanPPD Model	1 - No exploitation	≥3y	2 - Little innovation	1 - low	2 - TRL 5-6 - environmen	yes	1 - small	RTO	2 - Moderate Innovator
33	LeanPPD Transformation Toolkit (Lean T2)	4 - Full exploitation	≥3y	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	yes	1 - small	Company	4 - Innovation Leader
34	Local application of hydrophobic and/or hydrophilic coatings on polymer surfaces	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	yes	3 - large	RTO	4 - Innovation Leader
35	Manufacturing Service Management and Execution	2 - Demonstration in relevant environment	<3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	RTO	4 - Innovation Leader
36	Manufacturing Systems Ontology	2 - Demonstration in r	≥3y	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	3 - large	University	2 - Moderate Innovator
37	Metal 3D printing and flexible post processing	2 - Demonstration in relevant environment	<3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	RTO	4 - Innovation Leader
38	Multipurpose machine for laser cutting, marking and engraving of leather products	1 - No exploitation	≥3y	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	2 - medium	RTO	2 - Moderate Innovator
39	MYWEAR LCA tools	1 - No exploitation	<3y	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	University	4 - Innovation Leader
40	MyWear Smart integrated services	2 - Demonstration in relevant environment	<3y	2 - Little innovation	3 - high	1 - TRL 3-4 - lab	no	1 - small	University	4 - Innovation Leader
41	Nanoreinforced resins for EMF coils	1 - No exploitation	≥3y	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	yes	3 - large	RTO	2 - Moderate Innovator
42	Network part program - Network-part-program-based software tools for the generation and the on-line management of alternative process plans	3 - Pre-exploitation	<3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	2 - medium	RTO	2 - Moderate Innovator
43	New design methodology: Copy part properties	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	2 - medium	Company	4 - Innovation Leader
44	New polymer for laser sintering	1 - No exploitation	≥3y	2 - Little innovation	3 - high	1 - TRL 3-4 - lab	no	2 - medium	Company	4 - Innovation Leader
45	Next generation milking robot parlour	3 - Pre-exploitation	<3y	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	RTO	4 - Innovation Leader
46	One Step Production Process	4 - Full exploitation	≥3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	2 - medium	RTO	2 - Moderate Innovator
47	Performance Measurement Toolkit	3 - Pre-exploitation	≥3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	3 - large	RTO	2 - Moderate Innovator
48	PLASMAPOUR	2 - Demonstration in relevant environment	<3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	2 - medium	RTO	2 - Moderate Innovator
49	Platform for interoperability of digital factory tools	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	1 - low	2 - TRL 5-6 - environmen	no	3 - large	RTO	2 - Moderate Innovator
50	PPIs (Production Performance Indicators) Structure and Definition	2 - Demonstration in relevant environment	<3y	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	2 - medium	University	2 - Moderate Innovator
51	Production metrology for micro/sub-micro scale features of polymer components and surfaces	4 - Full exploitation	≥3y	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	3 - large	University	4 - Innovation Leader
52	Production process for structured current collector foils for battery cells	1 - No exploitation	<3y	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	yes	2 - medium	RTO	4 - Innovation Leader
53	Rapid design toolbox for scanning and gathering non-existing or broken parts in 3D-CAD	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	2 - medium	Company	3 - Strong Innovator
54	S-MC-S assessment model	3 - Pre-exploitation	≥3y	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	University	4 - Innovation Leader
55	S-MC-S Customized diamond wire technology	2 - Demonstration in relevant environment	≥3y	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	Company	2 - Moderate Innovator
56	S-MC-S Design tools for supply chain	2 - Demonstration in relevant environment	≥3y	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	University	4 - Innovation Leader
57	Solvent free Dry-blend application of functional materials on current collectors for Li-batteries for E-mobility	2 - Demonstration in relevant environment	<3y	4 - High innovation	3 - high	2 - TRL 5-6 - environmen	no	2 - medium	RTO	4 - Innovation Leader
58	Surface modification of nanopatterns for local selectivity	1 - No exploitation	≥3y	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	yes	3 - large	RTO	2 - Moderate Innovator
59	Test pattern for laser galvo scanner performance analysis	1 - No exploitation	<3y	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	yes	3 - large	University	4 - Innovation Leader
60	Virtual reality industrial safety tool	3 - Pre-exploitation	≥3y	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	3 - large	Company	2 - Moderate Innovator
61	VIWET- Value Identification and Waste Elimination Tool (IT tool)	2 - Demonstration in relevant environment	≥3y	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	1 - small	University	3 - Strong Innovator

EXPLORE

SEVENTH FRAMEWORK PROGRAMME

Exploitable R&D Result analysis template

1 – Result description (Public information to publicize)
Basic info
1. Name of R&D result
2. Main objective
3. Short Description
4. Owner of result
5. Responsible
6. Keywords
•
Innovation
1. Benefits for user
2. Innovation brief description
Main innovation and advantages in relation with the state of the art
3. Innovation evaluation
Please evaluate in the scale 1 to 4 ☐ *1 – Low innovation (merely reinforces existing competences)* ☐ *2 – Little innovation (incremental innovation character)* ☐ *3 – Considerable innovation (significant technological change)* ☐ *4 – High innovation (radical / disruptive innovation character)*
4. Market evaluation
Please evaluate in the scale 1 to 4 ☐ *1 – Mature market* ☐ *2 – Growth market* ☐ *3 – Developing market* ☐ *4 – New market*
5. Risks and limitations
6. Innovation domain(s)
•

1

Figure 5 - Template for sample collection during the EXPLORE project

7. Technology readiness Level (TRL)
Exploitation
1. Industrial sector(s) of application
•
2. Other potential sectors of application
•
3. Patent(s) / Licenses / Copyrights …
4. What is being searched? (new applications, buyer, take-up, licensing, further development, …?)
•
Dissemination and demonstration
1. Dissemination activities of result
• Dissemination at result level: scientific papers and conference presentations *(title, authors, publication/event, location, year)*   • Dissemination at project level: booklet, poster, international fairs, conferences, press releases, press articles, website
2. Demonstration activities of result (including reference installations)
3. Photos and Videos
4. Other materials
Project
1. Project acronym
2. Project title
3. Project date start and date finish
4. Finished Project? (yes/no)
5. Project short description
6. Project website
Obs./other

2

Figure 5 – Template for sample collection during the EXPLORE project (cont.'d)

4.

Technology and Context Patterns in European-funded R&D projects in manufacturing: a clustering analysis

Technology and Context Patterns in European-funded R&D projects in manufacturing: a clustering analysis

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Abstract

Innovation is regarded as a means to economic growth. The European Union (EU) has been focusing its efforts in large Framework Programmes (FPs) which aim at enabling organizations to improve their research and development in order to create value from new technologies. Both industrial and research organizations collaborate in consortia to complement their capabilities and develop more sophisticated and innovative technologies able to respond to new global challenges.

The characteristics from resulting technologies can be clustered in patterns sharing similar characteristics but also presenting relevant differences. However, these are often disregarded by policy making and funding instruments leading to a possible lack of focus and effectiveness. Our main goal with this work is to identify and analyse such patterns, expecting to contribute to public policy improvement. We collected and study a sample of 61 FP technologies resulting from European-funded R&D projects. Applying a hierarchical cluster analysis, we identify five clusters and corresponding patterns. Many characteristics are common among the clusters, which is relevant by itself given the degrees of freedom provided by FP calls. We also point out specific differences, that combined with the identified patterns aim to provide relevant insights for policy and management. It is apparent that in more innovative geographies there is a more balanced proportion between little and considerable advantage technologies. Also, both market readiness and application breadth are different depending on the technology's intellectual

property rights. On the other hand, in less innovative contexts, technologies seem to present rather medium advantages, mostly being owned by research organizations which may seek intellectual property protection.

Taking this identified diversity of situations into account, funding instruments may be better developed to be more focused and effective, increasing the impact and value-creation from the investment carried out both by the public and private sectors.

Keywords

Innovation; Strategy; Public Policy; European Union; Framework Programme; R&D Policy; Technology Exploitation; Technology Commercialization; Exploitation Scale; Funding Instruments; Hierarchical Clustering Analysis; Manufacturing Industry.

1. Introduction and overview

The EU has been strongly investing in R&D in order to be at the forefront of global innovation and overcome its competitors. With that aim, the EU created the FPs which have promoted collaboration, traditionally concentrating more on programmes and projects that strengthen the European research system as a whole instead of near market projects (European Commission, 2009). A solid and broad foundation of knowledge-based innovation can be achieved through collaborative R&D among countries, regions, and organizations.

The FP of Research and Technological Development is the main policy instrument for supporting Research and Technological Development at EU level. It is probably the largest competitive R&D programme in the world, funding a significant volume of research and innovation (Bach et al., 2014). The FPs comprise a very wide range of research thematic areas each with specific topics further detailed in corresponding calls for projects. The complex nature of such programmes is obvious, where so diverse organizations cooperate – and compete – among themselves.

This is the R&D environment where companies, research institutes, and universities collaborate in diverse consortia combinations. The different kinds of partners participate in these consortia for different reasons and achieving different goals, but, in order to work together, they must find common ground, frequently precompetitive research that can later be developed and taken to the market (European Commission, 2009). Collaboration between research and industry is seen as one approach to drive innovation by facilitating the flow and utilization of technology-related knowledge and experience across sectors (e.g. Ankrah and Tabbaa, 2015). Nevertheless, since most funding instruments at European level seem to be too general concerning e.g. participants and innovation contexts, it is plausible that a higher level of focus and specialization could enable more effective application of public and private investment in R&D. It is acknowledged that policy may need a reconfiguration and reorientation, thus having to develop specific incentives and mechanisms that foster links between knowledge and business ecosystems (Clarysse et al., 2014).

Consequently, improved understanding about R&D dynamics is necessary to support policy-making recommendations towards the design of more specific funding instruments that can create more value and positive impact. It is, furthermore, recognized that research should focus on the importance of conditions in consortia formation as well as technological aspects. Namely, information about R&D cooperation depending e.g. on the type and number of partners can be gained and implications for public policies drawn (Duysters and Lokshin, 2011; Becker and Dietz, 2004) and further research was also found to be needed about technical variables (Astebro, 2004).

The present exploratory work aims to better understand the relationship between inter-organizational arrangements and R&D outcomes by identifying and analysing the technology and context patterns, while closing literature gaps. From that analysis, it may be possible to assess similarities and differences that may ultimately lead to a (re)design of public policies towards improved funding instruments. This work identifies and analyses those technological and consortia patterns in collaborative EU-funded R&D projects, focused on (late) FP6 and FP7 finished projects, in the thematic area of new Production Technologies. In order to do so, the remainder of this article is organized as follows: chapter 2 reviews the literature, chapter 3 presents the research context and methods, chapter 4 shows the findings, chapter 5 discusses the results and draws implications from this research, while the final chapter 6 refers limitations and suggests future research.

2. Literature review

2.1. European-funded R&D programmes

The increasing dynamic of technical progress, the growing complexity of technology and the expanding stress of competition and costs underline the necessity to collaborate in R&D (Becker and Dietz, 2004). Collaboration in R&D complements internal resources during the innovation process, thus enhancing firms' R&D intensity and boosting the effort of developing new products. R&D partnerships have been thoroughly analysed as organisational answers to the requirements of innovation-based competition and rapid technological change (Miotti and Sachwald, 2003).

Publicly financed R&D programmes seek to support projects that otherwise would not be carried out by the private sector due to their high risk and the complexity associated with the research. The European Union (EU) promotes technological R&D mainly through its broad Framework Programmes (FPs) of Research and Technological Development. In fact, at the EU level, there is broad evidence from a large number of evaluation studies that FPs play a significant role in the European R&D landscape (Spanos et al., 2015).

The fundamentals for their structure are supported in research evidence in order to optimize effort and improve results from R&D. The structuring work is carried out with numerous key stakeholders in Advisory Groups (European Commission, 2015; Arnold, 2012) from industry and academia. They define the R&D roadmaps to address industries' following challenges and needs. This public support provides coordination and promotes competition within these areas (Arnold, 2012). For several areas and themes, public-private partnerships (PPPs) between the European Commission and both industries and research were created in order to simplify and focus the consultation and decision processes, towards more efficient and valuable R&D.

In their work, Bach et al. (2014) point out that a policy of simple and stable funding instruments should be followed within EU FPs. The general characteristics of projects (subsidy, collaboration/partners, networking, information sharing, and rigidity of design/proposal) have a greater impact on the selection of calls to which participants apply to than the specific characteristics of each instrument. Moreover, keeping the instruments simple and stable over time should also save on the administrative high costs.

Developing a joint R&D project implies both a technological process and an organizational structure to support it. This set of partners (companies, research centres, universities and others) participate in such R&D process through a series of stages (identification of needs, technological description, and so on), carry out technological activities (basic or applied research, prototype, etc.) to achieve their goals (patents, new products, training, etc.) (Arranz and Arroyabe, 2006).

Most of the research calls for proposals specify the basics for the consortia formation and usually follow the general Rules of Participation (European Commission, 2006). In FP7, these require consortia to have at least 3 partners from 3 different member states (or associated countries). The specific partner types or countries are not mentioned. However, in specific funding such as the SME Instrument, a further level of detail concerning the participants is provided. Here, consortia must have at least 3 Small or Medium Enterprises (SMEs) and 2 RTOs, also from at least 3 different countries.

An EU study (European Commission, 2009) shows that FP participants are generally characterized by: (1) R&D intensities that are above the average of their sector of principal activity; (2) being significantly more networked with clients and universities than average; (3) being significantly more oriented towards international markets than average; and (4) a patenting activity significantly higher than average.

In addition, each call for proposal explicitly details its project goals in terms of theme, concept, and sometimes, specific deliverables or results. In addition, broad technological characteristics were also provided, as the Technology Readiness

Level (TRL) (specific or interval), or Intellectual Property Rights (IPR) protection. FP6 and earlier FP7 calls aimed to low TRLs, until 3-4, whereas later FP7 calls aimed to medium TRLs, namely 5-6, already comprising technology demonstration. Usually calls did not oblige consortia to protect IPR (very few exceptions considered).

The EU study cited above (European Commission, 2009) shows that FP projects are, on average, characterised by: (1) lower commercial risk; (2) longer term R&D horizon; (3) more interest in 'peripheral' technologies outside the core technologies of participants; (4) focus on exploration (rather than exploitation) strategies; (5) lower degree of flexibility; (6) higher administrative burden.

2.2. The interplay of technologies and context in collaborative R&D

As summarized by Becker and Dietz (2004), the benefits of R&D cooperation mainly are: joint financing of R&D; reducing uncertainty; realizing cost-savings; and realizing economies of scale and scope. According to these authors' review, the disadvantages of joint R&D are mainly caused by transaction costs especially for coordinating, managing, and controlling the activities of the different parties involved. Transaction costs are mostly related to the following topics: coordinating distinct organizational routines, styles, etc.; combining complementary assets, resources, etc.; fixing transfer prices of intangible goods, for example information or know-how; regulating the exploitation (appropriation) of the results (rates of return) of joint R&D.

Joint R&D projects are carried out in consortia with a diverse set of partners which leads to learning opportunities with regard to both cooperation and innovation skills and is therefore expected to improve organizations' innovation performance. Their complementarities between knowledge and resources from multiple areas of expertise and application domains are necessary for successful development and introduction of innovations (Beers and Zand, 2014). The selection of R&D partners depends on the type of complementary resources organizations need to access, which, in turn, depends on their skills and expertise (Miotti and Sachwald, 2003).

Complementarities arise as different types of partners provide diverse types of knowledge and technological opportunities. They collectively contribute to the effort and the probability to successfully develop and commercialize innovations (Belderbos et al., 2006). Nevertheless, Paier and Scherngell (2011) and Scherngell and Barber (2009) concluded that R&D collaborations occur most often between organizations that are located close to each other in technological space, even if with diverse skills.

Consortia usually need a mix of heterogeneous parties in R&D cooperation which releases synergies and enhances research productivity (Becker and Dietz, 2004). Therefore, a significantly positive contribution from partner diversity to innovation performance is expected, which is stronger for radical as compared with incremental innovations. A diverse portfolio of R&D partners provides access to a broad range of experiences, technological knowledge, market information, intellectual property rights management, and other complementarity skills (Duysters and Lokshin, 2011).

Each type of partner has different resources and capabilities and exhibits different kinds of behaviour in R&D partnership. These differences affect the profitability and the efficiency of R&D collaboration; thus, the effect of R&D collaboration on product innovation varies depending on partner types (Beers and Zand, 2014; Kang and Kang, 2010). Beers and Zand (2014) point out that manufacturing and high-technology companies need complex and divergent skills and knowledge to develop innovative products. These authors concluded that the effects of partner diversity on innovation performance are more profound in high-technology and knowledge-intensive industries because of higher degrees of product complexity, market volatility, and riskiness/uncertainty of innovation projects in these sectors. Furthermore, Barbolla and Corredera (2009) also refer the need to assess the level of needed know-how by consortia to carry out the project, given by technology maturity.

According to Allarakhia and Walsh (2012), projects in consortia have moved from pre-competitive research to, in some industries, technology-based product development. Partners have to address new product development challenges and following these developments if proven worthwhile. Specific consortia partners often carry out these developments during project later stages (or even after the project ends). They depart from platform technologies resulting from the project towards focused or niche-oriented applications to target their own markets. In such case, partners' geographical diversity contributes to the successful adaption to different local requirements such as technical standards, market regulations, and customer needs (Beers and Zand, 2014). Platform technologies development requires multifunctional groups while contributing to the reduction of resource consumption in product development (Halman et al., 2003). It is, therefore, prone to be performed in consortia. The development of a platform technology may lead to numerous products and applications, lowering the associated average time and cost (Chai et al., 2012).

Collaboration between partners to develop products raises concerns about management of intellectual property rights (IPR) generated by consortia members and the projects results become critical (Allarakhia and Walsh, 2012). Frequently, there is a thin balance in intellectual property management, since e.g. companies would often prefer to keep their research results secret until they have been patented while researchers' focus is to publish them since they usually have a scientific and economic incentive to this goal (Lhuillery and Pfister, 2009).

Consortia dimension plays also a central role to projects' R&D performance as it significantly affects team dynamics. The size may be measured by the number partners involved in the consortium (Spanos et al., 2015). The number of consortia partners not only affects R&D commitment positively, but also the likelihood of accomplishing product innovations. Nevertheless, large number of partners might increase the likelihood of opportunistic behaviour by partners and consequently produce a negative effect on project performance (Arroyabe et al., 2015). Following a similar concept, Clarysse et al. (2009) refer that output additionality (related to the innovation output such as the introduction of new products) does not increase with the number of partners in a project.

In addition, several authors point out the types of different partners composing R&D consortia and eventually up-taking the technologies. One broad distinction is the extent to which the R&D consortium consists of organizations from industry vs. academia (Spanos et al., 2015). Then, they can be further distinguished as companies (technology suppliers/providers and customers), research and technology organizations (RTOs), and universities (e.g. Von Raesfeld et al, 2012;

Kang and Kang, 2010; Lhuillery and Pfister, 2009; Aschhoff and Schmidt, 2008; Belderbos et al., 2006; Miotti and Sachwald, 2003). In such R&D value chain classification, companies are the industry end, universities the academia end, while RTOs stand in the middle with the interface role (Albors-Garrigós et al., 2014). It is widely believed that interaction between companies, research organizations, and universities is a necessary condition for successful innovation in the knowledge-based economy, particularly in knowledge intensive industries, and, broadly for improving competitiveness (Scherngell and Barber, 2009).

Consortia partners manage technological, knowledge, team member size and profile, and commercialization matters (Allarakhia and Walsh, 2012). Therefore, it is recognized that a critical question in R&D collaboration is the identification and selection of relevant partners (Nieto and Santamaria, 2007). Partners in consortia typically share information about R&D background in the project area, funding and collaboration opportunities, and support product development (Allarakhia and Walsh, 2012). In consortia, complementary assets and resources can be combined, generating synergies and cross-fertilization effects (Becker and Dietz, 2004) thus forming R&D value chains.

Von Raesfeld et al. (2012) argue that there is a strong positive impact of value chain complementarity of partners on both technology development and commercial performance of collaboration projects. These authors define value chain complementarity as "the diversity of value chain roles per project, i.e., different types of organizations play complementary roles in the R&D process", namely by organizations types focused in this work: companies (both suppliers and customers), RTOs, and universities. Several authors also identify geographical diversity, i.e. diverse locations/countries of partners, as a key determinant to successful R&D in consortia (e.g. Beers and Zand, 2014; Paier and Scherngell, 2011; Scherngell and Barber, 2009). The innovation context in which they are immersed therefore plays a significant role in technology development. This diversity was found to be important to incremental innovation performance. Nevertheless, Lhuillery and Pfister (2009) mention the concern that large geographical distance between R&D partners may limit R&D spillovers.

2.3. Technology and context characteristics

In this section, we briefly summarize a review of the key characteristics of technologies and context that we address in our study. For a more extended review, please refer to our previous paper Teles et al. (2018).

Kirchberger and Pohl (2016) identify Technology Assessment and Technology Radicalness, while Jung et al. (2015) refer Innovativeness (radical/incremental), as characteristics that determine the innovative character and corresponding potential value of a new technology concerning customer or user impacts. We have associated our sample's Technological Advantage attribute with these factors.

The capability to create different product concepts from a same technological base is another important factor for technology exploitation (Kirchberger and Pohl, 2016). We have related our sample's Platform Potential attribute with such factor as identified in the literature.

The Technology Readiness Level (TRL) is a systematic metric and measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology (Mankins, 1995). Deriving from the original NASA scale of technology readiness, the European scale was adapted by the European Commission in order to classify technologies resulting from European R&D projects and is widely used in such context. This scale also comprises 9 levels and provides a measure of technology maturity throughout its development cycle, from inception (TRL 1 – basic principles observed) to real environment testing (TRL 9 – actual system proven in operational environment) (European Commission, 2014).

Intellectual Property Rights (IPR), understood as the ability of the developer of a technology to obtain property rights and protect the research, are also mapped to our sample's characteristics, and have been identified by Kirchberger and Pohl (2016) as a main exploitation success factor.

Kirchberger and Pohl (2016) refer that Team Size affects technology commercialization. In our work, we have related Consortium Dimension with this factor. The number of members of the development team impacts the way the technology is exploited since consortia with a larger number of members allow for larger and broader developments for a certain project duration, and for the inclusion of more diversified project partner profiles. On the other hand, more limited consortia may be more focused and oriented to specific developments.

The type of source (organization) owning the technology may also impact its commercialization outcome (Kirchberger and Pohl, 2016). We relate the Owner attribute in our sample with the technology source, i.e., the type of organization that becomes the owner of the technology at the end of the R&D project. From the literature, three main organisation types participating in R&D projects, across the full R&D value chain, were identified as relevant to our research: Companies (industrial end), Research and Technology Organizations (RTOs) (in the middle, with an interface role), and Universities (academic end) (Fabrizi et al., 2016; Eurostat, 2014; and Von Raesfeld et al., 2012). Previous studies have found that while all these organization types (institutional sectors) benefit from joint R&D projects, the main beneficiaries are universities and research centres, while private companies benefit less. Fabrizi et al. (2016) argue that cooperation makes universities and public research centres more concerned about appropriability and possible commercialisation of inventions.

The location of research institutions has been highlighted by Chiesa and Piccaluga (2000) as an important factor to be considered in the exploitation of research results, while Furman et al. (2002) refer the important of public policy to the innovation capacity and success. Colyvas et al. (2002) point out the importance of Industry Closeness and Resource Availability, characteristic of the technology owner's region, as determinants of technology exploitation. Innovation Context (geography and innovation score) is the attribute of our sample that we have related with such factors.

3. Research context and methods

3.1. Sample identification context and process

In this section, we briefly summarize the characteristics of our sample and the collection process. For a more extended description, please refer to our previous paper Teles et al. (2018).

Our sample comprises 61 technologies in the area of advanced manufacturing (production) developed in FP6 (2002-2006) and FP7 (2007-2013) projects within the selected theme of "Nanosciences, Nanotechnologies, Materials, and new Production Technologies" (NMP) (with similar name and goals in FP6 and FP7) and focused on new production technologies.

The sample was mainly collected during the EXPLORE (Extended Exploitation of European Research Projects' Knowledge and Results, 2013-2015, grant agreement no. 609226, FP7). The project's main goals were (1) to support and promote the commercial exploitation of R&D results developed in EU-funded projects in the topic of production technologies, and (2) to provide recommendations to the European Commission for policy improvement concerning technology commercial exploitation.

The first author worked three years in the EXPLORE project, from concept development, consortium formation, and proposal writing, through work development and coordination, to closure and evaluation, thus obtaining a deep and broad knowledge about the technologies and an enhanced global view of European R&D in manufacturing.

In detail, the sample collection task, carried out between June 2014 and April 2016, included an initial search for EU-funded R&D projects in the topic of new production technologies, which resulted in 437 such projects. From these, 152 "Production"-related projects were then selected. A second round of selection reduced the number to 57 projects with a close relationship to the EXPLORE partners. The leaders of those projects were contacted personally, by telephone or email. From those, 27 responded to our contact with the identification and characterization of 46 technologies that resulted from their projects. Afterwards, 15 additional technologies were directly identified and characterized, and added to the sample, leading to a total of 61 technologies.

3.2. Sample description

The classification proposed by Abernathy and Clark (1985) was adapted for the sample's Technological Advantage attribute: 1 – Low innovation; 2 – Little innovation; 3 – Considerable innovation; and 4 – High innovation (radical / disruptive innovation character).

In order to develop an assessment of Platform Potential, we explored a functional perspective (Simpson et al., 2001) via two characteristics: (1) the technology areas, and (2) the industrial sector(s) of application (i.e., markets). From the two classifications – technological areas and industrial sectors of application – a platform potential classification was derived, as illustrated in Table 1.

Table 1 - Platform Potential classification

Technology Area	Industrial Sector	→	Platform Potential
Single	Single	→	Low
Single	Multiple	→	Medium
Multiple	Single	→	Medium
Multiple	Multiple	→	High

To address excessive granularity, we defined the following TRL three classes, supported by a rational of relatedness among TRLs: 1 - TRL 3-4 – lab; 2 - TRL 5-6 – environment; and 3 - TRL 7-9 – exploitation.

The technology owners were also asked if the technologies had any kind of IPR. The expected answer was simply "yes", or "no".

The consortia that developed the technologies in our sample have very diverse sizes, ranging from 6 to 49 partners. We have adopted a classification of consortia sizes considering three classes: 1 – small (less than or equal to 12 partners); 2 – medium (between 13 and 17 partners); 3 – large (equal to or more than 18 partners), in order to balance each class.

The owners of the technologies included in our sample can be: 1 – Companies; 2 – RTOs; and 3 – Universities.

We considered each technology's country to be the country of location of its owner, and in order to provide a measure of the support available in the corresponding innovation context, we used the Country Innovation Score Label, a classification from the European Innovation Scoreboard (European Commission, 2017): 1 – Modest Innovator (not present in this sample); 2 – Moderate Innovator, corresponding in this sample to the countries Italy, Portugal, Greece, and Spain; 3 – Strong Innovator, corresponding in this sample to the countries Belgium, United Kingdom, and France; 4 – Innovation Leader, corresponding in this sample to the countries Switzerland, Finland, Denmark, Germany, and The Netherlands.

3.3. Research method

To group technologies and context, on the previously described dimensions, we performed a Hierarchical Cluster Analysis (HCA) on our sample, using Ward's method (Ward, 1963) supported on the Gower distance metric (Gower, 1966). Then, C-index (Hubert and Levin, 1976) and Dunn index (Dunn, 1974) were used to assist in the selection of the number of clusters.

Data preparation and analysis were carried out using the R system for statistical computing, version 3.4.3 x64 (R Development Core Team, 2014) in RStudio, version 1.1.442 (Racine, 2012), and the packages: 'cluster', version 2.0.6 (Maechler et al., 2017); 'factoextra', version 1.0.5 (Kassambara et al., 2017); 'NbClust', version 3.0 (Charrad et al., 2014, 2015); 'fpc', version 2.1.11 (Hennig, 2018). R itself and the packages are freely available under the terms of the general public licence (GPL) from the Comprehensive R Archive Network (CRAN) at http://CRAN.R-project.org/.

4. Findings

We converged on the choice of five clusters for our analysis, taking into consideration the fact that this is the number between two and nine for which C-index is minimum, while Dunn index is maximum between two and five (table 2), added to the higher quality of the interpretation, that we attempted for a variety of neighbouring numbers of clusters. Above five clusters, in particular, there are multiple instances of minor differences between clusters, leading to inconclusive results.

Figure 1 shows the five cluster dendrogram for the HCA. The numbers on the horizontal axis are technology-context identifiers. In Annex, Table 5 details each technology and respective cluster, and Figure 2 illustrates each cluster's silhouette.

Table 2 – C-index and Dunn index values for k clusters

K =	2	3	4	**5**	6	7	8	9
C-Index	0.487	0.417	0.436	**0.399**	0.427	0.473	0.464	0.445
Dunn index	0.222	0.222	0.250	**0.250**	0.286	0.333	0.333	0.333

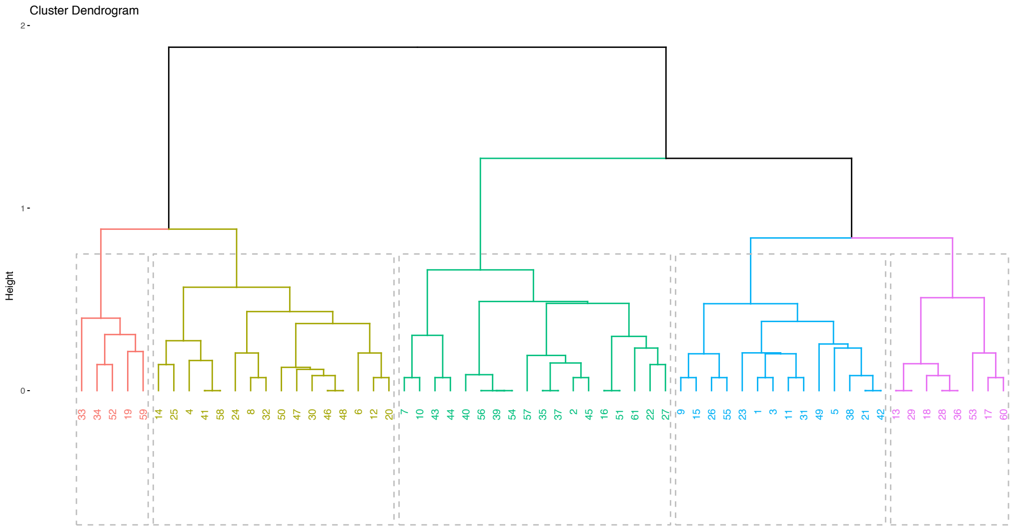

Figure 1 – HCA's dendrogram - 5 clusters

The cases included in cluster 1, "Full Appropriability", consist of owners in innovation leading countries with IPR on technologies featuring little/considerable advantage and low/medium TRL, and medium/high platform potential. Cluster 2, "Patent Pending", includes mostly RTOs from moderately innovative countries with IPR on technologies with considerable advantage, medium platform potential, and medium/high TRL. Cluster 3, "Resource Based", consists of owners of little/considerable advantage, high platform potential technologies, in innovation leading countries, without IPR. Cluster 4, "Agent of Change", includes mostly RTOs from moderately innovative countries with technologies featuring considerable advantage, medium TRL and small/medium-sized consortia, without IPR. Finally, cluster 5, "Network Explorer", consists of companies and universities from moderately innovative countries, participating in large consortia, with technologies with considerable advantage, high platform potential at low/medium TRL, without IPR.

The characteristics of each cluster are summarized in Table 3. The variables are grouped in the two main areas – technology and context – and the most relevant value(s) for each cluster-variable pair is(are) presented. Relevance was assessed based on the sample distribution for each cluster. When the distribution is homogeneous, a classification of "distributed" is used in the table.

Table 3 – Summary of clusters' characteristics

		Cluster 1 *Full Appropriability*	Cluster 2 *Patent Pending*	Cluster 3 *Resource Based*	Cluster 4 *Agent of Change*	Cluster 5 *Network Explorer*
Technology	Technological Advantage	Little + Cons.	Considerable	Little + Cons.	Considerable	Considerable
	Platform Potential	Medium + High	Medium	High	Medium	High
	TRL	Low + Medium	Medium + High	Distributed	Medium	Low + Medium
	IPR	Yes	Yes	No	No	No
Context	Consortium Dimension	Distributed	Distributed	Distributed	Small + Medium	Large
	Owner	Distributed	RTO	RTO + Univ.	RTO	Comp. + Univ.
	Innovation Context	Leader	Moderate	Leader	Moderate	Moderate

Table 4 presents the detailed distributions for each cluster, following the same structure as Table 3 (clusters, main areas, and variables).

In particular, the technology "Test pattern for laser galvo scanner performance analysis" is the paradigm of the cluster "Full Appropriability". Its owner is located in an innovation leading country, with IPR and features little advantage, medium TRL, and medium platform potential.

Technology "One Step Production Process" can represent the "Patent Pending" cluster, since it is owned by an RTO in a moderate innovator country, it has IPR and presents considerable advantage and medium platform potential, and high TRL.

Then, technology "MYWEAR LCA Tools" is the example for the "Resource Based" cluster, since it is little innovative, has high platform potential, does not comprise IPR, and its owner is located in an innovation leading country.

To represent the "Agent of Change" cluster, the technology "Last milling machine for footwear rapid customized production/prototyping" is owned by an RTO located in a moderately innovative country, and features considerable advantage, medium TRL, was developed by a small-sized consortium, without IPR.

Finally, the "Network Explorer" cluster can be illustrated by the technology "Virtual reality industrial safety tool", owned by a company located in a moderately innovative country, was developed by a large consortium and presents considerable advantage, high platform potential, medium TRL, without IPR.

Table 4 – Distribution of technologies per cluster and variable

			Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Technology	Technology Advantage	2 - Little innovation	2	3	8	4	0
		3 - Considerable innovation	3	11	9	10	8
		4 - High innovation	0	2	1	0	0
	Platform Potential	1 - low	0	4	0	2	0
		2 - medium	3	10	4	9	1
		3 - high	2	2	14	3	7
	TRL	TRL34	2	3	5	1	3
		TRL56	3	7	8	9	4
		TRL79	0	6	5	4	1
	IPR	no	0	0	18	14	8
		yes	5	16	0	0	0
Context	Consortium Dimension	1 - small	1	4	9	8	0
		2 - medium	2	6	6	5	1
		3 - large	2	6	3	1	7
	Owner	Company	1	0	2	2	3
		RTO	2	14	9	12	0
		University	2	2	7	0	5
	Innovation Context	2 - Moderate Innovator	0	16	0	12	7
		3 - Strong Innovator	0	0	1	2	1
		4 - Innovation Leader	5	0	17	0	0

5. Discussion and implications

In this study we have analysed a sample of 61 technologies resulting from European R&D projects during FP6 and FP7 in the area of manufacturing technologies, looking for patterns in technologies and consortia.

Clusters "Full Appropriability" and "Resource Based" feature organizations from Innovation Leader countries with little/considerable advantage technologies. They differ on IPR protection, TRL, and platform potential, with the former including IPR-protected technologies with lower TRL and platform potential.

More developed ecosystems in Innovation Leader countries will very likely include industries that are established innovation leaders themselves, and thus naturally carry out a substantial amount of incremental innovation (Clarysse et al., 2014; Banbury and Mitchell, 1995). This may justify the more balanced proportion between little and considerable advantage technologies. The negative correlation between IP protection and TRL and platform potential may also be related to the level of development of the ecosystem. On one hand, the richness of complementary assets present in more mature industries may be required and sufficient for technologies with a high breadth of potential applications to be effectively exploited (Halman et al., 2003; Teece, 1986) as may be the case of the technologies comprised in the cluster "Resource Based", where the value appropriation from technology is mainly supported on the resources already available in the mature innovation ecosystem. On the other hand, at a lower TRL and for narrower possibilities of application, even within complementary asset-rich environments, uniqueness increases in importance (Rahal and Rabelo, 2006; Teece, 1986), thus owners may achieve the value "Full Appropriability" with such technological and contextual pattern.

Clusters "Patent Pending", "Agent of Change", and "Network Explorer" feature organizations mostly from Moderate Innovator countries, and mostly with considerable advantage technologies. Clusters "Patent Pending" and "Agent of Change" include technologies owned by RTOs and present very similar platform potential and TRL profiles, with the former focused on IPR protection and slightly more on higher advantage, and the latter on smaller consortia. Without the support provided by more developed ecosystems, technology owners in Moderate Innovator countries on the one hand would be expected to actively seek protection but on the other hand may be less capable of effectively doing so (Furman et al., 2002). Consequently, cluster 2 is described as "Patent Pending" since the value appropriation from its technologies may depend on achieving the protection of their IPR. Additionally, RTOs as owners in cluster 4 act as "Agent of Change" since even without protecting their IPR, they act as enablers of the moderately innovative ecosystem, using smaller R&D consortia to that goal.

Cluster "Network Explorer" has no RTOs, and a focus on higher platform potential, lower TRL and large consortia, without IPR. In this cluster we may be seeing Universities and Companies with a more exploratory positioning aiming at developing future relationships and expand their networks, within larger consortia, and future technology capabilities, at lower TRLs (Petruzzelli, 2011).

While the above discussion points to the existence of a number of distinct patterns for participation in European projects, with different sets of purposes, opportunities, and challenges, the terms of reference for European calls hardly acknowledge this diversity, failing to feature a portfolio of customised requirements or support instruments that may improve the effectiveness of those participations.

These can range from requiring and supporting RTOs in Moderate Innovator countries in carrying out formal invention disclosures and patentability assessments for the outcomes of their participation, to explicitly requiring and supporting large-sized consortia in explicitly developing evidence-based forward-looking collaboration concept notes, or strategically aligning in their portfolios of activities longer-term lower TRL advances and nearer-term higher TRL results to meet more immediate needs. In addition, policy makers can make ongoing use of analysis methodologies such as this one to monitor and improve policy implementation and impact.

6. Limitations and future research

One limitation of our work is the fact that the sample is not perfectly random, as a result of the data collection process and assumed constraints. Nevertheless, our assessment of potential biases provides confidence in the robustness of the findings. The study was restricted to technologies resulting from R&D projects funded by the European Union within FP6 and FP7 in the area "Nanotechnologies, Materials, and Production technologies" and the specific topic "Production", so the results are not generalizable to other topics.

The possibilities for future research in this area are broad and we believe can help to support improved decisions concerning the whole context of European-funded

R&D projects. Consequently, our study can be further developed by identifying gaps in the patterns, i.e., which characteristics have not emerged. From there, one can aim to explain the reasons and motives behind those gaps as a contribution to improved policy.

Then, it would be very relevant to advance the current analysis by co-relating its data with resulting exploitation or commercialization as a success measure. This would allow to assess cluster's commercial success towards improved design of policy instruments.

Research can additionally be developed with a wider and deeper sample to enable generalization of results. This may include other R&D areas and topics such as nanotechnology, advanced materials, or biotechnology, or other funding themes as Information and Communication Technologies.

Finally, it would be interesting to analyse a new, similar sample of technologies resulting from Horizon 2020 projects and compare its results with the ones from our work. This would allow comparisons and provide differences and similarities in the patterns between FP6/FP7 and Horizon 2020, as a complementary evaluation of more recent policy changes.

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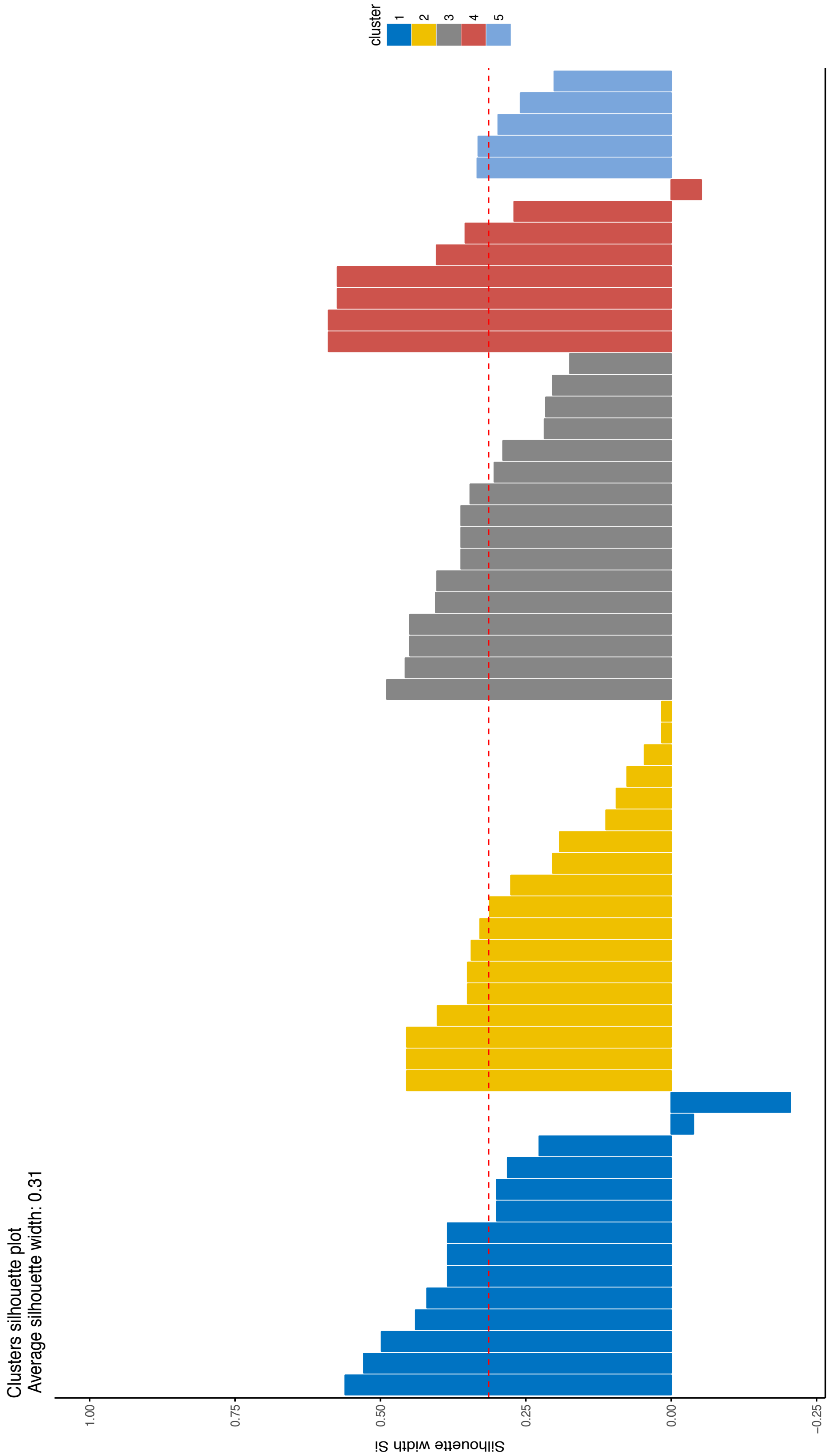
Annex

Table 5 - Sample's technologies and variables

#	Technology Name	Technology Advantage	Platform Potential	TRL interval	IPR	Dimension	Owner	Innovation Context	Cluster
1	A Novel Coaxially Laser-Assisted (COLA) Cold Spray System	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	1 - small	RTO	3 - Strong Innovator	4
2	Accurate robot positioning for robotic drilling through stiffness compensation and sensor based compensation	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	2 - medium	RTO	4 - Innovation Leader	3
3	AIV - Internal chip extraction system	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	1 - small	RTO	2 - Moderate Innovator	4
4	Assembly Product and Process Template Selector and Tracker	3 - Considerable innovation	1 - low	1 - TRL 3-4 - lab	yes	3 - large	University	2 - Moderate Innovator	2
5	Business Intelligence and Analytics for Manufacturing and Retail	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	2 - medium	RTO	2 - Moderate Innovator	4
6	CableBOT- Parallel Cable Robotics for Improving Maintenance and Logistics of Large-Scale Products	4 - High innovation	3 - high	2 - TRL 5-6 - environmen	yes	1 - small	RTO	2 - Moderate Innovator	2
7	Change Propagation Manager	2 - Little innovation	2 - medium	1 - TRL 3-4 - lab	no	2 - medium	RTO	4 - Innovation Leader	3
8	CODICE toolkits	3 - Considerable innovation	1 - low	2 - TRL 5-6 - environmen	yes	1 - small	RTO	2 - Moderate Innovator	2
9	Collaboration infrastructure for managing business networks	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	RTO	2 - Moderate Innovator	4
10	Conceptual off site industrialization process for FRP transport infrastructures	2 - Little innovation	2 - medium	1 - TRL 3-4 - lab	no	3 - large	RTO	4 - Innovation Leader	3
11	Cooperative Robot for stud welding operation in shipbuilding.	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	RTO	2 - Moderate Innovator	4
12	DIGIMET	4 - High innovation	2 - medium	2 - TRL 5-6 - environmen	yes	2 - medium	RTO	2 - Moderate Innovator	2
13	Dynamic Job Rotation Tool	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	3 - large	University	2 - Moderate Innovator	5
14	EMF concept on roll formed parts	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	yes	3 - large	RTO	2 - Moderate Innovator	2
15	ENEMAC Simulator - energy simulation of machine tools	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	no	2 - medium	RTO	2 - Moderate Innovator	4
16	Factory Layout Planner (FLP)	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	3 - large	University	4 - Innovation Leader	3
17	Factory Simulation Libraries	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	3 - large	Company	2 - Moderate Innovator	5
18	Flexible Robotic Fixtureless Assembly of Multi Functional Material-based products	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	no	3 - large	University	2 - Moderate Innovator	5
19	Formal digital representation language(s) of production modules and concept for usage.	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	yes	2 - medium	University	4 - Innovation Leader	1
20	Hydrogel waveguide sensor	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	yes	2 - medium	RTO	2 - Moderate Innovator	2
21	idkBLUE - Portable multichannel Machine-Tool oriented energy consumption monitoring system	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	2 - medium	RTO	2 - Moderate Innovator	4
22	Improved laser sintering process for aluminium	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	2 - medium	RTO	4 - Innovation Leader	3
23	Inductive infrared thermography on metallic component	3 - Considerable innovation	1 - low	2 - TRL 5-6 - environmen	no	1 - small	RTO	3 - Strong Innovator	4
24	Integrated safe@sea PPE system for fishermen	2 - Little innovation	1 - low	3 - TRL 7-9 - exploitation	yes	2 - medium	RTO	2 - Moderate Innovator	2
25	Integrated tool for plant configuration, simulation and performance visualization	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	yes	3 - large	RTO	2 - Moderate Innovator	2
26	iRAMP3 - Inelligent Reconfigurable Machines for Smart Plug&Produce Production	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	Company	2 - Moderate Innovator	4
27	IT-Integration of cloud-managed Dynamic Manufacturing Networks	2 - Little innovation	3 - high	3 - TRL 7-9 - exploitation	no	1 - small	RTO	4 - Innovation Leader	3
28	Knowledge Association Engine	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	3 - large	University	2 - Moderate Innovator	5
29	Knowledge Repository	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	3 - large	University	2 - Moderate Innovator	5
30	Laser cutting monitoring systems	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	1 - small	RTO	2 - Moderate Innovator	2
31	Last milling machine for footwear rapid customized production/prototyping	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	RTO	2 - Moderate Innovator	4
32	LeanPPD Model	2 - Little innovation	1 - low	2 - TRL 5-6 - environmen	yes	1 - small	RTO	2 - Moderate Innovator	2
33	LeanPPD Transformation Toolkit (Lean T2)	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	yes	1 - small	Company	4 - Innovation Leader	1
34	Local application of hydrophobic and/or hydrophilic coatings on polymer surfaces	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	yes	3 - large	RTO	4 - Innovation Leader	1
35	Manufacturing Service Management and Execution	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	RTO	4 - Innovation Leader	3
36	Manufacturing Systems Ontology	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	3 - large	University	2 - Moderate Innovator	5
37	Metal 3D printing and flexible post processing	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	RTO	4 - Innovation Leader	3
38	Multipurpose machine for laser cutting, marking and engraving of leather products	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	2 - medium	RTO	2 - Moderate Innovator	4
39	MYWEAR LCA tools	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	University	4 - Innovation Leader	3
40	MyWear Smart integrated services	2 - Little innovation	3 - high	1 - TRL 3-4 - lab	no	1 - small	University	4 - Innovation Leader	3
41	Nanoreinforced resins for EMF coils	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	yes	3 - large	RTO	2 - Moderate Innovator	2
42	Network part program - Network-part-program-based software tools for the generation and the on-line management of alternative process plans	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	no	2 - medium	RTO	2 - Moderate Innovator	4
43	New design methodology: Copy part properties	3 - Considerable innovation	3 - high	1 - TRL 3-4 - lab	no	2 - medium	Company	4 - Innovation Leader	3
44	New polymer for laser sintering	2 - Little innovation	3 - high	1 - TRL 3-4 - lab	no	2 - medium	Company	4 - Innovation Leader	3
45	Next generation milking robot parlour	3 - Considerable innovation	2 - medium	2 - TRL 5-6 - environmen	no	1 - small	RTO	4 - Innovation Leader	3
46	One Step Production Process	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	2 - medium	RTO	2 - Moderate Innovator	2
47	Performance Measurement Toolkit	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	3 - large	RTO	2 - Moderate Innovator	2
48	PLASMAPOUR	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	2 - medium	RTO	2 - Moderate Innovator	2
49	Platform for interoperability of digital factory tools	3 - Considerable innovation	1 - low	2 - TRL 5-6 - environmen	no	3 - large	RTO	2 - Moderate Innovator	4
50	PPIs (Production Performance Indicators) Structure and Definition	3 - Considerable innovation	2 - medium	3 - TRL 7-9 - exploitation	yes	2 - medium	University	2 - Moderate Innovator	2
51	Production metrology for micro/sub-micro scale features of polymer components and surfaces	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	3 - large	University	4 - Innovation Leader	3
52	Production process for structured current collector foils for battery cells	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	yes	2 - medium	RTO	4 - Innovation Leader	1
53	Rapid design toolbox for scanning and gathering non-existing or broken parts in 3D-CAD	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	2 - medium	Company	3 - Strong Innovator	5
54	S-MC-S assessment model	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	University	4 - Innovation Leader	3
55	S-MC-S Customized diamond wire technology	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	Company	2 - Moderate Innovator	4
56	S-MC-S Design tools for supply chain	2 - Little innovation	3 - high	2 - TRL 5-6 - environmen	no	1 - small	University	4 - Innovation Leader	3
57	Solvent free Dry-blend application of functional materials on current collectors for Li-batteries for E-mobility	4 - High innovation	3 - high	2 - TRL 5-6 - environmen	no	2 - medium	RTO	4 - Innovation Leader	3
58	Surface modification of nanopatterns for local selectivity	3 - Considerable innovation	2 - medium	1 - TRL 3-4 - lab	yes	3 - large	RTO	2 - Moderate Innovator	2
59	Test pattern for laser galvo scanner performance analysis	2 - Little innovation	2 - medium	2 - TRL 5-6 - environmen	yes	3 - large	University	4 - Innovation Leader	1
60	Virtual reality industrial safety tool	3 - Considerable innovation	3 - high	2 - TRL 5-6 - environmen	no	3 - large	Company	2 - Moderate Innovator	5
61	VIWET- Value Identification and Waste Elimination Tool (IT tool)	3 - Considerable innovation	3 - high	3 - TRL 7-9 - exploitation	no	1 - small	University	3 - Strong Innovator	3

Figure 2 – Clusters' silhouette



5.

Conclusion

The EU wants to carry on at the forefront of the world's innovation and competitiveness. Facing pressures of globalisation, economic and social crises, and fierce competition, the EU intensely invests in S&T as a long-term strategy to overcome societal challenges, outperform competitors, and create economic value within the overall picture of improving quality of life to its citizens. It is in such context that numerous R&D programmes have been developed and implemented over the years both by the EU and its Member States in a strong effort to foster innovation and create value to their society.

Nevertheless, despite developing excellent science, Europe seems to struggle when attempting to achieve commercial success of such results (Dosi et al., 2006). Technologies that not achieve the market drain resources and are waste value.

It is therefore imperative not only to understand how technological R&D projects are planned and developed to address needs and challenges, but also what determines their results' commercial success (European Commission, 2010). Public policy should consequently be redesigned accordingly to nurture innovation ecosystems able to solve societal challenges (Clarysse et al., 2014).

With this mindset, our main goal in this work was thus to contribute to a more efficient application of R&D funding, capable of delivering excellent results to society. To do that, we developed three different and complementary approaches covering the three stages of the R&D process: input, output, and transformation. We started by studying the planning of two large projects in Portugal in order to understand alignments and misalignments with market needs and innovation strategic lines with the aim to contribute to improve knowledge and practice, reflected in this research's first article. Then, at European level, we were able to gather a rich sample of technologies resulting from EU-funded projects in order to identify determinants associated with their commercial exploitation providing theoretical contributions and practical recommendations to enhanced knowledge and management, detailed in the second article. Lastly, using the same sample, we analysed patterns of characteristics from the technology development perspective which allowed to contribute to a superior knowledge about and management of R&D dynamics in the referred context, described in the third article. These steps enabled us to propose improvements and recommendations both to public policy and to management, both at European and national levels.

We revisit next the RQs and provide the corresponding empirical findings that answer them. Then, we describe our work's theoretical contributions, as well as practical and policy implications. We close with this work's limitations and propose avenues for future research.

1. Empirical findings

During our literature review, we identified a set of research gaps and opportunities, which we gathered in the corresponding RQs to which we answer below:

RQ 1.1. Are national structural projects for manufacturing overall aligned with market needs and European strategic innovation lines?

We found a substantial alignment between the studied structural projects and both market needs and European strategic innovation lines. This fact may indicate a relevant potential impact of results, since there is a substantial fit between what was planned for development and potential market adoption.

In fact, representatives of all industrial sectors participate in project activities related with the two most relevant strategic innovation lines. This totals for almost half of the project budget and the highest number of participants, including diverse profiles (as supported e.g. by Beers and Zand, 2014).

RQ 1.2. Are there critical misalignments?

There are a few critical misalignments in the projects. We verified that the project activities dealing with the third most important strategic innovation line lack the participation of a considerable part of the industrial sectors, two of those have stated that this specific line presented high priority. Also, two industrial sectors with no apparent interest participate in such R&D activity. In the end, more than half of the sectors are misaligned with the activities in this line.

Then, strategic innovation lines with high priority at European level were given low to none priority by the industrial sectors. Again, critical misalignments happened in project activities participation.

Finally, for all project activities and almost all participating industrial sectors, there are gaps of organizational profiles. Only seldom occurs the participation of both R&D organization and user companies.

RQ 2.1. Is there a clear time length for the valley of death?

We have found a clear time length of 3 years counting from the end of the R&D project until a full commercial exploitation, when this eventually happens (Markham et al., 2010; Markham, 2002).

RQ 2.2. Which characteristics are significantly determinant to successful exploitation?

1. Technological Advantage

Technological Advantage was found to have a significant positive association with technology exploitation, with significant differences between the lowest and higher advantage levels. This analysis is supported by Spanos et al.'s (2015).

2. Platform Potential

Platform Potential was not found to be associated with technology exploitation. However, it is possible to observe in our descriptive statistics that technologies with high platform potential are those which advance the most in the exploitation scale as referred in literature (Kirchberger and Pohl, 2016). However, other authors contradict such argument and claim that technology development that responds to a specific market need may promote exploitation (Pinkse and Van den Buuse, 2012).

3. TRL

TRL was found to have a significant positive association with technology exploitation, with significant differences between the lowest and higher levels. This analysis is in line with literature arguments referring that more mature, application-ready technologies are more commercially viable and more easily exploited (e.g. Gilsing et al., 2011)

4. IPR

IPR were not found to be associated with technology exploitation. However, we observed in descriptive statistics that technologies with IPR were more successfully exploited than those without IPR. This fact confirms literature referring the commercial success of patented research (Link and Scott, 2013; Rothaermel et al., 2007).

5. Consortium Dimension

Consortium Dimension was not found to be associated with technology exploitation. This is aligned with the allegation that successful introduction of new products does not increase with the number of partners (Clarysse et al., 2009). Nevertheless, from our descriptive statistics, it was possible to see that technologies developed by larger consortia were on average more successful than those developed by smaller ones (Spanos et al., 2015). This may possibly happen due to profile complementarity between partners. On the other hand, Arroyabe et al. (2015) state that smaller R&D consortia perform better in terms of developing exploitable technology, since large number of partners may increase the possibility of opportunistic effects.

6. Owner organisation type

Owner organisation type was found to have a significant positive association with technology exploitation. Furthermore, a significant difference was found when the Owner is a Company instead of RTO, thus supporting RTOs' interface role of maturing and transferring technologies to industry (Albors-Garrigós et al., 2014). It can be observed in descriptive statistics that older technologies developed by Universities achieve, on average, better exploitation performance than technologies developed by RTOs. We may infer that they may commercialize their early-stage technologies (Colyvas et al., 2002) through e.g. markets for technology (Arora et al., 2001).

7. Innovation context

Innovation context was found to have a significant positive association with technology exploitation. As a matter of fact, the tests of transition from lower to higher Innovation Context level were almost all significant, as well. This seems to indicate that the location of a technology owner in an innovation-leading country is a key determinant to successfully exploiting technologies resulting from its R&D activities. These countries have innovation ecosystems favourable to exploitation with innovation-supportive public policies, available public and private funding, R&D and technological capabilities, or stronger industrial structure (Rasmussen, 2008; Furman et al., 2002).

RQ 3. Which technology and context patterns emerge from our sample?

The observation of the five identified clusters resulting from the HCA allowed to identify technology and context patterns. A first clear distinction was between technologies whose owner was located in innovation-leading countries and moderately innovative ones. In the former group, a further division was between technologies having or not IPR, and the levels of TRL and platform potential. In the latter group, technologies are mostly considerably innovative. There, ownership provided a further marked division between RTOs and Companies/Universities, with these mainly in large project consortia. Technologies owned by RTOs could also be divided between having or not IPR. These patterns allowed us to derive conclusions, thus providing contributions and recommendations.

2. Theoretical Contributions

The initial stage of this research work was able to verify a relevant level of alignment between the European strategic innovation lines for production technologies and the real needs of industrial sectors in Portugal. Since these manufacturing sectors are the customers of production technologies, this achieved alignment is a very motivating result to further roadmapping efforts performed both at European and national levels. The results from these processes are essential tools to steer technology providers in developing new products to the market.

The observed alignment was reached in several layers: (1) thematic, the technologies developed under the corresponding themes target specific customer sector needs; (2) profile participation, the organizations participating in each project theme have diverse profiles representing R&D and user sectors; (3) effort and budget, the largest numbers of participants and allocated budget correspond to the most important strategic innovation lines.

From these observations, we were able to infer that a broad positive impact could be eventually reached by these project's results. In fact, considering the broad application spectrum of production technologies in all manufacturing sectors, these developments have the potential to create a significant value.

However, not everything was perfect in these R&D projects. Partial misalignments, some substantial ones, were found between the priorities referred by the customer sectors and actual participation in the projects' thematic activities. This fact was more evident in terms of participation profile and budget. Such circumstance may be a consequence of several factors, such as: (1) (lack of) fit between sector-specific needs and project activities; (2) funding programmes constraints (e.g. budget, consortium composition); (3) resource availability within organizations; (4) agenda arrangements.

The second part of our research work focused on technology commercialization concerns. We provided evidence based on a collected sample of 61 technologies resulting from European R&D projects during FP6 and FP7 in the area of manufacturing technologies.

We firstly proposed a 4-stage exploitation scale following the need to measure each technology's status in the R&D process and since such instrument was missing from the literature. Its stages are: 1 – No exploitation, where nothing has happened with the technology since its development; 2 – Demonstration in relevant environment (such as factory or lab pilot lines), where the technology was demonstrated in an environment from which several conclusions about its performance in a "real" setting or implementation can be extracted; 3 – Pre-exploitation, where there is a contract, agreement, or other to commercially exploit the technology, that may require further development (at this stage there is no product in the market yet); 4 – Full exploitation, where the technology has become a commercial product (here, it is either ready to be placed in the market or is actually being sold).

We observed a pronounced valley of death lasting mostly 3 years after the end of the R&D project until eventual commercial exploitation. During this time, no exploitation happens, even if technologies go through several other exploitation stages towards the market.

Technologies that present significant innovation advantage to the market show more successful exploitation. However, being either marginally or radically innovative may be a barrier. Technology maturity, and therefore market-readiness, is critical to commercial exploitation. More mature technologies achieve a much higher rate of exploitation than less mature ones. Using the TRL scale, it was evident that technologies with higher TRLs were present in the final stages of the exploitation scale. Complementarily, technologies with lower TRLs were, on average, at lower exploitation stages and therefore distant from the market, which may be related with the need for longer, riskier development periods. We also showed that lower TRL, exploited technologies are absent from our sample, which may imply the need to provide more effort to the markets for technology as a way of reducing risk and capturing value.

We have not significantly confirmed that technologies having the potential to be implemented in diverse industrial sectors or applications greatly increase their exploitation opportunities, as supported by previous literature, even considering that these are platform technologies, which with minor adaptations or additional modules can result in several products to different applications. Additionally, technologies with a medium potential to be platform, thus with a less defined focus, show a somewhat relevant exploitation success. We believe this is due to the fact that they can be easily adapted towards broad or niche goals. Furthermore, we showed that niche technologies, or having a small platform potential, achieve, on average, lower exploitation success than the others. This may occur because their application is very focused and restricted. Although solving a specific (and maybe essential) need, their market is usually smaller, thus decreasing their exploitation opportunities. We also demonstrated, however, that younger and niche technologies achieve higher exploitation stages than the other technologies, although not reaching full exploitation then or later. These facts may suggest that consortia are not properly leveraging them towards commercialization, and that this should be more carefully considered.

Then, our sample's technologies without IPR double those with IPR. In this context, we provided evidence that protecting the R&D project results is not as frequent as initially foreseen, contradicting the common line of thought in literature. Moreover, even if technologies with IPR achieve a higher rate of successful exploitation than those without IPR, the difference is not substantial and was not significantly proven, contrarily to previous literature, and again this is a matter worthy of further care.

As far as project consortia are concerned, we could observe that larger ones increase the exploitation success, even if not significantly. Therefore, the benefits of larger consortia which include accommodating diverse R&D capabilities, organizational profiles, and positions in the value chain, allowing complementary developments and the technology transfer from the development stages to the market, may not be efficiently captured.

Furthermore, the type of technology owner features a significant association with exploitation success. As a matter of fact, companies significantly enable commercialization technologies when compared to RTOs, since they operate in the market as their core business. We also provided evidence of how universities also support the exploitation of older technologies, likely as a complementary funding source for their activities. As far as RTOs are concerned, they are the organization type which least promotes the market exploitation of older technologies, maybe because they transfer them beforehand to companies as part of their role in the R&D value chain. However, it is also noteworthy that, considering younger technologies, RTOs advance them the most in the exploitation scale (without reaching market commercialization). These technologies are likely later transferred to Companies who then place then in the market, as referred before.

Finally, we show how important the owner's innovation context is for successful exploitation. Using the innovation score, we provide significant evidence that owners located in Innovation Leader countries achieve much higher full exploitation rates than those located in Moderate Innovator countries. The latter have the vast majority of technologies in the initial exploitation stages, thus being inefficient in their efforts to advance them in the exploitation scale. Contrarily, owners in Innovation Leader countries have technologies much more balanced throughout the exploitation scale.

Lastly, the third part of our research work provided noteworthy results to understand the dynamics and patterns of technology development in the scope of manufacturing R&D project in EU FPs.

Using HCA, we gathered our sample's technologies in five clusters that explain both the technological and context patterns. A first relevant conclusion is that, despite showing particular characteristics, the clusters generally do not strongly differ among them which may induce that funding calls may be overlooking diversity, and therefore lacking to present specific instruments.

Nevertheless, we could distinguish that the five clusters could be divided between those whose owner was located in innovation-leading countries or in moderately innovative ones. The former group features two clusters whose technologies with little advantage, possible due to their highly innovative ecosystem, but then show two profiles diverging in IPR protection, TRL, and platform potential. This points out either to (1) a combination of high platform potential and high TRL, without IPR possibly due to the presence of mature industries, their complementary assets, and market closeness, or (2) lower TRL, niche markets, with IPR indicating the need for uniqueness.

The three other clusters whose owners were located in moderately innovative countries mostly comprise considerable advantage technologies and could further be divided into those owned by RTO and those owned by companies/universities. Technologies owned by RTOs can be distinguished between having or not IPR, depending also on consortia dimension: small or medium, respectively. This fact may point out that RTOs in smaller, less innovative ecosystems are not able to achieve protection and possible not extracting the full benefit from their portfolio, whereas in broader ecosystems may have a more solid network to achieve such protection and value. The cluster with companies/universities as owners appear to develop lower TRL, high platform potential technologies in large consortia possibly exploring future possibilities in larger networks.

3. Policy and Managerial Implications

Several implications can be drawn from our work, both to public policy and to management.

Public funding organizations can be more aware of project planning misalignments and their negative impacts, and therefore loosen or adapt the funding instruments' or calls' boundary conditions such as priority themes, or consortium composition (organizational profiles, geographical locations). Using the same information, project promoters – of which the cluster we studied is a reference – may attempt to influence, at an early stage, the definition of the calls' topics and parameters.

Considering that most research projects usually have to propose an exploitation plan, commercialization does not occur before several years after the end of the project. This fact should be recognized by public authorities and managers in order to align expectations for project activities as well as to foster technologies during that period. Consequently, national and European public policy should improve funding instruments to support or accelerate the introduction of new technology-based products in the market, minimizing – or smoothing – the 3-year valley of death.

Considering the technology and corresponding competitive advantage, it appears that incrementally innovative technologies already have substantial support and therefore disruptive technologies could benefit from increased funding due to their high economic value potential but high development and adoption risk.

We also discussed that technologies with high platform potential may solve problems and create value across a broad spectrum of industries and applications and therefore should be nurtured. Complementarily, niche technologies have poor exploitation performance despite a recognized potential to solve focused problems and thus being high-value solutions. As both of these types do not have a strong presence in our sample, this may imply that funding instruments seem to not recognize such key technological characteristics and, therefore, specific instruments could be designed to support such type of technologies with acknowledged value.

The commercial exploitation of less mature technologies (lower TRLs) should be supported (e.g. through markets for technology) as can be suggested by our sample. Not only these technologies can be enablers to many different, more mature ones, further developed during new R&D projects, but also the risk of developing only one complete, market-ready product is, this way, decreased. Additionally, these less mature technologies are often "forgotten" after the end of the corresponding projects by consortia and individual organizations, due to the difficulties in commercially exploiting them as well as the need to find new projects to fund their activities.

Furthermore, it is necessary to improve the incentives to IPR. Since usually protecting a technology's IPR provides competitive advantage, we believe that there may be an enormous value being lost when technology owners do not protect projects results.

Funding calls should also encourage large and diversified consortia. As seen earlier, this promotes complementarity in projects in terms e.g. R&D and exploitation capabilities, or position in the innovation value chain, even if at some cost of possible opportunistic behaviours.

Although we have observed the positive effect of company ownership of technologies for market commercialization, this type of organization is a minority in our sample, which may suggest it should have improved support from funding. The same happens with universities, along with the referred markets for technology.

Public policy should overall be strengthened at national and regional levels in moderately innovative countries to improve the technology exploitation context. Improvements can be carried out at several levels such as: available and accessible public and private funding, improved R&D and technological capabilities, reinforced industrial structure, intensified collaboration between R&D and industry, among others.

From the clustering patterns described previously, further implications can be drawn. Policies can target specific characteristics and therefore be more inclusive. Indeed, there are technological and context success factors referred in the literature and highlighted in our research that demand more attention in future funding instruments. They should acknowledge that diversity and be tailored to address particular technological and contextual features, thus enabling improved outcomes and effectiveness.

In that sense, policy improvements can be made to increase funding support to RTOs in Moderate Innovator countries to increase IP protection of R&D results, or to promote evidence-based exploratory R&D by large-sized consortia. Additionally, policy could facilitate technology portfolios combining long-term value-appropriation, possibly disruptive, low TRL technologies with those closer to the market that can drive more immediate results. Additional instruments can also be designed to enable organizations, mostly companies, to build ecosystems where they can develop complementary assets, allowing them to achieve substantial appropriability of R&D outcomes.

Overall, policy makers and funding authorities at European, national, and regional levels, can follow this work's methodology to better understand their policies' impacts and results. With such insights, they are able to define new policies, design new funding instruments, or improve existing ones towards the common goal of more effective investment in improved innovation, growth creation, and ultimately societal impact.

Moreover, managers and project promoters may provide opportunities and incentives to improve the basic alignment of the project participants with their priority themes and agendas. New projects may also be developed to close identified gaps. Further R&D activities such as smaller, more focused projects can be developed building on previous results and complementing previous projects in order to minimize the impact of the misalignments.

This work also pointed out paths for future technological projects in the studied cluster and others, as well as generally in production technology developers and industries. The architecture of future projects should be shaped to maximize the potential for application and impact of each theme on the relevant sectors, namely involving reference sectoral organizations such as Technological Centres.

Finally, based on inputs from that research stage, we coordinated the development of the first national roadmap for production technologies. The results about the alignment between national sectoral needs and European priorities for manufacturing technology development were essential to this works' impact. This technology roadmap served as guide for new developments during the following years.

Based on our insights and conclusions, organizations may improve their innovation and exploitation processes towards more efficient and valuable results. Managers may carefully plan how to overcome the valley of death. With our results, they have evidence of how long it can take, so they can allocate the necessary resources towards commercial exploitation.

Future consortia have here information about several technological and contextual characteristics so that exploitation opportunities can be maximized. Managers can use the information and methodology we proposed in this work when selecting funding instruments and calls, networking and decision-making to form consortia, or even during project development towards achieving improved results from their R&D and exploitation activities.

4. LIMITATIONS AND FUTURE RESEARCH

This research work has some limitations. The conclusion of our first work cannot be generalized due to the specific features of the case study research design, as well as the focus on a specific cluster in a specific context. However, since that we were able to access and gather a rich set of cross-sectorial data, we believe that the presented results are valuable to other technology clusters with comparable organizational, activity, and funding structures, and mainly to strategic innovation management overall.

Then, the sample we gathered to the other two parts of our research is not perfectly random, as a result of the data collection process and assumed constraints. Nevertheless, our assessment of potential biases provides confidence in the robustness of the findings. The study was restricted to technologies resulting from R&D projects funded by the European Union within FP6 and FP7 in the area "Nanotechnologies, Materials, and Production technologies" and the specific topic "Production", so the results are not generalizable to other topics.

Future research could replicate this work in other collaborative initiatives or clusters worldwide in order to assess the alignment success of their structural projects and resulting impact. Other noteworthy line of research would be to follow-up the cluster's activity after the end of the projects in order to understand how the alignments/misalignments influenced the impact of project results in industry. In addition, it would be interesting to analyse if the identified gaps lead to the development of new projects during or after the studied projects in order to overcome the negative impacts of such misalignments.

The possibilities for future research in this area are broad and we believe can help to support improved decisions concerning the whole context of European-funded R&D projects. Consequently, our study can be further developed in a wider, deeper, and totally random sample to enable generalization of results. This may include other R&D areas and topics such as nanotechnology, advanced materials, or biotechnology, or other funding themes as Information and Communication Technologies.

In addition, a longitudinal study could assess the evolution of the sample over time, making possible to understand the progress of the studied technologies in the exploitation scale.

Furthermore, it would be very relevant to advance the current clustering analysis by co-relating its data with resulting exploitation or commercialization as a success measure. This would allow to assess cluster's commercial success towards improved design of policy instruments. In addition, gaps could also be identified, i.e., to understand project configurations, currently without any support, and that might produce successful technologies.

Finally, this study could be further completed with the analysis of new, similar sample of technologies resulting from Horizon 2020 projects and compare its results with the ones from our work. This would allow to identify differences and similarities in the project patterns between FP6/FP7 and Horizon 2020, as a complementary means of evaluation of recent policies to improve funding policies.

The underlying rationale of the research work we have just presented was how to improve efficiency of public investment in R&D and consequently increasing its value creation. To do so, we analysed R&D projects and results, both at national and European levels, in the area of manufacturing technologies. We were able to collect data during two key periods in the context of public funded R&D, one in Portugal and the other in Europe.

As a result, we were firstly able to evaluate the fit between two Portuguese strategic projects and the needs of the customer sectors. Then, with data from technologies resulting from EU-funded R&D projects, we could point out determinants for technology exploitation, barriers hindering it, as well as patterns in those projects. Based on all that information, we could provide recommendations both to policy making and to management.

With our work, we expect to contribute to improve policy and management in order to better support and induce R&D so that every invested Euro is able create more societal and economic value than before. We believe that by understanding what already works best and what needs to be redesigned, all involved in the R&D and innovation value chain, from policy makers, to managers, to researchers, and even to customers can better target their efforts during such demanding process.

More than develop excellent R&D-based solutions, Europe has to be able to efficiently commercialize them, and from that generate societal and economic impact. With this work, we hope to be part of that challenging and exciting journey.

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Planning and exploitation of new production technologies in public-funded R&D

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