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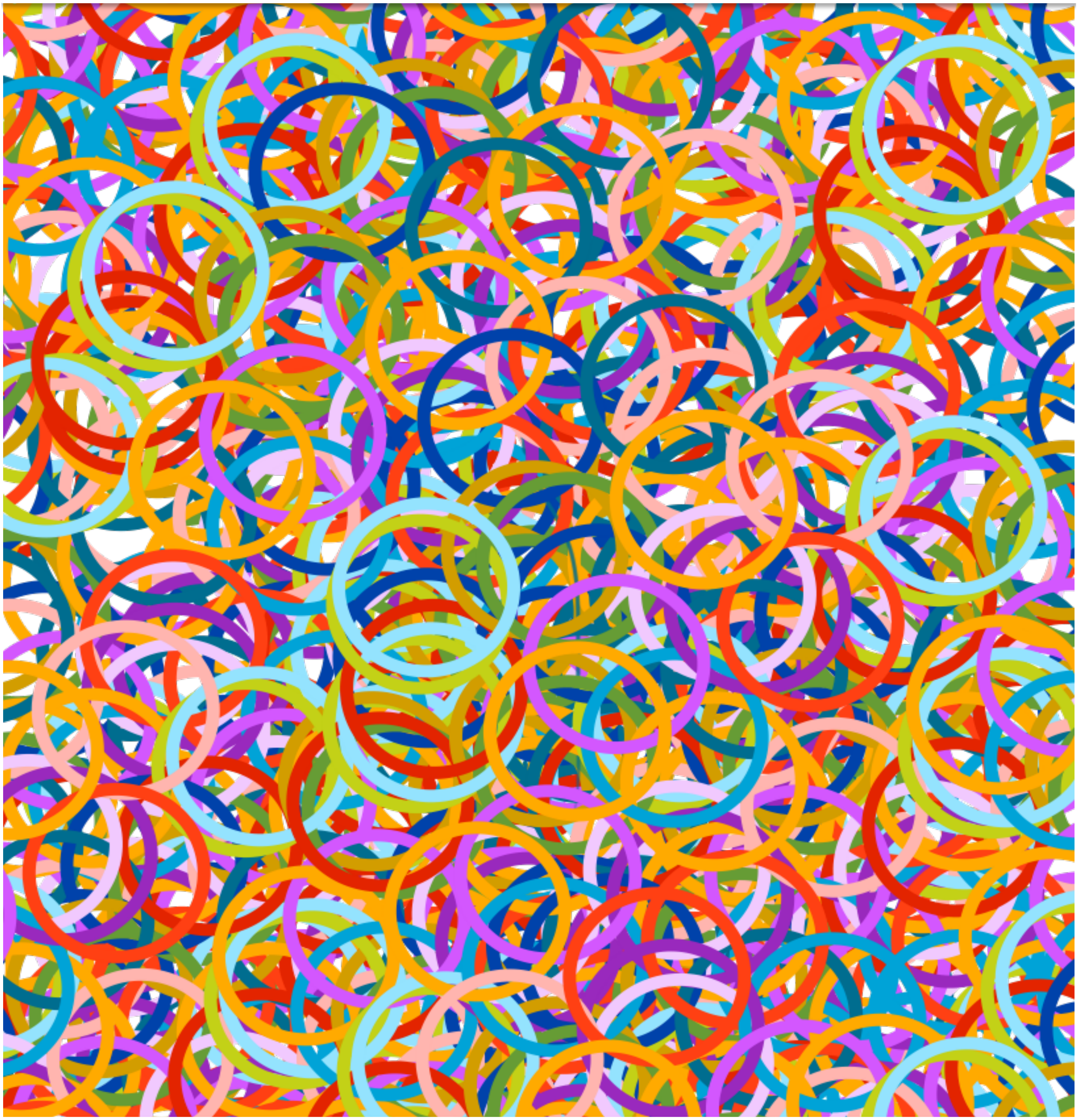

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Editorial

Winter is coming: The dawn of Innovation?

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As stated by the Cambridge on-line dictionary, Editorial, as a noun, is “an article in a newspaper that expresses the editor's opinion on a subject of particular interest at the present time”, whereas/and as an adjective, Editorial is “relating to editors or editing, or to the editor of a newspaper or magazine“. On the other hand, about the definition of a Journal, the same dictionary says “a serious magazine or newspaper that is published regularly about a particular subject”. This means that, in the Editorial, the editors express their perspectives or opinions “on a subject of particular interest at the present time“. It is in this context that we came across the idea of talking about Winter, as this issue was being prepared, Winter was indeed coming and this led to the title of this editorial. Then we thought about the southern hemisphere, where Summer was coming, we started wondering whether this would be acceptable and we realized it should be fine to restrict our thoughts to the winter season. We will come back to this... So let us talk about Winter and innovation, and the question is, would we say that Winter fosters innovation? We have no particular study on this issue, but if we associate Winter with extreme cold weather, we may start having some clues. And this argument stems from X-language proverb that “Necessity is the mother of invention”, and where X is likely to stand for most world languages. Going now back to the Summer, we could as well think about extreme hot conditions. We could add more variables such extreme humidity, or even drought. As we know, these extreme conditions emerge in very different world regions, causing trouble or discomfort, and are likely to trigger the production of innovations by people living in those regions.

With these ideas in mind,a search in SCOPUS was conducted (31/December/2015), limiting results to conference papers and articles. The following results were obtained for the selected keywords:

(KEY (extreme weather) AND KEY (innovation))	Count = 8 papers
(KEY (severe weather) AND KEY (innovation))	Count = 3 papers
(KEY (winter) AND KEY (innovation))	Count = 31 papers
(KEY (summer) AND KEY (innovation))	Count = 41-14=27 papers

14 Excluded: Summer School = 6 papers and Summer Camp = 8 papers

The publication dates for these papers range from 2006 to 2015. No limits were

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imposed for the search in the publication date range.

In total, we have 11 papers referring to either severe or extreme weather. However, if we cross this and look for papers whose keywords include winter or summer, there is no paper at all relating severe or extreme weather to winter or summer. This seems to be interesting, and is likely to result from the actual fact that extreme or severe weather conditions take place in areas of the globe where those conditions have been standing for generations and, as a result, innovations have been existing there for decades. Both the conditions and the novelties are part of the local culture and are not documented in the literature as such. It seems however that the actual trigger for the innovation is not the actual Season, but the extreme nature and conditions associated to it. On the other hand, if we disregard the extreme component and only refer to the occurrence in keywords of:

(Winter OR Summer) AND Innovation

the result is 58 papers where we have either Winter or Summer, and Innovation.

These numbers look very small indeed. In line with the above rationale, one would expect many more! The question to be asked is why? One possible cause is that most research papers would focus on the phenomena being studied and on the new principle or concept that was applied or developed, and the issue is no longer the extreme weather but, for example, the low temperature or even the air humidity. The application of those concepts, pre-competitive knowledge, seldom becomes published as the description of the actual innovation that those new principles or concepts have enabled. For understandable reasons, Intellectual Property issues and patent submission may actually hinder this publication process.

JIM aims at bridging this gap and we hope to have publications from all areas of knowledge telling us about how their science results have actually become innovations that have entered the market for the benefit of the whole world population.

This Winter issue, we would like to share with you a set of interesting letters and papers revealing the multidisciplinary nature of JIM. The first letter, a letter from academia, by Mike and Fu, is looking at University Spin-outs and argue that "it is important to develop a more comprehensive ecosystem for academic entrepreneurship that includes a wider range of actors and mechanisms" and includes a revealing literature review. The second is a letter from Industry by Almada-Lobo. By focusing on the Manufacturing Execution Systems (MES), this letter argues that in the move towards Industry 4.0, plants, fueled by technology enablers, will have to face a paradigm shift towards the manufacturing systems of the future.

In their review, Kesting et al. discuss about the different leadership styles and the contingencies between specific leadership styles and the types and stages of the innovation process. Their finding suggests that transformational leadership is not the prevailing leadership style associated to innovation, and that the effectiveness of different leadership styles is congruent to innovation stages, types and elements such as R&D and resistance.

Salmela et al. explore the front end innovation process and the extent to which time pressure is beneficial or detrimental in this early stage if the innovation journey. They empirically examine this question in the context of digital jewellery and highlight that time pressure can be productive if visionary leadership, project momentum and team collaboration are concomitantly present, and some positive stress is maintained at a level that keeps the group momentum in motion.

Exploiting two waves of the Mannheim Innovation Panel data, Bzhalava examine the relationship between R&D outsourcing and research output, captured both qualitatively and quantitatively. The study unveils that R&D outsourcing as well as the interaction between internal R&D efforts and R&D outsourcing are positively and significantly associated with innovation quantity. On the other hand, R&D outsourcing and the combined effects of internal R&D and R&D outsourcing are not positively and significantly associated with innovation quality, thus stressing the need to further delineate the composition of outsourcing deals and partners. The empirical analysis further sheds light on the fact that manufacturing firms are more likely to combine internal and external R&D strategies to develop novelties, which might be explained by the difficulties to capture innovation efforts typically encountered in such surveys.

In their empirical analysis of patent documents, Matron Kiss and Buzas identify the basic features of the mobility network of US inventors. They uncover the role of central nodes, community structures and unveil the hidden core of the network. Their implications revolve around the influence of a small number of nodes, which can efficiently and effectively absorb knowledge from the network. In this specific setting, the core is found to be mainly composed of IT and semiconductor companies, as well as large universities in the US.

Flipse et al. propose a decision support tool to support interdisciplinary innovation teams in their decision making process, embracing considerations and expertise which go beyond the techno-scientific insights. Their tool visualises the innovation project performance and success chances, based on past projects conducted within the organisation. The tool is aimed at fostering the communication and collaboration within interdisciplinary teams by offering practical improvement areas based on shared expertise, embracing socio-ethical, societal, economic and management related aspects.

Tsimiklis and Makatsoris elaborate an open innovation framework in an industrial mature industry, the food industry. Arguing on the benefits of adopting an open and collaborative approach to new product development, the authors advocate to work with customers and selected partners to design food products which would offer an integrated sensory experience of both food and packaging, and would embrace customization, health and sustainability desiderata.

Innovatively Yours,

João José Pinto Ferreira, Anne-Laure Mention, Marko Torkkeli
Editors

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University Spin-outs: What do we know and what are the policy implications? Evidence from the UK

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Letter from Academia

This letter from academia reviews the academic literature and provides an overview of the trends in spin-outs from universities in the UK. We argue that it is important to develop a more comprehensive ecosystem for academic entrepreneurship that includes a wider range of actors and mechanisms. We outline a framework of such an ecosystem and accompanying research agenda.

1 Introduction

As in many other countries, spin-outs by academic scientists have become a central means of research commercialization by UK universities. In this letter from academia, we argue that in the light of experience with spin-outs by academic faculty, it is important to develop a more comprehensive ecosystem for academic entrepreneurship that includes a wider range of actors and mechanisms.

There is now a considerable number of studies on spin-outs from UK universities (Table 1). Studies have been undertaken at several levels including the university and its TTO, the university department, the spin-out venture and the academic entrepreneurs involved.

These studies reveal a number of important insights regarding the development of academic entrepreneurship. At the university level, the importance of a clear strategy and having the resources and competencies to implement such a strategy are clear. But it is also evident that the most effective strategy is different for different universities, there being dangers in a one-size-fits-all approach. Universities may be able to create spin-outs but vary in their ability to create spin-outs that can attract external funding and subsequently create value.

Table 1. Studies on Academic Entrepreneurship in UK (Source: Adapted and updated based on Siegel and Wright (2015))

Author(s)	Data	Key Results
Franklin, Wright, and Lockett (2001)	Authors' Quantitative Survey of U.K. TTOs	Universities wanting to Launch Successful spin-outs Should Employ a Combination of Academic and Surrogate Entrepreneurship
Lockett, Wright, and Franklin, (2003)	Quantitative and Qualitative Surveys of U.K. TTOs	Universities generating most spinoffs Have elaborated Spin-out Strategies, Strong Expertise in Entrepreneurship, and Vast Social Networks
Nicolaou and Birley (2003)	UK academic entrepreneurs	Different embeddedness of academics in a network of ties external or internal to the university associated with different growth trajectories.
Vohora, Wright and Lockett (2004)	Case studies of UK spin-outs	Spin-outs need to address specific critical junctures if they are to evolve
Druilhe, and Garnsey, 2004	Cambridge University spin-outs	Five distinct types of business activities pursued by academic entrepreneurs; as business models evolve the ventures may enter different types of business activity
Chapple, Lockett, Siegel, and Wright (2005)	U.K.-NUBS/ UNICO Survey-ONS	TTOs Exhibit Decreasing Returns to Scale and Low Levels of Absolute Efficiency; Organizational and Environmental Factors Have Considerable Explanatory Power
Lockett and Wright (2005)	Survey of U.K. TTOs	Rate of spin-out creation Positively Associated with university expenditure on IP Protection, Business Development Capabilities of TTOs, and the Extent to Which its Royalty Distribution Formula Favors Faculty Members
Clarysse, Wright, Lockett, van de Elde and Vohora (2005)	Interviews and descriptive data on TTOs in 50 universities across 7 European countries inc. UK	Of five incubation models identified, only three match resources, activities & objectives: low selective, supportive & incubator, giving rise to different types of spin-outs. Competence deficient and resource deficient types involve mismatches and suggest universities need to adopt different approaches.
Garnsey, and Heffernan (2005)	Cambridge spin-outs	Growing areas of local competence identified based on sectoral distribution of activity over time and on clusters of related activity in the Cambridge area that are related to serial spin-out from the university and local businesses.
Smith and Ho, 2006	Spin-outs from Oxford and Oxford Brookes Universities and government establishments	Number of spin-offs in Oxfordshire increased rapidly over recent years at time of study due to national policy and entrepreneurial culture of the universities and laboratories. Academics in the region entrepreneurial for many decades
Wright, Lockett, Clarysse, and Binks (2006)	Surveys of TTOs and spin-outs	There is a mismatch between the demand and supply side of the market for funding spin-outs. In line with pecking order theory, venture capitalists prefer to invest after the seed stage but in contrast to pecking order theory, TTOs see venture capital as more important than internal funds early in the development phase
Mosey and Wright (2007)	Longitudinal qualitative interviews with UK academic	Nascent academic entrepreneurs frustrated by lack of assistance from TTOs and advice from TTOs less valuable than from other sources. Novice entrepreneurs

	entrepreneurs and TTOs	gave TTO assistance more credence than did nascents. Habitual academic entrepreneurs had mixed views on TTOs but TTO often seen as a barrier regardless of TTO capabilities.
Wright et al. (2008)	Survey, interview and archival data from mid-range universities, TTOs and spin-outs in UK, Sweden and Belgium	Mid-range universities need to focus on developing critical mass in small number of areas of expertise, rather than trying to emulate world class universities across many areas. They need to evolve a portfolio of university-industry linkages reflecting range of activities and firm types with which they interact.
Rasmussen, Mosey and Wright (2009)	Cases of spin-outs in UK and Norway	Spin-out entrepreneurs need to develop opportunity refinement, championing and credibility competences that enable them to interact with resource providers outside the university for the spin-out to grow
Wright, Mosey and Noke (2012)	Cases of postdocs involved in BiotechYes	Support needed to bridge the gap between those interested in starting a venture and those who actual do so as many of the former do not pursue their entrepreneurial intentions.
Mueller, Westhead and Wright (2012)	Survey of UK spin-outs	Spin-outs located outside 'golden triangle' can raise venture capital if can signal venture quality and entrepreneurial expertise
Lockett, Wright and Wild, 2014	Interviews with TTOs and archival survey data in UK	Spin-out activity affected by goals and behavior of different actors involved which may be in conflict
Guerrero, Cunningham and Urbano (2015)	UK data on university impact	Impact of spin-outs greatest for top echelon universities while other universities have greatest impact in other areas
Hewitt-Dundas (2015)	Telephone interviews with 350 university spin-outs	A range of demographics relating to spin-outs and their founders including: few founders commit full-time to the spin-out; only a quarter of spin-outs located at any stage in the University's incubator.
Rasmussen, Mosey and Wright, (2015)	Cases of spin-outs in UK and Norway	To enable spin-outs to grow strong and weak social ties need to change over time.
Bobelyn, Clarysse, and Wright (2015)	VC backed spin-outs and high tech start-ups exiting by trade sale	Patent scope has a negative effect on acquisition return, while patent depth is positively associated with acquisition return. Firms with a limited product portfolio experience higher acquisition returns than those with many products. Those with no products obtain even higher returns. Academic spin-offs were significantly less likely to earn high returns.
Weckowska (2015)	Case studies of 6 UK TTOs	Commercialization involves transactions-focused and relations-focused practicse. Both co-evolve in some TTOs while others are predominantly transactions-focused. For the latter the development of a relations-focused approach is difficult, but possible if there is strategic direction and if sources of inertia are removed by TTO directors.

Universities' technology transfer offices (TTOs) vary in their resources and capabilities and in their efficiency in developing spin-outs and other forms for academic entrepreneurship. The acceptance of a policy to develop spin-outs may also vary across universities (Lockett, Wright and Wild, 2014). Besides reflecting the different objectives of different actors, this may also be an indication that the appropriateness of a policy that focuses on academic spin-outs may differ across universities.

This is illustrated in the cases of mid-range universities in Wright et al (2008) and explored quantitatively in a recent study by Guerrero, Cunningham and Urbano (2015) who show that the economic impact of universities differs between top echelon and 'mid-range' universities. For mid-range universities the most important activities involve research and knowledge transfer through consulting, research contracts and research collaboration. In contrast, for top echelon universities, entrepreneurial spin-off activities have the greatest economic impact.

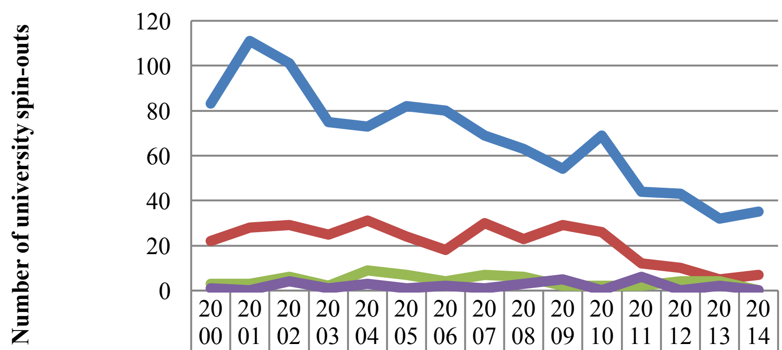
Regarding the spin-outs themselves, it is clear that they are highly varied in terms of sectors, IP and business models and that they face many challenges if they are to develop beyond the start-up phase. These challenges revolve around gaining access to the resources and capabilities they need to identify and reorient their business models through the various stages of evolution (Druilhe, and Garnsey, 2004; Vohora, Wright and Lockett, 2004). A central issue concerns not just having these resources and capabilities but in having the capabilities to acquire them and in particular to be able to shift to a commercial development trajectory from one determined by the academic context (Rasmussen, Mosey and Wright, 2009). In part, this capability depends on having network ties outside academia but also in being able to adapt the role of these ties as the spin-out venture develops (Rasmussen, Mosey and Wright, 2015).

Some academic entrepreneurs are serial entrepreneurs and have developed these networks with experience but this is not the case with nascent and novice academic entrepreneurs (Mosey and Wright, 2007). TTOs may oftentimes have a limited ability to help nascent and novice entrepreneurs to develop these networks while serial academic entrepreneurs may be able to act as mentors especially in academic departments that are positively disposed towards academic entrepreneurship through spin-outs.

2 Spin-out trends

Using firm-level data collected by the Spinouts UK Survey, it is clear that there has been a downward trend in the number of spin-outs formally recorded (Figure 1). A fuller description of the methods and spin-out trends is presented in Wright and Fu (2015). Classifying universities into quartiles on the basis of their position in the UK University League Tables, we can see that there is a clear link between the quality ranking of a university and the quantity of spin-outs created. Most (71%) spin-outs created in 2000-2012 came from the universities in the top quartile (Figure 1). The drop in spin-out creation among universities in the top quality is particularly noticeable, declining by a half over the period.

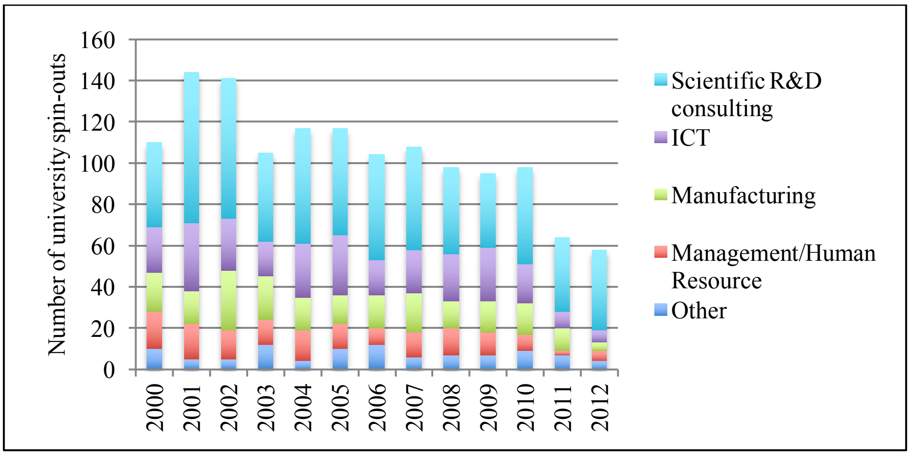
Besides this overall decline, it is also evident that other developments are occurring in spin-out activity. Despite attempts by universities to capture all spin-out activity through their TTOs, a significant number of start-ups by academics continue to bypass this route (Perkmann et al. 2014, 2015).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
top25%	83	111	101	75	73	82	80	69	63	54	69	44	43	32	35
top25-50%	22	28	29	25	31	24	18	30	23	29	26	12	10	5	7
bottom 50-25%	3	3	6	2	9	7	4	7	6	2	2	2	4	4	0
bottom 25%	1	0	4	1	3	1	2	1	3	5	0	6	0	2	0

Fig. 1. Quality of Universities and Their Spin-outs Over Time (Source: Authors' analysis based on Spinouts UK)

Further, while Scientific R&D remains the largest sector for spin-outs, there has been a sharp decline in formally registered spin-outs in ICT (Figure 2). Perhaps surprisingly as they do not attract much attention, spin-outs have also occurred regularly in management and human resources as well as commerce/entertainment.



Note: 'Other' includes Material/Energy/Environment sectors; Architectural/Civil Engineering sectors; Commerce/Entertainment sectors; Bio/Pharma sectors

Fig. 2. Sector Distribution of UK Spin-outs from 2000 to 2012 (Source: Authors' analysis based on Spinouts UK)

We used FAME (https://fame.bvdinfo.com) and Zephyr (https://zephyr.bvdinfo.com), to obtain data on whether spin-outs had received venture capital (VC) or business angel funding or had undergone a trade sale up to July 2015. VC and even less business angels play a minority role in funding spin-outs (Figure 3). Some 24% of spin-outs had received VC funding. Universities in the top quartile were somewhat more able to attract finance from this source but other universities in lower quartiles were also able to do so. This is consistent with other evidence from UK spinouts that universities that could signal the quality of their spinouts could attract VC even though they were located outside the so-called golden triangle of Oxford, Cambridge and London (Mueller et al., 2012).

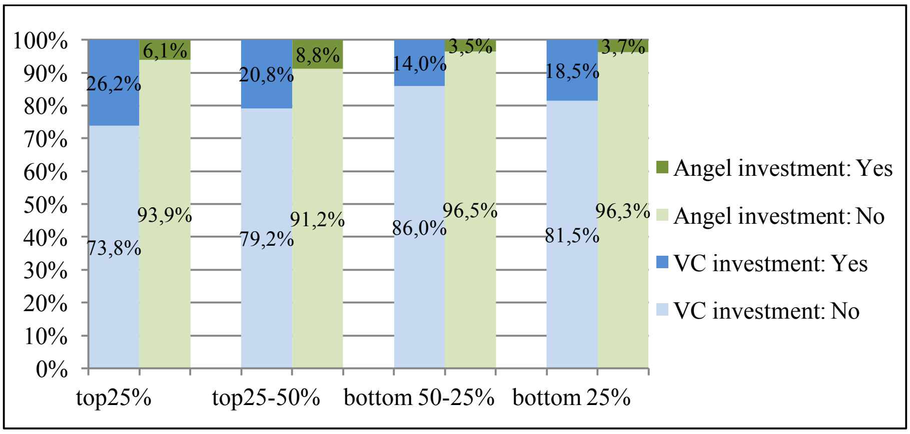


Fig. 3. VC/ Angel-backed Spin-outs across Universities (Source: Authors' analysis based on Spinouts UK)

Business angels, or informal VC typically involves high net worth individuals investing either individually or through a collective arrangements such as a syndicate, or increasingly through crowdfunding (Wright, Hart and Fu, 2015). Only 6.6% of spin-outs had obtained funds from business angels, with quartile two universities being more likely to attract funding from this source.

Although there have been major expectations regarding the financial returns to be generated from spin-outs, the actual overall outcome has been modest, despite a small number of stand-out cases. Under 1% of spin-outs had achieved an IPO by July, 2015(Figure 4), and these overwhelmingly involved spin-outs from the top two quartiles and those in the Scientific R&D sector.

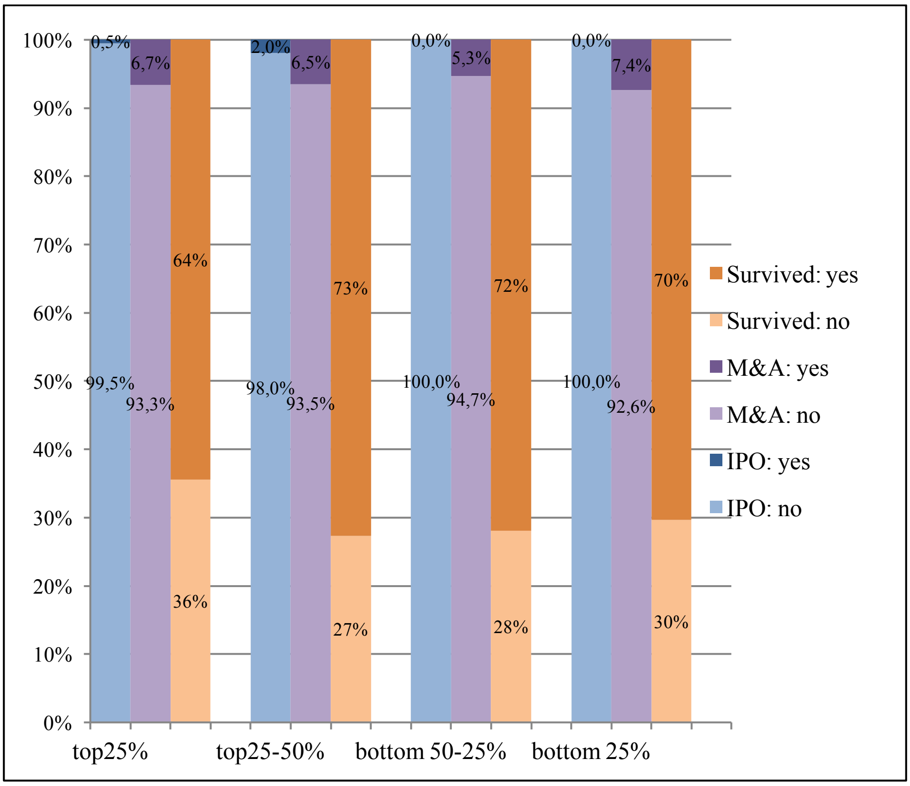


Fig. 4. Exit Routes of Spin-outs across Universities (Source: Authors' analysis based on Spinouts UK)

In contrast, some 6.6% had undergone a trade sale to an existing corporation. Bobelyn et al's., (2015) study in the UK also suggests that academic spin-offs were significantly less likely to earn high returns than other young high tech firms that exit through a trade sale. Spin-outs seem to be more likely to fail than other VC backed firms (Puri and Zarutskie, 2012). Some one third of spin-outs had failed by July, 2015.

3 Discussion and Conclusions

Our review of the literature and recent trends has yielded a number of insights concerning the development of academic entrepreneurship at universities especially in relation to spin-outs by academic faculty. These insights emphasize the heterogeneity of universities and their strategies, as well as the variety of the spin-outs that emerge from them and the challenges they face in accessing the resources and capabilities they need. It is also clear that there are shortcomings in the extent to which TTOs have performed the role of stimulating entrepreneurship and that other actors may also have important roles to play. This evidence also needs to be seen in the context of evolving government policy towards universities in the UK, which is increasingly stressing the need to take a broader perspective on the economic impact of universities (Wright, 2014; Guerrero et al., 2015). From an academic entrepreneurship perspective this involves consideration of the role of students and alumni in creating ventures as well as that of faculty.

Both the evidence on faculty spin-outs and emerging examples of venture creation by students indicate that support needs to include a wide range of mechanisms that go beyond traditional spin-outs with patents that have a need for large amounts of VC to with potentially worldwide markets to include student ventures with informal IP which may address more local markets and have lower funding needs.

There is fragmentary evidence that universities are developing a variety of mechanisms such as business plan competitions, entrepreneurial garages, pre-accelerators and incubators, to facilitate this broader scope of start-up and spin-out activity. However, as yet we lack a clear framework for analysis of the most effective ecosystems to stimulate this broader range of activities in different universities.

Building on recent research that highlights the variety of contextual factors influencing entrepreneurial ecosystems (Autio et al., 2014), we suggest that one element of the framework concerns the variety of university contexts in terms of scope, research quality ranking, location and local networks, resources, etc. We then envision that universities can develop a continuum of support activities ranging from very early stage support related to formulating opportunities through curricula, pre-accelerators, etc. that can help make embryonic venture ideas ready for the next phase. This phase involves entry into some form of incubator or accelerator that can help shape the business idea and identifies investors and potential markets. This range of support activities we see as being populated by the variety of potential entrepreneurs within universities, a variety of support actors and a variety of investors. Potential entrepreneurs include faculty, support staff, postdocs, students and alumni.

Support actors go beyond TTOs and departmental colleagues to include corporations, public agencies, regional actors, alumni, entrepreneurship centers, adjunct entrepreneurs, etc. Business schools also have a role to play, for example faculty and students can connect with science and engineering faculty and students through business plan and co-working projects. This under-exploited link may be particularly interesting as business schools develop beyond their traditional focus on large corporations (Wright et al., 2009).

Potential investors go beyond VCs, which as we have seen apply to a limited subset of spin-outs from universities to include crowdfunding, accelerators (Clarysse et al., 2015), university seed funds, greater efforts to attract business angels from among alumni, alumni endowments to stimulate entrepreneurial ventures by students, etc.

There is a need for further research to elaborate further the elements of this framework both conceptually and empirically.

In sum, although the last fifteen years have seen considerable progress in research academic entrepreneurship and in particular spin-outs by faculty, in the light of evidence on the impact of this activity and evolving policy towards universities, future research efforts need to turn towards a broader canvass. We hope that the framework sketched out here can provide the basis for this exciting new research agenda.

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The Industry 4.0 revolution and the future of Manufacturing Execution Systems (MES)

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Letter from Industry

Industry 4.0 dictates the end of traditional centralized applications for production control. Its vision of ecosystems of smart factories with intelligent and autonomous shop-floor entities is inherently decentralized. Responding to customer demands for tailored products, these plants fueled by technology enablers such as 3D printing, Internet of Things, Cloud computing, Mobile Devices and Big Data, among others create a totally new environment. The manufacturing systems of the future, including manufacturing execution systems (MES) will have to be built to support this paradigm shift.

Keywords. Industry 4.0, Cyber-Physical Systems, Manufacturing Execution Systems.

1 Introduction

Since the final report of the Industry 4.0 Working Group[1] was published in April 2013, both academia and industry professionals have been trying to fully comprehend the consequences for manufacturing. Of particular interest are the consequences for manufacturing IT systems.

That Industry 4.0 document aimed to define Germany's investments in research and development related to manufacturing for the upcoming years. The main objective was leveraging the country's dominance in machinery and automotive manufacturing in order to position it as a leader in this new type of industrialization.

Industry 4.0 is based on a concept that is as striking as it is fascinating: Cyber-Physical Systems (a fusion of the physical and the virtual worlds) CPS, the Internet of Things and the Internet of Services, will collectively have a disruptive impact on every aspect of manufacturing companies. The 4th industrial revolution, which unlike all others, is

[1] "Recommendations for implementing the strategic initiative INDUSTRIE 4.0",
Final report of the Industrie 4.0 Working Group,
http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf

being predicted, therefore allowing companies to take specific actions before it happens.

Manufacturers can begin now to define their target manufacturing model and then plan a transformation roadmap. Despite the significant hype around the topic, nobody knows what the exact consequences are for manufacturing operations or when will these happen, although there's a clear notion that the later-movers will most likely be forced out of the market.

While there's still a lot of confusion about the implications for manufacturing, the confusion starts with what matters in Industry 4.0. Considering the technology enablers for Industry 4.0. Include Mobile, Cloud, Big Data analytics, Machine to Machine (M2M), 3D Printing, Robotics and so on there are many companies with particular expertise. While these are in fact the disruptive technologies triggering the transformation, this Industry 4.0 revolution goes far beyond these.

2 Cyber-physical Systems

Cyber-physical Systems (CPS) are simply physical objects with embedded software and computing power. In Industry 4.0, more manufactured products will be smart products, CPS. Based on connectivity and computing power, the main idea behind smart products is that they will incorporate self-management capabilities.

On the other hand, manufacturing equipment will turn into CPPS, Cyber-Physical Production Systems - software enhanced machinery, also with their own computing power, leveraging a wide range of embedded sensors and actuators, beyond connectivity and computing power. CPPS know their state, their capacity and their different configuration options and will be able to take decisions autonomously.

As mass production gives way to mass customization, each product, at the end of the supply chain, has unique characteristics defined by the end customer. The supply chains of Industry 4.0 are highly transparent and integrated. The physical flows will be continuously mapped on digital platforms. This will make each individual service provided by each CPPS available to accomplish the needed activities to create each tailored product.

While the challenges at the supply chain level are quite big, the challenges at the factory level are not smaller. The combination of CPS and CPPS is likely to trigger significant changes in manufacturing production and control, towards completely decentralized systems.

Industry 4.0 advocates that the shop-floor will become a marketplace of capacity (supply) represented by the CPPS and production needs (demand) represented by the CPS. Hence, the manufacturing environment will organize itself based on a multi-agent like system. This decentralized system with competing targets and contradicting constraints will generate a holistically optimized system, ensuring only efficient operations will be conducted.

3 Reaction of MES providers

The direct consequence for centralized systems is that they will simply cease to exist. For Manufacturing Execution System providers, this will become a quite challenging scenario. Within the MES suppliers group, reactions to this upcoming disruptive future vary.

A first group, representing the big majority is simply ignoring Industry 4.0 and doing business as usual.

A second group is paying more attention to it. However, they claim Industry 4.0 defines a target model which will most likely take years or decades to reach. In the meantime, they say, companies should still try to continue investing in centralized MES systems and keep improving the performance of their operations. It is actually true that many industries are still in the dark ages of efficiency and quality and they should really evolve step by step, implement MES systems and related operations management practices, before dreaming about cyber-physical systems networking autonomously.

A third group however, argues that the decentralized systems will always need a centralized system due to compliance, optimization and monitoring. This is quite contradictory and frankly, these providers are truly missing the point. The shop-floor becoming a marketplace of capacity and production needs, where smart materials and smart equipment negotiate autonomously, guaranteeing the best possible efficiency contradicts the model of centralized system control. Where compliance is concerned, the solution proposed by Industry 4.0 lies in the vertical integration of smart materials and equipment with compliance-oriented business processes, while data reporting and analytics of such distributed systems is resolved by data lakes and big data.

4 Manufacturing Execution Systems of the Future

Manufacturing Execution Systems have been pivotal in the performance, quality and agility needed for the challenges created by globalized manufacturing business and will most likely continue to be. However, a completely new generation is required to cope with the new challenges created by Industry 4.0. The following are the four main pillars these systems shall consider.

4.1 Decentralization

One fundamental aspect which needs to be clarified is the notion of decentralization. This decentralization does need to be physical, but instead a logical one. What this means is that a smart product or CPS, as long as it has the capability to identify itself and connect to a physically centralized system, providing its position and state, the computing power can be elsewhere. In fact, with cloud computing, it's even arguable if such as system can be considered physically centralized. But the logical decentralization must still exist.

So the MES is still one application, but it acts decentralized with agents/objects representing the shop-floor entities. As an example, a smart product knows its state, its position, its history, its target product and its flow alternatives. Likewise, a piece of smart equipment, or more broadly a smart resource or CPPS will know its state, its history, its maintenance plan, its capacity, its range of possible configurations and setups, etc.

Smart materials and smart resources are not coupled entities. A dispatching operation shall represent the logical binding between a material to be processed and a resource to process the material. The first is a service consumer and the second a service provider.

Additionally, context resolution possibilities shall allow each product to be unique. When a product requires a certain service at a certain step, but adapted, or unique to its specific context, it shall differ from a combination of the flow with a target product type or specific product category.

Going one step further, the smart product may hold the recipe needed at a given processing step. When negotiating with the smart resource, it will transfer the recipe to the resource so that it can perform its unique transformation process.

4.2 Vertical Integration

Beyond the already referenced supply chain transparency, achieved through horizontal integration across the supply chain, the compliance, control or the fulfillment of any other related corporate business process is guaranteed through the vertical integration.

All services which the different CPS and CPPS entities can provide are exposed, allowing their orchestration in business processes that may be simple or complex for compliance or more broadly related to quality, logistics, engineering or operations. The MES must then be truly modular and interoperable, logically decentralized, so that all functions or services can be consumed by smart materials, smart equipment or any other shop-floor entity. As an example, a typical maintenance management process, often centralized, in this approach shall consist of a series of services that each piece of equipment might use.

4.3 Connectivity and mobile

Connectivity within the shop-floor can hardly be considered something new. What is changing now is how easy it is to achieve such connectivity, with significant impact in the overall manufacturing operations.

Advanced manufacturing environments have had such connectivity for a long time. As an example, some of the more sophisticated semiconductor facilities have RFID or transponders in the material containers and the equipment has bidirectional communication through interfaces, exposing readings from sensors, alarms or reports or allowing recipes to be externally selected or downloaded.

Now, industry 4.0 is creating a true democratization of such connectivity, allowing it to be widespread in manufacturing facilities of different sophistication levels.

- On one side, passive identification tags are increasingly affordable; these allow all shop-floor entities to hold their positioning coordinates. The logically autonomous MES entities can which store this location data and show it in real-time in interactive maps.
- On the other side, the IoT, in the industrial world called IIOT (Industrial Internet of Things), translates into very low cost hardware and lean OS (such as

Windows 10 IoT running on a Raspberry Pi), allowing true connectivity with equipment not requiring heavy systems and interfaces.

On the more operational MES front, connectivity and mobile combined shall allow more adaptable interfaces. MES will consist of different "apps", making the vision of getting to a piece of equipment, downloading and later using an app specifically built to operate that equipment will become a reality.

The same combination of mobile devices with the increase in reliable and inexpensive positioning systems will also allow the representation of real time positioning in 3D maps, opening the door to augmented reality scenarios. These are expected to bring tangible gains in areas such as identification and localization of materials or containers or in maintenance related activities.

4.4 Cloud computing and Advanced Analysis

Cloud computing and advanced analytics constitute the fourth pillar of the MES of the future. Both CPS and CPPS will generate huge amounts of data, which needs to be stored and processed. The Smart Factory vision of Industry 4.0 requires achieving a holistic view of manufacturing operations. Clearly this can only happen by integrating data from several different sources.

Advanced analytics are then needed to fully understand the performance of the manufacturing processes, quality of products and supply chain optimization. Analytics will also help through identifying inefficiencies based on historical data and allowing corrective or preventive actions to be performed.

The analyses are of two types.

- First, these can be offline analysis using very sophisticated statistical process models. These will need to be both in structured data, generally residing in a relational database or in data warehouse cubes, and in unstructured data, which is very difficult to analyze with traditional tools.
- Second, some actions must be triggered as quickly as possible, even before data is stored. This needs real-time analysis of data using techniques such as "in-memory" and complex event processing.

5 Conclusions

The very prediction of Industry 4.0 has created unique opportunities for defining target roadmaps for manufacturing operations in general and for manufacturing IT systems in particular. Centralized and monolithic production monitoring and control applications will eventually cease to exist, giving way to solutions capable of supporting this radically different vision of connected yet decentralized production and supply chain processes.

The decentralization of computing power does not need to be physical, but rather logical, allowing autonomous decisions in a market-like manufacturing environment composed by service providers and service consumers within the shop-floor, vertically and horizontally integrated for aligning with manufacturing business processes and the overall supply chain.

Solutions using these principles already exist today and are the ones which shall support manufacturers in creating their manufacturing wide picture and roadmap, with step by step actions, leading to the ultimate vision of Industry 4.0. As manufacturers build their Industry 4.0 roadmaps, it is critical that they understand these core principles so they are not faced with difficult replacement decisions.

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The impact of leadership styles on innovation management - a review and a synthesis

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Abstract. This paper reviews the insights that research offers on the impact of different leadership styles on innovation management. To do so, we develop a framework structuring existing insights into four generic dimensions: people, means, effects, and goals. Based on this framework, we review studies on: directive and participative leadership, interactive leadership, charismatic leadership, transformational leadership, transactional & instrumental leadership, strategic & CEO leadership, and shared & distributed leadership. We find strong indications that different innovation stages and types raise different demands on leadership. Against this background, transformational leadership is not the only style to lead innovations, but different leadership styles fit differently well with different innovation types and stages. However, the specification of this fit is still very incomplete and the answer to the question of how to lead innovations remains sketchy. Before closing, future research needs as well as practical implications are addressed.

Keywords: Leadership styles, Innovation, Leadership, Transformational Leadership

1 Introduction

There are strong indications that leadership is important for innovation management (Nadler and Tushman, 1990; Denti and Hemlin, 2012). Leadership plays a decisive role in enhancing organizational creativity (Mumford et al., 2002; Amabile et al., 2004), launching and driving innovation projects (Stoker et al., 2001; Bossink, 2007), and implementing innovation projects and overcoming resistance (Gilley et al., 2008). Somech (2006) concludes that corporate leaders are the key drivers, who either promote or inhibit innovation management in the organization. According to Bel (2010), different leadership styles are likely to have different impacts on employee involvement and commitment, which in turn influence the climate for innovation management. Deschamps (2005) goes even further, saying that the failure of innovation projects is most likely due to ineffective leadership skills (see also Bass 1990b).

Against this background, it is hardly surprising that a large number of publications have already addressed various aspects of the relation between leadership and innovation management (Rickards and Moger, 2006). Since sketching the relationship between leadership and innovation in general is too complex a topic for a single paper, the focus of this review is exclusively on leadership styles with regard to innovation management. The main advantage of focusing on leadership styles is that they are representative of different lines of thought and comprehensive at the same time. Of the different leadership styles that have been identified and described over the years, we will only focus on those that have already established significant links to innovation management. Relevant contributions can be both, conceptual or empirical. What counts is that they explicitly and substantially contribute to the knowledge about the links between a certain leadership style and innovation management. In this paper, we will review how these links have been conceptualized and look at available empirical evidence.

We do not believe that a mere survey of peer-reviewed journal articles gives an accurate picture of the relevant research body, therefore scholarly essay collections and monographs are also included. Specifically, an initial search has been grounded on the authors' previous knowledge of the field as well as on a systematic search in the database: "Business Source Complete – EBSCOhost". The terms used for the search did not only include the generic terms "leadership" and "innovation", but also related terms like "manager", "change agents", "champions", "change" and "transformation" (a detailed account of all used keywords and the number of hits can be obtained from the authors). However, to get a more comprehensive picture of the research body we also included publications referenced by reviewed articles. Additionally we followed up the forward citations ("cited by") of some key publications in Google Scholar.

2 Key constructs

2.1 Leadership

According to the definition of Bass (1990a: 19), "leadership consists of influencing the attitudes and behaviors of individuals and the interaction within and between groups for the purpose of achieving goals." Chemers (1997) defines leadership as "a process of social influence in which one person is able to enlist the aid and support of others in the accomplishment of a common task." Because of their general acceptance among scholars, we have taken these definitions as a conceptual foundation for this review. They imply the existence of four generic dimensions in leadership:

People – By its very nature, leadership is a supra-individual concept that requires a logical distinction between leaders and followers. This distinction can be explicit or implicit, temporary or persistent, but without it, leadership is pointless.

Means – The essence of leadership is that leaders lead, i.e. they carry out certain activities in order to direct or influence followers. The review below will show that these means can include very heterogeneous activities like coaching, empowering, or even servicing. But without such activities there is no leadership.

Effects – The effect of leading is to induce a certain reaction in the followers, i.e. to make them follow. The review will show that the effects can include very heterogeneous reactions, like increased enthusiasm or commitment, implicit convictions, the rational optimization of rewards, etc. But without any effect, leadership efforts go nowhere.

Goals – Leadership is ultimately associated with certain goals. These goals can be broad visions of promising future states, but they can also be very concrete targets. In either case, leadership points towards a direction. In the context of this paper, goals are essential as leadership here is always directed towards the goal of innovation – this is what this review is about.

The four dimensions (people, means, effects and goals) allow for systematizing the review of the specific leadership styles as they organize logical distinct elements in a consistent way. This allows for creating a systematic and stringent overall analytical framework, making it much easier to compare across leadership styles with regard to the 'essence' of leadership (i.e. the four dimensions). To our knowledge, the “people-means-effects-goals framework” has not been used by other researchers so far.

According to House and Aditya (1997: 451), the term of leadership styles refers “to the manner by which leaders express specific behaviors.” Leadership styles are important, since they represent different ways of practicing leadership. In relation to this, the traits of leaders reflect the ability of individuals to practice specific leadership styles. Contextual factors shape the conditions for different leadership styles, specifically the effects they have and the goals that they serve. Therefore, contextual factors cannot simply be added as a “fifth dimension” to the framework; instead, the framework is only valid with respect to specific contextual factors. Against this background, the differences in leadership styles can be specified in terms of the four key dimensions of the “people-means-effects-goals framework”. That not all key dimensions have been specified with regard to a specific leadership style does not mean that they do not exist, only that the research is incomplete.

Although there are several constructs closely related to leadership, lack of space means that the discussion of this relationship remains very short. While there have been countless discussions about the relation between leadership and management (Yukl, 1989; Kelley and Lee, 2010), the essence of leadership is that it includes both formal and informal authority, and that it has a very strong focus on the (new) goals to be achieved. Management research is included inasmuch as it meets these criteria. The same applies for other related constructs like change agents (Nikolaou et al., 2007), champions (Howell and Higgins, 1990), etc.

2.2 Innovation

There are perhaps at least as many definitions of innovation management as there are of leadership. According to a rather broad definition by Baregheh et al. (2009: 1334), “Innovation is the multi-stage process whereby organizations transform ideas into improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace.” Amabile et al. (1996: 1155) understand innovation management as the “successful implementation of creative ideas within an organization.” Creativity is therefore a necessary, but not sufficient, condition for innovation (Amabile et al., 2004). However, we know of no conceptualization that does not qualify innovation as a kind of change. Therefore, change is broadly understood as the genus of innovation, and innovation is broadly understood as a subset of change (there is no innovation without change). Differences in the conceptualization of innovation result from different specifications of change (the differentia) with regard to substance (what is the subject of change) and impact (what types of change count as innovation). Since leadership and innovation are too broad concepts to be addressed in one review paper, we limit our focus on research contributions investigating the effects of different leadership practices (leadership styles) on innovation processes (innovation management).

It is generally assumed (and this is important for this review) that innovations are typically complex procedures, consisting of a variety of different activities. One classical approach to structure this complexity is the distinction between different innovation stages or phases, like the distinction between ideation and implementation (Amabile et al., 1996; Anderson et al. 2004) or the distinction between conceptualization, development, and commercialization (Stemberg, Kaufman and Pretz, 2004). Creativity is typically seen as an element of the ideation or conceptualization stage and the impact of different leadership styles on creativity is therefore included in this review, but only inasmuch as it relates to innovation (and limited to insights that research offers on leadership). Another classical distinction is that between different innovation types with regard to substance (for instance: product, process, organizational, and market innovation, Schumpeter 1934) and impact (for instance: radical and incremental innovation, Dosi 1982). Also more specific elements of the innovation process have been distinguished, like R&D, resistance and path dependence, creativity, task completion, and others.

These distinctions are relevant for this review because there are strong indications that different activities make different demands on leadership (Nijstad and de Dreu, 2002; Anderson et al., 2004; Gilley A. et al., 2008, see also the review below). This has an important impact on goal setting. With regard to leadership, it is not sufficient to specify the goal as being merely "innovation" as such, but it is necessary to distinguish between different stages, types and specific elements that are functionally related to innovation. We argue that leadership styles are relative to these more specific innovation aspects. The question is then how different leadership styles contribute to the achievement of these more specific, innovation-related goals.

3 Leadership styles and innovation

This section reviews the insights produced by research into different leadership styles with regard to innovation management. Among the different leadership styles available in the literature, we have selected only those who make substantial contributions, and are thus already related to innovation management. We review each style separately and focus on the insights with regard to the four key dimensions: people, means, effects, and goals. Here, we proceed as follows: People – most of the contributions do not make people an issue and many implicitly assume that there is only one leader. We have only included research that explicitly addresses this issue. Means – we have reviewed insights into how leaders are supposed to act (conceptually) and also how they actually practice leadership (empirically). Effects - we have reviewed empirical insights into the effects of the different leadership styles on followers. Goals – we have reviewed empirical indications for the support of innovation-related goals by the different leadership styles. For instance, Elenkov et al. (2005) offer empirical indications that strategic/CEO leadership can be supportive to achieve organizational innovations. That strategic/CEO leadership is the only leadership style that has been associated with organizational innovation in this review does *not* mean that no other styles have the potential to do so, but that to date no empirical support has been given for any other leadership style to do so. We conclude each section with a "profile", summarizing the most important findings with regard to the four key dimensions of leadership.

3.1 Directive and participative leadership

According to Lornikova et al. (2013: 573), directive leadership "is associated with a leader's positional power and is characterized by behaviors aimed at actively structuring subordinates' work by providing clear directions and expectations regarding compliance with instructions." In contrast to that, Somech (2006: 135) defines participative leadership as "shared influence in decision making". In both cases, the final decision-making power rests with the leader. The main differences relate to both the extent to which leaders consult with followers and the extent to which followers are allowed to express their opinion in the decision-making process. We discuss both styles jointly in this section to compare insights regarding the impact of different forms of participation on innovation. Basically, directive and participative leadership are to be seen as opposite ends of a continuum. However, we acknowledge a potential confusion in the structure. In consequence, we have separated them as LS1a and LS1b in table 1, 2 and 9.

Research offers a few insights into the means, i.e. how directive and participative leadership are executed in innovation projects. In her case study, Kanter (1982) finds that directive leaders drive innovation processes by controlling, monitoring, instructing, and hierarchical influence. Somech (2006: 140) specifies that directive leaders provide "team members with a framework for decision making and action in alignment with the superior's vision." Burpitt and Bigoness (1997) found that participative leaders succeeded in encouraging team-level innovation by getting involved early, and staying involved throughout the entire project, but giving team members the freedom to develop new solutions at the same time.

Research on innovation provides evidence on the specific benefits of directive and participative leadership with regard to different innovation-related goals. On the one hand, research shows that directive leadership is particularly beneficial for establishing clear rules (Somech, 2006). On the other hand, several studies show that participative leadership stimulates creativity and the development of new ideas (Frischer, 1993; Nijstad et al., 2002). Possibly as a side effect of that, Yan (2011) found in a study of 201 companies that participative leadership generally raises the conflict level during the innovation period. This line of research gives the general impression that participative leadership is beneficial during the early innovation stages, whereas directive leadership may be required more in the later stages. With regard to innovation types, Stoker and colleagues (2001) found that participative leadership is particularly supportive for product innovations and R&D.

Table 1. Profile of existing research on directive leadership (LS1a).

People	Means	Effects	Goals
One leader (direct)	Controlling, monitoring, instructing, hierarchical influence Providing a framework for decision making and action	Establishing clear rules	Implementation

Table 2. Profile of existing research on participative leadership (LS1b).

People	Means	Effects	Goals
One leader (consult)	Freedom to develop solutions Early involvement in projects	Innovative climate Increased conflict level	Ideation Product innovation R&D

2 Interactive leadership

The concept of interactive leadership dates back to a study of female leaders by Rosener (1990). In this study, Rosener singled out four core characteristics of interactive leadership: encouragement for participation, widespread sharing of information and power, efforts to enhance self-worth of employees, and energizing employees for different work tasks. With regard to innovation, Bossink (2004: 216) has specified that the interactive leader "empowers others to innovate, cooperates with them to innovate and shows them how to become innovation leaders in the organization themselves." In this sense, not only individuals, but also teams can be empowered (Burpitt and Bigoness, 1997). However, in contrast to distributed and shared leadership, this empowerment is restricted (typically to a project or functional base) and still carried out under the control of the interactive leader. In this sense, empowered leaders act as delegates of the interactive leader.

Research shows that interactive leadership typically involves some kind of guidance, showing empowered employees how to innovate by coaching and providing them with other relevant support (Bossink, 2007). Markham (1998) found that interactive leaders have also used cooperative tactics to direct the activities of empowered employees. Regarding the effects, research demonstrates that interactive leadership is particularly suited to encourage followers to participate and contribute, and that this has a positive effect on the innovation climate, raising the general level of enthusiasm about innovation (Bossink, 2004). However, some researchers argue that this leadership style may not be sufficient for innovation due to its inherent lack of a specific future vision, and thus recommend carrying it out in combination with other leadership styles (1998; Norrgren et al. 1999).

Regarding the goals, research offers some evidence that interactive leadership does indeed contribute to firm innovativeness. In their investigation of 60 teams in 20 companies, Burpitt et al. (1997) found that teams have been most innovative when actively engaged and empowered. Bossink's (2004) case study gives some indication that interactional leadership can contribute to the success of innovation projects. There is no further specification of innovation stages or types, however.

Table 3. Profile of existing research on interactive leadership (LS2).

People	Means	Effects	Goals
One leader (delegate)	Temporary empowerment of individuals or teams Coaching, guiding, supporting	Encouraging participation Raising enthusiasm Emphasizing involvement Creating Commitment	Unspecified positive effect on innovativeness and innovation success

3.3 Charismatic leadership

According to Weber, charismatic leadership is "resting on devotion to the exceptional sanctity, heroism or exemplary character of an individual person" (1921/78: 215). In the same vein, Shamir et al. (1993) argue that creating a sense of collective identity is essential to being a charismatic leader.

With regard to the means of leadership, there is some solid empirical indication that charismatic leaders lead innovation projects primarily on the basis of their "behavior, beliefs, and personal example" (House et al., 1991: 336; see also Eisenbach et al., 1999). Personal engagement mediates this effect (Nohe et al., 2013). Several studies have reported that charismatic leaders typically attract followers by visualizing a promising future rather than creating dissatisfaction with the status quo (Nadler and Tushman, 1990; Ford and Ford, 1994; Pawar and Eastman, 1997).

There is ample evidence that charismatic leadership can increase commitment, generate energy, and direct individuals towards new objectives, values or aspirations (Nadler and Tushman, 1990; James and Lahti, 2011). Avolio et al. (1991) have noted that charismatic leaders create admiration, respect, loyalty, and a collective sense of mission. In accordance with that, other studies have established a positive link between charismatic leadership and perceived team innovativeness (Eisenbach et al., 1999; Paulsen et al., 2009).

However, there are strong indications that charisma alone is not sufficient to make innovations a commercial success (Nadler and Tushman, 1990). In a study by Bossink (2004), the failure of an innovation project was found to be related to the inability of a charismatic leader to participate in a knowledge network and collect professional information. Bossink further supports this finding in a follow-up study (2007: 140), finding that a charismatic leader was not able to "absorb useful information and knowledge during the project." These results support the conviction of many researchers that, although charismatic leadership supports the creation of an innovative mindset, it has to be complemented by other leadership qualities in order to ensure organizational transformation successfully (Bass, 1985; Nadler and Tushman, 1990).

Table 4. Profile of existing research on charismatic leadership (LS3).

People	Means	Effects	Goals
One leader (direct)	Personal example Visualizing a promising future Leader engagement	Creating commitment, loyalty and a sense of collective mission Generating energy Directing individuals towards new objectives Low absorption of information	Ideation Execution deficits

3.4 Transformational leadership

Transformational leadership was originally introduced by Burns (1979) and further developed by Bass (1985). It has generally been understood as a further development of charismatic leadership (Smith, et al., 2004); some studies even use the two concepts almost interchangeably (Paulsen et al., 2009). Yukl (1989) sees the main motivation of transformational leadership research in the conceptualization of an appropriate style to transform organizations. Against this background, transformational leadership is also the most actively researched leadership style with regard to innovations and change.

Much research has been concerned with the question of what leaders have to do, in addition to charismatic leadership, to master the innovation process successfully. Here, particularly Avolio et al. (1991: 22) have singled out that, besides “idealized [charismatic] influence”, “inspirational motivation”, “intellectual stimulation”, and “individualized consideration” are the most important elements of transactional leadership. Bass (1990b) emphasizes the necessity to work on goals jointly and to keep followers continuously updated. With specific regard to innovations, Howell and Higgins (1990) establish a link between transformational leaders and “champions” that envision and motivate others, have extraordinary personalities, know exactly what to do, and are able to take risks.

Research also offers various insights into the effects of transformational leadership on followers in an innovation context. They are very similar to insights into charismatic leadership since transformational leadership also increases self-efficacy, raises intrinsic motivation, and contributes to employees’ psychological empowerment (Gumusluoğlu and Ilsev, 2009; Paulsen et al., 2013); influences followers’ attitudes optimistically and creates an overall positive culture (McColl-Kennedy and Anderson, 2002); and raises followers’ performance expectations, transforms their personal values and self-concepts, and moves them to a higher level of needs and aspirations (Jung et al., 2003; Kahai et al., 2003). In addition, some authors have found that transformational leadership could increase the level of trust (Dirks and Ferrin 2002; Jung, et al. 2003).

Ultimately, however, there is no agreement about whether transformational leadership can fulfil its aspirations and overcome the shortcomings of charismatic leadership. Gumusluoğlu and Ilsev (2009) are rather positive, and argue that, in contrast to charismatic leaders, transformational leaders not only promote innovative activities within the organization, but also ensure their market success. However, Jamaludin and Rahman (2011) are much more skeptical. In a recent study, they conclude that transformational leadership seems to be more appropriate for stimulating creativity and generating ideas than for implementing innovations. Similarly, Nadler and Tushman (1990) suggest a combination of charismatic and instrumental leadership for organizational transformation, and Bass and Avolio (1994) a combination of transformational and transactional leadership. All in all, the strong link between transformational and charismatic leadership seems to reveal a basic common sense among many researchers, namely that innovations require strong, "charismatic" leaders which is in line with early concepts of entrepreneurship, e.g. Schumpeter (1934).

Table 5. Profile of existing research on transformational leadership (LS4).

People	Means	Effects	Goals
One leader (consult or delegate)	Personal example Visualizing a promising future Inspiring motivation Intellectual stimulation Individualized consideration Updating followers continuously	Increasing self-efficacy Raising intrinsic motivation Psychological empowerment Creating a positive culture and trust Raising performance expectations Creating needs and aspirations	Ideation Implementa-tion (?) Radical innovations (?)

3.5 Transactional/instrumental leadership

The key principles of transactional leadership date back several decades, however, the concept has been shaped together with transformational leadership by Burns (1979). While there have been intense discussions about the relationship between the two leadership styles (Bass, 1990b; Bass and Avolio, 1994; Jamaludin and Rahman, 2011), researchers agree that, unlike transformational leadership, transactional leadership is not focused on change. Its basic approach is to lead by clear definition and communication of work tasks (Avolio et al. 1991) and rewards and punishments, (Bass, 1990a; Eisenbach et al., 1999) focusing on the basic needs of the followers (Daft 2001). The concept of instrumental leadership is less widespread in research. Like transactional leaders, instrumental leaders also employ rewards and punishments, but focus more on goal-setting and control (Nadler and Tushman, 1990).

Research offers various insights into how transactional/instrumental leadership has been specifically applied to innovation projects. Daft (2001), for instance, found that leaders identify their followers' needs and design exchange processes based on these needs. Bass (1990b) proposes basing incentives on 'contingent rewards' (rewarding good performance and recognizing accomplishments) and 'management by exception' (active and passive search for deviations from existing rules and standards). Sillince (1994) suggests setting up clear goals, defining tasks and responsibilities, establishing standards, and also drafting action plans. In her case study, Bossink (2007) found that leaders hired external professionals to keep projects on track. Regarding the effects of transactional/instrumental leadership, studies show that followers indeed develop expectations about rewards that they receive in exchange for meeting a transactional/instrumental leader's expectations (Tracey and Hinkin, 1998), and that they act rather rationally in accordance with this (Deluga, 1990).

In general, transactional leadership is mostly seen as a means to keep things on track during the implementation phase (Howell and Avolio, 1993), and less suitable for the stimulation of new ideas (Pieterse et al., 2010). Thus, Keller (1992) stated that incremental innovations might be better led by transactional leaders, while radical innovations might be better led by transformational leaders. Sillince (1994) suggests that transactional leadership might be particularly suited to product innovations and R&D teams, since it helps achieve straightforward goals. However, Bossink (2004) presents a case where transactional leadership has worked during all the stages.

Table 6. Profile of existing research on transactional/instrumental leadership (LS5).

People	Means	Effects	Goals
One leader (direct)	Clear definition and communication of work tasks Contingent rewards Management by exception Detection of needs: reward and punishment	Forming clear expectations Rational optimizing of rewards	Implementation, task completion Incremental innovations (?) Product innovations (?) Ideation (?)

3.6 Strategic and CEO leadership

"The study of strategic leadership focuses on executives who have overall responsibility for an organization" (Finkelstein and Hambrick, 1996: 2). Several researchers have pointed to the particular importance of strategic decision-makers (and their hierarchical power) in advancing organizational innovation (Bossink, 2004; Michaelis et al., 2009; Makri and Scandura, 2010). The basic idea here is that CEOs and other upper-echelon decision-makers can use their institutional power "to initiate changes that will create a viable future for the organization" (Ireland and Hitt, 2005: 45).

With regard to the means of CEO/strategic leadership, findings point in two directions in particular: On the one hand, strategic leaders shape the organizational environment by creating organizational structures, processes, and a culture that support innovation (Michaelis, et al., 2009; Sternberg et al., 2004). On the other hand, strategic leaders serve important innovation roles in that they advance new ideas from the conceptualization phase to the development and commercialization phase (Sternberg et al., 2004; Wong, 2013), and devote substantial time to discussing technical matters and detailed designs (Nam and Tatum, 1989). Research has also shed light on the importance of personal traits that strategic decision-makers need to become successful strategic/CEO leaders. Elenkov et al. (2005) point to a person's ability to anticipate, envision, maintain flexibility, think strategically, and work with others, and Harmsen et al. (2000) to commitment and the ability to take risks. None of these authors mention charisma, which again underlines the difference between strategic/CEO and charismatic/transformational leaders. As regards the effects, Norrgreen et al. (1999) found that strategic/CEO leadership generally facilitates employees' innovative capabilities. Concerning the goals, Elenkov et al. (2005) provide some indications that strategic/CEO leadership is suited to supporting both product and organizational innovations.

Table 7. Profile of existing research on strategic/CEO leadership (LS6).

People	Means	Effects	Goals
One leader (direct or delegate)	Shaping organizational environment Advancing ideas	Enhance followers' competences and innovative capabilities	Implementation Product innovation Organizational innovation

3.7 Shared and distributed leadership

Both shared and distributed leadership challenge the (often implicit) assumption of previous leadership styles, that there is only "one person in charge and the others follow" (Pearce et al., 2009: 234). According to Pearce et al. (ibid.), "Shared leadership can be understood as a dynamic, unfolding, interactive influence process among individuals, where the objective is to lead one another toward the achievement of collective goals." In contrast, in the case of distributed leadership, there are multiple leaders within a group (Mehra et al., 2006). According to Harris (2007), the main difference between the two styles is that distributed leadership focuses on the allocation of power and management skills, while shared leadership focuses on the mutual influences among team members or team leaders.

In the case of innovation, research particularly emphasizes the importance of coaching and guidance in making sure that teams are on the right track (Muethel and Hoegl, 2010). Additionally, Friedrich et al. (2010) point to the importance of rewards in motivating distributed leaders, thereby establishing a link between distributed and transactional/instrumental leadership. Barry (1991) points to the importance of trust for distributed leadership. This trust relates to people, and not (as with transformational leadership) to a future vision. Hackman (1990) found that commitment is important for distributed leaders, but also that leaders have a dynamic and open attitude, expertise in managing autonomous teams, and strong communication skills. However, according to Barry (1991), the flip side of the coin is that distributed leadership is time-consuming and difficult.

To date, there are only few empirical insights into the impact of distributed leadership on innovations. Pearce and Manz (2005) argue that shared leadership appears to be especially important for continuous innovation; but there is no further specification of innovation stages or types.

Table 8. Profile of existing research on existing research on shared/distributed leadership (LS7).

People	Means	Effects	Goals
Multiple leaders (shared or distributed)	Coaching and guiding Rewards Commitment	Trust in people Negative: High effort	Continuous innovation

4 Discussion and conclusion

Table 9 lists the key findings of the previous sections regarding the four key dimensions: people, means, effects, and goals.

Table 9. Structured integration of insights into the different leadership styles in relation to innovation.

People		
One leader Direct (LS1a, LS3, LS5, LS6) Consult (LS1b, LS4) Delegate (LS2, LS4, LS6)	**Multiple leaders** Shared (LS7) Distributed (LS7)	
Means		
Inspiration Personal example (LS3, LS4) Visualizing future (LS3, LS4)	**Shaping the micro climate** Creating structure and Processes (LS5, LS6) Shaping the culture (LS6)	**Supporting people and projects** Coaching, guiding (LS2, LS4, LS7) Detection of needs, serving (LS4) Acquiring external expertise (LS5)
Involvement Leader involvement in projects (LS1b, LS3, LS4, LS5, LS7) Followers' involvement (LS1b, LS4, LS7) Empowering and autonomy (LS1b, LS2, LS4, LS7)	**Creation of innovative structures** Goal setting, tasks and responsibilities (LS1a, LS5) Directing (1a, 5); Controlling, monitoring (LS1a, LS5) Reward and punishment (5)	
Effects		
Attitudes Energizing, enthusiasm (LS2, LS3, LS4) Loyalty (LS3, LS4, LS7) Commitment (LS2, LS3, LS4)	**Mindset** Directing towards new objectives (LS3, LS4) Innovative climate (LS1b, LS3, LS4, LS7)	**Trust** In people (LS4) In structure (LS5, LS7) In visions (LS3, LS4)
Behavior Specific activities (LS1a, LS5) Involvement (LS2, LS3, LS4, LS7) Rational optimization (LS5)	**Negative effects** High effort (LS7) Increased conflict level (LS1b)	**Others** Enhancing of followers' competences and capabilities (LS6) Directing individuals towards new objectives (LS3)
Goals		
Ideation (LS1b, LS3, LS4) Implementation (LS1a, LS5, LS6)	Incremental innovation (LS5) Radical innovation (LS4)	Product innovation (LS1b, LS5, LS6) Process innovation (LS1a, LS6) Administrative innovation (LS6) Resistance, task completion (LS1a, LS5)
LS1a – directive leadership LS1b – participative leadership LS2 – interactive leadership LS3 – charismatic leadership	LS4 – transformational leadership LS5 – transactional/ instrumental leadership LS6 – strategic/CEO leadership LS7 – shared and distributed leadership	

The numbers relate the different entries in the matrix to the different leadership styles. For instance the numbers (LS2, LS4, LS6) after "delegate" indicate that this entry can be related to interactive leadership, but also to transformational, and strategic/CEO leadership. Thus, the entries for the different numbers correspond to those in the seven previous tables (they are not identical though, as they have been partly integrated in more general categories). Again, this table does not show potential or theoretical links, but only links that have already been established by actual research. In other words: That, for instance, incremental innovation does not show an entry for LS4 – transformational leadership – *only* means that research has not yet offered empirical support for this link and *not* that this link cannot be established.

Clearly, the different entries in the table are not independent of each other, so they cannot be seen as a toolbox to pick from at discretion. First of all, some of the entries logically exclude each other (like directing and consulting). Other entries do not logically exclude each other, but they are generally regarded as being inconsistent and have never been combined (like rewards and punishment and specific forms of intrinsic inspiration). Basically, there is a "downstream" dependency in that the means depend on the people, the effects depend on the people and means, and the goals depend on all other elements. In table 9, the different leadership styles appear as combinations of different entries ("patterns" of entries) that have been regarded as being consistent.

As a result, table 9 gives a structured overview of all options for people, means, effects, and goals that have been specifically investigated with regard to innovation management so far. Table 9 thus integrates the key findings from each partial review on specific leader styles' effect on innovation management. This overview first of all shows that many of the known leadership styles have already been explicitly linked to innovation. In this sense, research is already quite comprehensive. Yet, there are two more specific insights that can be drawn from the overview in table 9: First, transformational leadership is not dominating or even all-embracing with regard to innovation. There are several other, structurally distinct, leadership styles that have been positively related to innovations. In this sense, the findings of this review clearly reject the idea that there is only one specific leadership style for innovations. Second and closely related to that, there are strong indications that different innovation stages and types raise different demands on leadership and that the effectiveness of different leadership styles is relative to innovation stages, types and specific elements (like R&D or resistance). However, table 9 shows that this fit between leadership styles and innovation stages, types and specific elements has been specified very incompletely and there are many "blank spots". For example, none of the leadership styles have ever been explicitly related to market innovations; transformational leadership has been related to innovation stages (and here even with contradicting findings), but only very incompletely to innovation types, etc. In this regard, research is quite inconclusive. This first of all has important practical implications.

4.1 Practical implications

If the choice of leadership styles is relative to specific innovation stages and types and if this relation is poorly specified, then research fails to give a clear answer to the question of how to lead innovations. To date, research is scattered and only offers some indications that certain leadership styles (particularly charismatic and transformational leadership) seem better suited to inspire and motivate followers and that this has a positive impact on the ideation stage and also seems to spur radical innovations. Other leadership styles (directive and transformational leadership, possibly also CEO/strategic leadership) seem better suited to structure organizational activity and to overcome resistance, and therefore have a positive impact on implementation and possibly also on incremental innovations. But what is with the ideation stage of an incremental process innovation? Here, existing findings do not form a coherent picture: There are no findings for this specific case and the related, more general findings contradict each other ("ideation" speaks for charismatic and transformational leadership while "incremental process innovation" for directive and transformational leadership). This is problematic since the effects of leadership styles are substantially different and often even opposite. The managerial implication is that there is no one-size-fits -all solution, but the choice of the most appropriate leadership style is relative to the specific innovation goals to achieve.

However, research on leadership styles offers instructive insights regarding the specific effects of various means that are relevant for innovations. There are relevant insights on how to produce specific effects regarding attitudes, mindset, trust, behavior, competence creation, etc. For example, there is comprehensive research on how to energize followers with regard to innovation; and a clear link could be established with interactive, charismatic and transformational leadership. It has been investigated how this effect can be produced and what it means for innovations. There are also valuable insights about counterproductive effects, particularly with regard to high conflict potentials, effort, and absorption of information. Table 9 relates these insights to different research streams and can therefore be read like a 'practical' manual, helping managers to realize dimensions of the relationship between different leadership styles and innovation management.

In this regard, research fails to offer the big picture of how to lead innovations, specifying the fit between leadership styles and different innovation types and stages; at the same time, existing research is quite instructive regarding various effects of leadership and how these can be brought about.

4.2 Future research avenues

There is certainly an obvious need for much more research on the link between different leadership styles and different innovation stages, types, and elements. This is mostly an empirical question as it aims at establishing factual relationships. It still requires some explorative research to further detect existing links and mechanisms, but most of all quantitative empirical research to investigate the validity of causal structures. These research needs can be derived directly from the findings in table 9. They include, but are not restricted to, a comprehensive investigation of the fit between charismatic and transformational leadership and different innovation types (product, process, market, organizational innovation); a closer specification of the effects of interactive leadership with regard to innovation stages and types; an investigation and comparison of the effectiveness of different leadership types for market innovations. Also more empirical research is needed to substantiate existing findings on the fit between different leadership styles and the ideation and implementation stage of innovation.

There have already been some valuable contributions on this (like in Nadler and Tushman, 1990, and Bass and Avolio, 1994), but more research is still needed to specify the link between different leadership styles and possible interactions in innovation projects. This is first of all a theoretical question as it addresses the logical structure of the different styles. To specify the link between different leadership styles requires decomposing them into different elements. At this point the proposed "people-means-effects-goals framework" might be of particular use as it helps to distinguish different dimensions according to a coherent logical structure. Empirical research is needed to specify the effects of different combinations of leadership styles in specific innovation settings, for instance the effects of changes in the power structure in the course of an innovation project.

With the "people-means-effects-goals framework", this paper offers a structural foundation for future research as it structures the different elements of leadership and indicates relationships. In this sense, this paper offers a master plan – future research "just" has to fill-in the different fields. An important limitation of this review, however, is that contingency factors could not have been included. The reason for this is that the complexity would then increase to an extent that is impossible to handle in one paper. Seen from a systematic point of view, contingency factors enter the picture as they moderate the relation between the different elements of the table. Technically, this requires adapting the entries and relations (numbers) of table 9 to different contexts. There is quite some research investigating the role of contingency factors for leadership with regard to innovations (for a review of this research see Denti and Hemlin 2012). However, this research is too complex to be integrated in this review.

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Is Time Pressure an Advantage or a Disadvantage for Front End Innovation – Case Digital Jewelry

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Abstract. Time pressure is not usually seen as an advantage in front end innovation (subsequently referred to as "FEI"), but rather it is believed that ideas should be left to develop freely without a tight schedule. Instead of strictly formalized operations, creating ideas generally necessitates a certain level of freedom. The starting point for this research was to challenge this general view by imposing severe time pressure in FEI. The FEI process was reviewed from recognizing problems/creating ideas up until the selection of the best concept for further development. The research was executed as a qualitative in-depth investigation of a case. In the case, FEI took place over a three-week period, and the target for the FEI was to generate concepts of digital jewelry with business potential. The time pressure was seen as appropriate – with certain conditions – in FEI. The results also present the advantages and disadvantages of time pressure, combining it to the stress theory.

Keywords. Management of Human Resources, Co-development, Product Development, Digital Technology, Front End Innovation, Time-pressured Innovation, Innovation Management, Collaboration, Co-creation, Digital Jewelry, New Technology, Case Study, Stress Theory.

1 Introduction

Increased global competition, shorter product life cycles, and faster technological development have made a fast go-to-market strategy an essential competitive factor (Defee and Fugate, 2010; Langerak et al., 2010). As a result, speeding up innovation and development has become a critical objective of innovation management (Acur et al., 2010). It is important to recognize the success factors which help innovation and development projects succeed regardless of time pressure (Chen et al., 2010). Usually, process acceleration has been considered to be a factor that reduces the originality of innovations (McDermott and Handfield, 2000). Instead of the acceleration and formalization of the innovation process, flexibility has been seen as an important factor for success in radical innovations (Chiesa et al., 2009) – especially in front end innovation (subsequently referred to as "FEI") processes (Vandenbosch and Clift, 2002; Bierly, 2002).

The pursued quality of the ideas should be taken into consideration in FEI. Often the goal is to create 'great ideas' prior to deciding to begin the development work. However, there are opposing views on what the best goals are for FEI as part of an end-to-end innovation process for the full process to be as successful as possible. It is said that starting with a mediocre idea and testing its functionality quickly in the field of expected use case environments is more important than the creation of great ideas. With the feedback from the field, great ideas can surface iteratively. Therefore, the quantity of iterations should be increased to create great ideas. Of course, this depends on the context in which the innovation is performed (Sims, 2011).

Innovation work and activities have been studied a great deal at a conceptual level but in-depth context-sensitive information is still lacking (Langerak and Hultink, 2008; Crevani et al., 2011; Kach et al., 2012). Thus, there is a need for micro-level innovation research in which innovation is studied at a detailed level in a certain environment (e.g. individual field/organization), in a certain innovation target (e.g. product or process), in a certain phase of the innovation process (e.g. FEI), and regarding a certain innovation type (e.g. radical or incremental innovation) (Nobelius and Trygg, 2002; Langerak and Hultink, 2008; Crevani et al., 2011; Kurkkio, 2011).

In addition, at a detailed level, there is also very little research on how time pressure in FEI affects the outcomes. For example, what advantages and disadvantages are caused by time pressure related to the goal of FEI. This article focuses on this phenomenon by studying one innovation case with severe time pressure on FEI and examining the consequences. In the studied case, a heterogeneous group of 27 persons with different industrial and academic backgrounds radically created ideas and conceptualized new products, namely digital jewelry (Fig. 1.). Digital jewelry refers to electronics and information technology embedded in jewelry, which provides opportunities to produce new kinds of value for the users. Alongside the esthetic and emotional value of traditional jewelry, digital jewelry could have a strong functional value element, as well. Furthermore, digitalization may strengthen the traditional value elements of jewelry.

Fig. 1. Prototype of a digital effect jewel for the movie Iron Sky: The Coming Race.

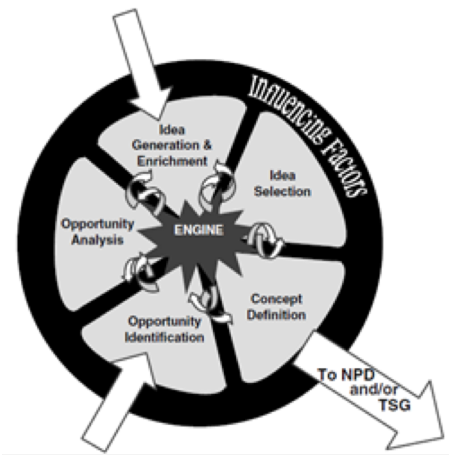
This article proceeds as follows. The following section examines time-pressured, collaborative and radical FEI based on earlier scientific literature, connected to the research of productivity vs. level of stress as part of the work process, and finally presents the theoretical framework applied in the study. This is followed by the research methodology. Subsequently, section 4 presents the background of the innovation case which was the target of the research. This is followed by the analysis and results of the case study. Then, the findings and the theory are discussed. Lastly, the conclusions and the need for further research are presented.

2 Time-pressured front end of collaborative and radical innovation

This section discusses concepts and theories important for the research context, including FEI as well as radical, collaborative and time-pressured innovation, with connections to the stress level vs. productivity research.

2.1 Front end innovation

Theoretically, an innovation process is divided into three main phases: FEI, development, and commercialization (Koen et al., 2002). FEI has evoked increased research interest (Björk and Magnusson, 2009), as it plays a significant role in the creation of innovations (Koen et al., 2002). On the one hand, FEI has been considered as the most difficult part of the innovation process to manage (Kim and Wilemon, 2002) because it involves a significant amount of uncertainty (Chang et al., 2007). On the other hand, decisions made at this stage will have a significant impact on subsequent phases of the innovation process (Apilo and Taskinen, 2006).



NPD =
New Product
Development

Fig. 2. Front end innovation for developing a new product concept (Koen et al., 2001).

Fig. 2 presents tasks included in FEI from the point of view of developing a new product concept. The process begins either with a recognized possibility/problem or a new idea (Koen et al., 2001) and ends in the decision to launch or not to launch an actual development project (Kim and Wilemon, 2002). In a FEI process, one essential part, is in fact, idea refining (Griffith-Hemans and Grover, 2006). Miller et al. (2006) emphasize the importance of refinement especially in the creation of radical innovations. Then again, the best innovations are not usually born from one idea but from the combination of different and multiple seeds of ideas (Apilo, 2010). The ability to combine ideas is, in fact, essential for good innovators (Dyer et al., 2011). In FEI, it is normal to make several go/kill decisions where the continuation of ideas is decided (Cooper, 2008). The evaluation of the ideas and decision-making can be supported by tools that include different evaluation criteria (Paasi et al., 2007). Especially at the end of FEI, ideas should be evaluated from multiple different perspectives, e.g. considering technological feasibility, user experiences and potential business revenues (Khurana and Rosenthal, 1998). An innovation process performed once is not usually sufficient in FEI, but the process must be iteratively repeated several times before a great idea is found (Sandmeier et al., 2004; Sims, 2011).

2.2 Collaboration

For innovation creation, the active engagement of network partners in collaboration is needed (Miles, 2000) since in this way the different experiences, knowledge and know-how of different people can be combined (Fay et al., 2006). Networking and interaction between people can collaboratively create ideas, which individual persons are not capable of creating by themselves (Wiseman and McKeown, 2010). In this regard, heterogeneous groups have been seen as an important success factor, especially for the creation of radical innovations (Dyer, 2011; Sims, 2011). Innovation research should, therefore, concentrate especially on network-level studies (Apilo, 2010), as networks possess considerable innovation potential (Crevani et al., 2011).

2.3 Success factors for radical innovations

Literature recognizes a wide array of success factors for incremental innovation (e.g. Filippini et al., 2004; Carbonell and Rodriguez, 2006). The success factors of radical innovations, however, have received less attention (Kach et al., 2012). This is a significant deficiency since the characteristics of radical and incremental innovations differ considerably (McDermott and O'Connor, 2002). Thus, the success factors will most probably differ, as well (Kach et al., 2012). For example, radical innovations usually include greater uncertainties and risks than incremental innovations (Calantone et al., 2006), and especially FEI is complex and involves multiple uncertainties (Vandenbosch and Clift, 2002). In addition, the high level of uncertainty and risks usually means that the utilization of formal methods to facilitate the innovation process is challenging (Li and Atuahene-Gima, 1999). McDermott and Handfield (2000) mention that the acceleration of innovation may e.g. weaken the originality of the outcomes. Instead of strict formalization, more flexibility is needed, e.g. in regard of given schedules (Chiesa et al., 2009). According to Kessler and Bierly (2002), the acceleration of the innovation process might fit into the realm of incremental innovation projects, but not that well into the area of radical innovations.

2.4 Time pressure in radical innovations context

Several studies do examine the acceleration of development (e.g. Kessler and Chakrabarti, 1996; Chen et al., 2010), but there is no comprehensive research on the effect of time pressure in the context of radical innovations. However, at least Kach et al. (2012) have studied the phenomenon and found different variables which explain the effect of time pressure on radical innovation. The variables are divided into three groups: antecedent, intervening and outcome variables. The theoretical framework they have built has been presented in Fig. 3.

According to the research by Kach et al. (2012), visionary leadership, maintaining project momentum, and team collaboration have an essential impact on the success of a radical innovation project. The leader helps to ensure the clarity and direction of the project and secures the commitment of people to the project. The project focus is maintained, as well as the creative and result generation. Through team collaboration, the members are ready to invest extra effort in order to achieve the goals in the desired schedule.

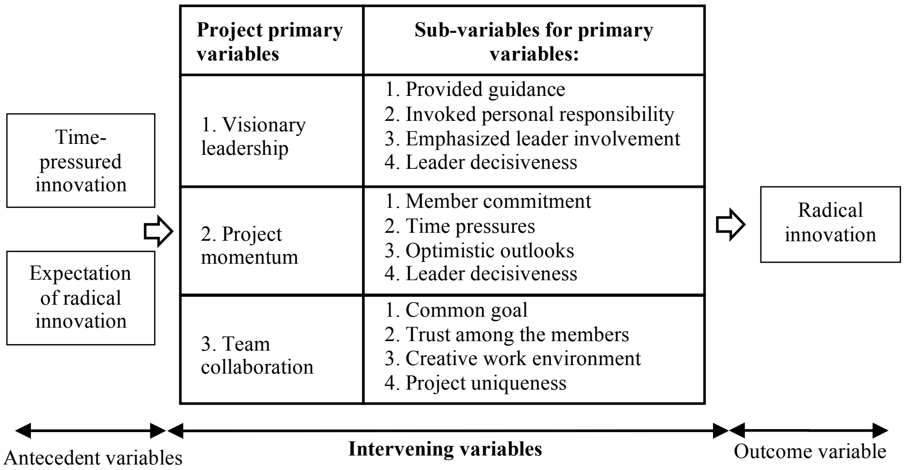


Fig. 3. Framework for time-pressured innovation in its development phase (Kach et al., 2012).

The research by Kach et al. (2012) focuses mainly on the *development phase* of the innovation process. In this article, the framework they have created for the development phase is applied to the *FEI phase* – in other words, an earlier phase of the innovation process. In the study by Kach et al. (2012), the miniature airplane had already been chosen for development, whereas in our research the target of the innovation process is to create a broad variety of different and new ideas about digital jewelry, where only one will be chosen for further development. The difference between these two research scopes is illustrated in Fig 4.

Fig. 4. Differences of the case studies, based on the phase of the innovation process

Both these studies do focus on radical innovations, implemented collaboratively under a time pressure. Related to Fig 4, it is also important to note that the acceleration of the innovation process is also possible with radical innovations, but it is not clear how far the acceleration can be applied without problems. The illustration does present a distinct point between FEI and the development phase, but in reality the changeover point might not be that clear. This fuzziness of the change point can make the decision of when and where to apply time pressure and acceleration quite difficult. To facilitate these decisions, the effects of time pressure and people's acceleration-related stress levels in the work groups should be known by the team leaders.

2.5 Theory of the effect of stress related to productivity and outcomes

Stress as a term is highly subjective, which means in principle that the term defies definition. Nevertheless, e.g. Selye (1936) defined stress as "*the non-specific response of the body to any demand for change*", showing with numerous laboratory animal experiments that by subjecting them to acute but different noxious physical and emotional stimuli (e.g. extreme noise levels) all test subjects exhibited the same sort of pathologic changes indicating higher stress levels. From the research point of view, in this time-pressured FEI study, it was important to understand how time pressure stress impacts people participating in a time-pressured FEI process. For example, could a certain amount of stress applied into the innovation process be advantageous in terms of the outcomes, without harmful side-effects, as e.g. Selye was already suggested in 1936?

Stress is typically seen only in a negative light; some older dictionaries even define stress as "*a condition or feeling experienced when a person perceives that demands exceed the personal and social resources the individual is able to mobilize*". This negativity overweighs the possible positive side-effects stress might have. Luckily we currently know that stress can enhance performance, and it can motivate people to accomplish more than otherwise would be possible. These positive sides of stress are reflected e.g. in the research of Nixon (1979), with a model relating performance to stress arousal levels. The model presents a certain comfort zone and a zone above the comfort area where added stress continues to assist performance without generating adverse effects, as show in Fig. 5.

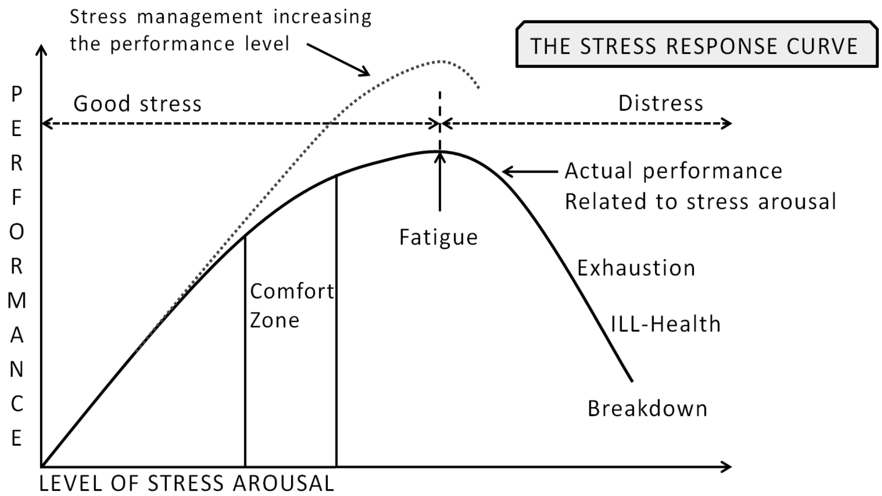


Fig. 5. Relationship between the level of stress and performance depicted in the form of an inverted U-curve. Based on the work of Nixon (1979), illustrating the effect of stress management methods on performance.

What makes the relationship between stress and performance so interesting, especially in FEI and the time pressure context, is the research work following Nixon (1979), relating stress properties to human reactions to it. For example, according to Tache and Selye (1985), nervous and hormonal responses to stressors aid the survival of an individual. It was believed that the demand-induced neuro-hormonal changes in the body are carefully balanced to enhance the organism's capacity to meet challenges. Consequently, the neuro-hormonal changes would also be adaptive, which is in line of basic assumption that only part of a person's behavior is written in genes and the rest is dictated by our actions and by the environment. Considering high stress levels and the breakdown point, Nixon's (1979) model suggests extreme end results for extreme amounts of stress. Related to that, Simonton et al. (1978) and Goodkin et al. (1986) have suggested a direct connection between stress and e.g. cancer and heart disease (Matthews and Glass 1981).

In this study, the stress in the FEI process is directly related to the level of uncertainty felt by the participants towards the feasibility of a task in a given time. Time pressure was not believed to be the explanation to the stress level. In fact, the explanation was believed to be the level of uncertainty related to the time and task given to the participant. This interconnection of stress and uncertainty relates to the way McEwen and Stellar (1993) model biology and behavior. Responses that are stressful result from the interpretation of, and behavioral and physiologic responses to the environmental challenges. They state that a challenge may be stressful to some and less or not stressful at all for others. Also based on the work of Gunnar and Quevedo (2007), in general, some people succumb and others thrive when they are confronted with similar challenges.

The above-mentioned challenges change the "rules of the game", which consequently changes the quality of life and conditions surrounding a person. In situations like these, McEwen and Wingfeld (2003) state that people undergo physiological changes as a response to the challenges. These changes are an attempt to restore the optimal state, e.g. through a launch of immune responses. In a low frequency, these changes are not dangerous or harmful, but in dramatic loads and attempts to achieve stability, an overload is possible, which may result (McEwen and Wingfeld, 2003) e.g. in the development of mental and physical illnesses through effects on the body and brain.

This study expected to witness people starting to manage their stressful events, increasing their performance level as shown in the adapted model of Nixon (1979) in Fig. 5 (better performance through stress management). By applying stress management methods to repeated stressful events, participants should start to perform better when the study continues. This is of course assumed to happen only if the stress is not related to well-known, deeply ingrained personal habits, which are difficult to change (e.g. Adams, 2003). Similarly, a higher tolerance to stress might develop e.g. if a person is under significant stress due to an outside output or requirement without the tools and means to manage the stress. With guidance, education and mentoring from outside, the person can learn to manage the particular requirements. With help, the stressful situation is changed into a more commonplace requirement, which makes it easier to cope with. As a practical example, when a person is learning to drive, public roads may be a very stressful environment. Later on, when the driving process becomes more familiar, driving itself will become less and less stressful. Through this learning process, the driver can focus more on the quality of driving, and his or her performance on public roads is improved.

3 Planning the research

The first aim of the research was to identify the advantages and disadvantages of time pressure in collaborative and radical FEI. The second aim was to evaluate the fit of the theoretical framework of Kach et al. (2012) in the FEI context, which precedes the development phase for which the framework was originally developed. As third aim of the research, was to research the balance between added stress and time pressure and the relative productivity and creativity of the participants. This is then reflected with the theoretical context of stress related research, to support the main aim of the research.

The research was performed as a case study of one FEI project, where the success of the project was measured on the Likert scale from a quantitative and qualitative (radicality of ideas) viewpoint with the following questions:

- How radical is the best concept created in the project? Radicality was defined based on the importance of problems the concept could solve.
- Aside from the winning concept, were some non-winning ideas or concepts discarded too early during the FEI process?
- Number and radicality of rough ideas.
- Number and radicality of conceptualized ideas.

The above-mentioned questions were answered by the four members of the project team months after the project had ended, at which point some distance had been attained to the project. The respondents played different roles in the project: one was a visionary leader, one an operative and artistic leader, and two were idea creators, idea refiners and experts.

Furthermore, these persons also qualitatively evaluated how they experienced the progress of the project. This evaluation took place from the viewpoint of the intervening variables presented in Fig. 3. The research data was created with the self-documentation method, i.e. all four persons wrote down their own views of each intervening variable independently of each other. Self-documentation is one sub-method of interviews (Hyysalo, 2006). The self-documentation form is presented in Appendix 1.

The implementation and outcome of the project were also evaluated by an outside evaluation group: an industrial steering group. The group's task was to ponder how the implementation and outcome of the project could have been improved. The evaluation group was composed of altogether 12 persons, whose task was to provide qualitative answers to two questions:

- What would you have done differently?
- What question did the implementation and outcome of the project especially invoke?

In the data analysis, the most recurrent similarities and greatest differences in the answers of the four respondents were identified and examined. In the case of divergent views, reasons behind the different views were evaluated by interviewing the participants. After this, the cause and effect relationships of the intervening and outcome variables were examined, i.e. which intervening variables especially affected the outcome variable, i.e. the radicality of the project's output. Finally, the views of the innovation group and the industrial steering group were compared. The presented research results are the advantages and disadvantages created as a result of time pressure in a collaborative FEI, taking into consideration the stress level experienced during the project. In addition, the research results assess the suitability of the theoretical framework of Kach et al. (2012) for the FEI process.

4 Description of the innovation project

In this approximately three-week long project, the innovators were industrial representatives (especially form the jewelry industry), researchers, academics from universities and students in polytechnics. The participants came from six different departments/knowledge areas: the jewelry industry, business, industrial management, ICT, mechanical engineering, and art. Thus, the innovation group members had very different backgrounds and areas of know-how. The age range was between 20 and 45 years. The outcome (concept) evaluator was a serial entrepreneur, who had no ties to any of the participants or their organizations. Fig. 6 presents the innovation group and its most important interaction relationships.

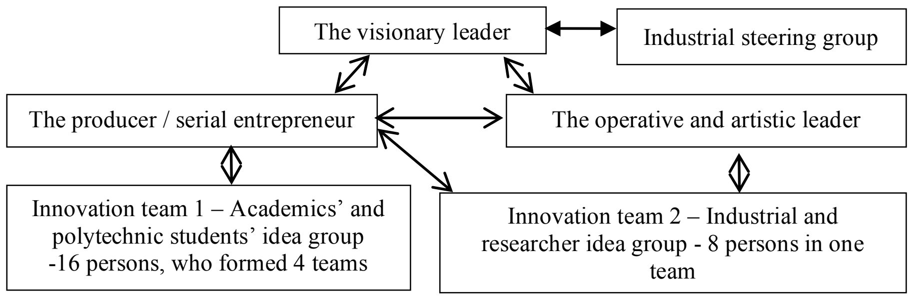


Fig. 6. The innovation group and its most important interaction relationships.

The visionary leader gathered and organized the project group, set the goal and schedules for its activities, and gave a briefing (shown in Fig. 7).

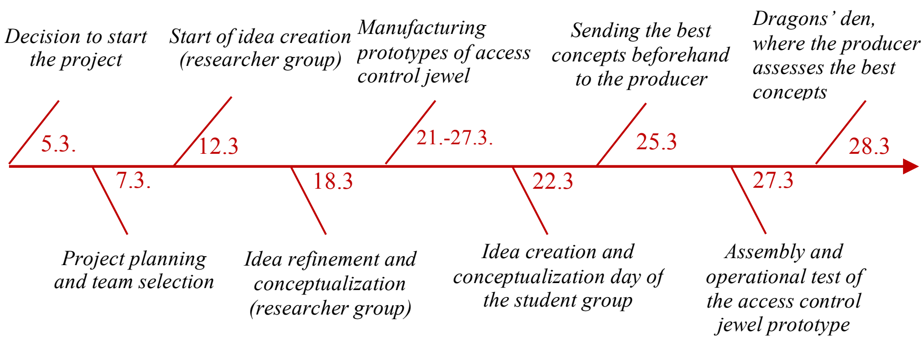


Fig. 7. Schedule and main events of the FEI project.

The goal was to create 5 to 10 quality ideas for the dragons' den, where ideas suitable for further development and commercialization would be chosen. The visionary leader did not participate much in daily operations, which were run by the operative leader, according the guidelines given by the visionary leader. The idea creation and conceptualization by the innovation team 1 was quite intensive, as it only last a day. The idea creation and conceptualization of innovation team 2 consisting of industrial representatives and researchers was carried out over approximately a two-week period.

As a whole, the innovation team 2 spent approximately twice as much effective working time on creating ideas than the innovation team 1.

During the project, the innovation teams 1 and 2 created altogether 203 rough digital jewelry ideas. A total of 27 conceptualized ideas were created and 23 concepts were delivered to a producer prior to the dragons' den. The serial entrepreneur (dragon) chose five concepts for the dragons' den. Four of them came from the innovation team 1 and one from the team 2. The ideas that proceeded to the final stages were: mosquito/tick repellent jewel, access control jewel, sleep jewel, baby monitor jewel, and a flower stick indicating the need to water a plant. On the basis of business potential, feasibility, and the user viewpoint, the producer finally chose the access control jewel as the best concept. Fig. 8 presents the idea creation process as a funnel image from the perspective of selecting the most feasible ideas and concepts and making go/kill decisions of ideas and concepts.

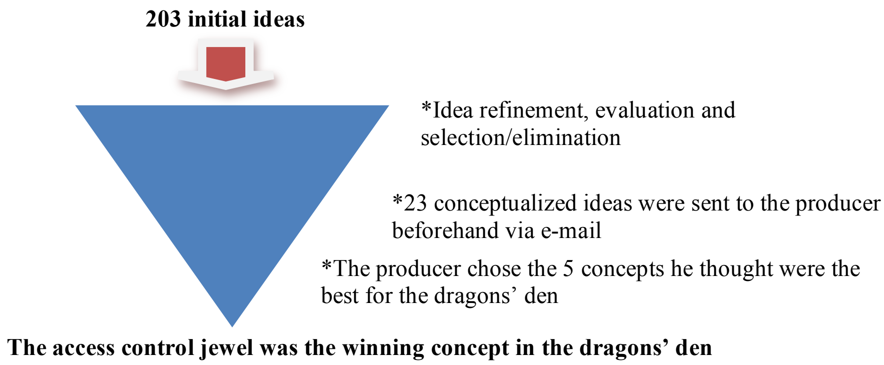


Fig. 8. Idea funnel of the innovation project.

Fig. 9 illustrates the winning concept, the access control jewel. From the left: a 3D model, quick prototype, and operational test. The frame of the prototype was made with a 3D plastic printer. A RFID tag was placed between the frame and jewel stone.

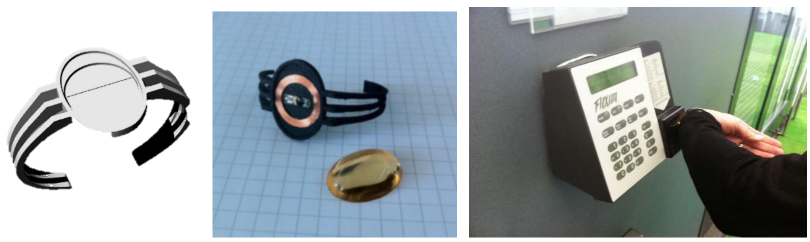


Fig. 9. 3D model, quick prototype and operational testing of the access control bracelet.

In addition to a bracelet, quick prototypes were also made of a ring and a tiepin. In the dragons' den, the serial entrepreneur stated that a killer solution would have been an access control wedding/engagement ring. The prototype tag would have been too large for the ring, but smaller tags are already available at the market. A weak market test was later conducted for this idea by presenting it to a lead designer of a jewelry factory, who saw potential in the idea. In fact, the designer started to develop new vision of the concept for busy people with a difficult smoking habit.

5 Analysis and results of the innovation project

This section presents the analysis and results of the studied innovation project. The first subsection examines the outcome variables and the second subsection examines the intervening variables from the viewpoint of the FEI project participants. In the third subsection, the innovation project is evaluated based on the feedback provided by the industrial evaluation group.

5.1 Outcome variables – Quantity and quality of the created ideas and concepts

The four participants in the project were asked to answer five questions on the Likert scale (Appendix 1), measuring the success of the project. The answers are presented in Table 1.

Table 1. Evaluations of the quality and quantity of the created ideas and concepts.

Indicator	*Visionary leader*	*Operative leader*	*Idea creator 1*	*Idea creator 2*
Radicality of the winning concept	3	3	2	3
Possibility for an outcome more radical than the winning concept	4	5	4	4
Number of initial ideas	4	4	3	3
Radicality of initial ideas	2	2	2	2
Number of conceptualized ideas	5	4	4	4
Radicality of conceptualized ideas	3	3	3	3

The participants of the innovation project largely agreed on the results of the project. With regard to radicality, the winning access control jewel concept was considered satisfactory. Everyone believed that it would have been possible to create a more radical outcome based on other ideas or a combination of them. The number of rough ideas was considered high, given the time to innovate. The radicality of the initial ideas, on the other hand, remained at a tolerable level. The quantity of conceptualized ideas and their radicality was considered satisfactory. It is noteworthy that the radicality of rough ideas and conceptualized ideas was seen as tolerable and satisfactory, but it was believed that good or even excellent concepts could be derived from them. In practice, this means that the participants thought that the initial ideas could have been improved, but this would have necessitated further refinement of the ideas as well as combining different ideas.

5.2 Intervening variable inspection

Next, views on the course of the project of the visionary leader, the operative leader, and the two idea creators who participated in the FEI project are presented with regard to the three key variables as well as their sub-variables (framework in Fig. 3). The most similar and divergent views of the group have been highlighted. After the examination of the three key variables, Tables 2-4 present direct quotes from the participants regarding the different sub-variables.

Primary variable - Visionary leadership. *Sub-variable 1. Guidance – providing clear project understanding*. The visionary leader issued clear goals, instructions, duties, and checkpoints, which held the project together. The outside serial entrepreneur was also committed and given a role in the project by the visionary leader. The operative leader became a part of the project in a somewhat surprising manner. The visionary leader asked the innovation team 2 who would be willing to take on the role of an operative leader. The newest member of the team was the most enthusiastic. One goal of the project was to make prototypes of an earlier idea, the access control jewel. Later it became apparent that this choice was both an advantage and a disadvantage. The advantage was that the concreteness motivated people – "*Hey, this works!"* The disadvantage was that the access control jewel rose to a privileged position compared to the other ideas. Then again, the prototypes could also make it more difficult to receive follow-up ideas, as the idea was considered to be "finished". The level of description of the ideas varied significantly between the idea creators, so more instructions would have been needed for this. The visionary leader gave the operative leader the final go/kill decision for the idea. Retrospectively, more joint discussions would have been needed inside the group in decision-making situations. Furthermore, in the project's checkpoints the evaluation of ideas easily focused more on feasible rather than radical ideas. The visionary leader should have emphasized the pursuit of radical ideas from the very beginning.

*Sub-variable 2. Responsibility – taking personal ownership***.** Both the visionary leader and the operative leader were very committed to the project. Without their complete commitment the project goals would not have been reached. This inspired some other group members to strive towards the same. However, all participants did not comprehend what the leader was after, which caused frustration and, therefore, a varying level of participation and ideas. Furthermore, not everyone considered the theme of digital jewelry as sufficiently inspiring.

Sub-variable 3. Leader decisiveness – to provide direction, not to control. The direction, goal and schedule had been provided, but in other regards the idea creators were free to work as they wished. In the end, there was relatively little communication between the team members although the operative leader encouraged it. For some, the use of e-mail in refining ideas was problematic. Not everyone produced the requested amount of rough ideas. This revealed that not everyone was wholly committed to the project. Then again, 85% of the persons produced the requested number of rough ideas and participated actively in the refinement of ideas and conceptualization. There were more commitment problems in the innovation team 2. The amount of work necessitated by the project also came as a surprise to some. From the start, everyone should have been asked personally whether they could fully participate in the project and how enthusiastic they were. The operative leader was very decisive in considering idea viability and making the go/kill decisions. Too decisive, according to some, as the rest did not have enough say in the matter. This may have weakened the motivation of the rest of the group and distorted the end result.

Table 2. Quotes related to visionary leadership.

Sub-variables	Quotes
Provided guidance	*-I Tried to keep things as clear and simple as possible because of the tight schedule -Without hesitation I immediately announced my willingness to take on the role of operative leader.* *-Unprejudiced attitude and encouraging instructions of the visionary leader convinced me that the project would succeed.* *-At most 75% of the decisions should have been made by the operative leader and at minimum 25% by others.*
Invoked personal responsibility	*-I wanted this to work.* *-As an operative leader, I was very committed and highly motivated. I was active as I desired to prove to the prejudiced team that an artist is not just a bohemian walking around with a beret on his head.*
Leader decisiveness	*-I didn't have to interfere in matters much since mainly everything worked smoothly. My only concern was that the group didn't work together enough.* *-In retrospect, the project flow would probably have been considerably better if a common spirit would have been achieved through meetings.*
Emphasized leader involvement	*-After the initial instructions, I gave the operative leader free reins. I helped a couple of times after being asked to.* *-Between the work stages there should be a time during which there would be no communication messing up the process.* *-Couldn't stay away from idea creation once a reasonable idea had been created.* *-In order to achieve the planned goals, I had to do a lot myself. Activating less-motivated members would probably have taken up precious time.*

Sub-variable 4. Leader involvement – hands-off but attuned. The operative leader participated closely in the operations, as was the purpose. At the same time, the leader let the group work in peace and did not interfere in their activities. However, the operative leader carried too much responsibility especially regarding the refinement of ideas and conceptualization. The others were free to work in peace partly due to the fact that the operative leader carried out other people's work, as well. Some would have wanted to know the deadlines in more detail, meaning that the timetable provided in the beginning was not clear to everyone. The visionary leader supported the operative leader when the rest of the team did not provide the necessary input. Furthermore, the visionary leader participated a little in the idea creation. One idea of the visionary leader was refined the most enthusiastically by the group – it is unclear whether this was due to the quality of the idea, the way it was presented, or the leader's surprising participation in the team work.

Primary variable 2 – Project momentum. *Sub-variable 1. Member commitment – to an important and rare opportunity.* The innovation of digital jewelry was an interesting new subject for many, as was the possibility to have ideas assessed by a serial entrepreneur. However, there were quite remarkable differences in the commitment of the group members – especially in the innovation team 2. It is important to find people who are genuinely enthusiastic and have time for the project. This has to be made clear already before the project begins. Then again, beforehand the work started, the work time loads did seem to be favourable with almost everyone.

Table 3. Quotes related to project momentum.

Sub-variables	Quotes
Member commitment	*-Surely it wasn't nice for those who, due to a lack of time, couldn't carry out the agreed tasks in full.* *-The committed participants were fully involved.* *-For some, the anticipated and realized working time resources didn't match at all.* *-Considering the starting point, the commitment and outcome were at a surprisingly high level.*
Time pressures	*-We did get the job done, but at the expense of the quality of the ideas.* *-Could we have utilized something in idea creation that would've guided our thoughts to new paths?* *-Working together towards a common goal would have been necessary to reach better results.* *-There was pressure to focus more on quantity than quality and that was seen in the outcome.* *-Group meetings would have been needed, but we couldn't find the time.*
Optimistic outlooks	*-The project didn't feel like work as it was so different from the rest of the typical duties during a working day.* *-Although we were busy, no one complained much. Having to work in the evenings as well as the operative leader's too big role in decision-making caused some grumbling.* *-Participants with a positive attitude helped to cope with the trouble of dealing with those who lacked commitment.*
Leader decisiveness	*-There wasn't even time to ponder irrelevant matters; we just had to go for it.* *-Somehow we could sense it from the very beginning, that this could be done.*

Sub-variable 2. Time pressures – limited time as an asset. Time pressure was an asset in that the members did not get stuck on trivial matters. They pushed forward and were inspired by the achieved intermediate results. Then again, especially at the stage of refining and combining ideas the schedule was too tight, as a result of which some members had to work during evenings and weekends as well. This surely influenced their energy levels and, eventually, also the quality of the ideas and concepts. At that stage, it was seen that the stress became excessive, affecting the results and also some follow up work too. In the end, the busy schedule probably prevented the creation of any truly great idea. In addition, the members would have wanted methods or tools to promote the creation of ideas. In practice, the participants were not provided any, which may have been a crucial mistake. They would have been useful especially in the joint sessions. Due to the high time pressure, working together was generally insufficient, participants pursued the goal set and when they achieved it, a new goal was already given. With regard to the outcome, there seemed to be no considerable difference in the innovation team's one-day-long idea creation and the longer idea creation period of the innovation team 2. The concepts created by the innovation team 2 were, however, slightly better described.

Sub-variable 3. Member outlook – optimistic. The enthusiasm and positive attitude of the committed group enabled the completion of the project. In addition, many saw the dragons' den and meeting with a serial entrepreneur as an important motivator, which further increased their performance.

The optimism of some members was weakened by the lack of time, which led to working during the weekends and evenings as well as unfinished work, and was later on also reflected in the stress level vs. performance analysis.

Sub-variable 4. Leader decisiveness – quick and effective. The leader was very determined, which partially helped to see the challenging process in a more positive light. This motivated most of the others to adhere to the deadlines. It was also noted that in this type of FEI process, it seems to be better to make quick and, at times, poor decisions than not to make any decisions at all.

Primary variable 3 – Team collaboration. *Sub-variable 1. Common goal – Let's achieve great results***.** Regarding the schedule, the goal was clear since a date had initially been set for presenting the created concepts in the dragons' den and for choosing the best concept. What was less clear was what level of ideas and concepts pursued. The visionary leader was not so worried about this – if everyone would do their best, the outcome would be successful and provide a good starting point for FEI. On the other hand, the pursuit of radical ideas should have been emphasized more. In addition to digital jewelry, some other ideas were created. However, they were somehow mainly related to ornaments. When making prototypes for the access control jewel was added to the goal, this motivated some group members – especially as it was known that this would require working together. All in all, the goal was challenging but still realistic. The visionary and the artistic leader boosted faith in the project with their own behavior.

Sub-variable 2. Trust – there is no time not to trust one another. The project proceeded smoothly without greater friction between the participants. It was generally easy to present and comment on ideas; the atmosphere was relaxed. The members of the innovation teams already knew each other, which had an impact on the matter. Then again, especially the team 2 had not worked together extensively, and the operative leader was a complete stranger to many. Trust was established between the visionary and the operative leader immediately during the first meeting. However, the operative leader experienced a lack of trust from some group members. This may have been the reason why these members were indifferent towards the checkpoints and requests for urgency. Also the fact that the people were busy had an impact on the matter, as was previously mentioned. The lack of face-to-face group meetings during the first half of the project in part weakened the building of trust. Ideas and concept descriptions delivered late meant rush work for the operative leader at the end of the project. Still, the leader managed to keep to the schedule. Thus, if not even earlier, by this point the operative leader had managed to earn the members' trust. During the final meeting with the serial entrepreneur, the whole group had a very open discussion.

Sub-variable 3. Work environment – beyond the call of duty. As a whole, the work atmosphere was good. This was facilitated by the fact that the goal and the roles of the group members were quite clear. Some were bothered by the fact that they could not participate in a way necessitated by their role. For some, it was not convenient or even possible to work during evenings and weekends, which was at times called for. On the other hand, the matter can be reversed, i.e. if the members wanted to invest in the matter during evenings and weekends, they found the project very interesting. The operative leader was bothered by the indifference of some members regarding schedules and the quality of ideas. On the other hand, operative leader was a new member in the team and as such did not have as many other responsibilities as the other participants did, which might have made the operative leader incapable of making this evaluation objectively.

Sub-variable 4. Project uniqueness – one of a kind. The project was a unique experience to nearly everyone. For many, the exceptional speed, challenging goal, and working together in a group were as important or even more important than the actual target of innovation, i.e. digital jewelry. The icing on the cake was the presence of the serial entrepreneur. In fact, after the project many members said that they had never been involved in something like this before.

Table 4. Quotes related to team collaboration

Sub-variables	**Quotes**
Common goal	*-At first, the whole sprint seemed extremely challenging, almost impossible for some. Especially making the prototypes generated more challenges.* *-Some seemed to be a bit lost regarding the level of ideas sought for.*
Trust among the members	*-Trust was created also with the producer, and assessing the ideas with the producer was one of the best experiences in the different projects.* *-It felt like many members didn't take me seriously. Perhaps this was because I'm a strange guy with long hair and, on top of everything else, an artist.*
Creative work environment	*-Completing the project was fun and interesting, which boosted performance.* *-Among those committed to the project, the atmosphere was good, but at least I was annoyed that some people didn't respect the schedules.* *-Testing idea with an outside producer did challenged many to over-perform.*
Project uniqueness	*-As success factors, the uniqueness of the project was, alongside a beforehand created framework, the most important key to success.* *-The uniqueness of the project could be noticed from the fact that most of my free time was spent on this project.* *-A very educational, interesting, and unique experience.* *-The icing on the cake: a good and refreshing exception to everyday routines.*

Summary of the intervening variable analysis. With regard to all three primary variables, visionary leadership, project momentum, and team collaboration, things could have been done better. However, better leadership could have reduced problems in project momentum and team collaboration. But then again, three weeks was a very short time. Things were a little confusing right from the start as the visionary leader who started the sprint handed the responsibility over to the operative leader.

In the studied FEI project, time pressure was a double-edged sword. On one hand, it created exceptional movement and experiences of success in the innovation group. It had to be proven that viable ideas can be created in a short time. On the other hand, the outcome, i.e. the access control jewel chosen as the best concept, was considered merely as a satisfactory concept. However, the number of rough ideas was considered good, which supports the view of the Nobel laureate Linus Pauling, according to whom the best way to achieve good ideas is to create a lot of ideas (Dyer et al., 2012). Thus, the possibility to create great new ideas by combining ideas already generated grows exponentially. Nevertheless, in the studied project, ideas were not refined and combined enough, as a result of which the concepts were largely created merely by describing the initial ideas in more detail. In fact, the added stress level and lack of time in the middle and later parts of the project seemed to prevent working on and combining the ideas further, which consequently seemed to have a negative impact on the outcome of the project. Therefore, the time pressure might have a negative impact on the results if the process is not facilitated to allow or force participants to combine ideas. Perhaps the set timelines also directed too much attention to the number of ideas and on the deadlines instead of the refinement of ideas, leading the members to be satisfied simply with keeping to the schedules and meeting the numeric goal of ideas. The analysis of the project revealed that when planning the project, some participants overestimated the time they could actually spend on the project. This is quite a typical problem in a matrix organization (Dyer et al., 2011). Secondly, the leadership of the innovation project was not able to anticipate and sufficiently communicate how much working time the project would require. As for future research, the effects of the right leadership methods on radical innovation productivity in FEI should be studied more. For example, time pressure in FEI with operative leadership that push very hard to pursue a goal of high idea amount, but then realizing the importance of mentoring to use different tools to combine and add idea radicality. In short, the ways to make ideas better is more important goal to learn than to just purcue towards added amount of ideas.. According to Rehn (2012) a large number of ideas is necessary, but leadership approaches must be carefully thought through to be able to support people in pushing themselves to generate a large number of ideas.

However, a lack of time in itself does not explain the satisfactory level of the outcome. One clear reason for this was that the members strived to improve the ideas largely via e-mail. Only one joint face-to-face idea creation meeting was arranged prior to the meeting with the serial entrepreneur. Because of these working models, different people, ideas and thoughts did not meet very much at all. Rather, individual ideas were further refined during FEI. Genuinely enthusiastic interaction occurred only a few times between the group members. In addition, the persons who were not fully committed to the project had a negative impact on others. It would have been better to exclude them from the project altogether. Another important reason for the unsatisfactory outcome was the lack of methods offered to participants to support the innovation process. Refining and combining ideas was managed by dialogue, which alone does not seem to be enough – especially as the discussion was usually only directed at one idea at a time. Furthermore, creative work in general was unfamiliar to some. The third reason seemed to be as simple as the fact that some group members were used to work alone and not in a group. In practice, this could be seen in that they did not listen to each other enough and in this way raise the discussion to new levels. To remedy this, the previously mentioned support methods for innovation would be beneficial. In addition, a transparent idea evaluation template was missing altogether. The power of decision was in the hands of few and the grounds for the decisions were not sufficiently visible apart from the dragons' den. The decisions were largely based on favoring ideas that were feasible with current skills, which ate away at the radicality level; ideas were selected more based on their feasibility than their superiority, without even considering possible challenges in implementation.

Was the three-week-long project too short for the creation of a radical digital jewelry concept? Answering this question unambiguously is difficult. Firstly, without the views of actual clients the FEI group cannot say whether the access control jewel concept has great business potential or not. A weak market test was later on conducted by presenting the idea to a lead designer of a jewelry company, who saw potential in it. From the point of view of many people who wear jewelry the concept does seem to be very radical. This became apparent later when potential customers were asked about their viewpoints. Thus, the next question is whether there would be demand for access control jewels or not. This can only be known if the concept is commercialized and sales begin. The project group believed that the initial ideas could have been made into a more radical concept but, in this case, it would have required more and different kinds of idea refinement and combination work. This would also have necessitated more time, but first and foremost, a wider range of working and decision-making methods. In addition to time and working methods, also people from completely different cultures and education backgrounds could have been selected to be part of the FEI project to support positive idea collisions.

On the other hand, satisfactory results were gained in a very short time. With results like these, it might be just the right time to test a mediocre concept (of which the prototypes already exist) in the field. For example, Sims (2011), Sarasvathy (2008) and Leppänen (2013) all think that even mediocre concepts are worth testing in the field. Field testing provides valuable feedback, and even if the tested idea does not work, it still may lead to completely new ideas. Activities like these are natural for entrepreneurial behavior, i.e. effectuation (Sarasvathy, 2008). From this perspective, time-pressured innovation worked well. And as motion and iteration are important in innovation (Sims, 2011; Sarasvathy, 2008; Sandmeier et al., 2004), there is nothing preventing the refinement of the created rough ideas or combining them with new ones.

Finally, learning from the implemented innovation project is important. The following time the group will be better prepared for planning, leading and implementing a project, but does this mean that the outcome will be better? What happens if the composition of the group is modified, changing the range of know-how available? What if the decision-making criteria and the decision-makers are changed? Merely one extra joint session lasting a couple of hours could improve the outcome considerably. At this point, these matters can only be speculated on since there are plenty of variables in human-centered systems. Without a doubt, there is room for research in this area also in the future.

5.3 Feedback from the outside evaluation group regarding the innovation project

A total of 12 persons from different companies participated in the project's evaluation group. The visionary leader of the innovation project presented the progress of the project in stages as well as the intermediate results and the outcome to the group. Based on this data, the evaluation group recorded their own views on two questions: what they would have done differently and what question the project especially invoked. The group members' views are presented in Table 5.

Table 5. Views of the evaluation group regarding the idea creation project.

Respondent	What would you have done differently?	What question came up especially in the project?
1	-Creating ideas together from the start -Weekend work is not a good idea	-The novelty value and unexpectedness of the winning idea were weak. On what basis was the best idea chosen?
2	-Idea creation could be realized internationally by using dispersed teams and digital support tools -Ideas should have been combined more – taking the best parts of different ideas and iteration	-Reverse definition could be tried. For instance, what kind of a jewel could be created with the production costs of X euros?
3	-Would've left out the weekend work	-What are the tools for inspiring people from different organizations to genuinely create ideas together?
4	-Prototyping emphasized one idea, i.e. the ideas had different values	-On what basis were the ideas eliminated? Feasible, new idea, impossible…?
5	-A more extensive decision-making forum -Reversing the decision-making criteria -Iteration of ideas, i.e. starting from scratch every now and then	-A completely new viewpoint for idea creation is needed in order to achieve different kinds of ideas -When the starting point is a digital jewel, then two matters are glued together and nothing new is created
6	-The idea creation group should spend a week 'in a cave' 24/7	-Would be worth including engineers and designers in the idea creation
7	-The producer should have been more involved in the process	-
8	-There should've been more rough ideas. Crazy ideas only arise when we run out of easy ones -First finding a good idea and only then the design and technical execution. A prototype is not an end in itself	-Was the funnel too narrow and decision-making in the hands of too few? For example, voting, preventing the promotion of one's own idea. -Was the team really multidisciplinary or did they share the same viewpoint?
9	-In the ideas, services and processes should maybe be pondered more. Too much focus on product ideas.	-
10	-Idea creation outside the familiar group – e.g. on Facebook	-
11	-Prototypes from more ideas -Is the view of producer sufficient?	-How was the project experienced by the different parties?
12	-	-How had the task originally been briefed? Ideas were quite one-sided – idea creation of a technical product

The views of the evaluation group corresponded largely with the views of the other project group. The most significant new issues that came up were the utilization of a more multidisciplinary and international idea creation group in the creation of ideas, moving away from product-centered thinking, as well as making the serial entrepreneur a more active participant.

5.4 Time pressure as a source of stress in the innovation project

Based on the comments of the participants, it seems that for the innovation team 1, the performance and stress levels were mostly higher than in the innovation team 2. On the other hand, it is well known that in this case the innovation team 1 had a clearly defined time period to work on the project, which may naturally improve both the focus and time pressure and also the end results.

From the innovation team 2, e.g. the following comments were recorded: *"Felt like many members didn't take me seriously. Perhaps this was because I'm a strange guy with long hair, and on top of everything else, an artist."* It does seem to indicate that some of the participants did not feel too much pressure or stress during the process and considered results making as optional option. They seemed to produce results only when they felt inclined to do so. As such it would indicate a stress level within the comfort zone.

In contrast, the following comments indicated high pressure:

- "*There wasn't time to ponder irrelevant matters; we just had to go for it.*"
- "*There was pressure to focus more on quantity than quality and that was seen in the outcome.*"
- "*We did get the job done, but at the expense of the quality of the ideas.*"

These comments also link to each other and those are in line with the other findings of this study. For instance, some people considered the time pressure related stress to exceed their tolerance level, and what they produced was quantity, not quality. After the dragons' den, some people speculated that because of the time pressure, they tended to generate ideas mostly from their areas of specialization, pointing out that to meet the schedules, they did not challenge themselves, but in fact kept working in their comfort zone.

Examining the comments and the results of the research and group, it seems that the operative leader was the only person to truly challenge and push the group in a sufficient manner. The operative leader stated: *"Among those committed to the project, the atmosphere was good, but at least I was annoyed that some people didn't respect the schedules."* This shows a clear frustration towards the team, as the level of participation was not as high as what the leader personally considered having invested in the project. The stress levels vs. performance of participants are illustrated in Fig. 10.

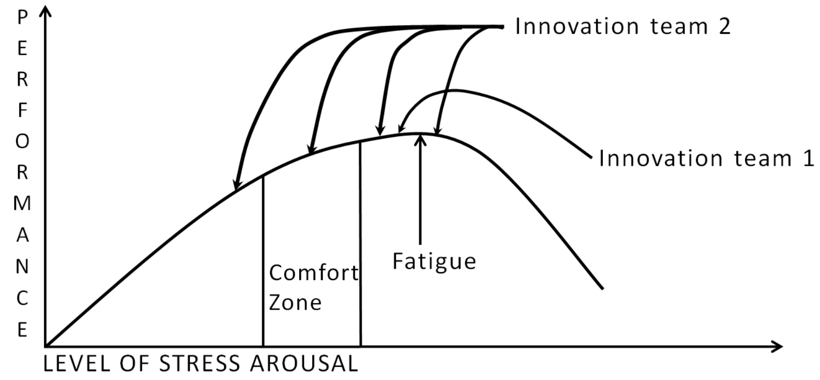


Fig. 10. Stress level of different participants in the innovation project.

The leader commented on the stress levels and the FEI process as follows: "As the role of operative leader and the implementer of applying of technology into the jewelry apple to produce medium+ size concepts, I would say that everyone was out of comfort zone. Personally it can be said that I pushed myself really hard. It was especially challenging when most people in the innovation team 2 did not seem to follow the timetables and did not work as guided. Given the time pressure the team 2 did not seem to be able to produce the expected results, so I had to do their part too, and as a result I did not have the time to worry about stress. And finally, if anything, I think the only way to really understand why things happen like they do and how people really react to stress is to do things with them and be part of the real life experimentation".

6 Discussions

This research has expanded on the work of Kach et al. (2012), in which the focus was mainly on the development phase of the innovation process, by testing the applicability of the model in the FEI phase – an earlier phase of the innovation process than the model was originally designed for. Based on the results, the theoretical framework of Kach et al. (2012) for variables that explain the effect of time pressure on radical innovation is extendable to the FEI phase of the radical innovation process in addition to the development phase, for which it was originally intended. Based on the study, the theoretical framework created by Kach et al. (2012) for the development phase of the innovation process works also in the analysis of the FEI process, and as such its extensibility to other parts of the innovation process should be researched more in the future.

From the time perspective, it was found out that a clearly defined and short project makes people focus their thoughts on what is essential. Similar results have also been achieved in the context of the agile development sprint model, named as Scrum. In addition to development sprints, Scrum also includes visioning sprints related to the FEI (Sims, 2011; Goldstein, 2013). On the other hand, Griffith-Hemans and Grover (2006) have stated that in the FEI process, one essential part is idea refinement, and also this study showed that if e.g. time pressure is taken too far, refinement will not take place in the most productive ways and/or people take short cuts, which will reduce the quality of refinement. In this study, two short cuts were noticed, 1) people did not take enough time to work face-to-face and 2) ideas were not field tested with actual assumed end users. Based on the findings, this research elaborates on the findings made by Griffith-Hemans and Grover (2006).

Considering the perceived quality of the ideas, combinations of different ideas were not explored in the desired way. This could explain the perceived quality of the ideas, as according to Apilo (2010), the best innovations are not usually born from one idea but from the combination of different and multiple seeds of ideas. Also in accordance with the findings of Sandmeier et al. (2004) and Sims (2011), this research indicates that an innovation process performed once is not usually sufficient in FEI, but there is a need to iteratively repeat it several times before great ideas emerge.

Even if the quality of the ideas had not been affected by the time pressure and process acceleration, based on the experiment in this study, the acceleration did not seem to weaken the originality of the outcomes and as such this study does not support statement made by McDermott and Handfield (2000) in that regard. Also as the innovation target was to produce something completely new, research did not find clear support for the claims of Kessler and Bierly (2002), stating that the acceleration of the innovation process might fit into the realm of incremental innovation projects, but not that well into the area of radical innovations.

Considering the time pressure and stress related issues, whatever methods are selected for the FEI process to easy up the stress levels, the feedback and comments by the participants indicated that for some the time related stress was excessive, and that others would have required more cooperation and interaction to improve their performance. All in all, it seems that in innovation projects like these, participants should be taught time and stress management to enhance performance. For this, there should be more facilitated stress with mentoring to the participants how to control the stress. this should be done in a way, which supports and enhances to enhance the performance level, without going overboard in stress and time pressure. This is illustrated simply in Fig. 11.

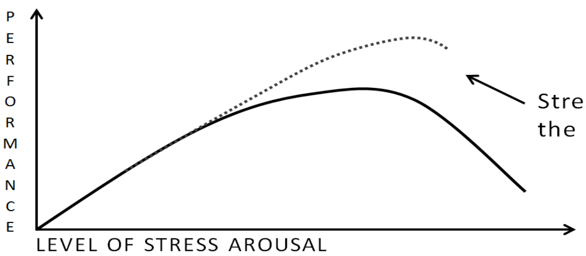


Fig. 11. Simplified illustration of stress management as a method to increase performance level without adding on stress arousal.

Based on this, this research elaborates on the findings of Gunnar and Quevedo (2007) stating that in general, some people succumb and others thrive when they are confronted with similar challenges, as was the case in this study. At the start of the study, it was expected that people would start to manage their time pressure related stress, which would enhance their performance, as modeled by Nixon (1979). Such findings were made, but not in the way expected. In fact, the participants stated that e.g. *we did get the job done, but at the expense of the quality of the ideas* and *there was pressure to focus more on quantity than quality and that was seen in the outcome*. In other words, people did get better at managing their time pressure, but this was partly at the expense of the experienced quality produced in the process. The research thus expands on Nixon's (1979) model, but not exactly as expected at the start of the research. As for future research, the comments of the participants, e.g. w*orking together towards a common goal would been necessary to reach better results* suggest that Nixon's (1979) model and similar ones could be studied more from the managerial and/or leadership point of view in a time-pressured FEI context. Methodologies applied in the process should be further researched to allow people more efficiently to manage their time in time-pressured situations (e.g. providing help and guidance in how to combine ideas) to produce higher quality, not only high quantities of ideas.

7 Conclusions and need for further study

Based on the study, it became clear that success factors in FEI do not necessarily differ much from the success factors of a development project. Also time-pressured FEI can be successful if visionary leadership, project momentum, and team collaboration are in order, and positive stress is maintained at a level which keeps the group momentum in motion.

This project can be considered as a visioning sprint that provides input for future visioning or development sprints. The time pressure of the studied FEI project had the following advantages: most of the people were committed to the project, an inspiring challenge for a group, people worked together, the focus remained on the goal, concrete results were gained quickly, being open was necessary, and decision-making was fast. On the other hand, time pressure had the following disadvantages: at times decision-making was too fast, it was difficult to organize joint face-to-face meetings, there was not enough time to provide the support and extra guidance needed, there was enough time only to make prototypes of one idea, it was not possible to expand the idea creation group, work had to be carried out also during evenings and weekends, and ideas were not refined and combined sufficiently.

Through the connection with agile development, the studied project is linked with the theories of experimental innovation/learning (Sims, 2011; Kolb, 1984), the principles of which are based on creating new information through experiments. Knowledge is created by going into the field. Field testing, which was largely neglected, should have been conducted in a completely differently in this study. In terms of the radicality of the outcomes, challenging views from the field could have raised the ideas in completely new levels. Through successes and failures, an idea can finally lead to new business possibilities. On the other hand, along the way an idea can transform into a completely new one that finally creates new business. The most important aspect of these models is movement and the continuous collection of customer feedback instead of planning matters in isolation. It is difficult to predict reactions something that is completely new (Sandmeier et al., 2004; Sims, 2011; Tuulenmäki, 2012). From this perspective, the access control jewel would be ready for its first, more extensive field test. Time will tell whether this concept will create real business. It may already be reality when this article is published, as jewels seem to be digitalizing at a fast pace.

The research also brought forth needs for further study – not least due to the fact that this study only dealt with one case. Human-centered systems, such as the studied one, have an enormous number of different variables. It seems important to keep time pressure as a so called standard factor in the studies since, based on the research and despite opposing views, it would appear to be a force that promotes innovation. Also Sherwin (2010) has reached similar conclusions. From stress level point of view, there should be multiple groups working side by side, where the stress level (e.g. required number of new ideas within a given time, etc.) is varied between the groups, applying just the right amount of stress for every group. Especially in group work, it is important to find the most natural way to innovate for everyone. This is influenced by people's habits, ways of working, personalities, and a large number of other human factors.

The research suggests that in the time-pressured FEI the influence of the following factors on the outcome of the FEI process should be studied more:

- A variety of decision-making models and different decision-makers
- Methods that support radical innovation, such as TRIZ
- A heterogeneous and international group
- Only the most committed and motivated persons involved in the innovation team
- A preparatory "test" to select participants for the project
- Working methods that highly encourage people to innovate in the same space and at the same time to achieve genuine collaboration
- Methods that force people to combine their ideas with those of others, e.g. to establish whether this reduces the adverse effects of short cuts people take under time pressure
- An operational model with an even stricter schedule, which would then force innovations

Let us take an example of the last factor. Even a month-long FEI project could entail several forced cycles, i.e. so-called mini sprints. With an agreed specific timetable, each person or team should take turns in adding an agreed number of improvement suggestions to the base idea. Also new ideas created as a by-product of the original idea creation should be recorded, as corresponding cycles could be initiated for them. If the person or team does not respect the agreed schedule, the whole cycle will suffer. Thus, social pressure would guide the actions of people. The cycle would continue until no one has anything to add. It is noteworthy that in this model people could choose whether they want to create ideas alone, in pairs, or in a small team. This allowed everyone to innovate in a way that comes naturally to them. Some feel energized by working alone and some by immediate interaction. On the other hand, even those who work alone receive feedback through the idea cycle.

In addition to the presented 'artificial' forced innovation, people and organizations usually take action after a shock or an exceptionally positive event. For instance, people know very well that they should take care of their health. However, usually they only start to act when faced with a serious illness. Correspondingly, companies start to act only under threat of bankruptcy. Nevertheless, for instance a significant new partner, order, or business opportunity may be surprisingly inspiring. In principle, everyone has the key to success, but only a few know how to use it in their own organization. Therefore, concrete measures should be sought to motivate busy and stressed modern people and encourage them to act in the best interest of their organization. In innovation, alongside processes and operations models it would then be important to study the human side, which has thus far been neglected in research and especially in practical operations.

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The Innovative Performance of R&D Outsourcing[1]

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Abstract. Firms increasingly outsource their R&D activities to external actors, but little is known about how this R&D strategy relates to the value of their research output (in terms of invention quantity as well as quality). To study this issue, I analyse a pooled cross-sectional dataset of German manufacturing firms. The results obtained from the data analysis suggest that R&D outsourcing as well as the interaction between this strategy and internal R&D are significantly and positively associated with invention quantity but not with invention quality. Furthermore, the estimation results show that manufacturing rather than service companies are more likely to explore both internal and external R&D strategies to generate inventions. Besides that, the data analysis indicates that R&D outsourcing is more important innovative input for firms operating in science-based industries than in scale-intensive and specialized-supplier sectors.

Keywords. R&D Outsourcing, Internal R&D, Patent, Invention Quantity, Invention Quality, Pavitt's Sectoral Taxonomy.

1 Introduction

Nowadays, firms are under great pressure to reduce the costs of their R&D activities and to speed up their new technology and product development to respond efficiently and effectively to the increased global competition, the fast pace of technological changes and shortened product life cycles (Chesbrough, 2003; Chesbrough et al., 2006; Holcomb & Hitt, 2007; Keupp & Gassmann, 2009). All these requirements lead firms to open up their R&D boundaries to access required external resources timely. Drawing on the R&D management literature, scholars differentiate two generic strategies for sourcing external knowledge via formal contracts: i) outsourcing R&D functions and ii) developing innovation jointly (Narula, 2001; Nakamura & Odagiri, 2005; Grimpe & Kaiser, 2010); the external actors are then R&D suppliers and innovation cooperation partners, respectively. The former strategy implies the acquisition of a research outcome from external actors, whereas the latter strategy refers to a joint effort of the partner firms to

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develop valuable knowledge assets. The main advantage attributed to R&D outsourcing[2] or external R&D is that this strategy allows firms to purchase ready R&D results without substantial involvement in the innovation activities, which are contracted out to external actors (Grimpe & Kaiser, 2010). In this context, R&D outsourcing permits firms to concentrate on core R&D activities internally and to outsource rather peripheral R&D tasks to specialized external suppliers (Quinn, 1999, 2000; Grimpe & Kaiser, 2010). As a consequence, R&D outsourcing may allow firms to acquire high-quality knowledge inputs from specialized suppliers and to share the costs and risks of R&D projects with them (Mowery, 1983; Dess et al., 1995; Gilley & Rasheed, 2000). Furthermore, by distributing R&D tasks among different external actors, firms shift their R&D activities from serial to synchronous actions so that these activities are implemented independently and simultaneously, resulting in an increased speed of R&D processes (Howells et al., 2003; Langlois, 2003; Ebrahim et al., 2009).

Although R&D outsourcing promises the above-mentioned advantages, this governance mode also has its drawbacks. First, distributing R&D activities among external providers may induce a firm to specialize in combining externally available technologies rather than to develop its own (West et al., 2006). In this context, outsourcer firms may shift their knowledge creation capabilities to specialized external suppliers (Bettis et al., 1992; Gilley & Rasheed, 2000; West et al., 2006). As a result, R&D outsourcing may deplete firms' research competencies and deteriorate their R&D performance (Bettis et al., 1992). The second issue is that the knowledge-based resources acquired from external actors via contracts may not be unique, because competitors may have access to the expertise of the same supplier (Grimpe & Kaiser, 2010). In other words, knowledge may unintentionally spillover from a supplier to multiple clients firms while working with them. Moreover, R&D outsourcing may replace learning-by-doing activities in internal R&D and, hence, deteriorate a client firm's integrative competencies. Consequently, this strategy may hamper the overall innovative performance of the firm (Bettis et al., 1992; Weigelt, 2009). Given these mixed potential value-creating outcomes of R&D outsourcing, the question arises of whether those firms that outsource R&D tasks generate a higher-quality research output from their R&D processes than their counterparts that do not invest in this strategy.

Motivated by this question, a number of studies examine the relationship between R&D outsourcing and R&D output, in which the quality of the R&D output is most commonly measured as sales from product innovations (Grimpe & Kaiser, 2010) and patent counts (Beneito, 2006). These papers contribute significantly to our understanding of the performance implication of R&D outsourcing, but the indicators of R&D output (e.g. sales from product innovation, patent counts) used in the studies may not reflect the overall quality of outsourcer firms' research processes. For example, a product innovation might be a result of combining externally available knowledge inputs, and it may not be a good indicator of the quality of the internal research process. In other words, the knowledge and production boundaries of a firm may differ (Brusoni et al., 2001). An

[2] The terms R&D outsourcing and external R&D are used interchangeably in this study.

alternative measure of R&D output, such as patent counts, shows firms' property rights upon their inventions, but patents may vary significantly in terms of their quality and innovative contents (Griliches, 1990). Therefore, further research is required to understand how R&D outsourcing is associated with the quality of a firm's research output. Besides that, little is known about how firms operating in different industries explore internal and external resources to generate high quality inventions. The importance of internal and external R&D strategies may depend on the features of industries' technological regimes and trajectories, market structure and appropriability conditions. Based on these characteristics, Pavitt (1984) differentiates four major sectoral patterns of innovative activities such as supplier-dominated, scale-intensive, specialized-supplier and science-based industries. Supplier-dominated firms are least innovative and mainly oriented towards process innovations. In contrast, remaining three sectoral classes belong to medium- and high-technology industries and they may explore both internal and external knowledge sources to innovate. Hence, further research is required to understand whether all firms benefit from combining internal and external knowledge sources or it depends on sector-specific characteristics of innovation activities (Cantner & Savin, 2014).

The empirical analysis is based on the data obtained from Mannheim Innovation Panel (MIP) and the European Patent Office (EPO). The former provides detailed information about the innovation activities of German firms (e.g. expenditures on internal and external R&D, product and process innovations, R&D cooperation partners, etc.), whereas the latter provides data about the patents applied for by German firms at the EPO. To measure the quality of a firm's R&D output, I use the average forward citations that the firm's patents obtain in subsequent seven-year windows after the filing year weighted by its patent counts. Besides that, I take patent counts as a dependent variable in the econometric analysis to measure firms' invention quantity.

Considering the total sample (manufacturing and services sectors together), the data analysis shows that R&D outsourcing is significantly and positively associated with invention quantity. As inter- rather than intra-firm knowledge-based resources are more likely to vary, those companies acquiring R&D from an external provider may have more chance of accessing diverse knowledge inputs and, as a result, performing better in invention activities than their counterparts that experiment only with internal knowledge. In other words, this strategy may help firms to access complementary knowledge inputs and, in this way, to improve their invention performance. However, the positive performance implication of R&D outsourcing does not appear to hold for invention quality. Similarly, the joint implementation of R&D outsourcing and internal R&D is only significant and positive for invention quantity but not for invention quality. Moreover, the estimation results suggest that firms operating in the manufacturing sector are more likely to use both internal and external knowledge sources (e.g. internal R&D, R&D outsourcing) to generate inventions than companies coming from the service sector. Besides that, the data analysis indicates that R&D outsourcing is the most important innovative input for firms operating in science-based industries than in scale-intensive and specialized-supplier sectors.

The rest of this chapter is organized in the following way. Section 2 discusses the theoretical arguments for the hypotheses development. Section 3 reviews the database and variables used in the econometric analysis. Section 4 presents the econometric methods. After that, Section 5 provides the estimation results and Section 6 concludes.

2 Literature review and hypotheses development

In this section, the relationship between R&D outsourcing and the inventive performance of a firm is examined. R&D outsourcing may allow firms to accelerate and improve their innovation activities and to respond swiftly to new market threats and opportunities (Quinn, 1999, 2000; Gilley & Rasheed, 2000; Howells et al., 2003; Calantone & Stanko, 2007; Howells et al., 2008). However, this strategy may also involve considerable risks in terms of declining internal R&D activities, depleting firms' research or knowledge-creation competencies and, as a result, deteriorating the overall performance of their R&D processes (Bettis et al., 1992; Weigelt, 2009). Therefore, the conditions under which it might be advantages to organize R&D activities internally or externally require careful consideration. In this context, insights from transaction cost theory (TCT) and the resource-based view (RBV) of the firm can be helpful. These two theories attempt to explain the boundaries of the firm, but from different perspectives. While TCT is considered to be a cost-based approach, the RBV of the firm is seen as a resource-oriented framework.

2.1 Transaction cost theory

TCT considers internal and external governance modes based on their relative costs; when the market offers a certain good or service at a lower price than organizing the same activities internally then a buy strategy is considered to be optimal (Coase, 1937; Williamson, 1975). TCT assumes that 'transactions within integrated companies may be insulated from competitive pressure and subject to bureaucratic phenomena' (Geyskens et al., 2006: 520). In this context, the market mechanism might be superior to the internal organization form, because the market competition forces suppliers to improve their efficiency and to lower their prices. However, the transaction or coordination costs might increase when firms use the market mechanism instead of the internal governance mode, because monitoring and enforcing a contract performance is often problematic due to bounded rationality, opportunism and asset specificity (Williamson, 1975). According to Simon (1955), humans have limited cognitive ability in spite of the assumption of their rationality. Hence, limited cognitive ability prevents firm managers from foreseeing all the possible opportunistic actions of their contractors. Opportunism is defined as the disregard of the contract partners or the defeat strategy that may also reduce the total welfare. To avoid such situations, firm managers attempt to write a complete contract; this, however, is only accomplishable when the contracted quantity and quality of specific assets are readily observable and measurable, which certainly is not the case with the outcome of product and process innovation activities. Usually, those activities are characterized by high levels of uncertainty with regard to outcomes (Mudambi & Tallman, 2010). Related to that, it is difficult to estimate the period of time and the resources required fulfilling certain research and development tasks. Hence, contracting those activities out will lead to high transaction costs (for monitoring the processes and results). To avoid excessive transaction costs, internal, rather than external, organizational forms for innovation activities appear to be more appropriate.

However, the transaction costs related to the market mechanism will be substantially lowered if a firm manages to modularize its innovation activities. Modularity implies that a complex engineering system is decomposed into discrete components, which are developed separately and then interconnected with a standardized interface to assemble the final product (Mikkola, 2003). This makes the inter-organizational division of labour possible at very low transaction costs through minimizing the interdependence between sub-components or modules (Mikkola, 2003). Hence, the modularization of product development functions enables firms to acquire some parts of R&D activities in the open marketplace. However, TCT alone does not explain why firms organize certain R&D activities internally and certain ones externally. As TCT is considered to be a cost-based approach, it neglects the learning processes embodied within internal and external governance modes. In other words, TCT focuses on minimizing transaction costs when considering which activities should be retained internally and which should be contracted out, but it ignores the ideas and technologies available inside and outside the firm (Barney, 1999). Therefore, to provide a complete picture of how firms set R&D boundaries, I present insights from the RBV of the firm in the next section.

2.2 The resource-based view of the firm

The RBV of the firm further discusses the resource allocation issue and shifts the attention from a cost-based approach towards a resource-oriented framework (Penrose, 1959; Barney, 1991; Peteraf, 1993; Barney et al., 2001). In particular, the RBV of the firm suggests understanding the performance of a firm via its combination of specific resources. Resources can be tangible and intangible assets, such as physical assets, financial capital, human capital, organizational knowledge, information, managerial capabilities, etc. (Grant, 1991). According to the RBV, firms should possess valuable, rare, inimitable and non-substitutable (VRIN) resources to attain above-normal profits (Barney, 1991; Peteraf, 1993). Valuable and rare resources enable firms to satisfy consumer requirements better than their competitors (Peteraf, 1993). Resources should also be inimitable and non-substitutable, because competitors should not be able to duplicate the valuable resources of the firm or to attain a comparable performance based on other resources. To develop VRIN resources, firms should define their organizational strengths and weaknesses relative to their rivals so that they can focus on the economic activities that they can perform best (Barney, 1991). As the internal governance mode is also considered to be one of the most powerful isolating mechanisms, organizing strategically important economic activities internally enables firms not only to build up valuable and rare resources but also to protect these resources from imitation (Wang et al., 2009; Grimpe & Kaiser, 2010). This is especially true in the case of R&D activities because protecting strategically important knowledge-based resources from imitation can be difficult once they have been revealed or contracted out to external actors (Grimpe & Kaiser, 2010). The knowledge-based view (KBV) of the firm, which is largely influenced by the RBV, considers knowledge as the most important resource of a firm (Grant, 1996). It suggests that tacit knowledge is relatively immobile and difficult to imitate and, therefore, it constitutes the basis for a superior performance. For this reason, firms should organize strategically important R&D functions internally and use the market mechanism for rather peripheral or non-core activities (Prahalad & Hamel, 1990; Grimpe & Kaiser, 2010). Inter-firm division of R&D labour has become more relevant in the current fast-changing market environment, because rapid technological changes and a shorter product life cycle deplete firms' valuable resources and put pressure on them to pursue innovation (Chesbrough, 2003).

As technological and product innovation also spans different scientific disciplines, many firms face a cognitive limitation in carrying out all the R&D tasks internally (Keupp & Gassmann, 2009). The internal impediments to innovation are more critical under rapid technological changes, because undertaking radical transformation and developing new competitive capabilities internally, in the short run, can hardly be achieved without external collaboration (Powell et al., 1996; Chesbrough, 2003; Keupp & Gassmann, 2009). Therefore, firms outsource some R&D activities to external specialized suppliers to gain timely access to required resources that are otherwise unavailable (Powell et al., 1996). In this context, R&D outsourcing may serve a complementary purpose and improve firms' invention performance.

2.3 R&D outsourcing and invention quantity

Several potential benefits can be realized as a result of R&D outsourcing. First, the division of R&D tasks among firms enables them to shift their R&D activities from serial to parallel working processes and, hence, to accelerate new product and technology development (Howells et al., 2003; Ebrahim et al., 2009). Second, by the division of R&D labour, firms increase the organizational commitment to the R&D activities that they can perform best and use the R&D service of specialized research organizations for rather peripheral innovation activities in which they lack competency (Quinn, 1999, 2000; Grimpe & Kaiser, 2010). In other words, inter-firm division of R&D labour enables companies to devote their financial and human resources to their core research activities and to acquire rather peripheral R&D functions from a specialized research organization to which these are the key activities (Prahalad & Hamel, 1990; Grimpe & Kaiser, 2010; Mudambi & Tallman, 2010). Accordingly, the specialized R&D organization may possess superior knowledge-based resources as well as a more appropriate research infrastructure and, therefore, it may carry out these R&D tasks better than they can be implemented by the client firm (Quinn, 1992; Gilley & Rasheed, 2000). As a result, R&D outsourcing may help firms to improve the efficiency and effectiveness of their R&D activities. In fact, prior research provides empirical evidence that the external R&D strategy is the important source of technology and product innovations (Cassiman & Veugelers, 2006; Beneito, 2006; Grimpe & Kaiser, 2010). Based on these arguments, a positive relationship between R&D outsourcing and invention quantity can be expected. Hence, the following hypothesis is proposed:

H1a: R&D outsourcing is positively associated with invention quantity.

2.4 R&D outsourcing and invention quality

Considering the composition of knowledge resources, the KBV of the firm suggests that a complementary rather than a substitutive relationship is more likely to result in superior performance (Nelson & Winter, 1982; Rosenkopf & Nerkar, 2001). Complementary resources allow firms to reconfigure their competencies by generating new combinations of existing resources to respond timely and effectively to new market opportunities and external threats. Moreover, given that an innovation is considered to be a new combination of the existing knowledge (Schumpeter, 1934), a firm that possesses a heterogeneous stock of knowledge and competencies has more opportunities for knowledge recombination and performs better in innovation than others that apply a rather homogeneous knowledge base (Nelson & Winter, 1982; Rosenkopf & Nerkar, 2001; Cantner & Plotnikova, 2009). Taking into account that firms are heterogeneous in terms of their resources due to their different routines and operation systems, which cause the formation and accumulation of diverse capabilities and competencies (Nelson & Winter, 1982), R&D outsourcing can help firms to access miscellaneous knowledge inputs and, as a result, to improve the quality of their R&D activities. Although knowledge-based resources sourced from R&D suppliers may not be unique and they might also be accessible by competitors, these external resources may enable firms to pursue a unique combination of external and internal knowledge, resulting in firm-specific resources (Grimp & Kaiser, 2010). Hence, the following hypothesis is proposed:

H1b: R&D outsourcing is positively associated with invention quality.

2.5 The inter-relationships between internal R&D, R&D outsourcing and invention performance

Although the R&D outsourcing strategy involves a number of advantages, this governance mode also has its drawbacks. First, a client firms may not be able to internalize the tacit knowledge component of outsourced R&D activities via arm’s length transactions, because transferring such knowledge across organizational boundaries requires intensive interaction between transaction partners, which is not implied in this R&D strategy. Accordingly, R&D outsourcing may hollow out tacit knowledge applications in internal R&D and limit the firm’s insights into codified knowledge components of innovation activities (Weigelt, 2009). Third, R&D outsourcing may reduce the internal learning-by-doing and problem-solving activities (Bettis et al., 1992; Weigelt, 2009; Grimpe & Kaiser, 2010), which are considered to be the primary source of new skills and know-how. In this sense, this R&D strategy may deplete a firm's research capabilities and shift knowledge creation competencies from the firm to an R&D supplier (Bettis et al., 1992). To mitigate the negative side of R&D outsourcing, firms should invest internal R&D to enhance internal learning-by-doing activities and to develop absorptive capacity. Absorptive capacity refers to 'the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends' (Cohen & Levinthal, 1990: 128). In particular, it stands for the pre-existing knowledge stock that allows a firm to identify and exploit external knowledge. As Cohen & Levinthal (1990) suggest, prior knowledge structure within a firm determines its ability to learn and add new knowledge to its memory. In this sense, companies with a rich internal knowledge stock are more likely to gain from R&D outsourcing in terms of utilizing knowledge effectively from an external supplier than their counterparts that lack the required level of competencies. In other words, a firm is more likely to learn and acquire new knowledge in a particular area of the technological domain in which it has already accumulated some level of expertise. In contrast, learning in new and unfamiliar technological areas can be limited due to the lack of associated linkages between the firm's knowledge basis and the new technological domain. Therefore, firms that invest in internal R&D are more likely to build up required level of absorptive capacity and to utilizing knowledge from R&D suppliers more effectively than their counterparts with lack of internal competencies. In fact, prior studies find that the marginal returns of external R&D increase if a firm simultaneously invest in internal R&D (Cassiman & Veugelers, 2006; Beneito, 2006; Grimpe & Kaiser, 2010). In this context, I assume that the joint implementation of internal R&D and R&D outsourcing is positively associated with invention performance. Thus, the following hypotheses are proposed:

> *H2a: The joint implementation of internal R&D and R&D outsourcing is positively associated with invention quantity.*
>
> *H2b: The joint implementation of internal R&D and R&D outsourcing is positively associated with invention quality.*

2.6 Pavitt's sectoral classes

The way in which firms organize their R&D activities may depend also on sector-specific characteristics of innovation activities. Given that 'sectoral patterns of technological innovation are different, one may expect that firms in specific sectors use specific internal and external resources in order to innovate successfully' (Oerlemans et al., 1998: 302). In this context, the importance of investing in both internal and external R&D activities may depend on the nature of technological regimes and trajectories in specific industries. In particular, Pavitt (1984) suggests that the pace and rate of technological change in any industry depends on the source of technology, the degree of technological cumulativeness, market structure and the appropriability conditions. Based on these characteristics, he identifies four main categories of manufacturing industries such as supplier-dominated, scale-intensive, specialized-suppliers, and science-based sectors. To extend the taxonomy to the service sector, Castellacci (2008) and Bogliacino & Pianta (2009) re-examine Pavitt's sectoral classes and propose a unified or revised version of the taxonomy covering both manufacturing and service industries. This revised version of Pavitt's taxonomy can be described as follows[3]:

(1) Supplier-dominated sectors contain industries that provide final goods and services (Cantner & Savin, 2014). In these sectors, firms lack in-house capabilities and expertise to organize innovation activities internally and, hence, they acquire machinery and equipment from external suppliers (Castellacci, 2008; Bogliacino & Pianta, 2009). Innovation processes in this sectoral class are also relatively low technological content and mainly oriented towards cutting costs (Pavitt, 1984; Castellacci, 2008; Bogliacino & Pianta, 2009; Cantner & Savin, 2014).
(2) Scale-intensive sectors are composed of industries that produce simple materials and consumer durables (i.e. the automotive sector) as well as sectors that offer financial services (i.e. financial intermediation, pension funding, etc.). In these industries, firms are generally large and exploit economies of scale. They may rely on both internal and external knowledge sources to develop product and process innovations. In scale-intensive industries, innovation activities are mainly oriented towards improving efficiency of production process (Castellacci, 2008; Bogliacino & Pianta, 2009).
(3) Specialised-supplier sectors include industries that produce advanced equipments and machinery components to be sold into other sectors. Firms in specialised-supplier industries are generally small and their innovation activities are mainly based on internal knowledge sources. They also cooperate intensively with the advanced users (e.g. companies that acquire machinery components and high-tech instruments produced by specialised-supplier sectors) as well as collaborate other firms to acquire machinery from them (Cantner & Savin, 2014).
(4) Science-based sectors are composed of high-tech industries such as chemicals, electronics, telecommunications and computer related services. Firms operating in this area are generally large and develop product and process innovations internally as well as use external knowledge sources such as universities and research institutes in their R&D activities (Castellacci, 2008). Intellectual property protection in science-based sectors is mainly based on patents, secrecy, and tacit know-how.

Among the Pavitt's sectoral classes, supplier-dominated sectors are least innovative. As discussed above, firms operating in supplier-dominated industries lack internal R&D capabilities and mainly acquire machinery and equipment from other sectors, implying that they are less likely to perform both internal and external R&D. Therefore, supplier-dominated industries are excluded from the analysis. Remaining three sectoral classes

[3] Table 1 (in Appendix) provides more detailed explanation of the revised Pavitt's sectoral taxonomy.

belong to medium- and high-technology industries. Firms in these sectors (e.g. scale-intensive, specialised-supplier and science-based industries) may use both internal and external knowledge sources to generate product and process innovations, but the nature of generated innovations differ across these industries. In particular, technological innovation in scale-intensive sectors is mainly incremental, which is characterized by refinements and modifications in existing products or processes (Cantner & Meder, 2007). In other words, as scale-intensive companies use their technological skills to exploit economies of scale, their innovation activities are directed towards cutting cost and improving of production processes. Therefore, technological innovation in scale-intensive industries is expected to be relatively a low degree of novelty. Contrariwise, innovation activities in specialised-supplier and science-based industries is mainly directed towards generating breakthrough product and technology innovations rather than cost-reducing process innovations. As companies operating in this area often face rapid changes in technology and consumer preferences, they may generate technology innovations with a high degree of novelty than companies from scale-intensive sectors.

Taking into consideration the positive performance implication of internal R&D and R&D outsourcing, one should expect that the joint implementation of these R&D strategies is positively associated with invention performance in specialised-supplier and science-based industries. Contrariwise, this relationship might be limited or less significant in scale-intensive industries. Hence, the following hypothesis is proposed:

> *H2c: the joint implementation of internal R&D and R&D outsourcing is positively and more significantly associated with invention quantity and quality in specialised-supplier and science-based industries than in scale-intensive sectors.*

3 Data description

3.1 Sample

The dataset used in this study comes from the Mannheim Innovation Panel (MIP)[4] database. The MIP, which is the German part of the Community Innovation Survey, has been collected every year since 1993 by the Centre for European Economic Research (ZEW). The target population of the MIP is German innovative firms with at least five employees. The survey gathers detailed information on the innovation activities of the firms, such as the type of innovation partner, expenditures on internal and external R&D, product and process innovation, etc. This dataset is supplemented by patent data obtained from the European Patent Office (EPO) to study the relationship between R&D outsourcing and invention performance. The EPO provides information about the patents

4 The paper acknowledges access to the Mannheim Innovation Panel and patent databases from the Centre for European Economic Research (ZEW).

applied for by German firms at the EPO from 1978 until the end of the data (2011). In particular, I obtain information about the number of patents that German firms applied for at the EPO and the number of forward citations that these patents obtained in subsequent time periods. To have enough time windows to count the patent forward citations, which are used to measure the quality of a patent, the empirical analysis covers two waves (1997, 2001) of the MIP. Although the key interest variables of the study are also identified in other waves of the MIP (e.g. 2005, 2009), these waves cannot be used in the study because of providing not enough time windows for measuring the quality of a patent in terms of counting the patent forward citations. Hence, the pooled cross-sectional dataset are used in the analysis obtained from the 1997 and 2001 surveys of the MIP, which gives information on companies R&D activities during the three years period prior the survey. The sample is restricted to innovative firms, resulting in 4380 observations (2391 for manufacturing and 1989 for service industries, respectively). These observations are distributed across the sectoral classes as follows: 1051 firms come from supplier-dominated sectors, 972 from scale-intensive sectors, 1345 from specialized-suppliers sectors and 768 from science-based sectors. There are 244 companies in the sample which attributed none of the sectoral classes.

3.2 Dependent variables

Two types of dependent variables are considered in the empirical analysis. The first one (INV_N) is the number of patents filed by firm i in period t+3. In other words, INV_N refers to the number of patents that firms are granted in the periods 1998–2000 and 2002–2004, respectively to the 1997 and 2001 surveys (see Table 2 in Appendix). Given that patents vary significantly in terms of their quality and innovative contents (Narin & Olivastro, 1988; Griliches, 1990; Trajtenberg, 1990), as the second dependent variable, I use the average forward citations that a firm's patents obtain in subsequent seven-year windows after the filing year weighted by its patent counts.

3.3 Main explanatory variables

The first explanatory variable used in the econometric analysis is EXT_R&D, which is a binary variable and indicates whether a firm has expenditure in R&D carried out by an external actor not affiliated with the company. The second explanatory variable is INT_R&D, which has a binary outcome and shows whether a firm has investment in R&D undertaken inside its laboratory establishment.

3.4 Control variables

I consider several control variables that might be relevant in the econometric model for invention performance. First, I account for whether a firm has formal innovation cooperation with an external actor; the variable has a binary outcome and it is expressed as R&D_COOP. Cooperation in R&D is seen as an important instrument to acquire skills and specialized know-how from external entities, to minimize the costs and risks of R&D projects and, as a result, to improve the performance of R&D activities (Hagedoorn, 1993). Therefore, I expect a positive relationship between R&D_COOP and the invention performance. Second, to control for the international competition that firms face (Cassiman & Veugelers, 2006; Grimpe & Kaiser, 2010), I introduce the variable EXPORT, which has a binary outcome (1 if a firm has sales from export). As companies competing in global markets often face rapid changes in technology and consumer preferences, they might be more innovative than their counterparts operating only in the local market. In this context, I expect a positive relationship between EXPORT and invention performance. Third, I control for firm location, specifically whether it is in East or West Germany (LOCATION_EAST). Given that there are regional differences between East and West Germany with regard to the infrastructure and economic growth, firms located in East Germany might be lagging behind those located in West Germany in terms of invention performance (Grimpe & Kaiser, 2010).

Furthermore, I account for firms' prior accumulated knowledge in the econometric analysis. It can be expected that those firms that accumulated a high stock of knowledge in time t-1 are more likely to be innovative in period t. In other words, there can be path dependency in invention activities (Nelson & Winter, 1982; Cyert & March, 1992). Therefore, I introduce the PRE_INV_N and PRE_INV_Q variables into the regression models to control for path dependency in the invention performance. PRE_INV_N refers to the pre-sample patent counts in the five-year period. Given that the sample includes the 1997 and 2001 surveys and each survey contains information about the innovation activities of the firms during the three years period prior the survey (for instance, the 1997 survey provides information about the firms' innovation activities in the period 1994–1996), PRE_INV_N stands for patent counts in the period 1989–1993. To account for the quality of these pre-sample patents, I take the average forward citations that firms' pre-sample patents obtain in subsequent seven-year windows after the filing year weighted by their pre-sample patent counts (PRE_INV_Q). In the econometric models, the variables PRE_INV_N and PRE_INV_Q are introduced in logarithmic values. Given that some firms do not have any patent or forward patent citations, the logarithmic transformation of these variables results in missing values. To deal with this issue, I set the value to zero for the missing values (LOG (PRE_INV_N) = 0 if PRE_INV_N = 0) and introduce an additional dummy variable (zero for patent values and one for non-patent values; the same applies to average forward patent citations) (Beneito, 2006; Grimp & Kaiser, 2010).

Moreover, to control for firm unobserved characteristics, I introduce firm size and industry dummy variables. Firm size is measured as the number of employees transformed into logarithmic values (LOG_SIZE).

4 Econometric methods

As the first dependent variable (INV_N) used in the empirical analysis has non-negative count outcomes (denoted by y, y ={0,1,2,….}), I use count data methods to analyse the sample. The starting point of count data analysis is a Poisson model (Cameron & Trivedi, 2005, 2009), which is considered to be an appropriate econometric method when the variance and the mean of the dependent variable have equal values (referred to as an equal-dispersion property), which is often violated in an applied work due to the over-dispersion problem (Cameron & Trivedi, 2009). The standard method to cope with the over-dispersion problem is to use a negative binomial model, which preserves the mean and increases the variance. As the variance exceeds the mean in the dependent variable and, hence, there is an over-dispersion problem in the data, I used the negative binomial model in the econometric analysis.

The second variable (INV_Q) used in the analysis is the ratio of forward patent citations to patent counts. Given that the dependent variable contains decimal numbers, the count data models are inappropriate in this case. To account for the specific feature of the data, a generalized linear model (GLM) is used in the econometric analysis (Nelder & Wedderburn, 1972). The GLM is flexible and has the power to model the data with ratio and non-normal distributions when a proper family distribution and link function are defined in the model. I use the GLM with a gamma family distribution and a log link, because the variance exceeds the mean in the dependent variable. I also introduce a robust option into the model to obtain robust standard errors if the family distribution is incorrectly specified.

5 Estimation results

Considering the total sample (manufacturing and service firms together), Table 4 (in Appendix) shows that R&D outsourcing (EXT_R&D) is significantly and positively associated with invention quantity (INV_N). The result, which is in line with the H1a hypothesis, suggests that those firms outsourcing some parts of their R&D activities to external entities are more innovative than their counterparts that do not invest in this R&D strategy. This might be related to the fact that R&D outsourcing can help firms to focus on the activities that they can perform best and to use the services of external actors for tasks in which they lack expertise. As a result, this strategy can support firms to improve their R&D performance. Moreover, the data analysis indicates that there is a significant positive relationship between internal R&D (INT_R&D) and invention quantity (INV_N), implying that those firms that carry out R&D internally generate more inventions than other companies that do not invest in in-house R&D activities. Generally speaking, internal R&D is considered to be a key source for enhancing the learning process within a firm and developing new products and technologies. As expected, the interaction term of internal R&D and R&D outsourcing is also significantly and positively associated with invention quantity. Hence, in line with my H2a hypothesis, the empirical analysis indicates that those companies using both internal and external knowledge sources in R&D activities displace better invention performance (in terms of invention quantity) than their counterparts relying only a single R&D strategy whether it is internal R&D or R&D outsourcing.

Furthermore, Table 5 (in Appendix) displays that there is a significant positive relationship between internal R&D and invention quality, but surprisingly neither R&D outsourcing nor the interaction between internal R&D and R&D outsourcing is significantly associated with invention quality. This may suggests that to understand clearly the invention performance of R&D outsourcing, it might be necessary to study the returns of this strategy more specifically in relation to whether R&D is sourced from suppliers, consulting companies or research institutions.

Looking at the sectoral patterns of R&D activities, the empirical results indicate that companies operating in science-based industries are more likely to employ the R&D outsourcing strategy to improve their invention performance (in terms of invention quantity as well as quality) comparing to firms coming from scale-intensive and specialized-supplier sectors (see Table 4 and 5 in Appendix). For scale-intensive sectors, R&D outsourcing is slightly significant and positive for invention quantity, but the variable is non-significant for invention quality. In a somewhat similar way, this R&D strategy presents a significant sign neither for invention quantity nor for invention quality when considering specialized-supplier industries alone. Contrariwise, internal R&D is the major source of technology for specialized-supplier sectors. Hence, firms operating in specialized-supplier sectors are more likely to show better invention performance (including invention quantity as well as quality) when they organize R&D activities internally rather than externally. For science-based industries, internal R&D is also significantly and positively related to invention quality, but surprisingly the variable is non-significant for invention quantity. This non-significant relationship between internal R&D and invention quantity might be partly due to the fact that the expenditures for internal R&D are not differentiated among basic, applied or developing activities.

For all sectoral classes (e.g. scale-intensive, specialized-supplier and science-based industries), surprisingly the joint implementation of internal and external R&D strategies presents a non-significant sign for invention quantity as well as for invention quality. To put it another way, the empirical results provide no evidence that firms coming from specialized-supplier and science-based industries are more likely to employ both internal R&D and R&D outsourcing strategies to innovate than their counterparts operating in scale-intensive sectors.

Furthermore, the study shows that manufacturing firms are more likely to combine internal and external knowledge sources in their invention activities comparing to service companies. In particular, the results indicate that the joint implementation of internal R&D and R&D outsourcing is significant and positive for invention quantity when I consider the manufacturing sector alone, while for the service sector it is not the case (see Table 6 in Appendix). This might be related to the fact that firms operating in the manufacturing industry experience strong approriability conditions comparing to companies coming from the service industry. Therefore, manufacturing firms are more likely to explore both internal and external R&D strategies in their innovation activities comparing to service companies. Besides that, considering the manufacturing sector alone, Table 6 (in Appendix) shows that internal R&D is significantly and positively associated with invention quality, but the significance level of the coefficient is lower for invention quantity. In contrast, R&D outsourcing is only significant and positive for invention quantity, but the variables present non-significant signs for invention quality. If I consider the service sector alone, there is a significant positive relationship between internal R&D and invention quantity as well as between R&D outsourcing and invention quantity, but both R&D strategies are non-significant for invention quality.

Having discussed the relationship between the main explanatory variables and invention performance, I shift my attention to the control variables used in the econometric analysis. Considering manufacturing and service sectors together as well as separately, the results show that R&D cooperation (R&D_COOP) is significantly and positively related to invention quantity, but it presents a non-significant coefficient for invention quality. This could be explained by the fact that for invention quality, not only cooperating with external actors in R&D, but also with whom this cooperation takes places, whether it is research institutions, suppliers, customers, etc. may be important.

Furthermore, the data analysis shows that past invention activities matter only for invention quantity but not for invention quality if I consider the total sample (manufacturing and service sectors together) and manufacturing sector alone. This might be due to the fact that the number of forward citations, which is used as an indicator of patent quality, depends on whether a firm's patent attributes technological knowledge of citing firms and their absorptive capacity (Hottenrott & Lopes-Bento, 2012).

Regarding export intensity (EXPORT) and firm size (LOG_SIZE), the variables are significantly and positively related to invention quantity as well as to invention quality. Besides that, there is a significant negative relationship between LOCATION_EAST and invention quantity, but LOCATION_EAST is non-significant for invention quality. However, the variable presents a significant and negative sign for invention quality for all sectoral classes (see Table 5 in Appendix). In general, as prior research also suggests (Grimpe & Kaiser, 2010), West German firms are more innovative than their counterparts located in East Germany.

6 Conclusion

The question of whether firms experience 'gains' or 'pains' from R&D outsourcing is a subject of ongoing research in the R&D management literature. A number of previous papers discuss this issue, yet little is known about how this strategy relates to the value of an outsourcer firm's research output. Motivated by this research gap in the literature, this study further discusses the prior research findings and provides new insights into the relationship between R&D outsourcing and invention performance (in terms of patent quantity as well as quality). In particular, considering manufacturing and service sectors together as well as separately, the empirical results show that those firms that outsource some R&D functions generate more inventions than their counterparts that do not invest in this R&D strategy. Given that R&D outsourcing allows firms to contract out R&D activities in which they do not possess high-class expertise and to concentrate on the activities that they can perform best, such inter-firm task division may help companies to devote their financial and human resources to their key research activities and, as a result, to improve the efficiency and effectiveness of their invention activities. Hence, the research suggests that firms can improve the invention performance of their R&D activities by outsourcing some R&D functions to external actors. In this context, policymakers should stimulate the inter-firm division of R&D labour among service and manufacturing companies to boost invention activities in the country. However, the data analysis indicates a non-significant relationship between R&D outsourcing and invention quality. This could be explained by the fact that for invention quality, not only using the R&D outsourcing strategy in innovation activities, but also with whom this collaboration takes places can be important. Hence, to understand clearly the invention performance of R&D outsourcing, it might be necessary to study the returns of this strategy more specifically in relation to whether R&D is sourced from suppliers, consulting companies or research institutions. In contrast to R&D outsourcing, internal R&D is significantly and positively associated with invention quality, implying that those companies that carry out R&D internally generate more inventions than other firms that do not invest in this R&D strategy. Chesbrough (2003) suggests that internal R&D has lost its strategic significance and companies have shifted their innovation activities from internal to external R&D, but the data analysis indicates that internal R&D is important innovative input to generate high quality inventions. This suggests that relying heavily on external R&D may hamper firms' innovation performance. Instead, the degree of R&D openness in innovation should be in balance with the internal R&D activities, which can help firms to gain from external R&D and to enhance their innovation performance.

The data analysis also shows that there are significant inter-industry differences the way in which firms organize their R&D activities. In particular, the research reveals that firms operating in science-based industries are more likely to employ the R&D outsourcing strategy to improve their invention performance (in terms of invention quantity as well as quality) comparing to companies coming from scale-intensive and specialized-supplier sectors. In other words, R&D outsourcing or external R&D is the important source of innovation for science-based companies. In contrast, internal R&D is the major source of technology in specialized-supplier sectors, implying that firms coming from specialized-supplier sectors displays better invention performance (including invention quantity as well as quality) when they organize R&D activities internally rather than externally. In science-based industries, internal R&D is also significant and positive for invention quality, but surprisingly the variable is non-significant for invention quantity. This non-significant relationship between internal R&D and invention quantity in science-based industries might be partly due to the fact that the expenditures for internal R&D are not differentiated among basic, applied or developing activities.

Furthermore, the study shows that manufacturing firms are more likely to combine internal and external R&D strategies in their invention activities comparing to service companies. Given that appropriability conditions are stronger in manufacturing rather than in service sectors, manufacturing companies are more likely to explore both internal R&D and R&D outsourcing strategies to enhance their invention performance. However, the joint implementation of these R&D instruments presents a non-significant sign for invention quality. Besides that, considering the sectoral classes separately (e.g. scale-intensive, specialized-supplier and science-based industries), the interaction between internal R&D and R&D outsourcing is neither significant for invention quantity nor for invention quality. Due to data limitations, I could not examine what factors prevent companies from achieving a positive performance outcome through combining internal and external R&D strategies.

The paper also suffers from other limitations that offer interesting avenues for future research. First of all, future study should examine the differences in the innovative performance of domestic and international R&D outsourcing. Second, further research is required to understand how different types of R&D outsourcing relationships, such as short- and long-term contracts, affect a client firm's invention performance. It could be also interesting to study what kinds of managerial practices and governance modes should be used to maximize the returns of the R&D outsourcing strategy.

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8 Appendix

Table 1. Revised Pavitt's sectoral taxonomy - Source: Cantner and Savin (2014)

Sector classification	Industry	NACE 2-digit
Supplier-dominated industries	Food products and beverages	15
	Tobacco products	16
	Textiles	17
	Wearing apparel; dressing and dyeing of fur	18
	Leather and leather products	19
	Wood and wood products	20
	Pulp, paper and paper products	21
	Publishing, printing and reproduction of recorded media	22
	Furniture, jewellery, musical instruments manufacturing	36
	Recycling	37
	Sale, maintenance and repair of motor vehicles and motorcycles	50
	Wholesale trade and commission trade, except of motor vehicles	51
	Retail trade, except of motor vehicles, repair of personal and household goods	52
	Hotels and restaurants	55
	Land transport, transport via pipelines	60
	Water transport	61
	Air transport	62
	Supporting and auxiliary transport activities	63
Scale-intensive industries	Rubber and plastic products	25
	Other non-metallic mineral products	26
	Basic metals	27
	Fabricated metal products, except machinery and equipment	28
	Motor vehicles, trailers and semi-trailers	34
	Other transport equipment (ships, railway, aircraft, spacecraft)	35
	Financial intermediation, except insurance and pension funding	65
	Insurance and pension funding, except compulsory social security	66
	Activities auxiliary to financial intermediation	67
Specialized-supplier industries	Machinery and equipment (including weapons, ammunition, domestic appliances)	29
	Medical, precision and optical instruments, watches and clocks	33
	Real estate activities	70
	Renting of machinery, equipment, personal and household goods	71
	Other business activities (incl. legal, accounting, book-keeping)	74
Science-based industries	Coke, refined petroleum products and nuclear fuel	23
	Chemicals and chemical products	24
	Office machinery and computers	30
	Electrical machinery and apparatus	31
	Radio, television and communication equipment	32
	Post and telecommunications	64
	Computer and related activities	72
	Research and development	73

Table 2. Descriptive statistics

Variable names	Variable definition	Obs.	Mean	Std. dev.	Min.	Max.
INV_N	Patent counts in the periods 1998–2000 and 2002–2004, respectively to the 1997 and 2001 surveys	4380	0.914	7.114	0	254
INV_Q	The average forward citations that the firm's patents obtain in subsequent seven-years windows after the filing year	4380	0.424	3.961	0	121
EXT_R&D	Binary: 1 if a firm outsources R&D activities	4380	0.292	0.455	0	1
INT_R&D	Binary: 1 if a firm invests in internal R&D	4380	0.572	0.494	0	1
R&D_COOP	Binary: 1 if a firm has R&D cooperation with an external actor	4380	0.273	0.445	0	1
EXPORT	Binary: 1 if a firm has sales from export	4380	0.533	0.498	0	1
LOCATION_EAST	Binary: 1 if a firm is located in East Germany	4380	0.340	0.473	0	1
PRE_INV_N (logs)	Pre-sample patents in the period 1989–1993	4380	0.127	0.540	0	5.568
PRE_INV_N (d)	Binary: 0 for patent values and 1 for non-patent values	4380	0.893	0.308	0	1
PRE_INV_Q (logs)	Average forward patent citations obtained for the pre-sample patents in the seven years after the filing year	4380	0.089	0.498	-2.484	6.089
PRE_INV_Q (d)	Binary: 0 for patent citation values and 1 for non-citation values	4380	0.924	0.264	0	1
LOG_SIZE	Firm employees in logarithmic values	4380	4.470	1.745	0	13.009

Table 3. Correlation table

	Variable names	1	2	3	4	5	6	7	8	9	10	11	12
1	INV_N	1.000											
2	INV_Q	0.144***	1.000										
3	EXT_R&D	0.112***	0.080***	1.000									
4	INT_R&D	0.073***	0.065***	0.377***	1.000								
5	R&D_COOP	0.092***	0.049***	0.295***	0.235***	1.000							
6	EXPORT	0.079***	0.089***	0.231***	0.324***	0.149***	1.000						
7	LOCATION_EAST	-0.068***	-0.069***	-0.065***	-0.048***	0.007	-0.200***	1.000					
8	PRE_INV_N (logs)	0.419***	0.154***	0.139***	0.119***	0.124***	0.166***	-0.135***	1.000				
9	PRE_INV_N (d)	-0.294***	-0.157***	-0.171***	-0.159***	-0.126***	-0.244***	0.177***	-0.522***	1.000			
10	PRE_INV_Q (logs)	0.262***	0.108***	0.109***	0.080***	0.075***	0.146***	-0.095***	0.458***	-0.516***	1.000		
11	PRE_INV_Q (d)	-0.324***	-0.130***	-0.154***	-0.131***	-0.115***	-0.203***	0.154***	-0.531***	0.521***	-0.522***	1.000	
12	LOG_SIZE	0.206***	0.119***	0.232***	0.125***	0.177***	0.211***	-0.228***	0.285***	-0.284***	0.169***	-0.273***	1.000

Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses.

Table 4. Results for invention quantity (manufacturing and service sectors together)

	Invention quantity (INV_N)							
	Negative binomial models							
	Manufacturing and service firms							
	Total sample		Scale-intensive industries		Specialized-supplier industries		Science-based industries	
	1	2	3	4	5	6	7	8
EXT_R&D	0.509***	-0.354	0.466*	0.080	0.028	-0.809	1.109***	0.018
	(0.128)	(0.350)	(0.257)	(0.625)	(0.190)	(0.577)	(0.286)	(1.018)
INT_R&D	0.619***	0.460***	0.447	0.360	0.607***	0.472*	0.211	0.053
	(0.140)	(0.151)	(0.275)	(0.303)	(0.225)	(0.241)	(0.354)	(0.377)
R&D_COOP	0.497***	0.483***	0.539**	0.526**	0.142	0.132	0.455*	0.419
	(0.121)	(0.121)	(0.256)	(0.258)	(0.182)	(0.182)	(0.259)	(0.261)
EXPORT	1.001***	0.989***	1.517***	1.516***	1.408***	1.399***	0.538*	0.547*
	(0.145)	(0.145)	(0.315)	(0.316)	(0.230)	(0.230)	(0.286)	(0.285)
LOCATION_EAST	-0.478***	-0.466***	-0.455	-0.448	-0.165	-0.174	-0.044	-0.050
	(0.144)	(0.144)	(0.306)	(0.307)	(0.233)	(0.233)	(0.312)	(0.311)
PRE_INV_N (logs)	0.460***	0.448***	0.585***	0.577***	0.530***	0.516***	0.213	0.217
	(0.097)	(0.098)	(0.208)	(0.210)	(0.125)	(0.127)	(0.191)	(0.191)
PRE_INV_N (d) (no pre-sample inventions)	-1.802***	-1.815***	-1.165***	-1.182***	-1.553***	-1.596***	-2.351***	-2.307***
	(0.182)	(0.183)	(0.398)	(0.400)	(0.227)	(0.231)	(0.427)	(0.426)
LOG_SIZE	0.497***	0.497***	0.559***	0.561***	0.625***	0.617***	0.459***	0.457***
	(0.036)	(0.036)	(0.087)	(0.087)	(0.061)	(0.060)	(0.068)	(0.068)
EXT_R&D*INT_R&D		0.994***		0.462		0.931		1.187
		(0.375)		(0.688)		(0.609)		(1.065)
INTERCEPT	-3.916***	-3.786***	-5.148***	-5.098***	-4.577***	-4.404***	-2.720***	-2.637***
	(0.365)	(0.367)	(0.718)	(0.722)	(0.490)	(0.499)	(0.590)	(0.594)
Industry dummy	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	4380	4380	972	972	1345	1345	768	768
LR chi2	1061.01	1068.01	240.77	241.21	490.62	492.88	208.61	209.85
Prob>chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses.

Table 5. Results for invention quality (manufacturing and service sectors together)

	Invention quality (INV_Q)							
	Generalized linear models							
	Manufacturing and service firms							
	Total sample		Scale-Intensive industries		Specialized-Supplier industries		Science-Based industries	
	1	2	3	4	5	6	7	8
EXT_R&D	0.609	-0.392	0.485	-0.002	0.019	-1.686	0.814**	1.076
	(0.379)	(0.633)	(0.480)	(0.765)	(0.472)	(1.221)	(0.380)	(1.136)
INT_R&D	1.447***	1.288***	0.121	0.018	1.179**	1.020**	0.883**	0.944**
	(0.396)	(0.440)	(0.399)	(0.446)	(0.469)	(0.506)	(0.438)	(0.439)
R&D_COOP	-0.086	-0.097	-1.037**	-1.040**	-0.166	-0.201	0.684*	0.697**
	(0.322)	(0.317)	(0.418)	(0.419)	(0.390)	(0.395)	(0.362)	(0.350)
EXPORT	2.520***	2.557***	3.387***	3.370***	2.623***	2.580***	1.294***	1.292***
	(0.494)	(0.492)	(0.672)	(0.656)	(0.635)	(0.628)	(0.439)	(0.440)
LOCATION_EAST	-0.415	-0.454	-1.681***	-1.669***	-1.543***	-1.527***	-1.190*	-1.187*
	(0.517)	(0.507)	(0.511)	(0.506)	(0.394)	(0.397)	(0.708)	(0.708)
PRE_INV_Q (logs)	-0.107	-0.079	0.005	0.002	0.043	0.059	0.036	0.033
	(0.219)	(0.227)	(0.200)	(0.198)	(0.211)	(0.212)	(0.182)	(0.182)
PRE_INV_Q (d) #	-1.801***	-1.753***	-0.727	-0.724	-0.753*	-0.729*	-0.967**	-0.978**
	(0.497)	(0.505)	(0.453)	(0.448)	(0.385)	(0.387)	(0.450)	(0.450)
LOG_SIZE	0.938***	0.939***	0.518***	0.520***	0.716***	0.718***	0.488***	0.490***
	(0.114)	(0.114)	(0.107)	(0.107)	(0.138)	(0.141)	(0.122)	(0.123)
EXT_R&D*INT_R&D		1.161		0.571		1.789		-0.288
		(0.780)		(0.952)		(1.314)		(1.188)
INTERCEPT	-7.697***	-7.647***	-5.994***	-5.940***	-6.657***	-6.530***	-5.181***	-5.229***
	(0.974)	(0.977)	(1.122)	(1.096)	(1.250)	(1.262)	(1.130)	(1.149)
Industry dummy	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	4380	4380	972	972	1345	1345	768	768
Log pseudo-likelihood	9837.6	9904.3	-545.2	-544.5	-917.4	-913.9	-464.7	-464.6

Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses.

no pre-sample patent forward citations

Table 6. Results for invention quantity and quality

	Invention quantity (INV_N)				Invention quality (INV_Q)			
	Negative binomial models				Generalized linear models			
	Only manufacturing firms		Only service firms		Only manufacturing firms		Only service firms	
	1	2	3	4	5	6	7	8
EXT_R&D	0.384***	-0.329	0.861**	-0.405	0.609	-0.392	-0.225	-0.372
	(0.134)	(0.375)	(0.392)	(0.875)	(0.379)	(0.633)	(0.596)	(0.602)
INT_R&D	0.304*	0.168	0.820**	0.601	1.447***	1.288***	0.864	0.734
	(0.156)	(0.170)	(0.387)	(0.409)	(0.396)	(0.440)	(0.693)	(0.725)
R&D_COOP	0.420***	0.402***	0.716*	0.721*	-0.086	-0.097	0.505	0.483
	(0.127)	(0.127)	(0.372)	(0.373)	(0.322)	(0.317)	(0.610)	(0.603)
EXPORT	0.800***	0.792***	0.782**	0.773**	2.520***	2.557***	1.804***	1.780***
	(0.188)	(0.187)	(0.332)	(0.334)	(0.494)	(0.492)	(0.550)	(0.546)
LOCATION_EAST	-0.459***	-0.449***	-0.295	-0.269	-0.415	-0.454	-0.691	-0.699
	(0.162)	(0.163)	(0.362)	(0.363)	(0.517)	(0.507)	(0.900)	(0.904)
PRE_INV_N (logs)	0.520***	0.506***	0.260	0.287				
	(0.092)	(0.093)	(0.459)	(0.477)				
PRE_INV_N (d) #1	-1.418***	-1.441***	-2.585***	-2.491***				
	(0.181)	(0.182)	(0.745)	(0.754)				
PRE_INV_Q (logs)					-0.107	-0.079	-0.222	-0.217
					(0.219)	(0.227)	(0.212)	(0.208)
PRE_INV_Q (d) #2					-1.801***	-1.753***	-2.650***	-2.634***
					(0.497)	(0.505)	(0.588)	(0.581)
LOG_SIZE	0.507***	0.506***	0.507***	0.516***	0.938***	0.939***	0.500***	0.495***
	(0.045)	(0.045)	(0.090)	(0.092)	(0.114)	(0.114)	(0.145)	(0.143)
EXT_R&D*INT_R&D		0.813**		1.552		1.161		0.384
		(0.402)		(0.951)		(0.780)		(0.767)
INTERCEPT	-6.095***	-5.972***	-4.411***	-4.318***	-7.697***	-7.647***	-5.637***	-5.488***
	(0.521)	(0.523)	(1.366)	(1.378)	(0.974)	(0.977)	(2.081)	(2.074)
Industry dummy	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	2391	2391	1989	1989	2391	2391	1989	1989
LR chi2	766.56	770.52	173.22	175.94				
Prob>chi2	0.0000	0.0000	0.0000	0.0000				
Log pseudo-likelihood					9837.6	9904.3	-318.2	-316.3

Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses.
#1 no pre-sample inventions.
#2 no pre-sample patent forward citations.

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Communities and central nodes in the mobility network of US inventors

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Abstract. This study presents the basic features and community structure of the US inventor mobility network between 1999 and 2010, based on an analysis of patent documents. Since mobile inventors have proved to be among the most effective knowledge mediator entities, this mobility network can be seen as a knowledge diffusion network among innovative companies. During the investigation, we identified the basic features of the network, such as short effective diameter and scale-free degree distributions, and we also demonstrated the central nodes, community structure, and hidden core of the network. Our results indicate that there is a small number of nodes that can effectively absorb knowledge from the network and pool it. We also find that this core mostly consists of IT and semiconductor companies as well as the largest universities in the USA.

Keywords. Intellectual Capital, Knowledge Management, Industrial Structure, Knowledge Economy, Company Research, Diffusion of Innovation.

1 Introduction

According to Gassmann and Bader (2006), innovation and technologies are responsible for half of the economic growth in developed and industrialized economies, while leading innovative companies realize more sustainable profits than imitators and trend followers. However, R&D costs increase steeply due to shortening innovation cycles and the growing number of imitators, with empirical evidence indicating a positive correlation between the success of a company and the strength of its intellectual property, R&D, and patent portfolio (Gassmann and Bader, 2006). In innovation-driven economies, it is an obvious scientific question how knowledge as an essential resource of R&D activities is diffused among business entities. It is difficult to find an ultimate indicator for company innovativeness, but the most frequently used measure for it is patenting because patents provide a monopoly for their owners for a space in the technology arena. Approximately two-thirds of the market value of large companies in the USA can be traced to intellectual property, especially patents and trademarks (Shapiro and Pham, 2007).

Patents grant their owners monopoly rights over novel technologies. However, ideas about research directions or developments can be diffused from firm to firm and from inventor to inventor without infringing patent rights. The platform for knowledge flows can be formal agreements, collaborations, and informal social ties among researchers

(Freeman, 1991; von Hippel, 1987; Powell and Grodal, 2005). Mobility is also one of the possible ways in which such flows are realized; however, as has been pointed out by Breschi and Lissoni (2009), it has been proved to be one of the most effective mediators of knowledge and plays the most important role in knowledge spillover. In this paper, we investigate the exchange of inventors among firms, research institutions, and universities in the United States from 1999 to 2010. We can track the migration of inventors and knowledge by analyzing patent documents and recording which inventor created and patented technology, where, and when. On the basis of network analysis (Wasserman and Faust, 2009), we explore the structural properties, the organizing principle, and the community structure of this network. Our study is based on the transformed Harvard University's Patent Network Dataverse (Lai et al., 2011). In the following section, we summarize the existing literature on the economic impacts of innovation and patents, innovation networks, inventor mobility, and knowledge diffusion. This is followed by a description of the database we used and the basic properties of the mobility network. Then, we highlight which firms, research institutions, or universities play the most important role in the cohesion and shaping of the US mobility network. In parallel, we investigate the community structure of the organizations and the network core consisting of nodes with the greatest network power.

2 Related work and research conception

2.1 Patents in the economy

From the corporate to the national level, performance greatly depends on the stock of knowledge which can produce intellectual assets, such as patents, software, and organizational structures. A large proportion of R&D expenditures covers the wages of highly educated and skilled white-collar labor, an investment which sees returns in the form of these assets (OECD, 2006).

IP-intensive industries accounted for about $5.06 trillion in added value, or 34.8 percent of US gross domestic product, and for 40 million jobs in 2010. In the post-recession economy, employment in the IP-intensive industries is showing considerably faster growth than in non-IP industries (ESA and USPTO, 2012).

Intellectual properties are mainly embodied in patents and trademarks (Shapiro and Pham, 2007). According to the EPO, "A patent is a legal title granting the holder the executive right to make use of an invention for a limited area and time by stopping others from, among other things, making, using or selling it without authorization". This is an accurate definition; however, it only captures one aspect of patenting. In addition to the important function of protection and commercial exploitation of new technologies, patents provide important information for others on the market. According to Granstrand (1999), the contract between the patenting firm and society grants a temporary monopoly, on the one hand; on the other hand, it works as an information system that provides ideas about recent research directions for others. The patent system thus simultaneously stimulates invention and investment in R&D and public disclosure of technical information. Finally, it fosters technological progress and competition after patent protection has ceased (Granstrand, 1999).

2.2 Networks of innovation

The previous section shows the importance of intellectual property, i.e., a patent portfolio and the knowledge behind it, both for organizations and the economic system as well. However, knowledge and skills as sources of innovation and patents cannot be materialized; they are in the heads of the inventors and managers.

From the market participants' point of view, innovative ideas and knowledge can be considered a scarce resource. By pooling knowledge, firms become able to utilize complementary skills which are otherwise inaccessible and create new technologies or overcome resource restrictions (Penrose, 1959). Networks of innovation are the spaces where common knowledge creation and utilization take place among firms. The sharing of firms' resources leads to a decrease in the risk that the development, introduction, or application of a new technology entails (Freeman, 1991). Furthermore, it creates an opportunity to combine and access knowledge which would otherwise be impossible for individual organizations to attain (Freeman, 1991; Knell, 2011). Formal and informal networks play an equal role in the creation, transfer, and absorption of new knowledge and technology (Powell and Grodal, 2005). Formal networks are established based on collaborative innovation, in which case organizations utilize their resources in a cooperative manner to achieve their aims (Freeman, 1991). By today, these formal networks have developed into global cooperative systems and serve common knowledge-creating goals in several ways, e.g., research collaboration, joint ventures, technical assistance programs, and technological licensing agreements (Knell, 2011). Informal network ties are seen as undeclared platforms for knowledge flow, and they function via various social interactions among the company's employees; in many cases, they lay the groundwork for the development of formal network ties or enhance their sustainment (Powell and Grodal, 2005). Using the steel mini-mill industry in the United States as an example, von Hippel (1987) demonstrates the way in which the personal network among engineers and the norms of the professional community facilitated a flow of technical knowledge among rival companies.

Although networks can produce a significant knowledge surplus, companies have to face the geographical (Jaffe et al., 1993) and technological (Rosenkopf and Almeida, 2003) limits of the accessibility of external sources of knowledge. The path dependency characteristic among companies derives from the fact that the knowledge search often happens in the local network, and thus it is only the knowledge capital of geographically proximate companies that can be utilized. On the other hand, the absorption capacity of a particular company is basically determined by its technological portfolio; therefore, organizations are not able to utilize any of the complementary sources of knowledge (Rosenkopf and Almeida, 2003).

In the present study, we consider knowledge flow via researcher mobility a special case of informal (and, to a certain extent, formal) network relationships because with mobility the company utilizes external skills, usually without any formal agreement. However, it is important to note that the flow of researchers among companies is possible in the case of different strategic alliances, which makes such phenomena the outcome of formal agreements.

2.3 The impact of mobility on organizations and inventors

Rosenkopf and Almeida (2003) found that inventor mobility significantly fosters inter-organization knowledge transfer, while such an effect could not be detected in the case of strategic alliances. This result stresses the importance of mobility for knowledge transfer. Other studies have also investigated the impact of mobility on organizations in many ways. Employee mobility and employee enticement from rival companies generate a serious existential risk for the parent company; on the other hand, they create important developmental potential for the progeny company (Phillips, 2002). Newly established and less embedded companies are able to increase their innovative capacity and overcome resource restrictions by attracting talent (Rao and Drazin, 2002). The reason why mobility can have such an impact on knowledge flow is that during an employee move employees take not only their human capital away but also their social capital, along with company routine and practices (Pennings and Wezel, 2007). Nevertheless, the utilization of knowledge and routines strongly depends on the structure of the new company since operating practice is not an individual-level task but a group-level one (Phillips, 2002; Rao and Drazin, 2002; Pennings and Wezel, 2007). Breschi and Lissoni (2006) argue that it is social distance – direct and indirect ties among inventors – that is of the greatest importance in knowledge spillover. The greater and more diverse a researcher's social capital is, the more easily he or she can access external or new knowledge through personal contacts. These crucial interpersonal links are mostly established by mobile inventors who move from firm to firm and sell their brainpower to various business entities (Breschi and Lissoni, 2006; Moen, 2000; Lamoreaux and Sokoloff, 2009). This increased social capital among mobile inventors is one of the key factors in knowledge transfer (Breschi and Lissoni, 2009).

Moreover, mobility influences researcher productivity as well. The greater the size of the organization, the more productive its inventors are due to the availability of a significantly greater number of resources for R&D projects and the lower the perceived risk of company failure (Hoisl, 2007; Kim el al., 2004). Mobile researchers are more productive than their immobile fellows; nevertheless, increasing productivity decreases willingness for mobility due to effective research practice (Hoisl, 2007). Researcher productivity also increases if mobility happens in the direction of a less path-dependent organization and if the inventor possesses unique knowledge compared to the existing knowledge base of the particular company (Song et al., 2003).

2.4 Patent analysis methods in knowledge diffusion studies

Various studies using a variety of methods have relied on patent data to investigate knowledge spillover and the knowledge diffusion process. Numerous studies focus on patent co-citations, which represent the links between older (cited patent) and novel (citing patent) inventions and can therefore trace how existing knowledge affects new knowledge. A pioneer investigation in this field was carried out by Jaffe et al. (1993) in the area of patent co-citation and local knowledge spillover. The authors revealed the importance of localization in knowledge flows by finding evidence that with co-cited patents the cited patent is more likely to come from the same state and from the same metropolitan area than randomly selected patents in the same field of technology.

Wang et al. (2011) identified fields of technology among leading organizations by analyzing patent co-citations among Fortune 500 companies. Petruzzelli et al. (2015) also measured the inter- and intra-firm and -industry impact of biotechnology innovations through patent co-citations.

Xuefeng et al. (2012) investigated Chinese and American co-patenting companies based on USPTO datasets. Co-patenting in this sense denotes the sharing of developmental expenditures and rights of a patent between firms from the USA and China as well.

Breschi and Lissoni (2009) analyzed a co-invention network of inventors to investigate knowledge flow processes. Co-invention occurs when inventors jointly file at least one patent application. In that study, mobile inventors are defined as individuals who move across companies and file patent applications with different assignees. The authors found that co-citations of patents occur more frequently when inventors are closer to each other in the co-inventor network. These close ties between inventors are established by mobile inventors; they can therefore be seen as key figures in the knowledge spillover process (Breschi and Lissoni, 2009). This approach is incorporated into the present study. Although we describe the knowledge flow network based only on inventor mobility, we do not measure the co-citation and co-invention properties of the network in this study.

2.5 Concept of the mobility network of US inventors

Since inventor mobility has proved to be a key factor in inter-organizational knowledge transfer, tracing movements enables us to draw up the organization-level mobility network among inventors. The present study aims to detect and investigate researcher mobility and the network of inter-organizational knowledge flow through an examination of patent documents. Our approach identifies the mobility of inventors who file patents with changes in assignees over time. Thus, the network that we aim to investigate is that of companies with patent rights, while the knowledge flow among them is demonstrated through the continuous patenting activity of mobile inventors. Movements identified in this way do not necessarily mean that the researcher has physically changed jobs. However, it can be considered mobility in the sense that he or she utilizes his or her mental capacity and technological and organizational knowledge acquired at another company; hence, we see complementary skills and a flow of knowledge among organizations. It is important to emphasize the fact that this network is only one of the possible approaches to the entire knowledge flow among organizations. In this case, manager movements cannot be detected, nor can those cases when ideas flow via interpersonal relations such as through advice from researchers working for different companies. It is also impossible to detect knowledge flow which is generated by the mobility of inventors whose innovation is not manifested in patents. Furthermore, the flow of knowledge based on existing patents also remains invisible for this method. However, as we have seen in the introduction, protecting valuable knowledge with patents bears great economic significance; thus, researchers that create patents are considered key figures in knowledge creation, and the knowledge flow generated by their mobility is seen as a substantial aspect of the total knowledge transfer.

We believe that our study represents the first attempt to describe a network of inventor mobility in the United States and, thereby, a network of knowledge flow among organizations. Therefore, the first aim of our study is to explore the basic properties of this network. Our second aim is to investigate the community structure of the network, seeking answers to the following questions: Which organizations tend to interact with each other and why? What is the organizing principle of the communities? How do path dependency and technological distance influence the flow of knowledge and which organizations are able to overcome them?

3 Dataset and methods

3.1 Source data and transformation

Our investigation is based on Harvard University's Patent Network Dataverse (Lai et al., 2011). This is a cleaned and disambiguated dataset based on the NBER database and the US Patent and Trademark Office weekly publications from 1975 to 2010. In their study, the authors propose a disambiguation algorithm which is an application and further development of the existing *Author-ity* approach developed by Torvik and Smalheiser (2009). The primary input data of the disambiguation algorithm is a cleaned and formatted version of the data sources noted above. The processed dataset consists of the name of the inventor, the patent, the assignee of the patent, the technology class of the patent, and the location of the inventor. This data preparation process defines inventor-patent instances, which form the units of analysis. The algorithm applies a comparison function which returns the similarity vector of inventor-patent instance pairs. The dimensions of the similarity vector, and the scale of the similarity are the following: first name [0..4], middle name [0..3], last name [0..5], co-author [0..6], technology classes [0..4], assignee [0..6], and location [0..5]. Zero values were assigned when the variable values were completely different and maximum values were assigned when they were identical in the case of inventor-patent instance pairs. To decide whether the given inventor-patent instance pairs match or not, the algorithm uses an iterative blocking scheme. As a result of the classification process in the disambiguated database, the inventors receive unique ID numbers to distinguish them from others with very similar attributes. The primary aim of this dataset is to investigate the co-authorship and collaboration networks among inventors who have registered patents in the USA. The network files are split into three-year intervals, so the ties in particular files only contain collaborations during that specific time interval.

In the original network files, the nodes represent the inventors. Every inventor has the following attributes: *inventor ID, assignee, assignee ID, first name, last name, city, state, country,* and *patents*. If some of the attributes of the inventors change, one can trace them as a difference in attributes for the same inventor among network files applied to different time intervals. For example, if an inventor works for IBM and takes a patent out on some technology between 1999 and 2001, his or her assignee attribute in the network file will be "IBM". If this inventor later moves from IBM to Microsoft, his or her attribute in the corresponding network file will change to "Microsoft". We used the 1999 to 2010 time interval, because a longer interval would present us with older, obsolete edges in our network, which may represent knowledge flows which are no longer relevant. Although 1999 to 2002 seems remote from 2010, that period coincided with the dot-com boom, which indicated the growing importance of the IT industry in the economy. We therefore considered this interval an important turning point in technology development which created an industrial environment that is relevant even in our days.

The differences in the inventors' attributes among the network files gave us the idea of transforming the collaboration network to the network of firms, where the edges represent the migration of inventors detected through temporal changes of the *assignee* attribute in the network data. This network is directed, meaning we can name the source and target of the knowledge flow represented by the migration. The attributes of the nodes in our network are the following: *assignee, assignee ID, community, in-degree, out-degree, betweenness centrality,* and *multi-edge node pairs*. The assignee and assignee ID variables signify the name and the unique identifier of organizations that hold the patent rights. Inventors with no assignee have been excluded from our network. The other attributes of the nodes will be described later. On the edges of the network, we defined one attribute, *weight*. Weight denotes the number of mobile inventors that move from the source company to the target company. We wanted to focus on US inventors; hence, we viewed mobility as knowledge flow only in the case of US residents. This filtering was based on the country attribute of the inventor nodes from the Patent Network Dataverse. Although international innovation networks play an important role in knowledge creation (Knell, 2011), our assumption is that foreign inventors with patent applications in the USA tend to work for multinational corporations, while smaller foreign firms cannot file their patents abroad. If foreign inventors were present in the network, it would over represent multinational corporations. In spite of the fact that US firms hire inventors with foreign residency, we assume that restricting the mobility to US residents gives us a better and less biased picture of knowledge flow patterns in the USA.

3.2 Definitions and variables

In the following part of this section, we explain the basic definitions, which are crucial for an understanding of our results.

A network G consists of a set of nodes, $N=\{n_1, n_2, \ldots, n_g\}$, and a set of edges, $E=\{e_1, e_2, \ldots, e_l\}$. Nodes represent the entities we examine, while edges indicate the presence or absence of some relation between them (Wasserman and Faust, 2009). In our case, as we have already noted, companies, institutions, and universities are the nodes, and the migration of mobile inventors among them are the edges that we consider as knowledge flow. Our network is directed; therefore, we can count in-degrees and out-degrees on the nodes. In-degree is how many companies sent inventors to a particular node, and out-degree is how many companies received inventors from it.

Geodesic distance: the length of the shortest path between two nodes in the network. If a company shares an edge with another company, the geodesic distance between them is one. If a company has no edge with the other company, but they have a common neighbor, the geodesic distance is two. Breschi and Lissoni (2009) showed that short geodesic distance between inventors greatly increases the probability of knowledge flows. We also assume that the closer the organizations are in the mobility network, the more chance they have to reach each other's knowledge base.

Network diameter: the shortest path between the two furthest nodes; in other words, this is the longest geodesic distance in the network. Large network diameter may present a less effective feature of knowledge diffusion since there are nodes which are inaccessibly far away from others. This can happen when there is almost no knowledge exchange among industries or among strategic alliances.

Characteristic path length: the average geodesic distance between any nodes in the network. This is a very important feature of the mobility network because the smaller the characteristic path length is, the greater the chance for knowledge diffusion among nodes, and the more effective the network is.

Betweenness centrality: one of the most often used measures of the centrality indices besides the in-degree and out-degree values. Betweenness centrality indicates the proportion of pathways passing through the given node. If the betweenness centrality is high, the node serves as a mediator of information in the network (Freeman, 1979). In the case of the mobility network, nodes with large betweenness centrality values represent the backbone of knowledge diffusion. An enormous amount of knowledge is accessible for and is mediated by such organizations.

Multi-edge node pairs: the number of mutually connected neighbors. In our case, the number of neighbors who also send and receive knowledge from a given node. Organizations with multi-edge connections use each other's knowledge base. The parts of the network where multi-edge connections frequently occur can be seen knowledge pools.

Communities (or clusters): densely connected parts of the network, in which the nodes probably share some common property or play similar roles (Fortunato, 2010). Communities are densely connected internally and sparsely connected externally. In our case, we expect that communities will be based on industrial similarities, where nodes from the same industry exchange knowledge with each other more often than with other communities based on another industry. The community attribute of a node indicates the number of the community to which the organization belongs.

Modularity: a measure of how densely communities are connected to each other and how appropriate the network is to find communities in it. The modularity score represents the strength of the communities. The stronger the community structure of a network, the more edges exist inside those communities and the fewer exist outside. Strong communities in the case of a mobility network means that the potential circle of organizations is small for an inventor who would like to move from one to another. It also indicates the overall path dependency of the organizations since it restricts the circle of companies with which they can exchange knowledge. The modularity value varies between 0 and 1. The 0 value indicates a network without communities, and 1 characterizes graphs with perfect communities (where edges exist only inside the communities). The modularity score of real world-based networks often varies between 0.3 and 0.7 (Fortunato, 2010; Newman and Girvan, 2004).

4 Basic features, network structure, and centralities

4.1 Network coherency and statistics

On the time horizon of the investigation, we found 28,695 companies, universities, and institutions involved in inventor mobility. Among these, there exist 50,170 paths, where inventors move from one to the other. This network of inter-firm inventor mobility is an exceedingly sparse network with only a 0.0001 network density value. In other words, only 0.01% of the possible ways exist among the nodes. Network density value would be 1 if all the firms in the network were connected to all the others. On the pathways, we detected 83,640 inventors who changed their position between 1999 and 2010.

The biggest component in the mobility network contains a large number of nodes. 20,998 organizations out of 28,697 are connected to a giant component. Next to 73% of the nodes, this coherent subgraph contains 45,707 edges, 91% of all of them. This interconnected component is the core of the knowledge flow. Many of the firms are linked to this network by almost all of the mobility paths. This is the main platform where the entities compete for inventors' knowledge. If a company is tied to this network by a mobile inventor, it means that it transmitted or received knowledge from this common platform for knowledge exchange. Due to this connectedness, knowledge and experience can be accumulated in the network, since it is available for the interconnected nodes. We can consider this knowledge system as the space for knowledge recombination and for the acquisition of social capital.

The network diameter is 17, so seventeen hops separate the furthest companies from each other. Nonetheless, the characteristic path length is just 4.81, which means the average distance between any two firms in the network is slightly less than five paths (Fig. 1). This indicates a small world property, where despite the sparseness and size of the network, the indirect links between firms are quite short (Wats and Strogatz, 1998). Firms competing for the same inventors are similar in their knowledge needs. As we have noted, the closer firms are in the mobility graph, the more similar the knowledge required for their innovation practice. Therefore, it is striking that the characteristic path length is less than five among patenting firms in the USA, regardless of the location, industry, or size of the companies. This indicates that there must be a set of companies or technology fields which are less path-dependent with their considerable absorption capacity and are responsible for making the network with such diverse nodes so "small".

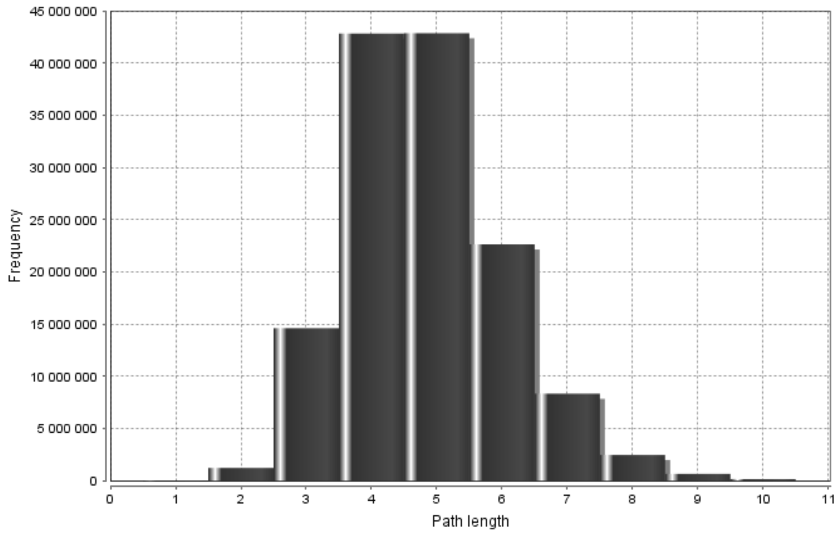

Fig. 1. The Frequency Distribution of the Shortest Paths in the Network

4.2 Degree distributions and correlation of network variables

In our first attempt to unravel the mystery, we investigate centrality indices for the firms. One of the most important traits of a network is the degree distribution or, in other words, the distribution of the edges among the nodes. This is a highly informative property of the graph; hence, it can ultimately describe the structure of the network. If the degree distribution follows a normal or Gauss distribution, the nodes in the network will have a typical value of edges connecting them to others. In the case of such a distribution, extremely large values are rare or not present and the average degree characterizes the biggest proportion of the nodes in the network. However, if the degrees follow a power-law distribution (i.e., the network is scale-free), there is no characteristic value at the edges. Many nodes have just a few links – and most have only one link – to other nodes, while a small but considerable group of them has a high or extremely high number of direct paths to others. The power-law distribution can be described with its exponent, which is -1.656 for in-degrees and -1.585 for out-degrees in our case. In classical studies of networks, for example, the World Wide Web, the exponents have been between -2 and -2.5 (e.g., Barabási, 2011). Where the exponent is closer to zero, there is a bigger chance of there being nodes with values higher than one.

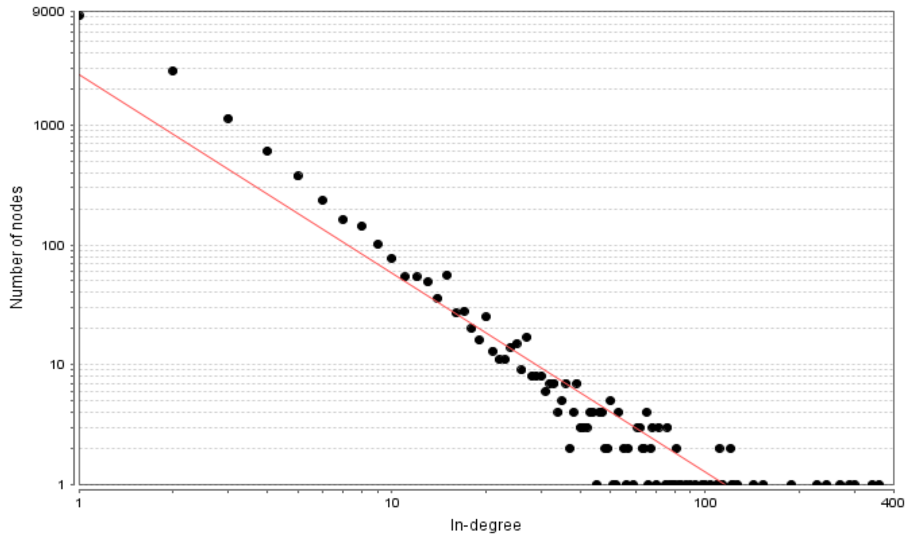

Fig. 2. In-degree Distribution of the Nodes on a Log-log Scale

As we can see in Fig. 2, the in-degree distribution of the mobility network is unbalanced. Instead of a characteristic or average edge value, many nodes (8153) have managed to obtain only one edge, but a small minority can absorb connections more frequently. Some of the nodes have more than 100 acquaintance organizations (the maximum is 360) that transmit knowledge to them directly. These powerful companies in the network are the greatest beneficiaries of the knowledge flow. Due to the fact that they are the most attractive for inventors, they represent the core of the competences and accumulated experience in the network. It is likely that the knowledge and social capital of the researcher at these centers grow multiple times compared to those at the peripheries. It seems these nodes serve as "black holes" in the knowledge network and can absorb a great amount of – and maybe more diverse – knowledge from it. The next question is whether they put something back into the common pot or not?

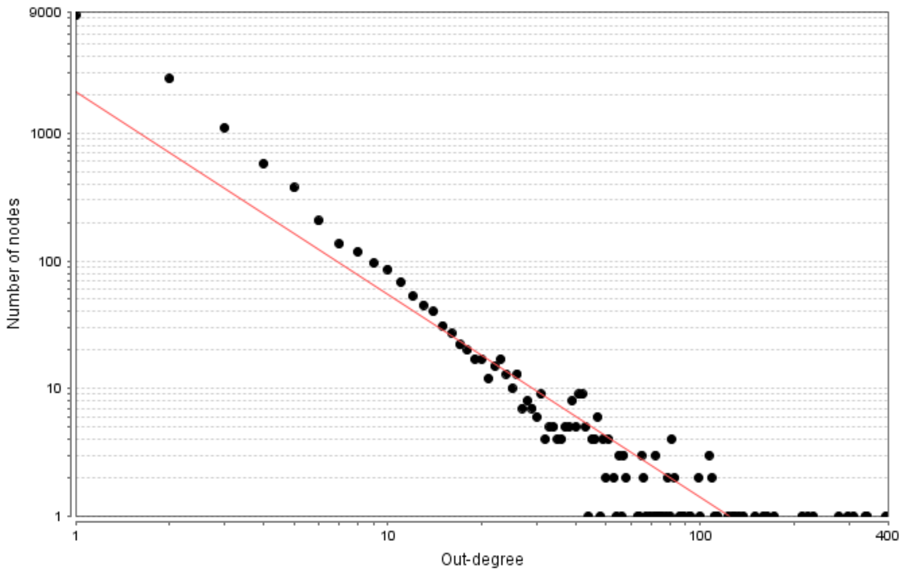

Fig. 3. Out-degree Distribution of the Nodes on a Log-log Scale

The function of out-degree distribution (Fig. 3) is quite similar to that of the previous one. Hence, there are firms, institutions, or universities in the network that do the opposite of the knowledge "black holes". The tail of the distribution, namely, the nodes with the greatest out-degrees, transmit knowledge to the network and continuously lose their researchers and knowledge base. The greatest giver in this case had to let its patenting inventors go to 394 different organizations. How could a firm survive such great losses? Maybe these great knowledge-providers went bankrupt or downsized.

As we can see in Fig. 4, there is an undoubtedly strong positive linear correlation between the in- and out-degrees of the nodes. In this sense, both the great knowledge takers and givers are the same entities. These strong nodes simultaneously serve brain drain and brain gain functions in the network. They function as cores of knowledge creation, accumulation, and distribution. These are junctions, the most frequent platforms where inventors with various corporate histories can meet and increase their professional skills and social capital. However, these organizations also mediate knowledge to the network through departing researchers with their rich human and social capital. This high equality of knowledge absorption and loss is also a feature of the less frequented nodes. Due to this strong linearity in the degree distributions, there is a low number and extent of outliers. A further interesting property of the network is the fact that the slope of the curve is very close to 1. This indicates that in general the number of organizations from which the company can recruit inventors tends to be equal to the number of organizations which can recruit researchers from that same company.

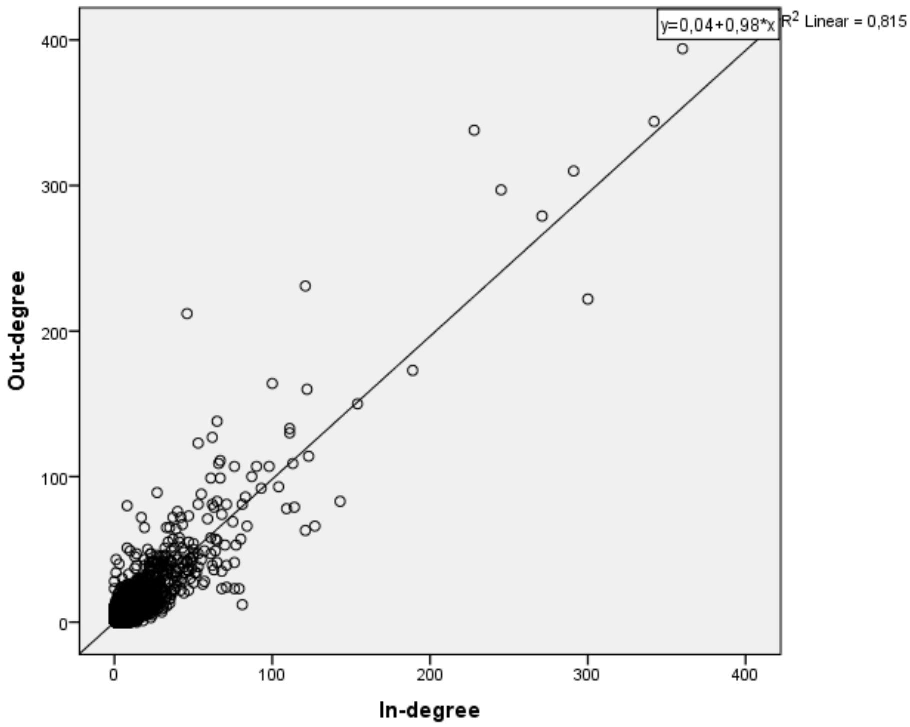

Fig. 4. Linear Regression of the In-degree and Out-degree variables. The regression is significant at the 0.01 level.

Although there are a few cores that frequently absorb and transmit knowledge, it is doubtful how effectively they do so. It is possible that they simply recruit from and hand over inventors and knowledge to a clique of nodes, and therefore the knowledge of this subset of companies circulates within a relative small space. Table 1 shows the correlation matrix of the main centrality indices and the variable of multi-edge node pairs, which is the measure of mutually connected neighbors of any node.

Table 1. Person Correlation Matrix. All the correlations are significant at the 0.01 level.

Person Correlation Matrix

	In-degree	Out-degree	Betweenness Centrality	Multi-Edge Node Pairs
In-degree	1			
Out-degree	0.903	1		
Betweenness Centrality	0.936	0.94	1	
Multi-Edge Node Pairs	0.936	0.926	0.943	1

According to the correlation matrix, betweenness centrality and multi-edge node pairs also show a surprisingly strong correlation with in-degree and out-degree scores. The betweenness centrality score indicates the proportion of pathways passing through the particular node. If the betweenness centrality is high, the node serves as a mediator of information in the network. The strong correlation between the degree centrality variables and betweenness shows that the cores of the mobility have far-reaching ties in the network, therefore functioning as the backbone of knowledge diffusion. On the other hand, the correlation between the three centrality indices and the multi-edge node pairs variable means that the higher number of edges a given company has, the more likely it is to send and receive knowledge from entities of similar size.

4.3 The top 30 central nodes in the network

Table 2 contains a list of the top 30 central nodes with rank scores of in-degree, out-degree, and betweenness centrality variables. In this case, the value "1" represents the highest value of a given variable. The table is sorted by in-degree ranks. Although the identity of the companies outlines the fact that the most IP-intensive industries are pharmaceuticals, communications equipment, and semiconductors (Shapiro and Pham, 2007), it is the dominance of IT and IT-related sectors that emerges from the data, while members of the pharmaceutical industry are at the back of the pack. It is a pleasant surprise that the four universities managed to make their way to the top 30. However, it is not surprising that they form a small elite of the world's leading universities. In the upper right quartile in Fig. 4, we can see seven dots separating them from the others. These are the most powerful nodes in the network. With one exception, they are the top-ranked entities in all three categories.

Table 2. The Most Central Nodes in the Network Sorted by In-degree Ranks

The Most Central Nodes In The Network Sorted By In-degree Ranks

Name	In-degree Rank Number	Out-degree Rank Number	Betweenness Rank Number
IBM	1	1	1
US NAVY	2	2	2
MICROSOFT	3	8	5
INTEL	4	4	4
GENERAL ELECTRIC	5	6	7
HEWLETT PACKARD	6	5	3
UNIVERSITY OF CALIFORNIA	7	3	6
CISCO TECHNOLOGY	8	10	10
HONEYWELL INTERNATIONAL	9	13	8
BROADCOM	10	34.5	27
APPLE	11	53.5	25
3M INNOVATIVE PROPERTIES	12	19	11
TEXAS INSTRUMENTS	13	12	12

MOTOROLA	14.5	7	9
QUALCOMM	14.5	59	36
BOEING	16	41.5	15
E I DU PONT	17	21.5	13
APPLIED MATERIALS	18.5	15	18
PROCTER & GAMBLE	18.5	16	14
BOSTON SCIENTIFIC SCIMED	20	43	22
BRISTOL MYERS	21	29	26
MIT	22	11	16
UNIVERSITY OF TEXAS	23	24	20
MICRON TECHNOLOGY	24	30	38
STANFORD UNIVERSITY	25	24	32
KODAK	26	26	21
WYETH	27	53.5	43
MEDTRONIC	28	33	29
ORACLE	29.5	37.5	41
GENERAL MOTORS	29.5	528	156

5 Community structure and the core of the network

In the previous section, we highlighted the basic properties of the inventors' mobility network. However, the main organizing principle of the network ties has still remained hidden! From whose knowledge base do companies tend to absorb external knowledge and why?

5.1 Modularity score and community structure of the mobility network

In this section, we investigate whether the network contains communities in which organizations tend to develop more ties with their community members than with outer nodes. Community structure can provide us with a better understanding of the organizing principle of the knowledge flow network. In order to identify these communities, we used the *fastgreedy* algorithm proposed by Clauset et al. (2004). Based on this algorithm, we found that the modularity value of the network is 0.72, which suggests an exceedingly strong community structure. The modularity value in real world networks very rarely reaches such a high modularity score. This indicates that many of the nodes keep in touch with restricted types of organizations with whom they are willing or able to exchange inventors. Presumably, this is the system-level outcome of the path dependency of individual organizations. When organizations absorb knowledge from others, the closer that knowledge is to their existing knowledge base, the easier it is to successfully achieve the absorption. Therefore, the strong cluster structure and high modularity value stress the fact that many of the nodes in the network must be highly path-dependent with a very restricted possible circle of knowledge absorption. It also predicts the importance of industrial differences in the knowledge flow system.

Although the fastgreedy algorithm found 268 clusters, the six largest of them contain more than 50% of the nodes. These six clusters were examined in this study for clear interpretability. We analyzed them as independent graphs; hence, only the intra-community edges are present in the statistics. Table 3 contains the number of nodes (Nodes), number of edges (Edges), characteristic path length (Cp), and network diameter (Nd) values of the communities as well as a list of the five most central companies per community.

All the communities can be seen as significantly separated subgraphs of the whole mobility graph. Surprisingly, their basic properties are very similar to the features of the parent graph. While not presented in the table, these subgraphs are also scale-free networks with power-law degree distribution. On the other hand, these communities can easily be characterized by their central nodes. Community No. 1 is led by pharmaceutical companies, the second consists of firms in the household, fashion, and cosmetics industries, and the third is made up of medical technology-related companies. The IT and communication industries, regardless of the hardware or software feature, form the biggest community with a very short diameter and characteristic path length. In the fifth cluster, we can find the US Navy and the prestigious universities, while the sixth cluster consists of the semiconductor industry. It seems that the main organizing principle of the network is the industrial structure of the economy. This is not surprising since every industrial area has specific knowledge needs. Although it is more striking that despite the strong impact of industrial knowledge needs on the network structure, the whole mobility network has almost as short a diameter and characteristic path lengths as the clusters in it do. It seems that, despite the strong community structure, there are companies which can overcome path dependency and that this ability increases the effectiveness of knowledge transfer on the system level.

Table 3. The Six Biggest Communities in the Mobility Network

The Six Biggest Communities in the Mobility Network

Community No. 1		Community No. 2		Community No. 3	
Nodes	1626	Nodes	2322	Nodes	1437
Edges	3351	Edges	3600	Edges	2331
Cp	4.46	Cp	5.49	Cp	5.169
Nd	11	Nd	15	Nd	16
Central Nodes	BRISTOL MYERS SQUIBB	Central Nodes	PROCTER AND GAMBLE	Central Nodes	BOSTON SCIENTIFIC SCIMED
	PFIZER		SUNBEAM		MEDTRONIC
	WYETH		S C JOHNSON SON		ETHICON ENDO SURGERY
	MERCK		NIKE		SCIMED LIFE SYSTEMS
	AMGEN		PEPSICO		ETHICON

	Community No. 4		Community No. 5		Community No. 6
Nodes	2998	Nodes	2252	Nodes	922
Edges	6354	Edges	3658	Edges	1221
Cp	3.8	Cp	4.06	Cp	3.86
Nd	10	Nd	11	Nd	12
Central Nodes	IBM	Central Nodes	US NAVY	Central Nodes	GENERAL ELECTRIC
	INTEL		UNIVERSITY OF CALIFORNIA		MOTOROLA
	MICROSOFT		MIT		LOCKHEED MARTIN
	HEWLETT PACKARD		3M INNOVATIVE PROPERTIES		SIEMENS MEDICAL SOLUTIONS
	CISCO TECH.		CALIFORNIA INSTITUTE OF TECH.		FREESCALE SEMICOND.

As we can see, the most central nodes in the whole network are the leaders of the communities as well. Moreover, according to the results in Table 1, which have been examined previously, the more central a particular node, the more mutual ties it has with other central nodes. Therefore, next to the strong cluster structure of the network, community leaders must have frequent contacts not just with their community members but potentially with other community leaders as well. It is possible that despite the strong modularity of the network, network leaders have formed a sort of elite club with dense and mutual ties.

5.2 The core of the mobility network

To examine the core of the mobility network postulated above, we used the *k-core algorithm* proposed by Batagelj and Zaversnik (2002), which finds the most densely connected and interconnected subgraph in the network. Fig. 5 shows a graphic representation of the result attained with this algorithm. The core of the mobility network consists of 58 organizations with at least 23 ties to other core members. The total number of edges in this subnetwork is 1112, which indicates high density since the maximum number of possible edges is 3306. The circular layout and spatial proximity help to identify common community memberships. Parallel to the size of the communities, the IT industry – the biggest circle of nodes – is by far the most overrepresented cluster in the core with 31 companies. Besides hardware and software companies, the dominant community in the core is that of the universities with 10 institutions of higher education, supplemented by the US Navy and 3M Properties. Semiconductor companies are also frequently represented in the core graph, but the pharmaceutical industry is not included.

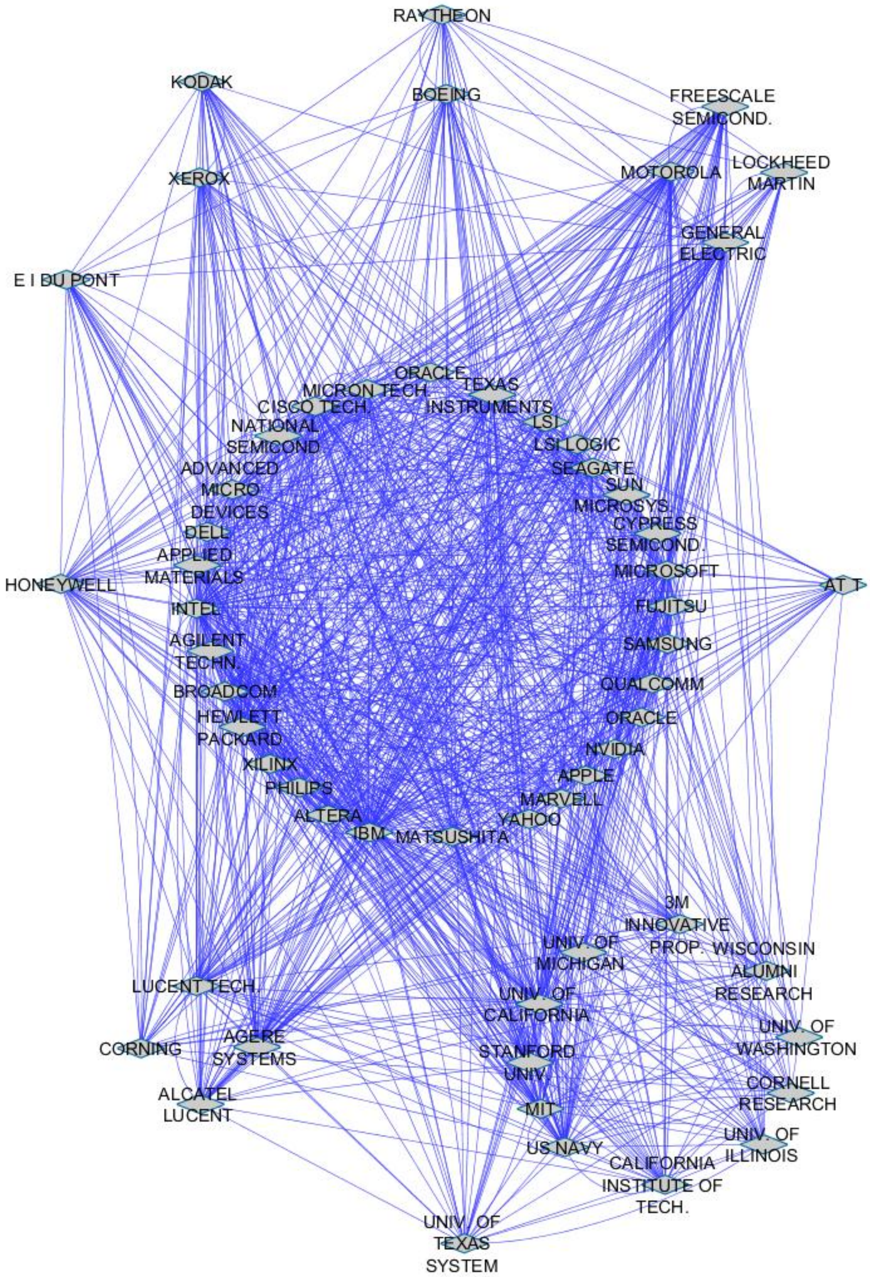

Fig. 5. The core of the US inventor mobility network with 58 organizations and 1112 ties

6 Conclusions and avenues for further research

6.1 Main conclusions

Our study has aimed to explore the mobility network of US inventors. Based on the transformed Harvard University's Patent Network Dataverse, the present paper has highlighted the knowledge flow network among US firms, institutions, and universities tracked by mobile inventors from 1999 to 2010.

Studies conducted so far in this area have investigated specific economic segments, such as the semiconductor and pharmaceutical industries. To the best of our knowledge, this is the first attempt to examine the inventor mobility phenomenon on a nationwide, multi-industrial level. Our findings may therefore provide a wider perspective on the inter-organizational knowledge flow processes via inventor mobility, such as inter-industry knowledge transfer, system level innovation communities, and identification of community and network leader organizations. Consistent with previous studies, our results underline the importance of knowledge pooling as well as informal innovation networks and researcher mobility in knowledge transfer. We have also pointed to the strong impact of path dependency on inventor mobility, but at the same time we found evidence of a previously hidden coherent network, where some of the nodes which manage to overcome path dependency can achieve significant advantages in knowledge absorption.

We have demonstrated that this system is a scale-free network with a short effective diameter and small characteristic path length, where central nodes simultaneously engage in both brain drain and brain gain functions. Giant communities in the graph reflect the set of the most frequent patenting industries, plus the unique cluster of the Navy and universities. Though the community structure is extremely strong in this network, community leader entities hold important intra- and inter-cluster ties as well.

According to recent outcomes, three main lessons can be learned from the core structure of the network. First, the IT and semiconductor industries have emerged as organizers of the mobility network with a high absorption capacity and low path dependency. The leaders in these industries are the far more central and interconnected nodes in the network. Their high betweenness enables these companies to search effectively in the network. The literature (Breschi and Lissoni, 2009) has highlighted the fact that mobile inventors' personal networks play a significant role in knowledge spillover and knowledge diffusion. With their far-reaching ties, these central firms are able to absorb knowledge from other communities and expand the search horizon to the social ties of new employees. On the other hand, scientists who leave these organizations bring valuable intellectual and social capital to periphery firms and mediate knowledge to them. The knowledge-emitting function of the core is supported by the fact that inventors were obtained from the 58 organizations noted above as follows: they were received by 1210 nodes out of a total 8153 nodes with 1 in-degree, 705 nodes out of a total 2833 nodes with 2 in-degrees, and 436 nodes out of a total 1139 nodes with 3 in-degrees.

The second remarkable consequence of the results is the central position of universities. It seems that they are no longer "ivory towers" of science but proactive creators and mediators of knowledge not only in educating people but also in patenting and exchanging inventors with others. Nonetheless, they are not just isolated points in the system, but leading and organizing entities within one of the largest communities of knowledge transfer.

Third, the dense mobility ties between rival firms underline the importance of the knowledge transfer represented by inventor mobility. It is very likely that companies must continuously search and obtain skilled inventors from rivals in order to keep up with rapid technological development and with the expanding knowledge base of their competitors. This frequent inventor exchange gives rise to an effective and coherent, but invisible and informal knowledge network among innovative organizations in the United States. Furthermore, in the center of the network, the dense core of the biggest companies form and run a valuable knowledge pool. It is possible that this pool serves a dual function. First, it levels knowledge among these firms, preventing individual organizations from breaking away and enabling them to use the most advanced technologies and ideas. Second, it preserves the technological advantage of the core members against the periphery.

6.2 Limitations

One of the greatest drawbacks of our work is the temporality feature of the source files, since the original Dataverse network files are split into three-year intervals. The disadvantage of this is if an inventor changes assignees more than once in three years, only one assignee can be indicated for him or her in the network file. A side-effect of this is that our analysis underestimates frequency of mobility in the graph. The other limitation factor of our study lies in the noise in the assignee names. Although inventor names are disambiguated, unfortunately, in some cases, the misspelling of assignee names creates false nodes in the network. The third limitation we faced during our research is associated with the size of the network. Since nearly twenty-one thousand organizations are represented in our network, we could not involve a further set of control variables in the investigation, only the network-based ones. We were not able to examine such properties as size, market value, profile, or type of organization (e.g., profit-oriented company, governmental institution, university etc.). In the case of the central nodes, we deduced these variables from the names of the organizations, but overall statistics cannot be displayed. We also could not filter mergers, acquisitions, and parent company and subsidiary relations.

6.3 Managerial implications

Our findings represent further evidence of the importance of inventors' mobility in technology development and knowledge transfer. As we have seen, large successful companies maintain a knowledge pool, which is a place for effective knowledge recombination. We also presented the knowledge absorption and emission feature of this core, where IT-related companies are overrepresented compared to other industries. Consistent with recent findings, acquiring external knowledge in order to catch up with advanced organizations on the market by hiring inventors from core organizations in the network can foster technology development, especially if the inventors come from the IT industry.

6.4 Avenues for further research

We believe that this approach toward the mobility of inventors and knowledge diffusion processes offers great potential for further research. One of the possible options for future studies is to analyze the evolution of the network. This could reveal how and when ways of knowledge diffusion have changed over time and how successful companies (such as Microsoft and Apple) have risen in the network. It may provide a better understanding of how knowledge flow supports emerging organizations. Another possible direction is to examine the career of inventors by measuring their productivity compared to the network properties of companies where they invent technology or to the diversification of the classes of technology to which their inventions belong. The third most promising path for future research is to analyze the specific features of individual communities. The remarkable importance of universities in the knowledge flow network, for example, raises the question of how academic inventors move between the academic and the business sector, or what specific features universities show in the network. Fourth, it would also be interesting to compare the mobility network of inventors with the patent co-citation network. Once we identify the similarities and differences between these two networks, we could gain an understanding of the different forms and mechanisms of inter-organizational knowledge transfer.

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Building Interactive Communication Tools to Support Interdisciplinary Responsible Innovation

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Abstract. Recent science policy encourages the installation of Responsible Research & Innovation (RRI) practices, which should help solve grand societal challenges and be more readily adopted by society. RRI may be implemented by setting up interdisciplinary innovation development teams, bringing together technical and non-technical experts from various disciplines and backgrounds, enabling engineers to let their work become inspired by – or even partly co-shaped by – societal insights and viewpoints, while societal actors get acquainted with techno-scientific context. We developed a Decision Support Tool to support interdisciplinary innovation teams, that visualizes innovation project performance and success chances. It supports communication and collaboration in interdisciplinary teams by proposing practical improvement areas, based on shared expertise, including socio-ethical, societal, economic and management related aspects. Still, further investigation is needed to learn how such a tool can be used to systematically integrate RRI in practice, to harness its full innovative potential.

Keywords. Responsible Research & Innovation, Communication, Innovation Support Tools, Innovation Management, Decision Making, Scenario Development.

1 Introduction

1.1 Context and background: Responsible Research & Innovation in practice

Much is expected of technological innovators in terms of addressing current and future societal challenges. Current academic technological research grant applications even have dedicated sections in which applicants are asked to highlight possible future technology implementations in light of resolving societal issues, regarding e.g. environmental sustainability and healthcare relevance. At the same time commercial and industrial research institutes are more and more expected to take corporate social responsibility not merely as a guideline, but as a starting principle for their innovation practices. So, both industrial and academic institutes are stimulated to deploy 'responsible research and innovation' (RRI) practices, either via market demand or via public policies.

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Yet while research and development organizations are encouraged to install and deploy RRI on an institutional level, the way in which such installment and deployment should and could work on the level of individuals remains elusive. We believe that this is in part due to the fact that innovators – i.e. the *people* who innovate, not their organizations per se – don't always know how to functionally apply considerations of social and ethical relevance in their daily work. Therefore, in this paper we present a tool that can support interdisciplinary teams during on-going innovation practices to explicitly discuss and consider RRI-relevant aspects.

1.2 Communication in relation to Responsible Research & Innovation

No innovation would exist without communication. Interaction between individual innovation team members is essential for innovations to take shape, particularly when the four elements or RRI mentioned above are to be deliberately and deliberatively considered. In this paper we follow the Stilgoe *et al*. (2013) description of what RRI entails. They distinguish four distinct features of RRI. These include *anticipation* of societal effects (insofar as possible), *reflexivity* of involved stakeholders on socio-ethical and socio-economic dimensions of (new and emerging) innovations, *inclusion* of considerations on these dimensions in scientific and technological development processes, and *responsiveness* of involved stakeholders to change shape or direction of developments in response to stakeholder and/or public values and changing circumstances. More specifically, they state *"responsible innovation can be seen as a way of embedding deliberation on these [four elements, SF] within the innovation process"* (p. 1570).

Following Schuurbiers & Fisher (2009), we consider RRI-relevant interactions on three levels of innovation practices: the *upstream*, *midstream* and *downstream*. In the *upstream*, decisions are made (based on interactions between individuals) on which research and development actions to authorize. This phase is important for RRI in terms of setting guidelines for new innovations (in determining what are the 'right things to do'). So, for RRI governance this phase is important to consider, even though no actual innovations are developed and made in the upstream.

In the *downstream*, decisions are made on how to implement new research and development ideas. To convey the functionalities of these ideas, communication is essential. Still, while decisions are made here on how to install innovations in society, and communication is deployed to support that process, also in the downstream no actual innovations are shaped.

We therefore wish to focus on the *midstream*, the phase where research and development actions are carried out, and actual innovations are shaped. More specifically, we focus on responsiveness of all involved actors towards socio-ethical and socio-economic aspects, which is essential for RRI to take shape. 'Responsiveness' on the midstream concerns 'doing things right'. From an RRI perspective, this includes more than taking anticipation, reflexivity, and inclusion *into consideration*. 'Consideration' in fact could mean that things are debated on, but not actually used to develop new innovative ideas – hence the contrast between consideration and responsiveness.

1.3 Towards a tool to support communication about Responsible Research & Innovation

Exactly at this last point, being responsive on the midstream, remains difficult for innovators on the laboratory floor, i.e. the actual scientists and engineers developing new innovations during their daily practices. Possibly they are preoccupied with their technological work (Brunner & Asher, 1992). Or, from a historical perspective, they may see ethics as a break on progress, where ethics indicates what scientists and engineers should *not* to do (*cf*. Van der Burg, 2009; Shelley Egan, 2010). Still, some researchers may be aware of the social and ethical aspects of engineering practices, but possibly fail to think about the repercussions of their own work (Patra 2011). More worrisome, some engineers are even explicitly asked to focus on technological development, and asked to ignore 'distracting' social aspects (*cf*. Fisher & Miller, 2009).

In our experience, scientists and engineers are neither unwilling nor unable to take socio-ethical and socio-economic considerations into account (Flipse *et al.,* 2013a). Still, these elements are initially 'blind spots' for them, not by definition high on their priority list. Even though such aspects are important to consider, to increase innovation project success. In order to be responsive to socio-ethical and socio-economic considerations, these considerations need to be made explicit. Apart from institutional support and voluntary participation, interaction with critical 'outsiders' is essential for that to happen. The potential positive role of such critical non-technical / non-scientific experts (Collins & Evans, 2002) to broaden research considerations has been identified and acknowledged earlier (Van de Poel, 2000; Wilsdon, 2005), but social scientific research to prove these effects have only recently appeared. The way in which we researched this effect in our earlier research, was through the installment of a 'collaborative space' in which scientists and engineers collaborated with an 'embedded humanist' who helped them reflect on social and ethical considerations (Flipse *et al.,* 2014a). 'Midstream Modulation' was used as the method to facilitate such interactions. In this method decisions of innovators are 'modulated' into the various elements that they are made up of (i.e. opportunities, considerations, evaluation of alternatives and projected outcomes, see e.g. Fisher 2007). The results of Midstream Modulation research are positive in the sense that the participating researchers appreciated 'opening up' their labs to external viewpoints, and letting their work become inspired not only by their own technological considerations, but also by social and ethical aspects. Similar studies show the ability and willingness of scientists and engineers (see e.g. Conley, 2011; Schuurbiers, 2011).

Still, these studies also show similar results in terms of their limitations. All studies are quite extensive (i.e. 12 weeks or longer), relying on sustained interaction between researchers and outsiders that are allowed to have a critical opinion on on-going innovation practices. Still, extensive collaboration places quite a burden on both the embedded humanist and the involved researchers and engineers. Possibly, 'responsiveness' effects in innovation practice could emerge more quickly if there was a way for embedded humanists or other critical outsiders to know sooner what social, ethical and economic contexts are *relevant* for researchers to include. Also, such effects could more readily emerge if researchers can more easily relate to such aspects in light of the *quality* of their own research. An interactive communication support tool could facilitate relevant and quality related interaction between the involved innovation stakeholders, and thereby support responsiveness to broader societal, ethical or economic considerations – and hence the emergence of RRI practices – more readily.

1.4 Earlier work: Identifying Key Performance Indicators in relation to Responsible Research & Innovation

In our earlier work we aimed to support interaction between multidisciplinary stakeholders in order to functionally shape RRI practices on the laboratory floor through Midstream Modulation. For that we first researched the possibility and utility of interactive communication between researchers and a critical outsider (called the 'embedded humanist'), without compromising the quality and speed of on-going innovation work. The results of this preliminary study (Flipse *et al.,* 2013a) showed that interaction is not only valuable for a more thorough and creative technological development process, but also appreciated by the involved researchers. They claim to explore more research trajectories (exploring more scenarios) than they would have done otherwise, and that they can prioritize their activities better when reflecting better on the societal implications of their research decisions. In any case, the research stresses the importance of communication between involved actors.

The observed effects could be considered important for RRI installment, however there was no 'tool' yet to support RRI, integrated in daily innovation practices. In the meantime, various approaches have been published that present approaches that allow for the 'mapping' of social responsibility (Glerup & Horst, 2014) and even quality criteria and indicators for RRI (Wickson & Carew, 2014). These are valuable starting points to make RRI more concrete on the innovation working floor. However, the direct link with innovation project success needs to be further evaluated. We consider such a link imperative for innovators in order to allow them to seriously consider RRI related aspects.

In a follow-up study we therefore developed a way for external outsiders to learn sooner what is the relation between 'external' broadening aspects and research quality, and for researchers to learn what are the relevant 'external' broadening (RRI-relevant) aspects to take into consideration to further their research. The idea behind this method is that both the outsider and the researcher mutually learn about one another's considerations. Such mutual learning is important for establishing a relationship in which critical viewpoints are not only tolerated, but also valued and actively taken into account (i.e. *responsiveness* towards socio-ethical and socio-economic aspects).

We shaped these broadening aspects into innovation Key Performance Indicators (KPIs), which form the backbone of the tool we are presenting later in this paper. The assessment method of KPIs is based on the Wageningen Innovation Assessment Toolkit (WIAT), developed by Fortuin & Omta (2007). WIAT was developed to help organizations in innovation project selection and execution, by providing relevant management information. Based on a statistical analysis of finished projects' features and success rates[1], we distilled how success chances depend on numerous project

[1] We elaborate on the method below. The elements used can of course differ per context. For an example of implementation, see Flipse *et al.*, 2013b.

characteristics. The eight KPIs identified in one case study at a Dutch research organization (Flipse *et al.,* 2013b) relate to external social aspects, including RRI-relevant aspects such as sustainability and health (1), available financial, material and people-based resources (2), communication and cooperation quality (3), technical skills available (4), the technological project superiority in relation to other available technologies (5), the culture of the (internal) customer's R&D culture (6), the clearness of (internal) customer's wishes and demands (7), and the strategic value to the customer (8). Of course, KPIs can differ per context, yet in any case KPIs are an important units of analysis when studying socio-technical innovation systems, especially when the aim is to find relevant improvements related to communication and decision making.

2 Methodological considerations for communication tool development

We designed a plan to develop a functional tool that supports interaction between stakeholders in innovation projects, eventually leading to more RRI-relevant decision-making. Below we describe first the requirements we had for making the tool that we present later, followed by a set of building blocks that the tool is made up of. How the tool looks is presented thereafter in the 'Results' section.

2.1 Requirements for tool

This tool should meet several requirements. *First*, the tool should help give insight into what could make innovation projects 'socially responsible'. As such, the 'soft' elements of innovation practices that could help guide projects in this direction should be includable. Yet, these elements can only be functionally included if they are assessed in relation to on-going project management. This means that the soft elements that could influence project performance first need to be assessed in relation to the organization in which the tool should be used. Such aspects may range from environmental impact to social impact of innovations, to worker safety and working environments, which may be different in every organization. So, the tool should have a dynamic character and be adaptable to different organizations.

Second, the tool should be considered functional in industrial innovation practices. This means that researchers and engineers should recognize its functionality. This implies that we should develop this tool in collaboration with industrial partners, with continuous user input to safeguard usability in practice. In addition, this means that the interaction with the tool should be such, that critical scientists and engineers are open to the tool's input and visualizations. This means that a certain degree of 'measurability' of quality performance should be incorporated into the tool, which should be visualized in a way that scientists and engineers are used to, such as graphs and relative scores.

Third, the tool should provide critical outsiders with relevant input on other project performance related elements that are considered important by the scientists and engineers who they work with within their joint collaborative space. This means that a certain degree of technical and economic project performance indicators should also be included, to help these outsiders make estimations on the extent to which projects can be influenced on these content-based elements. This should allow for faster knowledge and experience exchange between e.g. the researchers and the embedded humanist, allowing for responsible innovation elements to emerge more readily than they would without such a tool. As such, the second and third point combined, safeguard that all those involved in a multidisciplinary innovation project, have their 'blind spots' covered through some representation in the tool.

Fourth, the tool should also be considered relevant in terms of project management. So, the tool should visualize the effect of using the tool in time in terms of project performance, and therefore should provide insights into e.g. 'resources saved' (both on personnel and financial resources levels) and performance changes in time. Evidence on these levels should help organizations decide more readily that there is an institutional need for such a tool.

2.2 Building blocks for online project evaluation tool to stimulate communication

The tool should provide experts with visual output on which KPIs are scoring good, and which can be improved upon. To arrive there, innovation project team members should provide the input to deliver such visual output. Yet such input needs to be compared to a database of earlier projects, in order to be meaningful for that organization. Based on the presented requirements, we envisioned a digital communication tool to support RRI to work as follows.

First, the organization's innovation projects' KPIs are determined using an online survey system. Using a questionnaire with approximately 50-60 potential project success related elements, employees are asked to score a successful and a less successful finished innovation project on a 9-point Likert-type scale. What it means to be successful as a project depends on the organization[2]. Relevant success related criteria can then be identified partly based on innovation management literature relevant for the context in which it is used, and can be supplemented with organization-specific elements and social responsibility (e.g. environmental sustainability, and worker/producer safety) related elements, based on both experience and literature (see e.g. Wickson & Carew, 2014). In any case, this first step results in a list of questions and the involved innovators' answers for two kinds of projects: successful ones and less successful ones.

Second, based on the scores of these finished projects, the items are clustered into organization-relevant KPIs through statistical analysis based on exploratory factor analysis. The data could show that for only e.g. 30-40 of the total (50-60) items a statistically significant relation can be shown in relation to project success. Only these relevant items are included in KPI determination. Using logistic regression analysis, e.g. in SPSS, the identified KPIs and their interrelations and relation to project success are determined. The result of this step is an overview of KPIs and the elements (questions) of which they consist, each accompanied with an average value for successful and less successful projects.

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[2] In practice, we have observed to main characteristics of innovation projects: the project is successful if the (internal/external) client is satisfied with the result (regardless of the actual outcome of the project); or it is successful if it earns an organization more money than it has cost initially.

Third, this model is transformed into a visual benchmark that basically contains four 'lines' per KPI that can be mathematically calculated: the lowest possible score for a KPI (on a 9-point scale) is 1, then we have the average of all less successful projects, then a line for the average of all successful projects, and last a line for the maximum score for that KPI, i.e. 9. These lines can be normalized mathematically, so that the resulting graphs have three 'scoring areas' in which projects can be scored: from a minimum value to averagely less successful, from less successful to successful, and from successful to a maximum value.

Fourth, in a subsequent step, this benchmark model based on recently finished and evaluated projects is used to compare *running* projects to. This works as follows. Researchers working on innovation projects score their current projects in an online tool, the same way as in the first phase (except with fewer elements, since only the significant items are used now). Based on the project scores, the tool automatically makes a visualization of performance in relation to the developed benchmark. Based on the scores on different KPIs, the researchers and others involved in the project (e.g. outsiders, but also managers, team members, colleagues, etc.) get an idea of what is currently going well, and what can be improved on. In collaboration, the researchers can determine which elements to take decisions and action on. Frequently, this indicates that actions are required on their 'blind spots', things they have not been aware of (just yet).

Fifth, the various inputs of different users could be compared to one another. This way, differences in insights in project quality and performance can be highlighted, discussed, and potential issues can be solved.

Sixth and last, the KPI average scores are transformed into a model that (to some extent) can predict innovation project success chances. Using a Structural Equation Modeling (SEM) approach, e.g. using AMOS[3], the KPIs and their relation to innovation project success (as described above) are analyzed and mapped. This results in a model that links the KPIs to one another and to success. Using an agent-based modeling approach in combination with the model that results out of the SEM, the scores of current projects can be transformed into scenarios. Namely, based on the insights of successful and less successful projects in the benchmark, the model can estimate what happens to the success chance if one KPI of a currently running project is increased or lowered. The lower score on that one KPI can have an effect on another KPI, and eventually on project success. This way, users can use their scores in combination with the model to think about possible scenarios of things that could happen to a project, e.g. when they know that a certain KPI will drastically change in the following period (e.g. due to budget cuts, retirements, etc.).

3 Results

3.1 Outcomes

Based on the requirements presented above, the building blocks of the tool presented

[3] While AMOS can also be used to check, verify or improve existing models, it can also be used more in an 'engineering' way to estimate success models based on statistical data.

above, and our preliminary case studies, we developed a tool that aims to support communication about KPI based project performance in multidisciplinary innovation project teams in an industrial context, with an additional focus on enabling RRI through interaction. Here we elaborate on how we used the requirements for usability mentioned above in the design of a functional online 'dashboard' that project team members (both 'insiders' and 'outsiders') and their managers may use evaluate project performance. For visual representation of the first three building blocks, as presented in *Section 2.2*, we refer to our earlier work (Flipse *et al.,* 2014b). These primarily concern lists of KPIs and their values, as gathered and calculated using computer software like IBM's SPSS Statistics. The other elements are presented below.

The *fourth* building block can compare running projects to the database of earlier projects. This is depicted in *Figure 1*, which shows the performance of a dummy project (as scored by an imaginative innovator or his/her team). The benchmark element (building block 3) is depicted as the three areas in the graph, between the bottom line, less successful project line, successful project line, and above. This particular project apparently has many features in common with averagely less successful projects, as earlier defined by this dummy-organization. Communication about these aspects with team members or external advisors can be the strating point for improvement of these aspects.

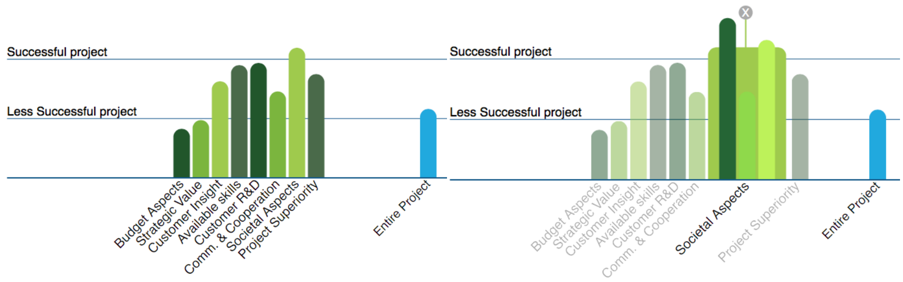

Fig. 1. (L) Scores of a dummy-project on 8 possible KPIs, as described earlier. The weighted average is depicted on the right of the figure. **(R)** When zooming in on one specific KPI, the dashboard displays the scores of various elements out of which the KPI is constructed. E.g. the KPI 'Societal Aspects' consists of 3 elements in this dummy-model. This way, the user gets information on which KPI-specific elements of this KPI are good, and which aspects can be improve on.

The *fifth* building block, the comparative analysis element, is depicted in *Figure 2*. It features the ability to compare different projects to one another, or to compare different moments in time for one project, or even to compare different input of a project by different team members at any given point in time. In terms of communication, the latter part is especially useful if two team members disagree on one particular KPI, so they can more easily resolve differences, possibly complementing one another's viewpoints.

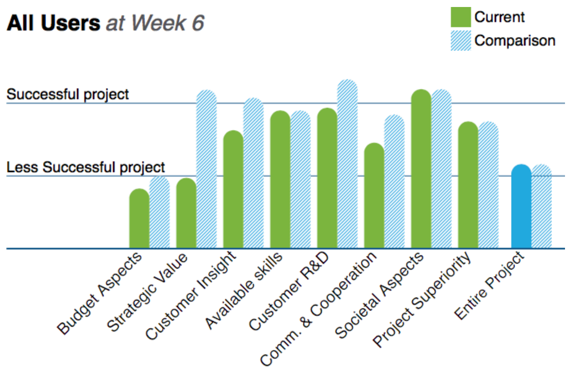

Fig. 2. Building block for comparison of projects, comparison of performance in time, or comparison of different team-members' input in a project at a certain point in time. In this example, the combined score of all users in week 6 of the project is compared to a random other project score.

Using the *sixth* building block, users can build scenarios that help them predict what happens to their projects' success odds if they change the value of a certain KPI. This is an additional tool functionality that allows for further exploration of potential improvements. The effect of hypothetical project changes is calculated based on the SEM outcomes. This model visually presents the hypothetical KPIs and their interrelations (*Figure 3*), may differ per context or per organization, and are based on the earlier project benchmark data (building block 2). *Figure 4* subsequently presents a possible function of this scenario prediction tool. E.g., increasing the score of one KPI score could mean that other KPI scores decrease, depending on the KPI interdependencies that are determined in the earlier statistical analyses. Based on the project team members' estimations, they may together determine courses of action on how to improve on certain KPIs. Also, they can visualize what would happen if e.g. budget would decrease suddenly, if team compositions change, or if (internal or external) customers change their attitudes towards the project (compare e.g. the left and right image in *Figure 4*). Together, the team members may then devise counteractions in order to prevent project quality decreases. By playing with these sliders, based on their predictions on how the project will change in time (e.g. due to staff and resource changes) or what they plan on doing (e.g. acquire more resources or improve communication with the customer), the users can estimate what the effect of their actions could be on entire project performance.

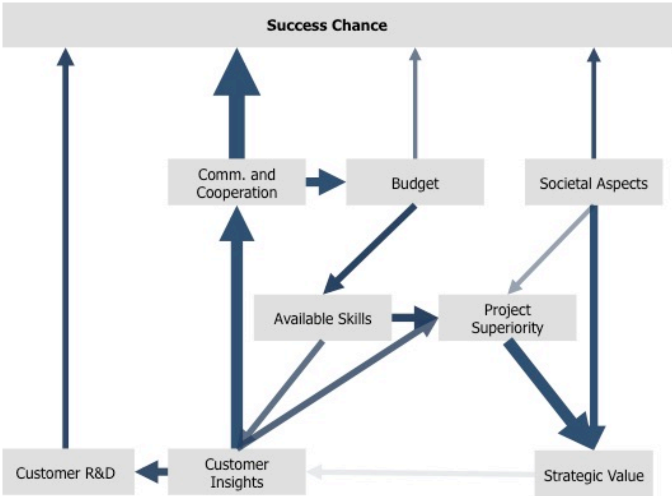

Fig. 3. Result of Structural Equation Modeling, depicting the relation between the KPIs and their relation to innovation project success.

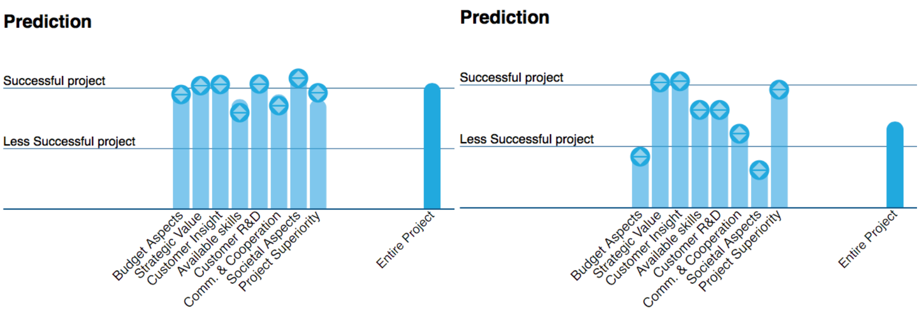

Fig. 4. Tool that helps users to explore which KPIs to improve on, with the largest effect on project success. (L) When users enter the tool, all scores are displayed as they were entered during the last project evaluation. Since the tool is based on an evaluation of the project portfolio of one organization, the significance of the elements will differ per company, meaning that each organization has its own version of the SEM-model in Figure 3. (R) When users play with the slider bars, the other values are also affected. E.g. in this case, the societal aspects KPI is lowered (e.g. hypothetically due to the fact that the innovation is apparently less eco-friendly as was initially anticipated). According to the SEM-model (Figure 3), hereby also other KPIs are affected, lowering their scores as well, along with the entire success chance of the project. This shows it is apparently important (in this dummy-model) to safeguard the value of societal aspects.

The different building blocks are combined into a single 'dashboard' (*Figure 5*).). This dashboard contains three elements, apart from the header with a title and short project summary. These three elements include 'input' area where users can determine what they wish to visualize (top left), a display of performance based on various KPIs (right), and a display that visualizes performance of the project in time (bottom). Through the use of filter settings for the visualizations, the users can select which information they wish to visualize in the dashboard. They can filter per project on date, on individual KPIs, and on different user inputs of the different team members who work on the same project. Using the comparison function, they can compare scores of different projects. Using the 'tool' button, they enter the scenario-building tool which was described above.

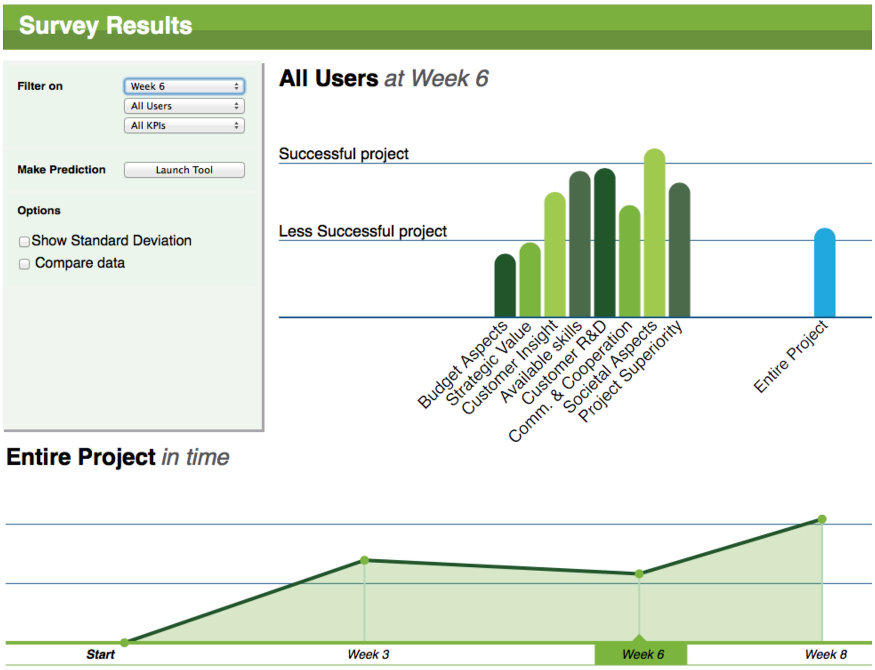

Fig. 5. Basic project overview dashboard with three distinct elements. The right part displays performance on various KPIs (green lines) and the overall project (blue line) in relation to successful and less successful previous projects (also see Figure 1). The bottom part displays overall project performance in time, an additional feature that allows for project quality monitoring. The top left part displays selectable project parameter display filters. From top to bottom, these are: project display selection, project evaluation moment, user selection, and specific KPI scores selection. Also, this part has buttons. One checkbox launches a dashboard in which projects can be compared to one another (Figure 2). The other launches a tool that estimates performance change when changing one KPI (see Figure 4).

4 Discussion and conclusion

4.1 Tool requirements

As stated above, we had four basic requirements in making this tool. The project performance in time should be monitored, it should explicitly include elements of Responsible Innovation, it should be useable by outsiders as well as insiders, and it should be functional in terms of suggesting possible improvement points. The bottom part of the dashboard display (*Figure 5*) visualizes project performance in time, so users have an immediate idea of how their current score compares to previous scores. The different 'entry dates' are clickable, so the users can click on an earlier date in order to see performance of earlier projects. If project performance is monitored on a regular basis, e.g. every two weeks, project score development can be monitored in time. But more importantly, this means that elements of responsible innovation, such as issues relating to environmental health or societal relevance, are continuously 'on the radar' of innovators through the tool, and not just during moments of explicit thinking about such elements during e.g. dedicated sessions. Such sustained attention to these elements should allow innovators to be more responsive to societal aspects, which is a staring point for RRI. In addition, if no significant improvements are monitored, this could lead to quicker decision-making on project go / no-go decisions, potentially saving resources for the organization. This way the tool provides innovators with a little more grip on uncertainty when it comes to their decision making in the dynamic and complex environment of innovation practice.

The elements of responsible innovation that are important to consider, can be part of the KPI composition. Additionally, if desired, even elements can be explicitly included that are outside of the statistical analysis. E.g., if an extra 'KPI' is proposed, it can be included in the model separately, if this would further support responsible innovation design thinking.

The usability by both insiders and outsiders is visualized trough the appearance of KPIs that the insiders and outsiders can relate to. E.g., technical content experts may relate more to the technical and skill related elements, but customer insights might be blind spots to them. In contrast, social elements might be more operationalizable by critical outsiders such as critical outsiders, who might initially have less knowledge of and experience with the technical content. Through communication, based on the tool scorings, these different stakeholders can interact more functionally, both not forgetting the final aim of the project, i.e. increasing project performance.

The aspect of proposing concrete improvement points is addressed in two ways. First, low KPI scores, or at least lower than the benchmark of less successful projects, indicates that there are possible improvement points on that KPI. The individual KPIs are clickable, and when clicked the different elements' scores that make up a KPI appear. By hovering on these elements, the different element descriptions appear. When project team members discuss why these values may be low, they together explore possibilities for improvement. Second, potential scenarios can be developed that can help innovators predict what happens to their project based on anticipated changes. These scenarios can then be the starting point of discussions aimed at preventing decrease in quality, or even help teams come up with concrete improvement points.

4.2 Prospects

Now that the tool has been developed, based on continuous insights and reflections with potential users, we plan on further implementing it in multiple professional innovation environments. In an earlier preliminary study, without this tool but with visualizations of performance, we tested the use of KPIs in the form of a project scoring benchmark as a means to start discussion with researchers on what they could improve in their currently running projects. In this study (Flipse *et al.,* 2014b) we asked researchers to evaluate their current projects on the same characteristics as those used to identify KPIs in the previous study, in collaboration with a critical outsider (the embedded humanist). We then compared their running projects' scores to the database of finished projects and visualized their projects' performance in comparison to the benchmark KPI scores. The results of that study show that researchers appreciate discussions based on such visualizations, since it makes 'soft' project characteristics such as communication and customer relations 'harder' through the use of visualized performance graphs.

In contrast, those researchers who were *not* involved in communication with a critical outsider, scored their projects significantly lower in performance after 12 weeks – i.e. without interaction with a critical outsider. We therefore concluded that interactions help identify potential project pitfalls (both on technical content level and on 'softer' elements regarding communication) sooner than would be the case without such interactions. However, the use of these data still required intensive preparation by the embedded humanist, since no automated visualization tool had been developed just yet. An interactive decision support tool could further speed up this process, allowing researchers to see even more readily what they can do to improve their work, and allowing external team members to more readily assess what they can contribute to the project.

In future research, we plan on testing the tool's functionality in terms of user-friendliness, but also in terms of stimulating responsible research and innovation decisions and actions. This means that an implementation testing phase would be accompanied by a qualitative assessment of its use, probably through the use of an embedded humanist who will be interacting with innovators while acting as a critical outsider. We could also test the tool's functionality with outsiders without any explicit affinity with the project, such as randomly selected consumers, members of the public or, also interesting, public policy makers or RRI advocates. Through the installment of interactive collaborative innovation spaces, where tools such as ours may be used, we hope to further the tool as well as RRI practices and their outcomes. Additionally, we hope to also encourage others to use our methods and critically reflect on our proposed ideas, in order to be able to harness its full innovative potential.

5 Acknowledgements

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An Open Innovation Framework for collaborative food product design & manufacturing

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Abstract. One of the most debated topics in actual global literature is Open Innovation. However, there are still many questions that have not been answered respecting the modern industry. One of them is the link between the corporate Open Innovation practices and the industrial structure of mature industries. Specifically, the food industry is a mature industry where its profit margins are thin and its R&D failure rate for new products is very high. Both facts indicate that a decent return on development investments cannot be provided and that the food industry still cannot rely on its traditional way of thinking and innovating. In addition, this sector recently perceived its end-users to be wary of radically new products and changes in consumption patterns. Hence, the main aim of that industry is to design new food products that consumers will buy and at the same time ensure that these products will reach them in time and at adequate quantity. Through a proposed conceptual framework which integrates a collaborative and shared knowledge framework based on "Open Innovation approaches", we propose to work with both customers´ data and selected partners to design new food products that offer an integrated sensory experience of food and packaging, encompassing customization, healthy eating, and sustainability.

Keywords. Food Industry, Collaboration, Conceptual Open Innovation Framework, New Product Development, Supply Chain.

1 Introduction

The food industry is a relatively mature and slow-moving industry, which exhibits relatively low levels of R&D investment and is conservative in the type of innovations it introduces to the market (Sarkar and Costa, 2008). A key difference between firms in the food industry and other manufacturing industries is that the products supplied to them, and often also delivered from them, are materials or ingredients, rather than, components (Frishammar et al., 2012). However, recent changes in the nature of both food demand and supply, coupled with an ever-increasing level of competitiveness and due to the high volatility of global markets, have changed innovation into a compulsory activity, as it is vital for the overall profitability and survival of any organization (Wu and Barnes, 2010).

Furthermore, within the next fifty years, the biggest challenge that the food industry is going to face is that it is expected to produce more food than it has produced in its entire history (UK Cabinet Office, 2008; Keating et al., 2010).

But, even if the food industry could be seen as one of the most active industries, with roughly 3,500 new products reaching the UK retailer shelves every year, at the same time it suffers from massive Research & Development (R&D) failure. About 80% of those new products are expected to fail within the first two years since their launch into the market (UK Cabinet Office, 2008). A key reason is that traditional Product Development techniques do not include the external collaboration and knowledge, which can be obtained from consumers and suppliers (Sawhney and Prandelli, 2000; Laursen and Salter, 2006; Annique Un et al., 2010; Henke and Zhang, 2010; Garriga et al., 2013; Mäkimattila et al., 2013; Pellegrini et al., 2014).

In the recent literature, we can find various examples in more "open mind-set" industrial sectors where the external collaboration and knowledge have been recognised as having large innovation potential for their New Product Development (NPD) processes (Sawhney and Prandelli 2000; Chesbrough, 2003b; Rometty, 2007; Slack et al., 2007).

To that respect, in this paper, we argue that by using Open Innovation models, we can create a collaborative environment in both NPD and Supply chain where we can understand customers´ needs and can act upon them by integrating a new Information & Communication Technology (ICT)-based product development framework with production and business systems. A new information conceptual framework can be generated, as well as, smart and on-demand manufacturing networks´ configurations demand allocations. By obtaining that, we can respond to those market segments by providing new food products in a rapid, cost-effective and sustainable manner.

The structure of this paper is described as follows: in section 2, Open Innovation Approaches in Food Industry are provided, including Definition of Innovation and a review on Food Innovations. In the same section, an overview of Open Innovation and ICT characteristics is provided. Then, in sections 3, we explain our conceptual framework and the underlying challenges the New Product Development (NPD) process entails and how the latter can be re-engineered. Furthermore, in the same section, we describe the most appropriate supply chain model for our framework. Next, in section 4, a case study is presented illustrating the use of the proposed conceptual framework. Finally, in section 5, we elaborate on our concluding remarks and recommendations for future research.

2 Open Innovation Approaches

2.1 Definition of Innovation

According to Baregheh et al. (2009), there is a vast diversity in the possible definitions of innovation in the literature.

The first definition of innovation was presented by Schumpeter in the late 1920´s (Hansen and Wakonen, 1997, p. 350) who stressed the novelty aspect and summarized innovation as 'doing things differently'. Later on, Thompson´s definition proposes (Thompson, 1965, p. 2): "Innovation is the generation, acceptance and implementation of new ideas, processes, products or services".

Then, according to Damanpour (1996, p. 694), newness is also associated with change and thus the definition of innovation proposed by Damanpour (1996, p. 694) is quoted as follows: "Innovation is conceived as a means of changing an organization, either as a response to change in the external environment or as either as a pre-emptive action to influence the environment". Hence, innovation is here broadly defined to encompass a range of types , including new product or service, new process technology, new organization structure or administrative systems, or new plans or program pertaining to organization members.

Other variations in the definition of innovation arise from knowledge management and according to Plessis (2007, p. 21), it is quoted as follows:

"Innovation is the creation of new knowledge and ideas to facilitate new business outcomes, aimed at improving internal business processes and structures and to create market driven products and services. Innovation encompasses both radical and incremental innovation".

To that respect, a distinction between incremental innovation and radical innovation has to be made. Bessant and Tidd (2007, p. 15) have defined that difference as "Doing what we do better" vs. "New to the world". In order to examine whether a product is really new-to-the-world, Makrides and Geroski (2005, p. 4) posed two conditions which have to be met:

1. They offer new value propositions that radically change existing consumer habits and behaviour.
2. The markets they create undermine the competences and complementary assets on which competitors build their success.

Furthermore, radical innovation causes marketing and technological discontinuities on both a macro and micro level, meanwhile, the incremental occurs only at a micro level and causes either a marketing or a technological discontinuity, but never both (Garcia and Calantone, 2002).

Hence, organizations, often, have to go through a period of trial and error in order to learn how to obtain knowledge and specially how to gain knowledge from an external source. It requires extensive effort and time to build up an understanding of all the norms, habits and routines of different external knowledge channels (Laursen and Salter, 2006; Saguy and Sirotinskaya, 2014).

When IBM conducted a Global CEO study (Rometty, 2007) on innovation based on interviews with 750 of the world´s top CEOs, 76% of those CEOs think that external collaboration with business partners and customers is key to innovation. But, only half of them believe their organizations are collaborating beyond a moderate level. Similar data have also been presented in a most recent survey, involving companies from three countries (UK, Italy and Spain) in the Food and Drink industry (Lazzarotti et al., 2012). This is because collaboration is a discipline (Rometty, 2007).

It is therefore obvious that whatever the actual or future definition of Innovation is, it must form part of the culture of any organisation and its main driver should be an organised and well established process for innovations targeting excellence in the implemented process (Lynn et al., 1999; Hoholm and Strønen, 2011; Mäkimattila et al., 2013; Pellegrini et al., 2014).

2.2 Food Innovation status

The food industry is a mature industry and is typically very conservative with the level of investment in new technology (Bigliardi and Galati, 2013). The European food industry particularly invests much less in R&D compared to other industries and radically new products are rare (Costa and Jongen, 2006; Bigliardi and Galati, 2013). They make up only 2.2% of the total launches of new products and the risk of failure is high (Costa and Jongen, 2006; Bigliardi and Galati, 2013).

On the other hand, we must not forget that the food industry was traditionally focused on the minimization of cost production, having, thus, paid little attention to customer needs by developing new products according to customers´ specifications (Lienhardt, 2004). In addition, in the majority of food companies, their new product development processes are still based on internal innovation – although a limited but growing number of food companies are starting to develop their new products adopting some success factors and best practices that reside outside their corporate boundaries (Sarkar and Costa, 2008; Huizingh, 2011; Wikhamn, 2013; Marques, 2014; Saguy and Sirotinskaya, 2014; Pascucci et al., 2015).

Moreover, research outcomes of extant literature, show that companies, which have a disciplined and step-wise new product processes, are more successful compared to those firms that have had the same processes in place for a longer time (Cooper and Kleinschmidt, 1995). However, management of innovation is the process of bringing monetary value to technological knowledge and creativity, and in recent years, a particular model of doing so has been named "Open Innovation" (Van der Meer, 2007).

Based on the Open Innovation (OI) paradigm, a firm can use an external idea, as well as, an internal one to develop a new product (Chesbrough 2003b; Huzingh, 2011; Monsef et al., 2012; Wikhamn, 2013; Marques, 2014). On the other hand, closed innovation is the traditional paradigm in which a firm generates its own ideas and then develops them internally (Chesbrough, 2003a; Sarkar and Costa, 2008; Huzingh, 2011; Bae and Chang, 2012; Wikhamn, 2013; Marques, 2014).

On the other hand, the need for new food products is driven by "five dominant forces" (Fuller, 2005) and their nature is a mixture of inside and outside boundaries aspects. Hence, when looking inside them by using an Open mindset, a clear advantage is provided versus the traditional innovation. The "dominant forces" are the following:

1. All products have a life cycle.
2. New products promote growth.
3. New markets may be created; e.g., functional foods, e-commerce, etc.
4. New knowledge and technologies may offer new opportunities, such as, nanotechnology, internet, social media, aseptic and long-life products, etc.
5. Changes in legislation, health and labelling regulations, agricultural policies, international social pressure movements such as SAVE FOOD, etc.

For that reason, in todays globalised competitive business environment, the Food manufacturing organizations have begun to realize that in order to gain and sustain the competitive advantage they have to deliver the best customer value at the lowest possible costs (Bigliardi and Galati, 2013; Hudnurkar et al., 2014). The customer is increasingly becoming highly demanding with respect to faster response time, shorter product cycle time, customised products and services (Bigliardi and Galati, 2013; Hudnurkar et al., 2014).

On that account, food firms are looking outside their organisational boundaries for opportunities to collaborate with supply chain partners so as to ensure efficiency and responsiveness of the supply chain as well as to leverage the resources and knowledge of both their suppliers and consumers (Flint, 2002; Menrad, 2004; Chesbrough and Crowther, 2006; Bigliardi and Galati, 2013; Hudnurkar et al., 2014; Saguy and Sirotinskaya, 2014; Pascucci et al., 2015).

2.3 Open Innovation & ICT collaborative tools with consumers for the Food Industry

Contrary to the traditional definition of closed innovation, Open Innovation (OI) has initially been defined as the paradigm in which:

> *"… valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well" (Chesbrough, 2003a, p. 43).*

Then reflecting on what was learned from the practice of OI, the definition was adapted to emphasize the intentionality of the knowledge flows inside and outside the firm (Chesbrough, 2006).

Most recently and according to Chesbrough and Bogers (2014), OI´s definition has been as follows:

> *"OI is defined as a distributed innovation process based on purposively managed knowledge flows across organisational boundaries, using pecuniary and non-pecuniary mechanism in line with the organization´s business model".*

Therefore, that mixture of knowledge can speed-up the time-to-market process, enrich the internal innovation environment and expand any company's market frontiers, far beyond, to new market segments (Chesbrough, 2003a). OI has been initially associated with fast-growing industries, like the information and communication technology sector or the pharmaceutical industry, but, there is increasing evidence that this concept may also prevail in more traditional and mature industries such as the food industry (Morcillo, 2007; Sarkar and Costa, 2008; Huizingh, 2011; Bigliardi and Galati, 2013; Theyel, 2012; Wynarczyk et al., 2013; West et al., 2014).

The current application of Innovation in the Food Industry mainly relates either to the closer engagement and relationship between food manufacturers and retailers (Fernie and Sparks, 2009) or to the closer engagement and involvement of suppliers in corporate R&D (Park et al., 2010).

But, in the era of OI, researchers, as well as, consultants ask for more active engagement of customers into NPD than traditional market research allows (Sawhney and Prandelli, 2000; Chesbrough, 2003a; Rizova, 2006; Saguy and Sirotinskaya, 2014). As a consequence, new methods are needed towards that direction (Lilien at al., 2002; Füller and Matzler, 2007; Bjelland and Wood, 2008; Christiansen et al., 2013; Mäkimattila et al., 2013; Saguy and Sirotinskaya, 2014; Pascucci et al., 2015). For that reason, open communication and collaboration patterns can be established in order to improve that missing communication with consumers which can be based on existing solutions combined with modern ICT tools (Kano, 1984; Füller and Matzler, 2007; Karantininis et al., 2010; Christiansen et al., 2013).

Digital technologies are impacting any type of world-wide businesses and their impact is conducted in unprecedented ways (Harrington, 2000). The proliferation of industry specific ICT, increased availability and accessibility of social media and interactive technologies including a wide range of smart gadgets, such as, mobile and tablet technologies and related applications, is a digital revolution that can affect any business, adding credence to this argument (Coleman, 1997; Harrington, 2000; Fitzgerald et al., 2013; Rodgers, 2013).

Over the last years, the world has witnessed continuous growth of ICT services. An analysis of Internet user statistics reveals some of the key challenges and opportunities that need to be addressed in order to bring more people online in developing countries. The ICT for development debate is witnessing an obvious shift: the focus is no longer on the mobile-phones development, but on the need for high-speed broad band Internet access. The affordability of ICT services is a key trigger to bringing more people into the information age (Coleman, 1997; ITU, 2011).

Thereupon, we propose the use of Internet as an interactive and multi-media-rich technology with low cost of mass communication that allows consumers to virtually experience new products and offer new simplified modes of large scale interaction between producers and consumers (Füller and Matzler, 2007). Customers should be seen as Source of Ideas, as Co-creators/Validators and as End-Users (Füller and Matzler, 2007; Saguy and Sirotinskaya, 2014).

Harvesting attitudes and perceptions from customers by using ICT should be the most important subjects to be investigated by any firm and to that respect we propose the integration of "the open innovation funnel" with an ICT platform to capture those initial ideas and perceptions directly from them. When customer value is assessed in the early concept stage of the innovation process the next benefits can be obtained (Füller and Matzler, 2007):

a. Reduction of market uncertainties
b. Identifications of future needs
c. Greater variety of ideas
d. Contacting new potential customers
e. Increased customer retention
f. Broader decision basis for the NPD team of a firm.

Users should not only be asked about their opinions, wants and needs, but they should be invited to contribute with their creativity and problem solving skills by generating and evaluating new product ideas (Sawhney and Prandelli, 2000; Lilien et al., 2002; Djelassi and Decoopman, 2013). There are various models to achieve such kind of interactions and some of them are hereby presented as follows:

a. By creating different types of web blogs, searching for customers´ needs and wants,
b. By using specific "web questionnaires" posted on Intranets (we must not forget that the employees of a food company are also consumers who can express their valuable opinion and vote the best new food ideas too) and corporate website,
c. Or even, the traditional customer-interview questionnaires and idea generators next to the shops but, based on an Idea Management System where any idea can be analysed, checked and voted by expert teams within an "Open" firm.

By reviewing the literature, we have managed to discover that Intranet is defined as an internet network utilizing internet and web protocols located within an organisation's information technology (IT) security domain and is primarily intended to be used by the organisation's members (Slyke and Belanger, 2003); in particular for organisation applications such as:

a. Dissemination of corporate documents, e.g. annual reports, corporate information and documents, health and safety and emergency procedures/manuals;
b. Searchable directories, e.g. keeping organisational directories up-to-date with easy traceability;
c. Providing departmental or divisional web pages information to all employees within an organisation who need access to information about their department or division;
d. Facilities for software distribution, licensing and accelerating the process of distributing software updates; and
e. Collaborative applications, such as, e-mail, chat facilities and conferencing; applications can be accessed via the intranet for managerial, administrative and team working tasks.

Furthermore, extranet has the potential to fill the gap that exists between internet and intranet networks (Finch, 2000). It allows project partners to exchange information securely by providing an authorized means of access to a portion of a company's intranet or by using a common network that links all partners. The penetration of internet, intranet and extranet technologies into the Information Technology workplace has already resulted in dramatic improvements in terms of quality and quantity, as well as, seamless integration in business processes (Gloor, 2000; Christiansen et al., 2013).

Still, it has also been identified that by using the Kano model (Kano, 1984; Löfgren and Witell, 2005) which is often used by firms to identify customer needs in NPD, customers have difficulties in articulating their needs (Füller and Matzler, 2007). This is because customers´ expectation toward product and service attributes can be grouped into 3 categories: a) basic factors, b) performance factors and c) excitement factors (Füller and Matzler, 2007).

Consumers clearly state performance factors and specify their level of requirements but, the innovation level of such products is rather incremental (Prahalad and Ramaswany, 2002; Prahalad and Ramaswany, 2004). In radical innovations where customers extract high value from the emotional meaning of the product, their input is of limited value. They are unable to express their needs and state a clear preference (Pascucci et al., 2015). Hence, they do not come up with solutions; as they are not experts for that part of innovation process (Matzler and Hinterhuber, 1998). It is the task of the NPD team to deal with this inability of the customers to come up with the needed solutions.

3 Challenges of the conceptual Collaborative Framework in NPD process

3.1 Developing a collaborative NPD framework

In this section of the paper, we are going to present a framework for New Product Development using a workflow, which encompasses the "Open Innovation funnel" and the "Double Diamond 4D Design" design frameworks (see Fig.1). This framework is intended to be used by food companies which are seeking to use Open Innovation approaches in their product development loop when designing new food products. As suggested in the literature (Karantininis et al., 2010; Saguy and Sirotinskaya, 2014; Pascucci et al., 2015), business environment can push towards collaboration in innovation activities. The proposed framework is cross cutting as it extends beyond New Product Development by integrating processes designed to use that information to directly drive the development of new product recipes and subsequently drive product specification and ultimately production within a collaborative environment.

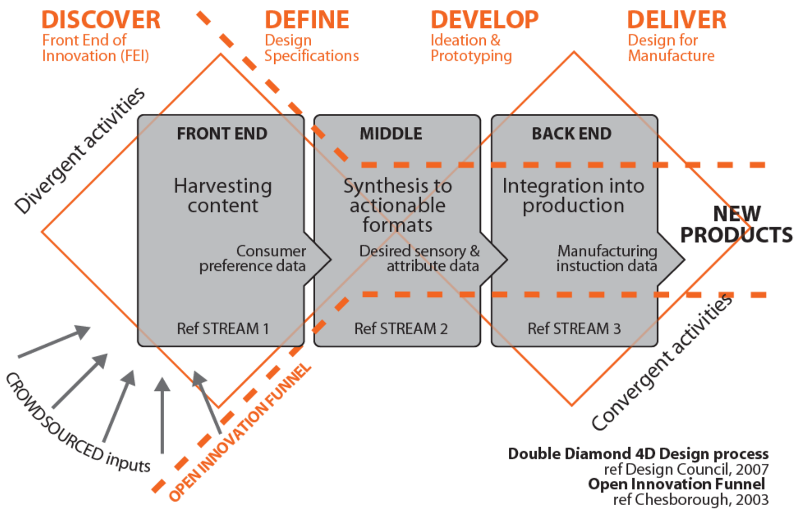


Fig. 1. The relationship of open innovation with the double diamond 4D design process model, reprinted from (Tsimiklis et al., 2014, p. 6).

The Double Diamond 4D Design diagram (UK Design Council, 2005) describes the design process in a simple graphical way. That process is divided into four distinct phases: Discover, Define, Develop and Deliver, and it maps the divergent and convergent stages of the design process. By looking inside those four distinct phases, we can see the following:

- Discover: This is the first stage of the model where the project starts. It begins with an initial idea or inspiration, which is often sourced from a discovery phase in which user needs are identified. These include:

  a. Market research;
  b. User research;
  c. Managing information; and

d. Design research groups.

- Define: it is the second stage and represents the definition part where interpretation and alignment of these needs to business objectives is achieved.
- Develop: it is the development stage where design –led solutions are developed, iterated and tested within the company.
- Deliver: it is the final stage where the resulting product is finalised and launched in the relevant market.

However, the research cost for the Discover stage of the previous processes is very high (Nambisan, 2002; Füller and Matzler, 2007; Henten, 2012), as well as, the needed time for investments in this stage.

In parallel, we have identified the Double Diamond 4D Design diagram as a discipline process to develop and bring new products to a relevant market (UK Design Council, 2005).

According to Monsef et al. (2012, p. 7), a problem is that traditional NPD is risky due to alarming failure rates and the large amounts of venture capital required. When investigating the reasons for the low success rates, studies concluded that failed product innovators did not fully understand customer needs, or they designed products that cannot be repeatedly manufactured, or even, they launched products without taking into consideration the realities of those who will use the product (Dougherty, 1992).

Open Innovation provides an approach to involve consumers in the loop of a New Product Development process (Chesbrough, 2003a; Chesbrough, 2006; Chesbrough et al., 2006; Saguy and Sirotinskaya, 2014) and enable the design and production of food products that are desired and will be consumed.

To that respect, we propose to use an information workflow in order to re-configure the whole innovation process by using Open Innovation techniques. The information workflow follows the patterns presented on Figure 1. Particular functional blocks that control those information flows are presented and discussed below (Fig. 2).

The "*HARVESTING CONTENT"* area is composed of an external data sourcing interface for harvesting attitudes/perceptions from final consumers or even retailers, suppliers and other external data information systems of a firm.

The second area named "*SYNTHESIS TO ACTIONABLE FORMAT*" is crucial for mapping the raw and abstract inputs from consumers or even retailers to actionable customer requirements. The main idea at this point is the transformation of all these inputs into customer requirements and hence, into Market Business Plans (MBP).

In our case, the key elements come from an expert and a reconfigurable internal team that participates to the NPD process. It is not a fixed team and is highly dependent on the nature of the project. That team is capable of creating the new product specs, the product´s Bill-of-Material (BOM) and the specs of the machinery and the installation to be used for producing the new product. Then, that team can work with selected suppliers to facilitate the availability of that product.

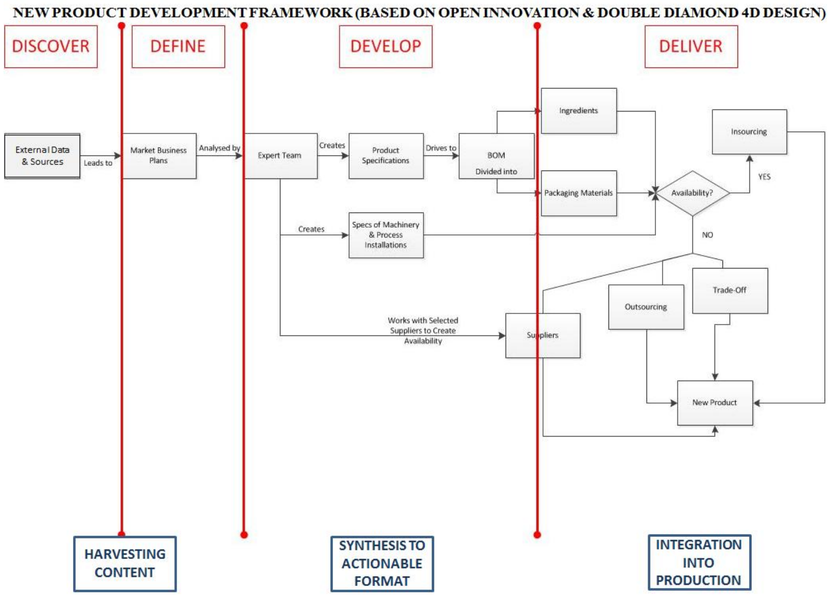


Fig. 2. Overview of new product development framework workflow, adapted from (Tsimiklis and Makatsoris, 2015, p. 5).

The last area of our model is related to the *"INTEGRATION INTO PRODUCTION"*. It is a How mechanism to fulfil the What´s of any Market Business Plan. These mechanisms are best stated as design requirements or as *the technical characteristics of solutions*, rather than as specific solutions. They transform consumers´ requirements into product specifications and finally manufacturing instructions.

As it is presented in our conceptual model (see Fig. 2), the BOM sufficiently creates the required information to check the insourcing availability of the needed ingredients and packaging material needed for the new product. On the other hand, the specs of the machinery and installation to be used for the production of the new product, deal with the internal availability of it.

The selected suppliers – experts on their subject and their selection is highly dependent on the nature of the project – can be used by the internal expert team to help them develop either the internal availability or the external one of the product (by outsourcing or by making trade-offs).

3.2 Challenge I: Barriers and Opportunities of the conceptual framework in the Food Industry

But, is it an easy task for any firm to incorporate Open Innovation in the NPD Process?

It is known that production decision-making in the food manufacturing industry has not changed enough so as meet the nowadays volatile challenges (Calantone et. al., 2002; Bigliardi and Galati, 2013). In many western companies, manufacturing management still takes a subordinate role in strategic terms to the marketing and finance functions. It continues to be primarily concerned with short-term issues (Christopher, 2000). In addition, marketing-led strategies in the food industry are usually based on the principle of growth through extending the product range. Invariably what happens is that new products are manufactured on existing processes and almost always within the same infrastructure. The logic for this is based on the principle of the economies derived from using existing plant capacity, where possible, and being supported by the existing overhead structure (Hoholm and Strønen, 2011). Over time the incremental nature of these marketing changes will invariably alter the manufacturing activity. The result is complexity, confusion and worst of all, a production organization which lacks focus and strategy (Christopher, 2000).

Furthermore, many executives are still unaware that, what appears to be one of the routine manufacturing decisions, it frequently limits the corporation´s strategic options, binding it with facilities, equipment, personnel, basic controls and policies to a non-competitive posture, which may take years to turn around (Laursen and Salter, 2006; Hoholm and Strønen, 2011; Garriga et al., 2013). The reason for this is that companies having invested inappropriately in process and infrastructure cannot afford to reinvest to put things right. The financial implications, system development, training requirements and the time it would take to make the changes would leave it seriously disadvantaged.

To avoid the above mentioned hurdles, companies need to be aware of and learn from the mistakes of their past mistakes (Cohen and Levinthal, 1989; Garvin, 1993; Akgün et al., 2006). The product development process is itself a form of problem-solving activity and associated search processes that involve investments in building and maintaining links, networks and communities with users, suppliers and a wide range of institutions inside the innovation process (Laursen and Salter, 2006). Those organizations that invest in broader and deeper search may have a greater ability to adopt, to change and therefore, innovate (Laursen and Salter, 2006; Garriga et al., 2013).

Furthermore, given that search strategies must be rooted in the past experiences and future expectations of managers, they should have been well documented, while at the same time the future expectations should be clearly managed, chosen and notified (Akgün et al., 2006; Laursen and Salter, 2006; Garriga et al., 2013).

In this frame of reference, changes must be driven top down and the whole management team must be totally committed to the changes (Chesbrough and Crowther, 2006). In addition, one of the toughest challenges for managers today is to get people focused on adaptive change to meet the demands of rapidly changing environments. Many problems have no ready-made solutions and require people throughout the company to think in new ways and learn new values and attitudes. This requires a new approach to management and a new kind of organization (Garvin, 1993; Sawhney and Prandelli, 2000; Rometty, 2007).

This new type of organization structure can be defined as one in which everyone is engaged in identifying and solving problems, enabling the organization to experiment, change and improve continuously and thus increase its capacity to grow, learn and achieve its purpose. The essential idea is problem solving, in contrast to the traditional organization designed for efficiency (Garvin, 1993; Sawhney and Prandelli, 2000; Rometty, 2007; Karantininis et al., 2010; Mäkimattila et al., 2013; Saguy and Sirotinskaya, 2014).

An important value in such an organization is the collaboration and communication across departmental and hierarchical boundaries (Karantininis et al., 2010; Mäkimattila et al., 2013; Saguy and Sirotinskaya, 2014; Pascucci et al., 2015). A majority of successful innovations is developed through the collective efforts of individuals in NPD teams. NPD teams are organisational workgroups where individuals from diverse personal and organizational backgrounds come together for a limited time and work in close collaboration towards creating, designing, developing and marketing a new product (Pinto, 2002). Self-directed teams are the basic building blocks of a collaborative organisational structure (Mäkimattila et al., 2013). That multi-functional expert group is normally formed by people from different functional departments such as Production, Marketing, Logistics, Finance, Engineering, Quality, R&D, Food Safety, Nutrition and Purchasing. These people on the team must be given the skills, information, tools, motivation and authority to make decisions central to the team´s performance, while responding creatively and flexibly to new challenges.

Resuming the above points, we can say that the next figure (Fig. 3) can represent a scenario of a collaborative framework using Internet/Intranet networks to speed up the information flow in a product development cycle and realize reduced development times and costs.

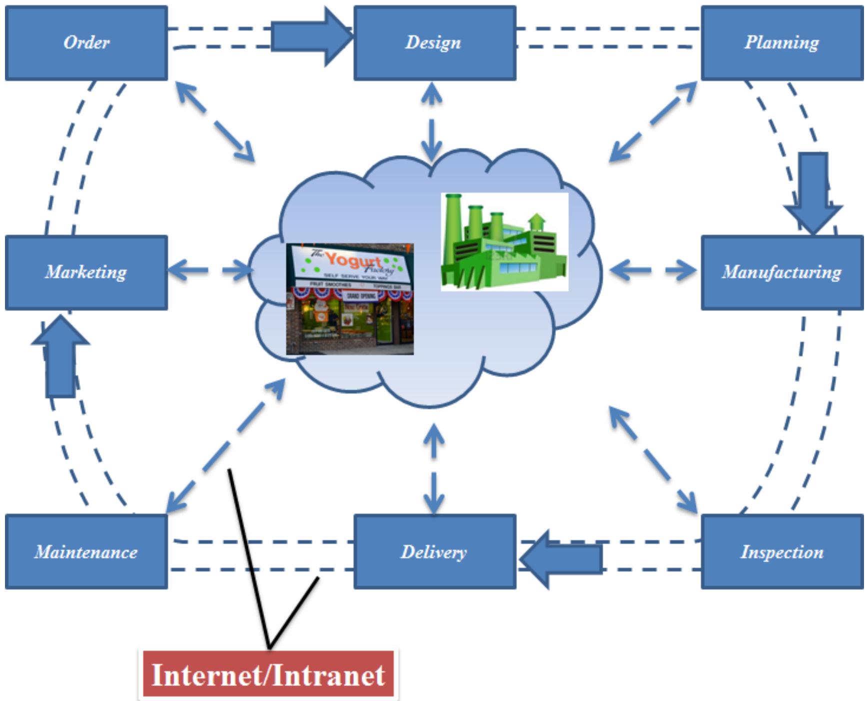


Fig. 3. A scenario of using Internet/Intranet to support information flow in product development cycles, reprinted from (Tsimiklis et al., 2014, p. 5).

Hence, the previous mentioned MBPs (see also figure 2) can be analysed by that multi-functional expert team and the obtained data are the initial product specifications that can finally be transformed into orders of purchases. The orders of purchases can be created by a clear characterization and specification of Bill-of-Materials (BOM) of the new products. These BOMs are either related to the Ingredients of the new product or the materials used for its packaging or both. The final list of BOM is compared to the free capacity, existing installations and existing ingredients and materials to identify the most convenient decision between in-sourcing or out-sourcing or even trade-off situations.

A trade-off situation involves a sacrifice that must be made to obtain a certain product, service or experience, rather than others, that could be made or obtained using the same required resources. Many factors affect the trade-off environment within a particular firm, including availability of raw materials, a skilled labour force, machinery for producing a product, technology and capital, market rate to produce that product on reasonable time scale, and so on. Such kind of situations can only be identified by having a clear list of BOM and their specifications.

Returning to our framework (Fig. 2), it is often the lead time of in-sourcing that limits the ability of a manufacturing organization to respond rapidly to consumers´ requirements. For that reason, in order to obtain the most accurate decision on the previous situation, it is vital to include as much suppliers´ information into the decision loop as possible and it is therefore crucial to have a suitable supply chain approach following the Open Innovation mindset (Annique Un et al., 2010).

3.2 Challenge II: Re-thinking and redesigning the Supply Chain

Operations Strategy is concerned with choosing the strategic decision making patterns and actions, which determine the role, objectives and activities of the organizations. There are the five basic performance objectives and they apply to all types of organisation (Slack et al., 2007):

3. Quality: consistent conformance to customers' expectations.
4. Speed: the elapsed time between customers requesting products and their receiving them.
5. Dependability: delivering or making available products when they are promised to the customer.
6. Flexibility: the quality of being adaptable or variable.
7. Cost.

Agile operations management aims at addressing these five performance objectives and this is a central component to our framework. Agility (Christopher, 2000) is defined as the ability of a system to rapidly respond to change by adapting its initial configuration. It is the ability that combines and adopts any business system to any of all those 5 objectives.

Agile Manufacturing (AM) is a company-wide strategy, which aims at responding well to unexpected change in all aspects of a company’s operations. We can define it in two contexts (Christopher, 2000):

- *Externally*, as perceived by customers: (AM) means responding to those customers’ needs by rapidly designing and manufacturing products customized to those requirements.
- *Internally*, in terms of a company’s own operations, (AM) focuses on reducing

the lead times for all tasks in a company, resulting in improved quality, lower cost, and of course, quick response.

However, up to now, the efforts surrounding an application of agile frameworks has been focused on the shortages of traditional energy sources. But, their price fluctuations and the demand for more energy-efficient products or products using alternative energy sources are clear. Opportunities exist to re-engineer many industrial products based on new ratio of energy costs and capital costs. New energy - conservation concepts and service - will be needed. The design and marketing of this range of products are challenging because of price fluctuations (Wild, 1992).

Changes in energy availability and prices are but one example of the many possible futures we face. The many changes to the status quo present problems for unchanging organisations but represent real opportunities for those organisations that adapt and evolve with new market offerings. The organisations that will not just survive but thrive will use a learning organisational concept with which will examine their role in society and our continuously changing environment. One of the important rationales for their existence is based on innovation and agility to fill societal and customer needs (Christopher, 2000).

Furthermore, it is known that a supply chain describes the series of linked activities amongst companies that may contribute to the process of design, manufacture and delivery of products. Its main objectives are (Yusuf et al., 2004; Waller, 2013):

a. customer enrichment ahead of competitors,
b. achieving mass customisation at the cost of mass production,
c. mastering change and uncertainty through routinely adaptable structures, and
d. leveraging the impact of people across companies through information technology.

An agile supply chain should extend to the highest levels within all participants of the NPD process (internal and external ones) and local teams of employees should think globally and take virtual initiatives with teams in other companies within the supply chain of a new product (Yusuf et al., 2004).

Returning to our framework in Figure 2, it is often the lead time of in-sourcing situation that limits the ability of a manufacturing organization to rapidly respond to consumers´ requirements. Accordingly, obtaining the most accurate decision on the previous situation is vital to include the maximum amount of suppliers´ information into the decision loop (Annique Un et al., 2010).

But, how can we guarantee the selection of the most appropriate supplier? There are 3 conditions that have been identified for obtaining a success relationship and collaboration with the selected suppliers (Christopher, 2005; Park et al., 2010):

1. It is obvious that the supplier base of any firm must be rationalized. The firms have to identify a limited number of “strategic” suppliers with whom they can work with as partners through linked systems and processes. While the dangers of single sourcing need to be recognized, the advantages of having a network of key suppliers able to synchronize their production and deliveries with the requirements of the company are considerable.
8. To achieve the previous advantages, it is necessary to dispose of a high level of shared information. In particular, there has to be a clear visibility on the

downstream demand; data on real demand needs to be captured, as far down the chain as possible, and shared with upstream suppliers, as well as, the information systems technology to make the transfer of information possible.

9. Finally, the biggest challenge from the suppliers' empowerment is the need for a high level of "connectivity". This implies not just the exchange of information on demand and inventory levels, but multiple, collaborative working relationships across the organizations at all levels. This last point proves for another time how necessary the use of an ICT network, which can cover and connect the inside and the outside boundaries of a firm, is.

It follows that, collaborative behaviour and activities in supply chain have gained considerable importance (Hudnurkar et al., 2014). The supply chain collaboration has been defined in different ways by different authors (Hudnurkar et al., 2014). A summary of relevant and available definitions is provided:

2. Collaboration is a cooperative strategy of supply chain partners with a common goal of serving customer through integrated solutions for lowering cost and increasing revenue (Simatupang et al., 2004).
3. Collaborative relationship as one in which an organization initiates and implements a knowledge creation endeavour, and a collaborating organization shares the expense and benefits of newly created knowledge, including its joint ownership through patents and licenses (Samaddar and Kadiyala, 2006).
4. The ability to work across organizational boundaries to build and manage unique value-added processes to better meet customer needs (Fawcett et al., 2008).
5. Collaboration describes the cooperation among independent, but related firms to share resources and capabilities to meet their customers' most extraordinary or dynamically changing needs (Simatupang and Sridharan, 2008).
6. A partnership process where two or more autonomous firms work closely to plan and execute supply chain operations toward common goals and mutual benefits (Cao and Zhang, 2011).

4 Example Case: On-demand yoghurt manufacturing

4.1 Introduction to the case study

The central part of an innovation process involves the search for new ideas that have commercial potential. Thus, firms invest considerable amounts of time, money and other resources in the search for new innovative opportunities. Such investment increases the ability to create, use and recombine new and existing knowledge, external or internal knowledge available to a firm, or both (Laursen and Salter, 2006). All recent models of innovation have highlighted the interactive character of the innovation process, suggesting that the more innovative firms rely heavily on their interaction with users, suppliers and with a range of institutions inside the innovation system (Brown and Eisenhardt, 1995; Szulanski, 1996).

The Open Innovation Project of the Dairy Company, presented in this section, had precisely this aim: to identify and filter yoghurt product ideas that can be successfully brought to market as there is a clearly recognised and unmet need by a specific market segment. At the same time the project aimed at maximising the usage of existing resources, as much as, possible with minimal additional investment. One key risk is that the degree of product innovation/differentiation does not lead to increasing returns but rather remains stagnant no matter how big the investment is (Sarkar and Costa, 2008). The open innovation approach, at the core of our proposed framework, mitigated that risk by allowing the market to be a crucial component in the development loop of the new yoghurt product by directly influencing development priorities and at the same time maximising innovation impact.

4.2 Harvesting Content

The mentioned project is a complex multi-dimensional project that requires many considerations and compromises to be made. Here, we summarize those initial considerations: Taste, Texture, Flavour, Appearance, Size/Volume of primary packaging, Consumption, Production, Distribution. A key target is to achieve sufficient differentiation compared to competition and this is embodied not only in the formulation of the product itself but also in the packaging, distribution and the design of the manufacturing and packaging processes themselves.

Initially, it is a "must" point to start such a kind of project by using the internal knowledge of the firm and to identify in a map where the actual business strategy of the firm is today and where it will need to be in the future when incorporating that new product (Slack et al., 2007).

An important value in an organization is the collaboration and communication across departmental and hierarchical boundaries. Self-directed teams are the basics building blocks of the internal knowledge of a firm. These teams are made up of employees with different skills who share their experience and knowledge to produce an entire product. The idea is to empower the well-known "Cross-functional teams". That multi-functional expert group is normally formed by people from different functional departments such as Production, Marketing, Logistics, Finance, Engineering, Quality, R&D, Food Safety, Nutrition and Purchasing. These people on the team must be given the skills, information, tools, motivation and authority to make decisions central to the team´s performance, while responding in a creative and flexible manner to new challenges. This type of team has been used to create the information needed to initially communicate with both customers and suppliers.

Then, a well-defined market investigation based on a qualitative research of concept and product, followed by a volumetric concept testing (on line or even next to the shops) can be used to indicate the appropriateness of the idea (Sawhney and Prandelli, 2000). The main points to be covered on such researches should follow the above mentioned considerations. Thus, those harvesting attitudes and perceptions from customers are then the important subjects to be investigated by our proposed model.

For that reason, all that we propose is the integration of "the open innovation funnel" with the "double diamond" 4D design process described above. That is linked to the *Front End* of our model and we can propose some of them:

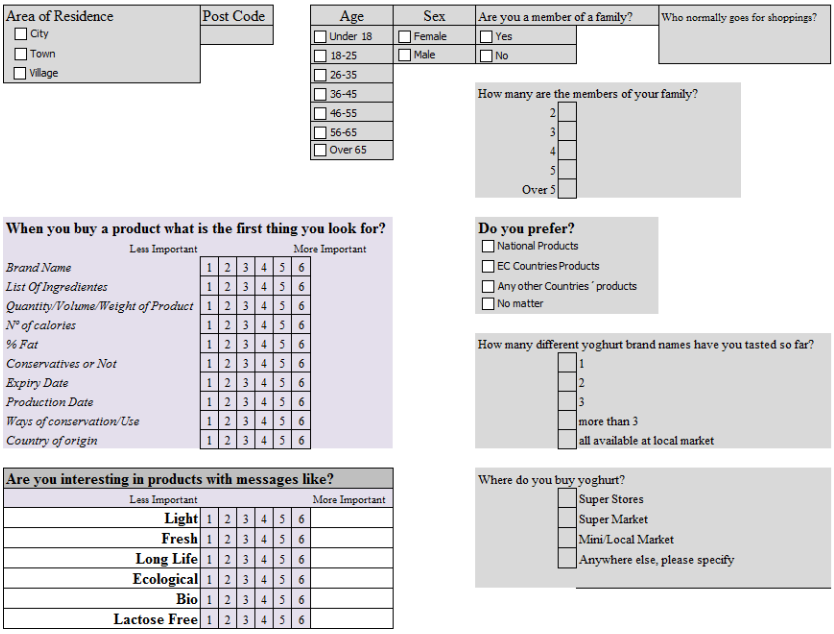
a. By creating different types of blogs and questionnaires focusing on customers´ needs and wants, posting them on social websites (developed by a multifunctional team as described above),

b. By using specific "web questionnaires" posted on Intranets and asking firm´s employees for new ideas or even, to vote new ideas (developed by a multifunctional team as described above),
c. It is worth mentioning that there are approx. 56,900,000 blogs which are exclusively dedicated to yoghurt. In these blogs, various characteristic words or indicators can be obtained, which express clear consumer necessities.
d. Then, there are many scientific and collaborative websites dealing with "yoghurt" as their topic of interest or its ingredients.
e. Finally, the traditional customer-interview questionnaires next to the shops are still useful to obtain information that can be transformed into knowledge.

Furthermore, the voices of the retailers and the distributors of the products can provide a lot of information for preparing both the strategic and tactic actions for a particular business; it is well known as a Market Business Plan and it is integrated within the Master Business Strategy of a firm (Szulanski, 1996). We have to mention that the ability to exploit external knowledge is a critical component of innovative performance (Cohen and Levinthal, 1989).

Along these lines, the framework presented above (in Fig. 2), allows a direct interaction with consumers and lead users. One of the possible approaches to this interaction involves the design of the correct questions to crowd source and obtaining their responses. Consumer preferences and opinions were harvested by a mixture of on-line and off-line versions of the questionnaires, which focused on product appearance, taste and packaging, Fig. 4, 5 and 6, show examples of questions that have been used to establish the needs of consumers by engaging them in the process. The questionnaires have been designed in such a way that those above the initial considerations could be addressed by the New Product Development Team and later on by the Manufacturing Process Development Team. For example, the key characteristics of the new yoghurt product that was under development included "Light", "Fresh", "Longer Life", "Ecological", "Bio" and even "Lactose Free". All these characteristics were also identified by the consumers; an initial sample of 500 consumers of the company´s products was used in that investigation. Those have been indicators of high priority to the consumers involved. Overseas consumers were engaged in the process by the extensive distribution network of the company, which was responsible for the collection and sorting of the data; a smaller sample of 50-100 persons was used in that part of investigation and the majority of them were not company´s consumers. Other important indicators that were identified included the following:

- Desire for flexibility
- Save Food
- Conserve natural resources
- Substitution behaviour
- On the go solutions
- Friendly use packaging
- Product appearance
- Recycled & "Green" Packaging aspects
- Nutrition & Health Aspects and information.


Area of Residence
City
Town
Village

Post Code

Age	Sex	Are you a member of a family?
Under 18	Female	Yes
18-25	Male	No
26-35		
36-45		
46-55		
56-65		
Over 65		

Who normally goes for shoppings?

How many are the members of your family?
2
3
4
5
Over 5

When you buy a product what is the first thing you look for?

	Less Important					More Important
Brand Name	1	2	3	4	5	6
List Of Ingredientes	1	2	3	4	5	6
Quantity/Volume/Weight of Product	1	2	3	4	5	6
Nº of calories	1	2	3	4	5	6
% Fat	1	2	3	4	5	6
Conservatives or Not	1	2	3	4	5	6
Expiry Date	1	2	3	4	5	6
Production Date	1	2	3	4	5	6
Ways of conservation/Use	1	2	3	4	5	6
Country of origin	1	2	3	4	5	6

Do you prefer?
National Products
EC Countries Products
Any other Countries´ products
No matter

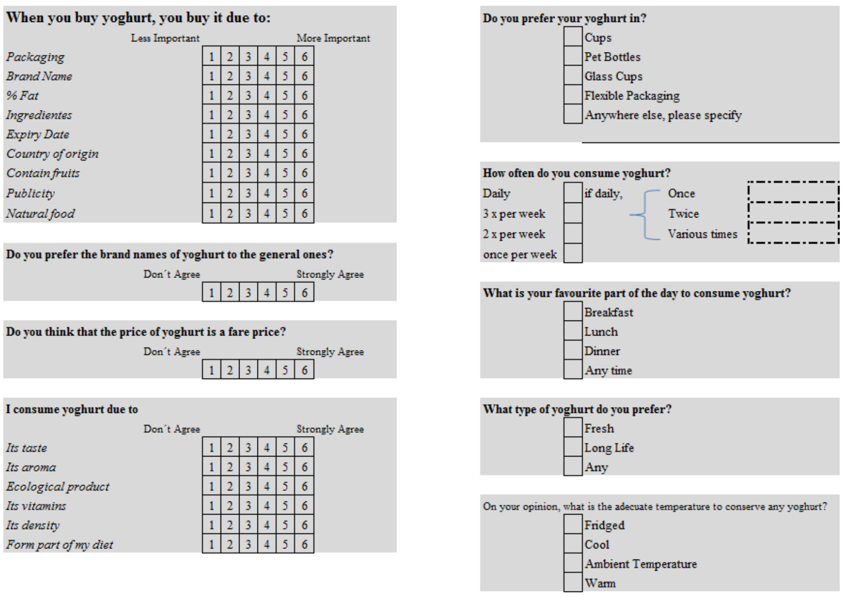
How many different yoghurt brand names have you tasted so far?
1
2
3
more than 3
all available at local market

Are you interesting in products with messages like?

	Less Important					More Important
Light	1	2	3	4	5	6
Fresh	1	2	3	4	5	6
Long Life	1	2	3	4	5	6
Ecological	1	2	3	4	5	6
Bio	1	2	3	4	5	6
Lactose Free	1	2	3	4	5	6

Where do you buy yoghurt?
Super Stores
Super Market
Mini/Local Market
Anywhere else, please specify

Fig. 4. Obtaining Consumers´& Lead Users´ inputs, reprinted from (Tsimiklis et al., 2014, p. 8).


When you buy yoghurt, you buy it due to:

	Less Important					More Important
Packaging	1	2	3	4	5	6
Brand Name	1	2	3	4	5	6
% Fat	1	2	3	4	5	6
Ingredientes	1	2	3	4	5	6
Expiry Date	1	2	3	4	5	6
Country of origin	1	2	3	4	5	6
Contain fruits	1	2	3	4	5	6
Publicity	1	2	3	4	5	6
Natural food	1	2	3	4	5	6

Do you prefer your yoghurt in?
Cups
Pet Bottles
Glass Cups
Flexible Packaging
Anywhere else, please specify

Do you prefer the brand names of yoghurt to the general ones?
Don´t Agree 1 2 3 4 5 6 Strongly Agree

How often do you consume yoghurt?
Daily
3 x per week
2 x per week
once per week
if daily, Once / Twice / Various times

Do you think that the price of yoghurt is a fare price?
Don´t Agree 1 2 3 4 5 6 Strongly Agree

What is your favourite part of the day to consume yoghurt?
Breakfast
Lunch
Dinner
Any time

I consume yoghurt due to

	Don´t Agree					Strongly Agree
Its taste	1	2	3	4	5	6
Its aroma	1	2	3	4	5	6
Ecological product	1	2	3	4	5	6
Its vitamins	1	2	3	4	5	6
Its density	1	2	3	4	5	6
Form part of my diet	1	2	3	4	5	6

What type of yoghurt do you prefer?
Fresh
Long Life
Any

On your opinion, what is the adecuate temperature to conserve any yoghurt?
Fridged
Cool
Ambient Temperature
Warm

Fig. 5. Obtaining Consumers´& Lead Users´ inputs, reprinted from (Tsimiklis et al., 2014, p. 8).

I prefer my yoghurt from

	Don´t Agree					Strongly Agree
Cows	1	2	3	4	5	6
Sheeps	1	2	3	4	5	6
Goats	1	2	3	4	5	6
Mix cows/sheeps	1	2	3	4	5	6
Mix sheeps/goats	1	2	3	4	5	6
Any other, please specify	1	2	3	4	5	6

I prefer my yoghurt to be

	Don´t Agree					Strongly Agree
Plain	1	2	3	4	5	6
Stirred	1	2	3	4	5	6
Long Life	1	2	3	4	5	6
With Fruits	1	2	3	4	5	6
Low Fat	1	2	3	4	5	6
Full Fat	1	2	3	4	5	6
Lactose Free	1	2	3	4	5	6
Full Vitamins	1	2	3	4	5	6

I prefer the size of the packging of my yoghurt to be

	Don´t Agree					Strongly Agree
100gr	1	2	3	4	5	6
125gr	1	2	3	4	5	6
150gr	1	2	3	4	5	6
200gr	1	2	3	4	5	6
250gr	1	2	3	4	5	6
500gr	1	2	3	4	5	6
1Kg	1	2	3	4	5	6
5Kg	1	2	3	4	5	6
Any other, please specify	1	2	3	4	5	6

Fig. 6. Obtaining Consumers´& Lead Users´ inputs, reprinted from (Tsimiklis et al., 2014, p. 8).

4.3 Synthesis to actionable formats

All those previously mentioned inputs represent what consumers value most. The responses are compared against existing practices, current knowledge of consumer preferences and market segmentation.

On the production and supply sides, knowledge of available processes, manufacturing and distribution capability, ingredient types and availability of them are taken into account. All these inputs and current knowledge are grouped together and mined for new relationships between the data that could reveal new desired product attributes and market segments.

All those considerations lead to the following key product targets:

1. The product should be available in an individual format.
2. The size of the primary packaging of the product should be small.
3. The design of the primary packaging should be developed in such a way that consumers always perceive a high quality product.
4. All legal information must be on the primary packaging in different languages.

The following table explains the relationship of the above points:

Table 1. A Synthesis Table, reprinted from (Tsimiklis and Makatsoris, 2015, p. 14).

Initial triggers	How addressed	OUTCOME
1.Intenational Financial Crisis	Individual Format and small packs or group of packs	Small Size (PP) polypropylene material with (IML) in-mould-labelling
2.The mean number of members of a family is getting less	Small primarily packaging and small group of packs	Format size: 100gr & 125gr
3. The "single" consumers prefer ready-to-use products in individual formats	Individual format and ease of use	Type of pot: On-the-go with spoon
4. Consumers of undeveloped countries cannot afford to buy huge format packs	Individual Format and small primarily packaging	Sell individually or in pack of 4
5. The new international labelling system requirements for the primary packaging	Legal information on primarily packaging	The label with legal information embodied on the pot
6. The necessity for a more flexible world-wide distribution	Legal information on primarily packaging in different languages	6 main languages to sell all over the world: EN, SP, FR, AR, CH, AR
7. The demand for more and more sustainable products without losing quality	Sustainable type of packaging and product	PP with IML Long life product (9 months) Fridge conservation is not needed

For that reason, the outcomes of the above synthesis, in combination with the inputs obtained from the crowd, lead to a set of basic technological requirements that can be used further. Figure 7, shows the technological requirements of a new yoghurt product.

Initial Technological Requirements:
Flexible primary packaging: Material, Design, Capacity, Usage, etc.
Material: PS or PP (with sleever or IML, in-mould-labelling/without sleever or IML)
Shape (Design): round, cylinder, rectangular, truncated cone, etc.
Split cups (with jam, honey, etc.)
Capacity: min., 100g., 125g., 150g., 175g., 200g., max.
Cups diameter/Cups Height
Other Features: Cups with snap-on-lid
Filling Flexibility: product viscosity, temperature of filling, etc.
Fruits, mix of fruits, etc.
0%, 5%, 10% M.G., Creamy products, etc.
Extra Calcium, without lactose, etc.
Soy products? (Allergens?)
Aseptic Hygienic Design (FDA, etc.)
Production Capacity: Not so high, but high flexibility 20.000-35.000 unidades/h
Format change-over: rapid and highly optimised (1-2h max.)
Flavour change-over (flavours, mix, fruits, etc.) – rapid and highly optimised (20/30 min.)
Cleaning procedures SIP/CIP, etc – rapid and highly optimised (20/30 min.)

Fig. 7. Basic initial Technological requirements, reprinted from (Tsimiklis et al., 2014, p. 9).

Initially, the key development activities for the product itself were conducted in a laboratory/pilot plant and those initial samples were evaluated by the NPD team. Then, product prototypes were replaced by test runs in full-scale production, where test batches for customers´ evaluation were made and the adequate process conditions specified.

The design of the primary packaging with all accessory components and characteristics was also defined by 3D virtual prototypes and finally by foam prototypes. The machinery to process such a kind of packaging and product was also defined by industrial trials and all other aspects, such as, additional formats, promotional formats, trays, palletizing patterns, etc. that were related to consumers´ needs were clearly defined and prototyped. Furthermore, a trial test with end users was carried out to verify the grade of acceptance of the prototypes. By doing this, the company could understand if the initial MBP was still accurate enough and where corrections had to be done before launching the new product.

It is clear that at this stage, manufacturing, R&D and marketing should work together as it is vital to have a fluent and harmonised communication among those three principal players within any NPD process (Calantone et al., 2002), even during the trial tests with the end users. Again, the use of an ICT network for rapid communication and data exchange should prove to be vital for such a kind of relationships among different departments, even within the same company.

On that account, manufacturing processes need to be developed that are scaled to meet market demand, not the demand of prototypes. Manufacturing can therefore provide essential inputs concerning what is feasible to produce, as well as, develop the expertise needed to move beyond current capabilities.

At this stage, coupling the external knowledge of selected lead machine and materials suppliers with the timely, open information sharing between them (Laursen and Salter, 2006; Garriga et al., 2013) proved to be a big advantage for reducing the product´s time to market.

Furthermore, it is important to mention that agility is a key component for success because all types of production machinery should be selected by having a reduction of the time to market in mind.

All those aspects were implemented with lead selected machine suppliers as their external knowledge was used by the firm to obtain a better innovation performance and easier conditions for integrating a new system into existing operations (Laursen and Salter, 2006). Following this, the BOM before the initial production of the yoghurt example was defined as follows (considering that the weight of the cup of the yoghurt of our example is 100gr):

Table 2. Bill of Materials, reprinted from (Tsimiklis and Makatsoris, 2015, p. 16).

Ingredients	*Packaging*
Milk (90% - 7.4% fat)	Cups with IML presentation (1 piece per 100gr)
Starch (1.5%)	Lids (1 piece per 100gr)
Sugar (8%)	Snap-on-Lids (1 piece per 100gr)
Gelatine (0.49%)	Trays (24 cups per tray) - (225 trays per EuroPallet)
Lactic ferments (0.01%)	
Pieces of Fruits or Aromas (Optional but, different %)	

4.4 Integration into production

The requirements were used to drive product development, the design and the execution of the supply chain operations. The framework in Figure 2 embodies the tools for the design and operation of a smart manufacturing network that ultimately can drive on-demand manufacturing, where demand allocation and the configuration of the network itself can be determined dynamically, as product requirements and demand evolve. At the design stage, simulation assesses possible manufacturing network configurations and planning algorithms project future execution. The outputs are then set points for manufacturing execution that conventional enterprise resource planning tools can plan against and feeding back actual manufacturing execution progress and exceptions. The next figure (Fig. 8) shows an example scenario of how a demand of 15,000 cups of yoghurt is handled by our framework.

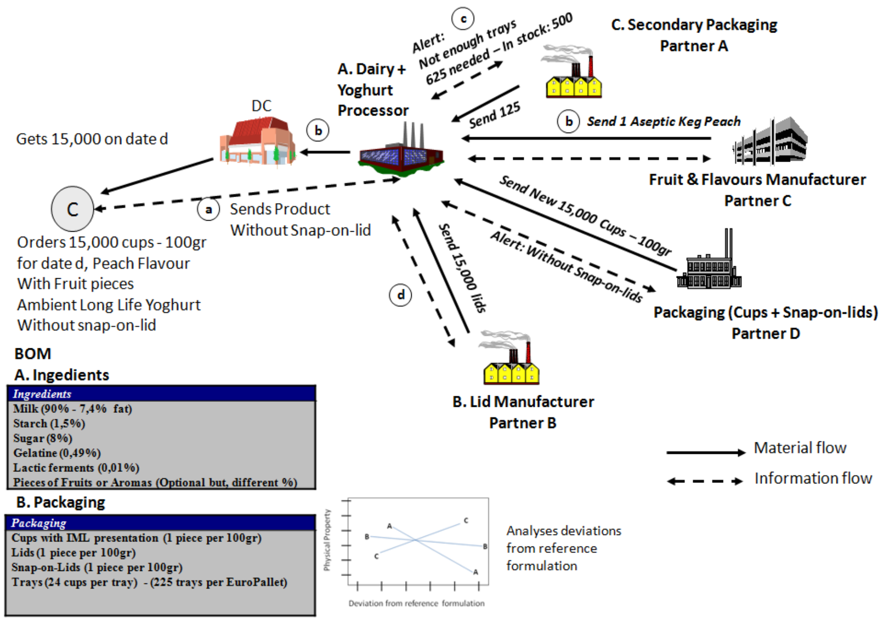


Fig. 8. Example Scenario of a smart on-Demand Yoghurt Manufacturing Network, reprinted from (Tsimiklis and Makatsoris, 2015, p. 17).

The customer (C) in Fig. 8 has sent an order of 15,000 cups of 100gr., to be received at a particular date, with the exact and specific requirements of a yoghurt product. The specific details and information of the order is directly received by the dairy processor and that piece of information is directly shared with the packaging and ingredients partners. By having centralised the formulation of the ordered product, the necessity of ingredients and their deviations are analysed from the reference formulation. Alerts of clear necessities are generated and immediately they are directly transmitted to the ingredients partners. The information is shared in a similar way with the packaging partners.

It is therefore the common information network that can provide a real on-demand manufacturing and a fast response to the customers´ demands. In our case study, such a common information network with suppliers is still under development due to license matters and confidentiality aspects that need to be solved. Meanwhile, the internal communication network for any NPD (New Product Development) process has already been developed and it has been in use for almost two years.

As a real case study, it is worth mentioning the following obtained project results:

1. A better primarily packaging has been designed thanks to the points presented below:
   i. The yoghurt recipients´ appearance and characteristics have been improved (see Figure 9 and 10). The primarily packaging has an improved visual appearance due to technology; It no longer uses Polystyrene (PS) but Polypropylene (PP) with an IML (in-mould-labelling) resulting in a packaging with an excellent balance of mechanical properties, chemical resistance, colour stability and moisture barrier properties (see also Table 3). Due to its opacity, (PP) provides better protection and resistance to sunlight.

Table 3. Comparison Chart (AIMPLAS, 2009; Alpha Packaging, 2011).

Material	Clarity	MVTR*	O2**	CO2**	Impact Strength	Recycle Code
PP	Poor	0.5	3,5	7	Fair	5
PS	Excellent	10.0	6	18,7	Poor	6

**MVTR stands for Moisture Vapour Transmission Rate in g-mil/100in. 2/24hr. MVTR is a measure of the passage of gaseous H2O through a barrier. The lower the rate, the longer the package protects its contents from moisture and ensures the moisture content of the product remains the same.*

***O2 and CO2 stand for Oxygen Transmission Rate (OTR) and Carbon Dioxide Transmission Rate (COTR) in cm3-mil/m2/24hr. OTR and COTR are measures of the amount of gas that passes through a substance over a given period. The lower the readings, the more resistant the plastic is to letting gasses through.*

Fig. 9. Initial and Final Design, reprinted from (Tsimiklis et al., 2014, p. 10).

   ii. The labelling of the packaging has improved (from a quality point of view and at the same time it consists of six different languages with all the legally required information).
   iii. The packaging has gained on versatility and use as it has been transformed to "on-the-go" pot thanks to its size, shape and spoon that has been attached on its snap-on-lid. The pot is available in two formats: 100gr and 125gr and both formats maintain the same diameter at their top so they can be filled by the same filling machine with minor change-overs (approx. 20 minutes).
2. A better and more versatile product thanks to the advantages of its primarily packaging and the product itself also improved thanks to the next two points:
   i. The shelf-life of the product is 9 months when other yoghurt products´ shelf-life is between 1 to 2 months (Cruz et al., 2010; Mataragas et al., 2011).
   ii. The product can be transported and stored at ambient temperature, so it can be sold all over the world, even at places where there is no electricity, transport refrigeration and domestic or commercial refrigerators.
3. So far, sales have been improved by almost 10%, the cost of quality has been reduced by almost 8-9% and transportation costs have been reduced by 5%.

5 Conclusions and recommendations

In this paper, we presented a collaborative conceptual framework based on ICT, which can be used to re-engineer any New Product Development process and, which encompasses consumer-centric Open Innovation and the more traditional design frameworks, such as, the Double Diamond 4D Design. Key features to our overall approach are a collaborative framework for innovation that extends beyond the boundaries of individual organisation and the subsequent mitigation and sharing of innovation risk not least because of the direct involvement of the consumer in the New Product Development loop. Although the present study had a geographical focus, there is no evidence to suggest that geography would restrict the applicability of our approach in any way. On the contrary, in the literature (Lazzarotti et al., 2012; Mäkimattila et al., 2013; Saguy and Sirotinskaya, 2014) it has been shown that , the country factor is irrelevant to cross border collaboration on New Product Development and Innovation activities, de-risking the process though even further. Furthermore, by embracing Open Innovation within a a company's strategy framework is far more important than just addressing day-to-day competitive pressures as it allows for better response to long term business challenges and market demands through the establishment of a culture of Innovation. With this motivation in mind, our framework targets all food companies seeking to apply Open Innovation in their New Product Development efforts.

In particular, the consumer-centric Open Innovation approach suggested in this paper, with crowd-sourcing as its key feature for consumer engagement, places end customers in the New Product Development process with the additional benefits of:

1. Discovering new market segments and understanding their needs.
2. Enabling the design and production of food products.
3. Supporting the needless consumption of energy and resources because the real demand and use of the products can be guaranteed.

Therefore, we think that such a kind of conceptual framework can help any food company empower its internal knowledge and talent by absorbing selected external information and knowledge. The application of new technology which supports the access, exchange, sharing and use of information is vital for the achievement of the previous statement. When all that enriched knowledge forms part of the culture and heritage of the company, at that moment, the organization will have "acquired" a big data system. It is therefore obvious that the development of a common information network and its limitations should be an interesting future work.

Furthermore, we also explained that in order to achieve everything listed above, any food manufacturing system and its whole supply chain should rapidly respond to change by adapting its initial configuration.

However, we think that as a further research, we should study simulation and optimisation models and techniques which can be used by expert users to discover the manufacturing capacity of any available installation, configure manufacturing networks and processes, select appropriate suppliers and assess risks associated with particular process and network configuration decisions.

In addition, agile processes are essential for a correct implementation and final success of such a manufacturing model. To a significant degree, the success of an Agile Manufacturing Unit or even the whole enterprise depends on the application of new technology, which comprehensively supports the access, exchange, sharing and use of information, while speeding up the information and work flow in the product development cycle. Agile materials, capacity planning and control systems are a must. A mechanism to achieve agility is the ability to provide forecasts throughout the supply chain of forthcoming demand without the buffering encountered in current supply chains; expired products and waste of food can be avoided. We think that this last part is also an interesting study for future research.

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